SIEMENS

SIMOVERT MASTERDRIVES

Voltage-Source DC Link Converters for AC Variable-Speed Drives

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Engineering Manual for Drive Converters E20125-J0001-S202-A1-7600

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Engineering Manual for Drive Converters

Drehzahlveränderbare
Antriebe

Variable-Speed
Drives

Dear Engineering Manual users,

Why have we created a Engineering Manual for drive converters?

Customers are continually asking the same questions about our new SIMOVERT P MASTERDRIVES AC drive converter series. It is becoming increasingly more important to be able to respond to these questions quickly and professionally as far as the drive converter series is concerned. Thus, we have decided to clearly document important subjects and issues and to make them available to you in the form of an Engineering Manual.

Why 2 Engineering Manuals?

As a result of the scope of these subjects, we think it is practical to divide the Engineering Manual into 2 sections; one section **"Engineering Manual for Motors"** and another section **"Engineering Manual for AC Drive Converters"**.

The **Engineering Manual for Motors** has already been published, and covers engineering the drive converter and motor, i.e. how to find a suitable motor and suitable drive converter for specific applications. In addition, you will find detailed information and technical data on the motors, especially for 1FT6 and 1FK6 servomotors as well as the compact 1PH6 and 1PA6 induction motors.

This preliminary **Engineering Manual for AC Drive Converters,** essentially focuses on subjects involving the drive converter power section and the open-loop and closed-loop control. This first edition is still not complete, and only contains the sections highlighted in the list of contents at the beginning of the document. The remaining sections will be made available as soon as possible. Thus, this edition is available as a loose leaf manual which can be supplemented and completed as required.

Just what does the Engineering Manual address?

In order to prevent any confusion and misunderstanding, we would like to clearly point out that an Engineering Manual can and must only be used as a supplement to the Catalog (DA 65). Please note that the Engineering Manual is not intended for customer presentations nor is it to be passed on to customers. We want to put **YOU** into a position where you can deal more effectively with your customers.

If you come across any mistakes, or if you would like to pass on your opinions and recommendations, then complete the attached sheet and return it to us. If you think that we should also include other subjects, then let us know.

SIMOVERT MASTERDRIVES - Engineering Manual for Drive Converters

2 Performance features of the open- and closed-loop control for Vector Control VC

The open- and closed-loop control of the CUVC board provides, in addition to open-loop control systems with V/f characteristics, also control versions with vector control. The gating signals for the IGBTs of the inverter are generated in a gating unit which generates the pulse pattern from the voltage and frequency data.

Pulse-width modulation technique

The IGBTs of the inverter act like switches, which switch the outputs of the converter at the positive and negative pole of the DC link voltage, Fig. 2.1.1. The phase-to-phase output voltage, and therefore the voltage at a connected motor are defined by the duration of the gating signals of these inverter phases and the magnitude of the DC link voltage.
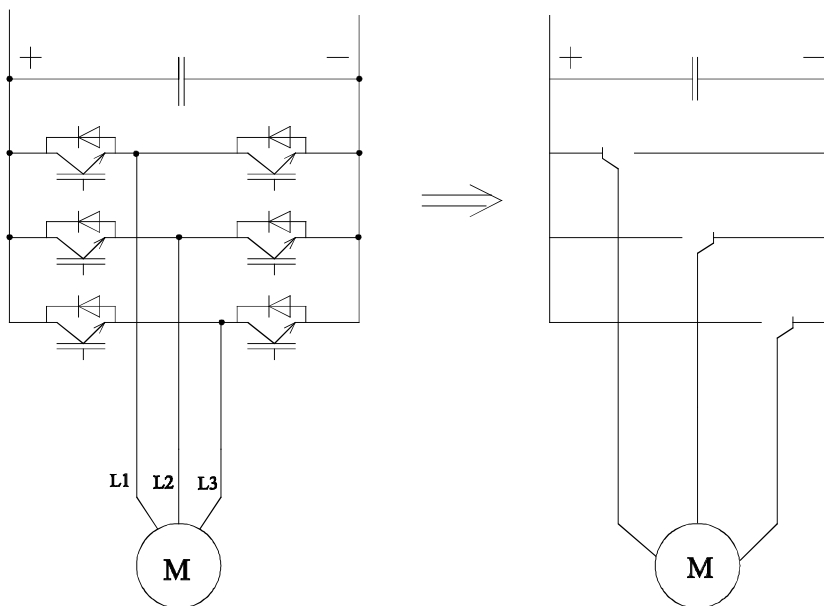
Fig. 2.1.1: Principle of operation of an inverter

There are a total of $2^3 = 8$ switching statuses according to Table 2.1.1, which have an effect in the motor which can be defined using the voltage vector.

Switching statuses	L1	L2	L3
U_1	+	-	-
U_2	+	+	-
U_3	-	+	-
U_4	-	+	+
U_5	-	-	+
U_6	+	-	+
U_7	+	+	+
U_8	-	-	-

Table 2.1.1:
Possible switching statuses and the voltage combinations of the inverter

For example, if as shown in Fig. 2.1.1, phase L1 is switched to the positive DC link voltage, phases L2 and L3 to the negative, corresponding to switching status U_1, then the voltage vector, is obtained which is in the direction of motor phase R and is designated with I, Fig. 2.1.2. The length of this voltage vector is defined by the DC link voltage.
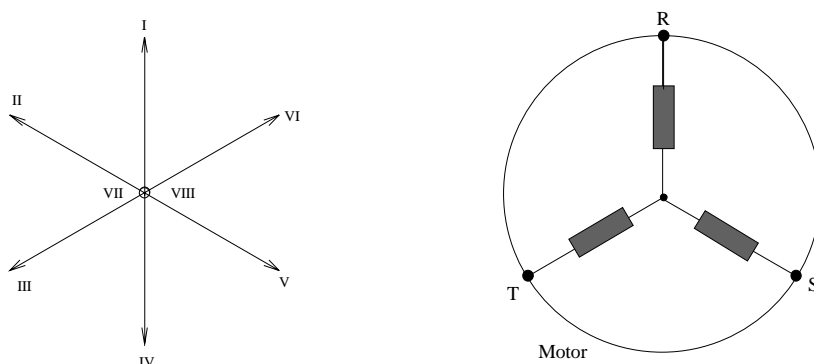
Fig. 2.1.2 Representation of the resulting motor voltages as space vector

If a transition is made from switching status U_1 to switching status U_2, the voltage vector jumps through an angle 60° el. due to the change of the potential at terminal L2. The length of the vector remains unchanged.

The resulting voltage vector is obtained in the same way from the switching combination U_3 to U_6.

The switching combination U_7 and U_8 generate the same potential at all motor terminals. The voltage vector with "zero" length (zero voltage vector) is obtained from the two combinations.

Generating a variable output voltage using pulse-width modulation

Voltage and frequency must be entered in a suitable fashion for a specific operating status of the motor, characterized by speed and torque. In the ideal case, this corresponds to the voltage vector $U_{(\omega t)}$ moving along a circular path with the rotational velocity $\omega t = 2 * \pi * f$ and the adapted absolute value.

This is implemented by modulating of actual voltage vectors which can be adjusted (pulse-width modulation). Thus, the instantaneous value of $U_{(\omega t)}$ is generated by pulses of adjacent voltage vectors which can be adjusted and the "zero" voltage.

By varying the ratio of the switch-on duration (pulse width) of adjacent voltage vectors to one another, the vector angle is adjusted to the required value by varying the switch-on duration of the zero voltage vector. This technique to generate the gating signals is known as **space-vector modulation**. The space-vector modulation provides the sinusoidal-modulated pulse pattern as shown in Fig. 2.1.3.

Phase R

Phase S

Phase voltage U$_{RS}$
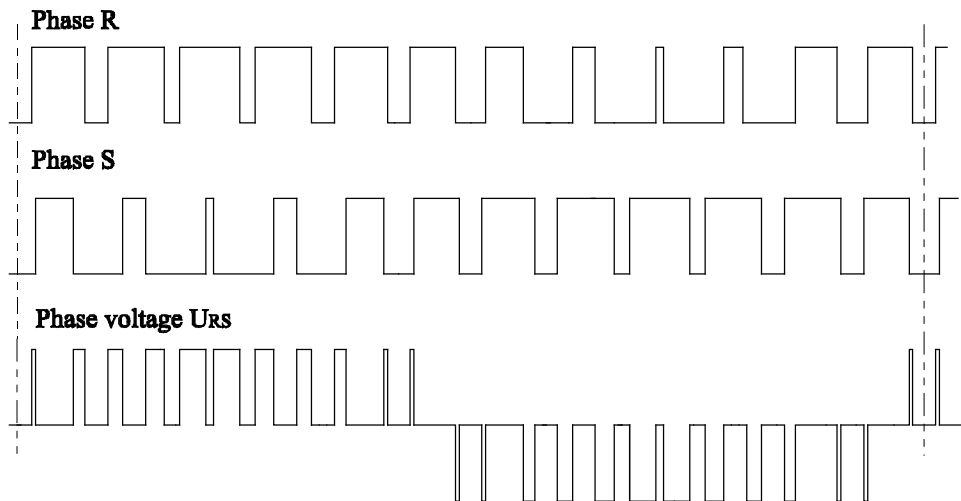
*Fig. 2.1.3   Gating signals over time for the two inverter phases L1, L2
               and the associated phase to phase output voltage. The magnitude of the voltage pulses
               corresponds to the DC link voltage*

The pulse frequency is set in the factory to 2.5 kHz. It can be changed up to 16 kHz depending on the inverter size, whereby in this case a de-rating of up to 50 % must be made. Also refer to the data in Catalog DA 65.10.

The principle characteristics and how this output voltage is generated is illustrated in Fig. 2.1.3. The following oscillogram, Fig. 2.1.4 shows how the output voltage and the resulting motor current at a 2.5 kHz, actually look like for a standard motor (50 Hz motor).

*Bild 2.1.4   Oszillogramm von Motorspannung und Motorstrom bei maximaler
               at maximum modulation depth of the space-vector modulation*
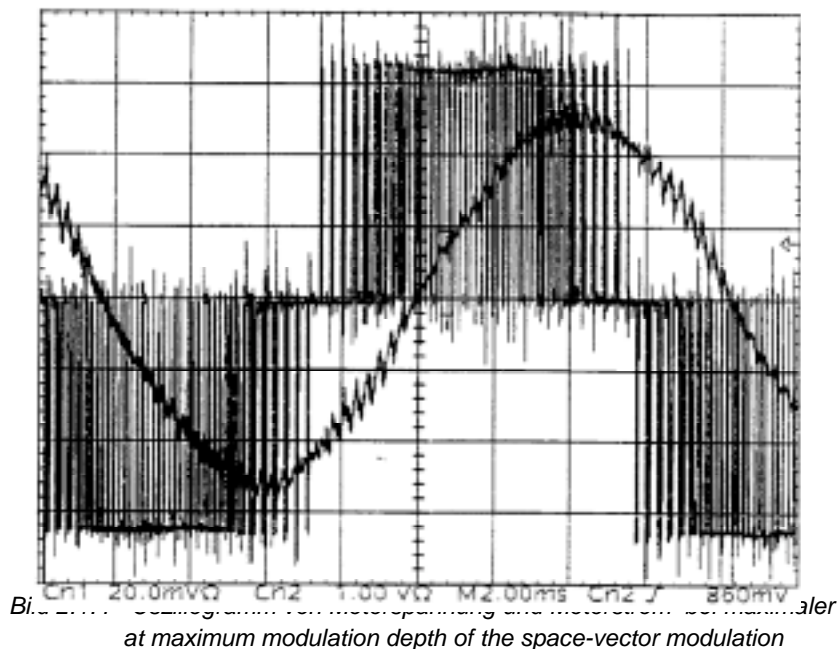
The rate-of-rise of the switching edges of the voltage pulses is defined by the switching speed of the IGBT involved. With its typical switching times of approx. 0.1 µs, voltage rates-of-rise are obtained of dv/dt = 5 ... 10 kV/µs. Depending on the motor feeder cable length, this results in voltage reflections in the motor terminal box; also refer to the comments under Section 3.7.

As a result of the high 2.5 kHz pulse frequency, the motor current is essentially sinusoidal, and the supplementary losses, generated in the motor as a result of harmonic currents, are minimal. If the pulse frequency is increased further, for standard motors (50 Hz motors) the supplementary motor losses are not noticeably reduced, but the (switching) losses in the drive converter are significantly increased.

If the pulse frequency is increased, this generally reduces the supplementary motor noise. If the pulse frequency is increased to values > 10 kHz, supplementary converter-related motor noise no longer occurs, as the human ear can no longer perceive the high frequencies. It may be practical to increase the pulse frequency in order to reduce the supplementary motor noise.

The maximum achievable output voltage with space-vector modulation

The space-vector modulation generates pulse patterns, which approximate an ideal sinusoidal motor voltage using voltage pulses with a constant magnitude (DC link voltage) and appropriate mark-to-space ratio. The peak value of this achievable maximum (basic fundamental) voltage corresponds to the magnitude of the DC link voltage $V_{DC\ link}$. Thus, the maximum motor voltage for space-vector modulation is theoretically given by

$$V_{RZ\ max} = \frac{1}{\sqrt{2}} * V_{DClink}$$

The DC link voltage $V_{DC\ link}$ is obtained by rectifying the line supply voltage. At full load this corresponds to approx. $1.35 * V_{supply}$, so that the maximum motor voltage for space-vector modulation is given by:
$$V_{RZ\ max} = 0.95 * V_{line}$$

This is only a theoretical value. As a result of voltage drops in the drive converter and interlocking times in the gating unit, lower values are obtained. The following values must be expected in practice:

$V_{RZ\ max} = 0.9 * V_{line}$ for a 2.5 kHz pulse frequency (as for VC and the factory setting)
$V_{RZ\ max} = 0.85 * V_{line}$ for a 5 kHz pulse frequency (as for MC)

As the interlocking times in the gating unit increase with increasing drive converter output, for drive converters with a rated current > approx. 100 A, it can be assumed that the achievable maximum drive converter output voltage is reduced even further.

As a consequence of this, the following is true:

For drive converters with Vector Control VC:
If a **sinusoidal filter** is used, then the sinusoidal filter can only be used in conjunction with space-vector modulation. Thus, the maximum motor voltage with sinusoidal filter is limited to

- 85 % of the line supply voltage for line supply voltages of between 380 and 480 V (6 kHz pulse frequency),
- 90 % of the line supply voltage for line supply voltages of between 500 and 600 V (3 kHz pulse frequency).

Thus, drive converter and motors must be (over) dimensioned.

Higher output voltages for VC up to the full line supply input voltage can only be achieved if a sinusoidal filter is not used.

For drive converter with Motion Control MC:

For Motion Control MC, only space-vector modulation is used. Thus, for MC the maximum output voltage is generally limited to 86 % of the line supply input voltage, which means that the drive converter and motors must be dimensioned for this.

Maximum achievable output voltage with edge modulation for Vector Control VC

The motor output voltage can be increased above values which are only obtained with space-vector modulation by no longer pulsing over the complete period, but only at the edges. This is known as "edge modulation". The motor voltage is then essentially as illustrated in the following Fig. 2.1.5.
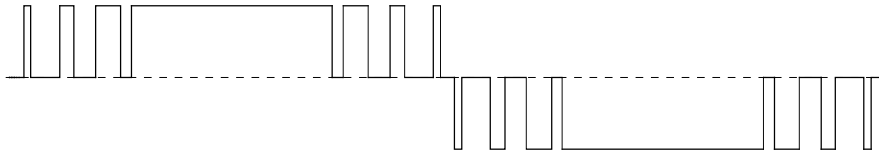
Fig. 2.1.5 Motor voltage for edge modulation

The maximum achievable output voltage is obtained if only the basic frequency is used for clocking, and is no longer "pulsed". In this case the output voltage comprises 120° square wave blocks with the amplitude of the DC link voltage. The basic fundamental of the output voltage is given by

$$U_{SQUAREWAVE} = \frac{\sqrt{6}}{\pi} * V_{DClink} = \frac{\sqrt{6}}{\pi} * 1.35 * V_{\sup ply} = 1.05 * V_{\sup ply}$$

Thus, with a pure square wave modulation, a slightly higher motor voltage than the line supply voltage can be achieved. However, the motor voltage has an unfavorable harmonic spectrum, which causes significant supplementary losses in the motor and that means that the motor is unfavorably utilized. Thus, the edge modulation is not quite fully modulated, but only to 96 % of that possible. Thus, the maximum output voltage which corresponds to the line supply voltage is then obtained, taking into account the voltage drops in the drive converter:

$$V_{drive\ max} = V_{line} \qquad \text{for VC} \qquad \text{(96 \% modulation level}\quad\text{100 \% line voltage)}$$

Optimized pulse patterns are used for this edge modulation, which only cause low harmonic currents, and which means that the connected motor can be well utilized. It can be assumed that commercially available standard motors for 50 or 60 Hz, can be operated at the rated operating point up to rated torque, by partially utilizing temperature rise class F (the winding temperature rise then lies between 80 and 100 K).

Effective pulse pattern in the frequency/voltage range for VC

Fig. 2.1.6 illustrates which pulse frequencies can be used in which ranges. This also illustrates the effective pulse frequency. For example, the effective pulse frequency in the "FLM 19" system is 19x the drive converter output frequency.

The abbreviations in Fig. 2.1.6 are as follows:

RZM   space-vector modulation with a specified pulse frequency

FLM   edge modulation with a pulse frequency as a specified multiple
            of the instantaneous drive converter output frequency
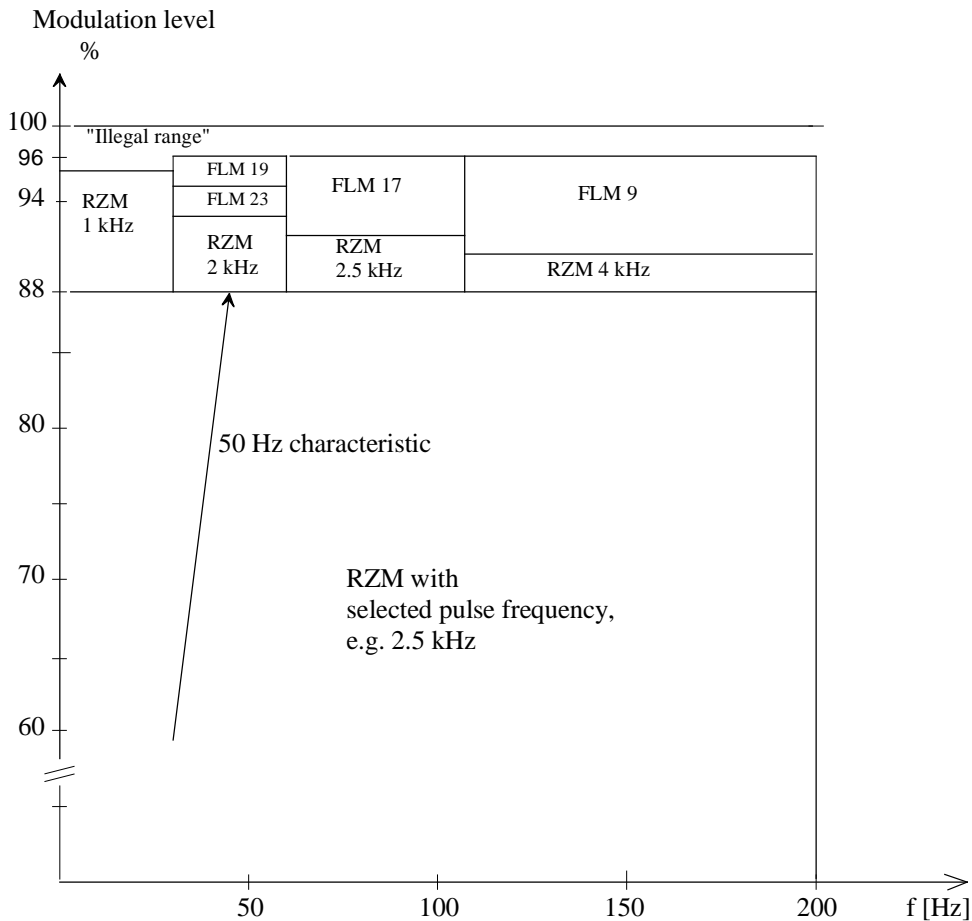
Fig. 2.1.6 Available pulse systems for VC as a function of the frequency and modulation level

As shown in Fig. 2.1.6, the pulse frequency, which can be set via parameter P340 is set in the factory to 2.5 kHz, is only effective in space-vector modulation up to approx. 88 % modulation level (= 92 % of the line supply voltage). For higher output voltages, the pulse frequency is initially reduced, and is then switched-over to the edge modulation systems.

Thus, if the pulse frequency, defined using P340, is deliberately set significantly higher than the 2.5 kHz set as standard in the factory, e.g. in order to reduce the motor noise and if this increased pulse frequency is not to be reduced to lower values at any load point, then as a consequence, the maximum drive converter output voltage should be limited to ≤ 92 % of the line supply voltage. Thus, the motor and drive converter must be (over)dimensioned.

Principle design of the gating unit

All of the open-loop and closed-loop control versions of Vector Control VC both on the CUVC board as well as on the older CU1 and CU2 boards, include a gating unit block, which has a basic design as shown in Fig. 2.1.7. The inputs are frequency f and control voltage V_{St}. The input frequency is converted into an angle α_s using an integrator. Thus, a voltage vector is essentially obtained with an instantaneous phase angle of α_{St}, which rotates at $\omega t = d\alpha_{St}/dt$. The required pulse pattern is calculated for the phase position defined for this voltage vector, which is then used to derive the gating signals for the inverter IGBTs.
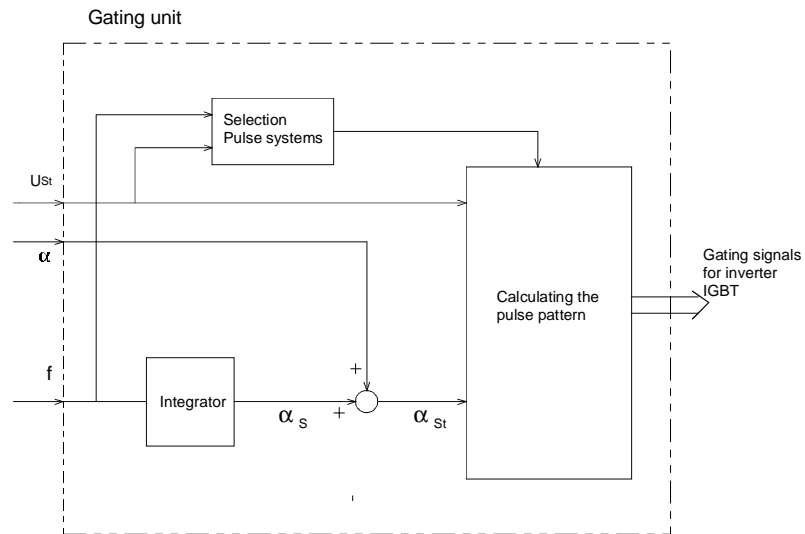
Fig. 2.1.7 Block diagram of the gating unit for VC

The additional input α is used for dynamic pre-control in conjunction with the vector control types. This is used to change the phase position of the voltage vector.

2.1 Open- and closed-loop control functions Vector Control VC

Most three-phase motors can be operated in the speed-controlled mode using Vector Control VC.

*Exception: 1FT and 1FK servo motors **cannot** be used in conjunction with VC. In this case Motion Control MC should be used!*

Various open- and closed-loop control functions are available in the standard software, which cover all of the relevant applications. These include

- open-loop control types with V/Hz characteristic for simple applications,
- vector control types for medium- up to high dynamic performance drives.

The characteristics of this open-loop and closed-loop control concept, such as the achievable speed accuracy and rise times, are listed at the end of the descriptions, under Section 2.1.3.

The following open-loop and closed-loop functions are available:

2.1.1 Open-loop control types with V/Hz characteristic

V/Hz characteristic with speed actual value encoder: P100 = 0

This involves V/Hz (open-loop frequency control) with higher-level closed-loop speed control, which can only be used with induction motors where there are no high demands regarding the dynamic performance, e. g. pumps and fans, simple traversing drives.

This version is suitable for individual drives with induction motors, if a high speed accuracy is to be achieved, which cannot be achieved by just using slip compensation. The speed actual value of an analog tachometer can be evaluated via an analog input, and that of a pulse encoder with 2 tracks, via the pulse encoder input.
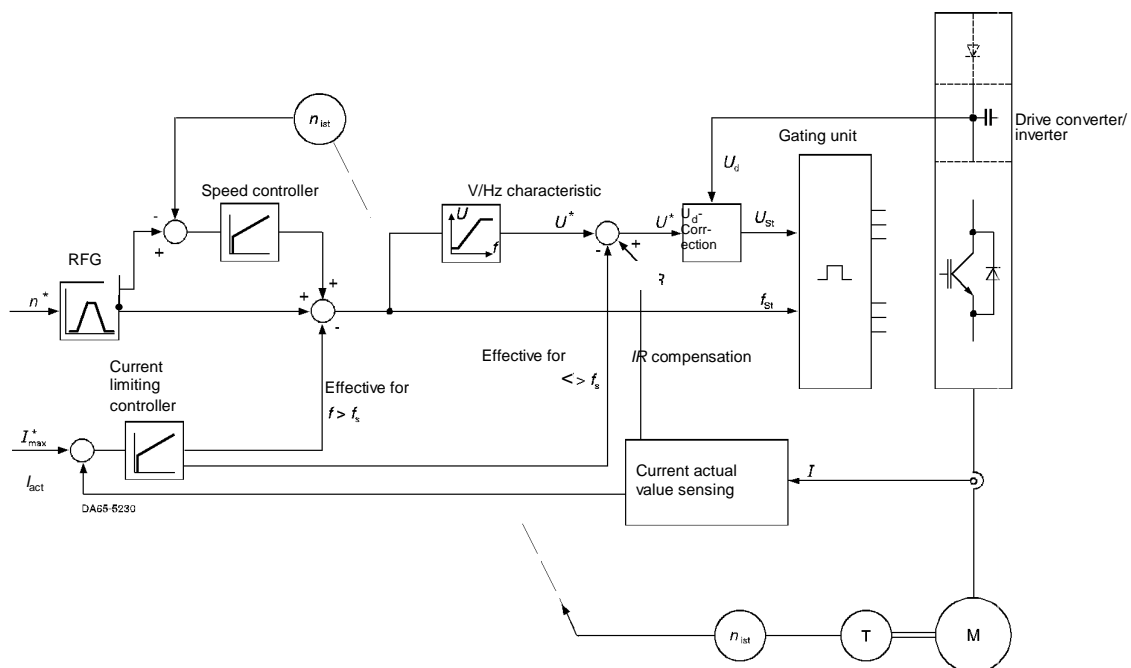
Fig. 2.1.8: Closed-loop speed control wit h V/Hz characteristic

The speed setpoint, fed via the ramp-function generator, is fed to the gating unit as frequency. The speed controller corrects this frequency pre-control and therefore compensates the motor slip.

The voltage is specified using a characteristic. The influence of a changing line voltage, and therefore the DC link voltage is compensated via the Vd correction. Thus, the specified motor voltage is correctly entered as absolute value as long as the modulation level (firing angle) does not go into limiting. This Vd correction is provided for all open-loop- and closed-loop control versions.

For the voltage input, either a linear or a parabolic characteristic can be selected.

For a linear characteristic, the motor is operated with constant flux up to the rated speed as is required for constant-torque drives.

For parabolic characteristics, the motor is operated with reduced flux at partial speeds. This should guarantee that the drive converter and also the motor have a especially high efficiency in the partial load mode. This is only possible, if, with reducing speed, the load torque decreases according to a square-law (e. g. $T \sim n^2$), which is the case for fans and pumps.

The characteristic can be increased at low speeds/frequencies in order to provide the required ohmic voltage drop. In the upper speed range > 10 % of the rated speed, a supplementary voltage is provided via the IR compensation, derived from the load current. This supplementary voltage should provide a constant motor flux independent of the load (this is only practical for linear characteristics).

Further, there is also a closed-loop current limiting control. This influences the voltage when the drive starts, and at low speeds ($f < f_s \approx 10 \% f_n$), i.e. it reduces the voltage if the current is too high. At higher speeds ($f > f_s \approx 10 \% f_n$) the current limiting influences the frequency, i.e. it reduces the frequency if the load torque increases to an excessive value or slows down the frequency rate-of-rise if, when accelerating, the ramp-function generator ramp-up time is set to a low value.

V/Hz characteristic for general applications: P100 = 1

This open-loop frequency control with slip compensation is designed for single-motor- and group drives using induction motors where no high demands are placed on the dynamic performance. This includes, for example, pumps and fans, simple traversing drives.
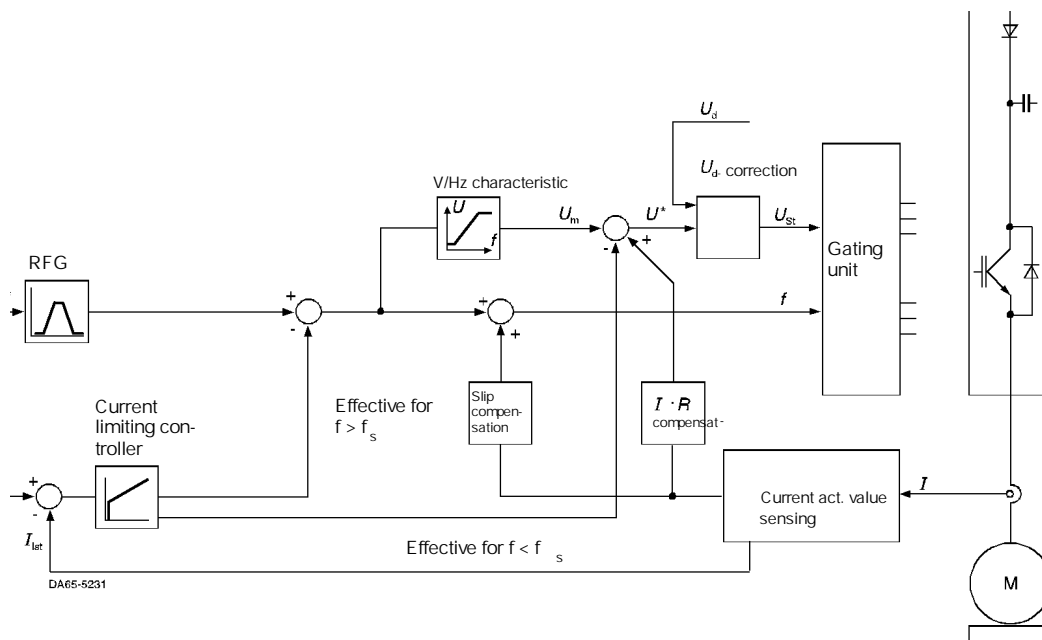
Fig. 2.1.9: V/Hz control without speed actual value acquisition

The closed-loop control structure is essentially the same as that illustrated in Fig. 2.1.8. The speed controller is not used but instead, slip compensation. The slip compensation specifies a supplementary frequency, depending on the load current, and therefore holds the speed constant when the load torque changes. The slip compensation is only effective at speeds > 10 % of the rated motor speed. This allows a speed accuracy of [0.2 *slip] to be achieved, which means that for motors above 30 kW (with a slip of $\leq$ 1.5 %), an achievable speed accuracy is obtained of $\leq$ 0.3 % referred to the rated motor speed. This is valid for speeds > 10 %. At lower speeds and at standstill or when starting, the speed can deviate from the selected setpoint by the complete slip speed (e. g. 1.5 % for a 30 kW motor).

V/Hz characteristic for textile applications: P100 = 2

This involves an open-loop frequency control for applications mainly in the textile industry, using SIEMOSYN- and reluctance motors.
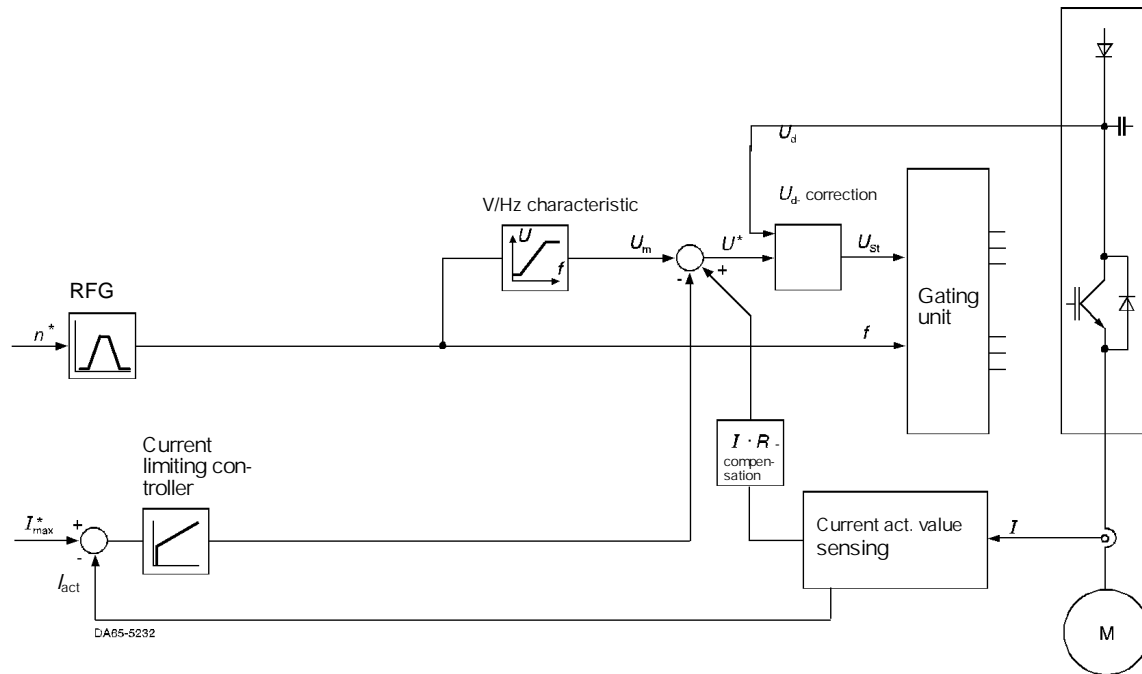
Fig. 2.1.10: V/Hz control for textile application

In this case, the speed- or frequency setpoint is transferred directly to the gating unit after the ramp-function generator. There is no signal conditioning made in the frequency channel. This guarantees that **synchronous** motors, such as SIEMOSYN- and reluctance motors run with precisely the specified frequency (= speed). The current limiting controller only acts on the output voltage, e. g. to limit the starting current of motor groups which are powered-up.

2.1.2 Vector control types or field-oriented closed-loop control

Vector control types are preferably used for **induction motors** and for single-motor drives or group drives with mechanically coupled loads.

What is vector control?

Vector control is dynamic closed-loop control, which allows a controlled dynamic performance to be achieved comparable to that of a DC drive. It was developed in the seventies by Siemens under the name TRANSVEKTOR closed-loop control. Today, a user-friendly and favorably priced version of the vector control is available with microprocessor technology, also for open-loop and closed-loop control tasks.

The name refers to the fact that the motor current is not just processed as absolute, scalar value. It is broken down into its

- flux-generating components (= magnetizing current)   and

- torque-generating components (= active current)

i.e. it is input, sensed and controlled as current vector. The specific advantages of vector control include:

- high dynamic performance, comparable to the dynamic performance of a DC drive,

- the drive can be easily adjusted to accelerate along the torque- or current limit, no undesirable overcurrents,

- stable operation: Oscillations (which frequently cannot be avoided when single-motor drives are open-loop controlled from 50 to 100 kW) are effectively damped and suppressed.

Vector control has continually established itself for single-motor drives. Frequently, the required operating characteristics can only be achieved for many manufacturing processes by using vector control.

Principle of vector control

The task of vector control is to enter and impress the motor current required for the particular load or torque, to the motor flux, so that the necessary torque can be achieved. Torque setpoint changes can then be executed as quickly as possible and without overshoot.

The vector diagram in Fig. 2.1.11 explains how vector control functions:

Under steady-state conditions, the current vector must revolve around the rotor with the slip frequency corresponding to the torque; under no-load conditions, with a slip frequency of zero. If a new (in this case: motoring) torque setpoint is entered, the current vector must be changed to its new value and rotated through the load angle ε. The new torque is now generated. In this case, a voltage component is required in the EMF axes. The changed current vector must simultaneously rotate around the rotor with the new slip frequency.

Fig. 2.1.11 Vector diagram of an induction motor with the
"no-load" and "motoring" operating conditions

In order to achieve this characteristic, in practice, 2 vector control or field-oriented control techniques have crystallized-out, which are designated in the following as "current model" and as "voltage model".

Current model
A speed actual value sensing function for the current model is required, e. g. in the form of an incremental encoder. The principle of operation of the current model is illustrated in Fig. 2.1.12.
The speed controller supplies torque setpoint M*, which is converted into an active current setpoint i_w*
using an arithmetic circuit. Further, M* is converted into a slip setpoint f_2. The stator frequency and at the same time the circumferential velocity, with which the flux should rotate in the motor, is obtained by adding the speed and the slip frequency, dependent on M*. Active- and magnetizing currents are determined in the current model as actual values from the motor phase currents relative to the entered phase position of the motor flux.
The EMF computer supplies the voltage V_{St} which has to be entered and the phase angle α by which the voltage leads the flux, from the active- and magnetizing current setpoints. Further, the i_w controller and the i_μ controller ensure that the specified current setpoints are precisely maintained.
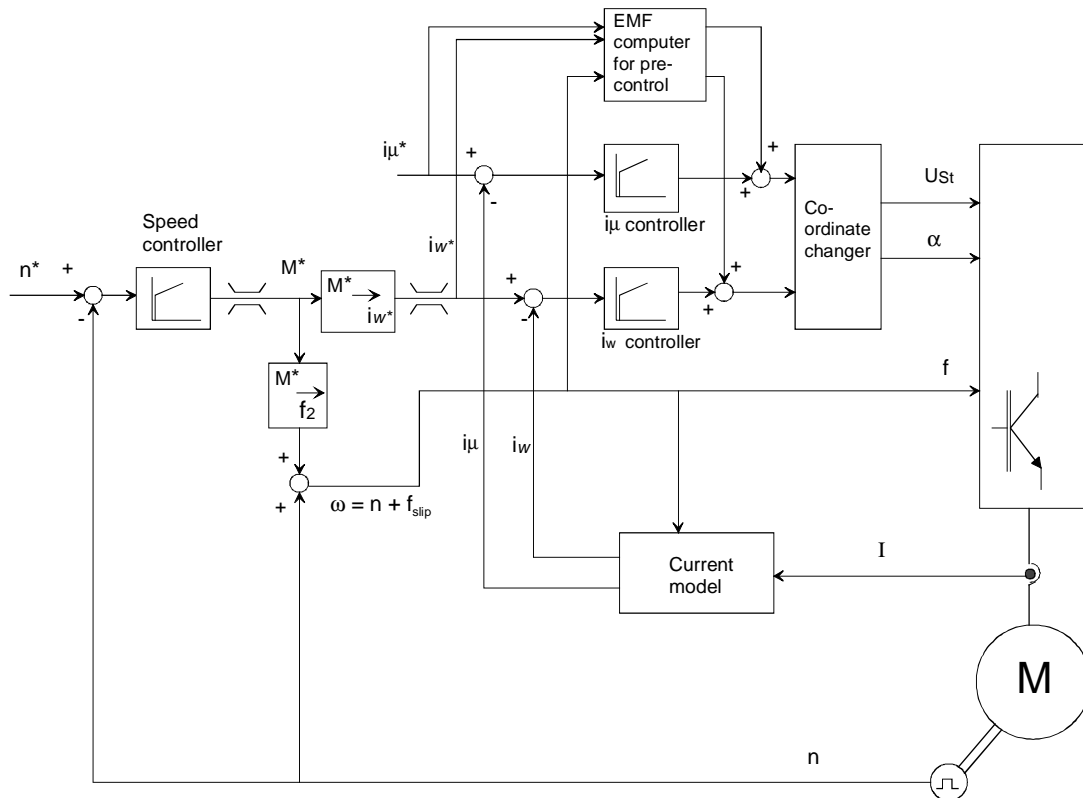
Fig. 2.1.12 Principle of vector control with "current model"

For example, if the speed controller changes the active current setpoint $i_W{}^*$ from "zero" (= no load) to 100 % (= rated motor torque), then, also refer to Fig. 2.1.11,

- the current is changed to the new value (increased),
- the current phase position is rotated through the "load angle" ε, and
- the current now rotates, with respect to the rotor, with the new slip frequency f_2.

Advantage of this control concept:
Full control dynamic performance offer the complete speed control range, including zero speed.

Disadvantages and limitations of this control concept:
A speed actual value sensing is required for the control concept which must be digital due to the high precision required, e. g. pulse encoder with 1024 pulses/revolution. Thus, this control concept cannot be used for drives which have no speed actual value sensing (tachometer/encoder).

The slip frequency, dependent on the rotor resistance, and the rotor time constant are included as essential parameters for a correctly functioning control concept. Unfortunately, the rotor resistance is not a "constant", but it changes with the motor temperature and fluctuates between approx. 60 % of its nominal value (when cold) and 100 % of its nominal value or above (when warm). In order that the control is not negatively influenced by the effect of the changing rotor temperature, the rotor time constant is corrected. The accuracy of the model used can be increased using a temperature measurement with a KTY84; also refer to P386.

Voltage- or EMF model

The motor EMF and therefore the position of the magnetic flux is determined in the voltage model from the voltage- and current actual values. The motor voltage actual values are required. These actual values are determined from the gating unit signals and the DC link voltage.

The motor EMF induced by the magnetic field is calculated in the voltage model from the motor voltage, taking into account the ohmic and inductive voltage drops.

The motor current vector is projected on this EMF or flux vector, and the active current (torque-generating components) and magnetizing current (flux-generating components) of the current vector determined. Voltage and frequency are entered so that the active current and magnetization current actual values which are input, coincide with the appropriate setpoints.

This voltage model concept essentially doesn't require any speed actual value sensing (encoder). It is also insensitive with respect to the temperature-dependent rotor resistance. The model is only dependent on temperature-dependent stator resistance at low frequencies.

However, this concept does not function at extremely low speeds and especially at zero frequency. Reason: At f = 0, the motor induced EMF is also zero, which means that if f = 0, there is never any EMF and the position of the flux vector cannot be determined. Thus, when accelerating from zero speed, the lowest speed range up to approximately 5 % of the rated speed must be passed through in the open-loop controlled mode.
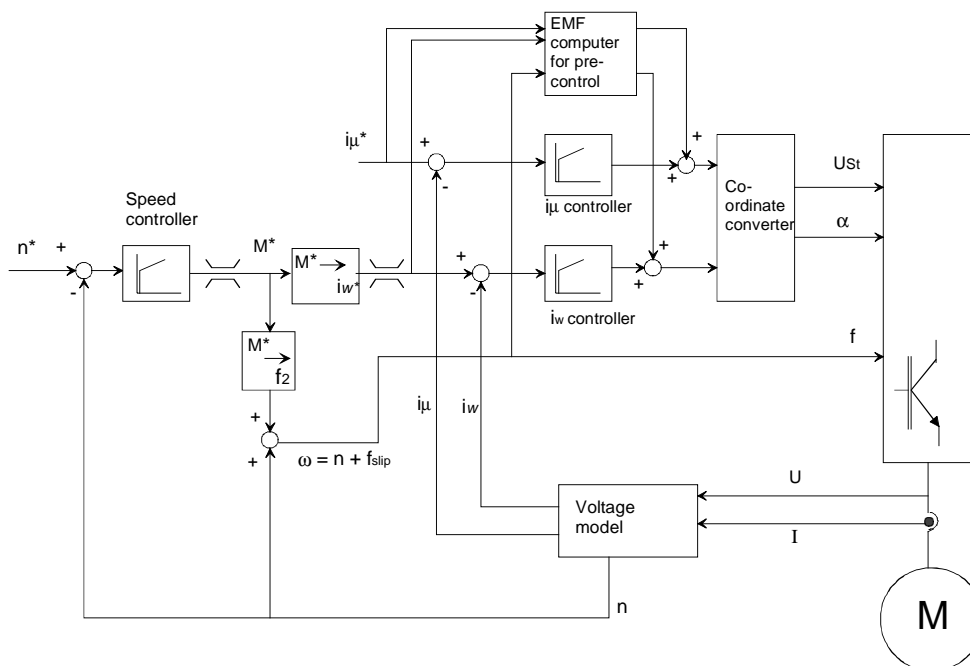
Fig. 2.1.13 Principle of vector control with "voltage model"

The speed is also calculated via the voltage model. The speed actual value determined in this fashion, corresponds under steady-state operating conditions, i.e. at constant speed and for frequencies > 10 %, to the stator frequency minus the slip frequency. The accuracy of the slip frequency is a function of the rotor resistor temperature, so that also in this case adaptation makes sense. This means that at speeds > 10 %, slip compensation is effective which guarantees precise closed-loop speed control. One can assume, that the slip frequency will be compensated to 90 %, i.e. a speed accuracy of: [0.1 x slip] will be achieved. Thus, with commercially-available standard squirrel-cage motors, from rated motor outputs of 30 kW, a speed accuracy of ≤ 0.3 %, referred to the rated motor speed can be achieved in this speed range n > 10 %.

Control versions implemented on the CUVC module

The possible field-oriented control types, which can be implemented for MASTERDRIVES VC using the CUVC module, are now briefly explained in the following.

2.1.2.1 Closed-loop frequency control or field-oriented control without speed actual value encoder: P100 = 3

In this case, the voltage model described above and illustrated in Fig. 2.1.13 is used; refer to the detailed circuit diagram, Fig. 2.1.14. Detailed block diagrams are included in the MASTERDRIVES VC Compendium.

For additional pre-control, an acceleration-setpoint torque is input, derived from the ramp-function generator. This concept is effective for frequencies > 10% of the rated motor frequency ($f > f_s$).

To accelerate away from zero speed and to pass through zero speed, a pure open-loop control concept is used, symbolized by the two changeover switches in Fig. 2.1.14. In this case, the frequency is directly entered via the ramp-function generator. A stator current I_{start}^* is simultaneously impressed in the motor via

- a steady-state component (P278) and a
- dynamic component (P279, only if the ramp-function generator is active).

The steady-state component must be set to the starting torque required under worst case conditions. For example, if for an extruder drive, 150 % rated motor torque is to be provided as starting torque, then P278 must be set to > 150 % (+ 10 % reserve). The dynamic component P279 is of no significance in this case.

> *Caution: The motor current, set using P278, which under certain circumstances, could be extremely high, flows as long as the drive is operated with a speed setpoint of < 10 %, independent of how high the load which actually has to be provided at that particular time.*

It only makes sense to use the dynamic component, if the load has an extremely high inertia, and the steady-state (friction) torque is low compared with the accelerating torque required.
Example: A centrifugal drive is to be accelerated with 150 % rated motor torque, and it is guaranteed, that under steady-state operating conditions at low speeds, when filling and unloading the centrifuge, only less than 30 % of the rated motor torque has to be provided. In this case, the steady-state component can be set via P278 to approx. 50 % and the dynamic component via P279, to approx. 100 %.
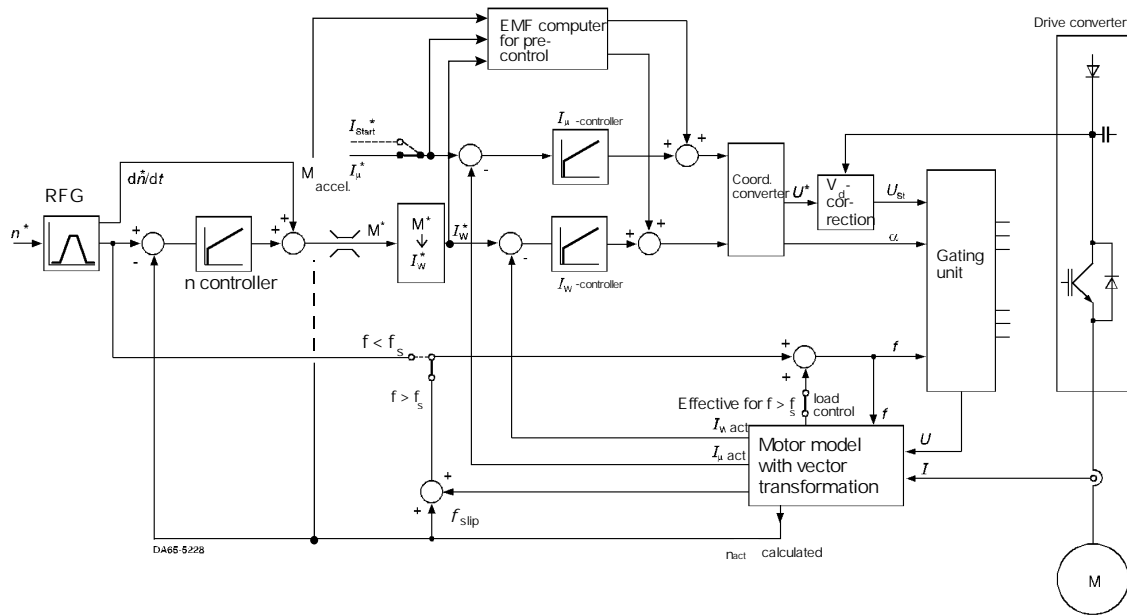
Fig. 2.1.14: Closed-loop frequency control: Field-oriented control without speed actual value encoder

This control version is best used for single-motor drives with standard induction motors with low up to high demands on the dynamic performance, for speed control ranges from up to 1:10, i.e. for a large proportion of industrial applications, for example, pumps, fans, extruders, traversing- and hoisting drives, centrifuges, mixers, conveyor belts, etc.
Refer to Section 2.1.3 for additional information about the dynamic characteristics of this control version, especially at low speeds. In this section, the issue is also discussed under which conditions a speed encoder (tachometer) is not required, or when an encoder (tachometer) is recommended.

2.1.2.2 Closed-loop speed control with speed actual value encoder: P100 = 4

For this closed-loop speed control, a pulse encoder, e. g. incremental encoder with 1024 pulses/revolution or above is required. A DC tachometer is not adequate as far as the accuracy requirements are concerned!

For this control version, refer to Fig. 2.1.15, the two concepts "current model" and "voltage model" are combined. In the lower frequency range < 10 % of the rated motor frequency, only the current model is used. For frequencies > 10 %, the voltage model is additionally enabled, i.e. the actual active- and magnetizing currents are determined from the position of the motor flux. Thus, the advantages of both concepts, namely full dynamic performance over the complete speed control range and, to a large degree, parameter-insensitivity, can be combined in a total concept.

Fig. 2.1.15: Closed-loop speed control: Field-oriented closed-loop control with speed actual value encoder

This control concept is used for applications with single- induction motor drives and where high requirements are placed on the dynamic performance, even at low speeds and increased speed accuracy, e. g. for lifts (elevators) and positioning drives, drives for continuous material webs, cranes with positioning requirements etc.

Refer to Section 2.1.3 for additional information regarding the dynamic characteristics of this control version. In this section, the question is discussed, under what condition an encoder is not required and when an encoder is recommended.

2.1.2.3 Closed-loop torque control as field-oriented control with encoder: P100 = 5

This closed-loop control concept is essentially identical with the closed-loop control concept described in the previous Section 2.1.2.2, refer to Fig. 2.1.15. The speed controller is in this case included in the torque processing and illustrated in the following diagram 2.1.16. The maximum speed setpoint for clockwise and counter-clockwise direction is input into the speed controller depending on the torque direction. The speed controller is then over-driven, as long as the maximum speed has not been reached, and then supplies the internal torque setpoint M*, which is then processed as shown in Fig. 2.1.15.

When the maximum speed (P452 for a positive torque setpoint, P453 for a negative torque setpoint) is reached, the speed controller acts as limiting controller and prevents the speed from further increasing.
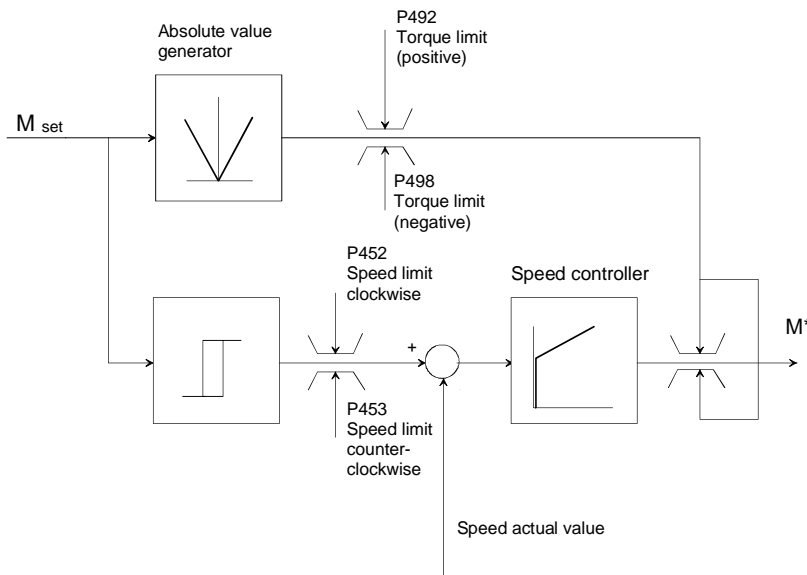
Fig. 2.1.16 Setpoint conditioning for closed-loop torque control

This control concept is used for applications involving single- induction motor drives where high requirements are placed on the dynamic performance, and if a specified torque must be provided as a result of the process; for example for winder drives, slave drives with closed-loop tension control and drives with master-slave characteristics.
An incremental encoder is also required for this control concept, preferably with 1024 pulses/revolution or higher. We recommend higher line numbers if there are higher demands on the smooth running characteristics at low speeds below 10 RPM; also refer to the information under Section 2.1.3. A DC tachometer does not offer sufficient accuracy!

2.1.3 Closed-loop control-related characteristics

The following AC motors can be used with the MASTERDRIVES VC drive converters:

- Standard motors with 50 Hz- or 60 Hz characteristics, as well as
  - motors with "87 Hz characteristic" (motor winding switched from Y $\to$ Δ),
  - motors with "29 Hz characteristic" (motor winding switched from Δ $\to$ Y),

- Special induction motors, if their rated frequency lies between 8 Hz and 200 Hz,

- Compact 1PA6/1PL6, 1PH6, 1PH4 motors,

- 1 FU SIMOSYN motors and 1FP reluctance motors with V/Hz characteristic.

Maximum permissible output frequencies: refer to Table 2.1.2.

Line supply voltages	Output kW	Maximum inverter frequency at	Maximum inverter frequency in the constant-flux range	Maximum inverter frequency in the field-weakening range	Maximum inverter frequency in the constant-flux range	Maximum inverter frequency in the field-weakening range
		V/Hz textile	V/Hz characteristics	V/Hz characteristics	Vector controls	Vector controls
3-ph. 200 to 230 V	2.2 to 22	500 Hz	200 Hz	300 Hz or 5 * f_n mot	200 Hz	300 Hz or 5 * f_n mot
3-ph. 380 to 480 V	2.2 to 37 45 to 200 250 to 710	500 Hz 500 Hz 300 Hz				
3-ph. 500 to 600 V	2.2 to 11 18.5 to 1100	500 Hz 300 Hz				
3-ph. 660 to 690 V	55 to 1500	300 Hz				

Table 2.1.2:   Maximum possible output frequencies

Pulse encoder evaluation on the CUVC board

For the SIMOVERT MASTERDRIVES Vector Control units, a pulse encoder can be evaluated in the standard unit. The pulse encoder must be connected to the following CUVC board terminals:

X103:23	Reference potential for the pulse encoder
X103:24	Track A
X103:25	Track B
X103:26	Zero pulse (this is presently not evaluated)
X103:27	Monitoring input (only for tacho monitoring)
X103:28	+15 V / 190 mA, power supply for the pulse encoder

Pulse encoders with the following specifications can be directly connected:

- HTL encoders with 2 tracks shifted through 90°:
- Power supply voltage V = 11 V to 30 V with zero track, checking track can be evaluated
- HTL signal level: H = 8 V; L = 3 V
- Input current: approx. 3.5 mA at 15 V
- Pulse numbers which can be evaluated, 60 - 10000 pulses/revolution
- Limiting frequencies: f_{max} = 400 kHz

Effect of the encoder pulse number on the smooth-running characteristics of the motor at low speed

The speed can be only be clearly determined, if the edge changes at least twice for the 2 encoder tracks, within the closed-loop control sampling time (= 1.2 ms). This minimum speed is given by:

$$n_{optimal} > 25000/Z \text{ [RPM]}, \quad \text{with} \quad Z = \text{encoder pulses per revolution.}$$

Below this "optimum" speed range, the speed is averaged or interpolated over several sampling periods, with a reduced control performance (slower) and poorer smooth-running characteristics. If good smooth-running characteristics are required over the complete speed control range, then the following minimum encoder pulse numbers must be used, corresponding to the following Table 2.1.3:

Minimum speed of the speed range	7.5 RPM	15 RPM	30 RPM	60 RPM
Required minimum encoder pulse numbers	4000	2000	1000	500

Table 2.1.3:   Recommended pulse numbers as a function of the lowest speed of the speed control range

Speed- and torque accuracies, rise times

Operating mode	V/Hz characteristic	V/Hz textile	Closed-loop frequency control	Closed-loop speed control	Closed-loop torque control
Setpoint resolution, digital	0.001Hz		31 bits + sign		0.1 % 15 bits +sign
Setpoint resolution, analog	f_{max}	/ 2048			
Internal frequency resolution	0.001Hz		31bits + sign		
Frequency accuracy		0.001 Hz			
Speed accuracy at n > 10 % at n < 5 % in field-weakening operation	$0.2 * f_{slip}$ [1] f_{slipf} [1]		$0.1 * f_{slip}$ [2] f_{slip} $f_{max}/f_n * f_{slip}/10$	0.0005 % [3] 0.001 % [3] 0.001 % [3]	
Speed rise time			25 ms for n > 5 %	20 ms	
Frequency stability		0.005 %			
Torque linearity					< 1 %
Torque accuracy in the constant-flux range, in the field-weakening range			< 2.5 % for n > 5 % < 5 %	< 2.5 % for n > 1 % < 5 %	< 2.5% for n > 1% < 5 %
Torque rise time			≈ 5 ms for n > 5 %	approx. 5 ms	approx. 5 ms
Torque ripple			< 2 %	< 2 %	< 2 %

[1]   These values are true for systems without speed actual value encoder. When a speed actual value encoder is used, the same values as in the "closed-loop speed control" are valid for steady-state operation. When an analog tachometer is used, its accuracy must be taken into account.

[2]   The slip values of standard motors have the following approximate order of magnitude:
6 % at 1 kW, 3 % at 10 kW, 2 % at 30 kW, 1 % at 100 kW, 0.5 % at > 500 kW.
This results in a speed accuracy of ≤ 0.3 % for motor outputs above 30 kW.

[3]   These values are true when a speed actual value encoder is used with 1024 pulses/revolution.

Table 2.1.4: Characteristics of the closed-loop control versions

Comments:
The percentages refer to the rated speed or the rated torque of the particular motor.

When is a speed actual value encoder required?

For specific applications, the question is frequently asked whether a speed actual value encoder is necessary. This involves a following basic question: Is the closed-loop control characteristics of the concept " *Field-oriented control without speed actual value encoder: P100 =3"* (called *closed-loop frequency control* in the following text) adequate for the drive, or is a concept with speed feedback required, with the better dynamic performance (called *closed-loop speed control* in the following text)?

The differences between the two concepts is especially noticeable at low speed, as summarized in the following Table 2.1.5:

Closed-loop frequency control	Closed-loop speed control
Dynamic performance of the closed-loop vector control only effective at frequencies > 10 %, close to zero speed, only open-loop controlled operation, i.e. "soft" control characteristics	Full dynamic performance of the vector control with 1 - 3 ms torque rise time (with a voltage reserve (margin) ≥ 10 %) and 20 ms speed rise time over the complete speed control range
Current impressed in the lower speed range corresponds to the maximum starting torque required, independent of the actual load torque at that time	Even at low speeds, only the motor current flows, which is required for the actual load torque, e.g. only the no-load current, if the load torque is zero
The result is the following: Generally a higher thermal motor stressing, if the drive is operated frequently, or over longer periods of time, with low speeds, and then it may be necessary to over-dimension the motor	Result: Generally lower thermal motor stressing if the drive is operated at low speeds frequently or over longer periods of time
A defined torque cannot be entered in the lower speed range < 10 %, it can only be guaranteed that the drive can accelerate against a specified maximum load torque	A defined, specified torque can be maintained over the complete speed range and this torque can be accurately set
A certain overload capability can be taken into account as a result of the open-loop controlled operation in the lower speed range, e.g. when accelerating against a rated motor torque a drive converter current of ≥ 120 % of the rated motor current must be available, which may result in the drive converter having to be over-dimensioned	A demanded load torque can be provided with the associated current. If, for example, the rated motor torque is available, the drive converter only has to provide the rated motor current and it is not necessary to over-dimension the converter
Instability can occur during load surges at speeds just above 10 %, if the speed is thus reduced so that the drive is switched into the open-loop controlled mode or it switches between the two open-loop control concepts	Stable operation during load surges over the complete speed control range

Table 2.1.5   Comparing the two control versions, closed-loop frequency control (P100 = 3) and closed-loop speed control (P100 = 4)

As a result of these closed-loop control characteristics, the question arises as to whether a speed actual value encoder is required or not. The following statement can be made:

A speed actual value encoder is not required and no problems are encountered, if the speed control range is not greater than 1:10, i.e. if the drive is only accelerated from standstill and a minimum speed of 10 % of the rated motor speed, is not fallen below.

A speed actual value encoder should be considered, if the drive is frequently operated at speeds < 10 %, or for longer periods of time (which can require, if a speed encoder is not used, to over-dimension the drive converter and/or motor)

A speed actual value encoder must be used, if

- highest speed accuracy is required,

- the highest requirements are placed on the dynamic performance, especially when accelerating from zero to maximum speed within less than 100 ms,

- closed-loop torque control is required in the control range > 1:10,

- if the speed is reduced to values < 10 % or is even forced to rotate in the opposite direction of rotation due to load surges,

- if, in a duty cycle, zero speed is approached regularly, and a specified torque must be maintained,

- positioning functionality is required.

It makes sense to make a comparison with **DC drives** in this case. There are also 2 different closed-loop control concepts for DC drives:

- A concept without tachometer, also known as "closed-loop EMF control", whereby the speed is approximately determined using the armature voltage (this is comparable with the closed-loop frequency control),

- Closed-loop speed control with tachometer (this is comparable with closed-loop speed control).

However, there is a certain difference in quality between the "closed-loop EMF control" for DC drives and closed-loop frequency control for AC drives in the lower speed range and at zero speed:

For DC drives, entering an armature current is the same as entering a motor torque. For AC drives on the other hand, it is not sufficient to just enter a motor current to define a specific torque. The motor current must be entered correctly depending on the position of the magnetic flux. This means that for DC drives, the motor torque can be more directly influenced than for an AC drive, which is more indirect or "soft". Thus, the following statement can be made:

- If a "closed-loop EMF control" can be used for a DC drive without any problem, then most probably closed-loop frequency control is sufficient for MASTERDRIVES, i.e. a speed encoder is not required.

- If, for a DC drive, "closed-loop EMF control" is just on the borderline of being acceptable, then closed-loop speed control must be provided for MASTERDRIVES drives, i.e. with speed actual value encoder.

- If, for a DC drive, closed-loop speed control is required, then, for a comparable AC drive with MASTERDRIVES, it is also necessary to use a speed actual value encoder.

2.2 Expanded functionality using supplementary modules

Additional functions, which are not included in the standard, can be implemented by optional, additive modules. These include the electronic modules as

- "Slot modules", which can either be mounted onto the CUVC control module (slot A or slot C) or on an adapter module ADB (slots D, E, F G); also refer to the information provided in Catalog DA65.10 (1998/99), Page 6/38-39,

- Communication- or technological modules, which can be inserted in the electronics box (max. 2 units)

- Adaption-, interface- and terminal expansion modules, for example, which can be snapped onto mounting rails in a cabinet.

If additional electronic boards are used in the Electronics box, then an LBA bus adapter is required, Order No. 6SE7090-0XX84-4HA0.

2.2.1 Additional modules as "Slot modules"

CBP communications module with the following Order Nos.

6SE7090-0XX84-0FF0 as spare part (only module)

6SX7010-0FF00   as mounting set for retrofits (module with parts for installation and mounting)

Communications via PROFIBUS DP can now be used. Also refer to Section 2.3.3. You'll find detailed information in Catalog DA65.10 (1998/99), Pages 6/41-42.
Caution: The mating connector (to retain the bus cable) is **no** (longer) supplied together with the CBP module. The required 9-pin sub-D connector is additionally required as standard PROFIBUS accessory (e.g. Order No. 6ES7972-0BA20-0XA0).

Comment: If PROFIBUS DP, i.e. module CBP, is used in conjunction with a technology module T100, T300 or T400, then it is **not** permissible to insert the communications module CBP in slots A or C. In this case, it **must** be located at slot G, and an adapter board ADB must be inserted at slot 3. Only then are perfect communications guaranteed between an external automation unit (PLC), technology module and basic drive converter software.

Communications module CBC with the Order Nos.

6SE7090-0XX84-0FG0 as spare part (only the module)

6SX7010-0FG00   as mounting set for retrofit (module with parts for installation and mounting)
The CAN bus can then be used. You'll find detailed information in Catalog DA65.10 (1998/99), Page 6/43-44.

Comment: If the CAN bus, i.e. module CBC, is used in conjunction with a technology module T100, T300 or T400, then it is **not** permissible that the communications module CBC is inserted at slots A or C. In this case, it **must** be located at slot G. In this case, an adapter board ADB must be inserted at slot 3. Only then are perfect communications guaranteed between an external automation unit (PLC), technology module and basic drive converter software.

Communications module SLB with the Order Nos.

6SE7090-0XX84-0FJ0   as spare part (only the module)

6SX7010-0FJ00   as mounting set for retrofit (module with 10 m fiber-optic cable, connector and parts for installation and mounting)

This allows a drive converter or inverter to be coupled together (drive coupling) via SIMOLINK.. You'll find detailed information in Catalog DA65.10 (1998/99), Page 6/45-46.

The SIMOLINK board SLB is suitable as peer-to-peer connection for fast setpoint cascades. Data transfer can include more than 5 words and up to 8 double words.

Comment: For synchronous operation applications for VC, the SIMOLINK coupling is, by itself, not adequate or is not required. Reason:

An appropriate software is required for the synchronous operating control. For VC (contrary to MC) this is not included in the basic software on the CUVC. (The freely-available function blocks are not adequate for this application!). For synchronous operating control for VC, a T300 or T400 technology module is required. In this case, the synchronous operating control is realized using two pulse encoder inputs on the module, which can be directly evaluated. A fast bus coupling, as is the case via SIMOLINK, with equidistant, jitter-free process data transfer is not required.

(For MASTERDRIVES MC, the required synchronous operating software is already available as technological software in the basic drive converter, so that an additional technology module is not required. This means, that using the SIMOLINK coupling, with its exact equidistant, jitter-free transfer of process data, synchronous operation can be implemented without requiring additional technology modules.)

Terminal expansion module EB1 with Order Nos.

6SE7090-0XX84-0KB0 as spare part (only module)

6SX7010-0KB00   as mounting set for retrofit (module, connector and parts for installation and mounting)

Thus, the analog and binary I/O on the CUVC module can be expanded by:
- 3 digital inputs
- 4 bi-directional digital I/O
- 1 analog input with differential amplifier input
- 2 analog inputs
- 2 analog outputs

All of the inputs/outputs are referred to the electronics ground, and are therefore **not** electrically isolated (non-floating). The terminal assignment is shown in Catalog DA65.10 (1998/99) on Page 6/58 and Page 6/59. The inputs/outputs can be assigned specific signals using the appropriate parameterization, corresponding to the data in the Compendium.

Comment: If the terminals on the EB1 are to be used, then the associated signal cable must be fed up to the Electronics box. However, if the customer requests that a terminal strip is used for the signal cable, which is easily accessible, then this can be implemented (instead of the EB1 module) using the SCI 1 or SCI 2 interface modules (however these are more expensive). These can be snapped onto a mounting rail at any accessible location in a cabinet, refer to Section 2.2.3.

Terminal expansion module EB2 with the Order Nos.

6SE7090-0XX84-0KC0 as spare part (only module)

6SX7010-0KC00   as mounting set for retrofit (module, connector as well as small parts for installation and mounting)

This allows analog and digital I/O on the CUVC module to be expanded by:
- 2 digital inputs
- 4 relay outputs, 1 changeover contact + 3 NO contacts
- 1 analog input with differential amplifier input
- 1 analog output

All of the I/O, with the exception of the relay outputs, are referred to the electronics ground, and are therefore **not** electrically isolated (non-floating). The terminal assignment is illustrated in Catalog DA65.10 (1998/99), Page 6/60-61. The assignment of the I/O with specific signals can be defined using appropriate parameterization; refer to the information/data in the Compendium.

Comment: If the terminals on the EB1 are to be used, then the associated signal cable must be fed up to the Electronics box. However, if the customer requests that a terminal strip is used for the signal cable, which is easily accessible, then this can be implemented (instead of the EB1 module) using the SCI 1 or SCI 2 interface modules (however these are more expensive). These can be snapped onto a mounting rail at any easily accessible location in a cabinet, refer to Section 2.2.3.

General information on EB1/2:

The analog inputs of the expansion modules EB1 or EB2 are read-in using the lowest possible cycle time, namely sampling time t_0 (factory setting 1.2 ms, refer to P357). This means that they are read-in faster than the analog inputs on the CUVC module with their cycle time of 5 ms (= 4 x t_0).

2.2.2 Additional modules in the Electronics box (maximum 2)

Communications module SCB1 with Order No. 6SE7090-0XX84-0BC0

This serial communications module includes a peer-to-peer link via fiber-optic cable. This can be used to implement a fast setpoint cascade to adjacent drives (distance: ≤ 10 m); the control commands can be output to all of the nodes (stations). The fiber-optic cable fulfills the requirements in accordance with VDE 0160 regarding protective separation and they represent an especially noise-immune link EMC. Further, the module has a serial I/O system, whereby analog and binary I/O signals can be processed, also via fiber-optic cable. Thus, in conjunction with the SCI 1 and SCI 2 interface modules, additional terminals are available for sufficient analog and digital I/O.
The necessary fiber-optic cables are supplied with the modules, and do not have to be separately ordered.
The SCB1 module should be used, if
- a terminal expansion is required with additional I/O,
- a fast peer-to-peer link is to be established over distances up to max. 10 m
  using noise-immune fiber-optic cables.

For more detailed information, refer to Catalog DA65.10 (1998/99), Page 6/62.

Communications module SCB2 with Order No. 6SE7090-0XX84-0BD1

This serial communications module includes a peer-to-peer link via an RS485 interface. This allows a fast setpoint cascade to be implemented to adjacent drives (distance: ≤ 200 m); setpoints can be sent to all of the nodes (stations).
A floating RS 485 interface with USS protocol can be alternatively used. In this case, it is possible to control and visualize (HMI functionality) a drive group consisting of up to 31 nodes.
The SCB2 module is mainly intended for floating communications using the USS protocol as well as interface to a third-party bus gateway.

For additional information, refer to Catalog DA65.10 (1998/99), Page 6/63.

Technology module T100 with Order No. 6SE7090-0XX87-0BB0

Technological functions can be implemented at a favorable price using this basic technology module. Applications such as closed-loop tension-, pressure-, quantity-, dancer roll controls and similar closed-loop control systems can be configured using closed-loop control-, logic- and arithmetic block which can be freely inter-connected.
A high-speed USS interface as well as fast peer-to-peer link to adjacent drives can be implemented using RS485 interfaces. Further, additional analog and binary I/O can be used via terminals on the front panel of the module.
8 digital inputs, 5 digital outputs, 5 analog inputs, 2 analog outputs.

If technological functions are to be implemented using the technology module T100, then the following documentation can be used:

	Order No.:
Instruction Manual, Hardware	6SE7080-0CX87-0BB0
Manual for the MS100 Software Module "Universal drive"	6SE7080-0CX84-0BB1

For additional information, refer to Catalog DA65.10 (1998/99), Page 3/65 (ordering data) and Page 6/47-49 (description and terminal assignment).

Comment: The freely-interconnectable function blocks on the T100 are also now available on the CUVC control module, i.e. in the basic drive software. Thus, when a specific technological application has to be implemented, the question arises: Does a T100 technology module have to be used, or are the freely-interconnectable function blocks in the basic drive converter software adequate? An essential criterion when answering this question is how many function blocks are used and how fast do they have to be processed.

The following is valid for the T100:
  All of the function blocks can be executed in a 2 ms cycle, so that, for example, a new actual setpoint can be transferred every 2 ms.

For the function blocks in the basic drive converter software on the CUVC, the following is valid:
  The processing cycle the complete software functions is, as standard 1.2 ms, of which approx. 0.8 ms are used to process the standard functions. To process free function blocks per time sector, only approximately 0.2 ms are available. If many free function blocks are used, then they must be processed, under certain circumstances, in several time sectors, which appropriately delays the processing of these technological functions. Processing times can, under certain circumstances, extend up to 20 ms or higher. Thus, it must be decided on a case-for-case basis, whether this delayed processing time can be tolerated.

The following can be considered as a rough rule of thumb: If a T100 technology board was used up until now, and a large proportion of the free-assignable function blocks were used and timing is critical, then it is almost certain that a T100 will be required.

Technology module T300

This allows comprehensive technological functions to be processed in the drive converter. In addition to customer-specific applications, which can be individually configured using Struc G PT (graphic) or Struc L PT (in list form), there are standard software packages such as axial winders, positioning, synchronous angular operation etc. A fast peer-to peer connection can be implemented to adjacent drives via an RS485 interface.

Further, additional analog and digital I/O can be used:
16 binary inputs, 8 binary outputs, 7 analog inputs, 4 analog outputs.

Comment: If the analog and digital I/O are to be used, then an SE300 terminal block is required which can be snapped onto an existing mounting rail. Dimensions: W x H x D = 224 x 60 x 60 mm. The terminal block and all of the associated feeder cables are included in the scope of supply of the technology module.
Refer to Catalog DA65.10 (1998/99), Page 3/66 (ordering data) and 6/50-56 (description and terminal assignment) for detailed explanations on T300.

Technology module T400

The T400 technology module is a new development, which, over the long term, will replace technology module T300. It offers the following advantages and differs from the T300 as follows:

	T400	T300	Advantage for T400
Resolution of the process data	32 bit	16 bit, 32 bit when specially configured	Higher resolution
Cycle time	500 μs typical, 200 μs minimum	> 1 ms	Higher dynamic performance
Encoders which can be evaluated	2 incremental encoders or 2 absolute value encoders (SSI, EnDat)	2 increment encoders	Can be universally used
I/O	5 analog inputs 6 analog outputs 8 digital outputs 4 bidirectional I/O	7 analog inputs 4 analog outputs 8 digital outputs 16 digital inputs	No terminal block SE300 required, signal cable can be directly connected to the T400
Configuring tools	STRUC L PT, STRUC G PT	SIMATIC STEP7/CFC	Compatible to SIMATIC S7

Refer to Catalog DA65.10 (1998/99), Page 6/57 and Catalog DA99 for detailed information on the T400.

TSY tachometer and synchronizing module with Order No. 6SE7090-0XX84-0BA0

This module includes an input for the rotary pulse encoder to digitally sense the speed. HTL logic signals (15 V logic) can be processed. (When using the CUVC control module, this function is already included as standard.)
Further, the module includes a synchronizing device which allows a drive converter to be synchronized to another, i.e. to the same output voltage, same phase position of the output voltage, for use, e.g. for drive converters for textile applications. Further, the TSY module can be used to synchronize the drive converter output to the line supply voltage. This can be used for example for bumpless transfer of motors to the line supply; also refer to the data in Sections 6.2 and 6.3 of the Engineering Manual.

Refer to Catalog DA65.10 (1998/99), Page 6/66 for additional data and recommended circuits.

2.2.3 Modules – snapping onto a mounting rail

In addition to these electronic modules, the following adaption modules can also be used. These are not accommodated in the Electronics box, but must be snapped onto mounting rails in a cabinet. These are:

TV1 to TV5 isolating amplifiers
The following is valid for the analog I/O of the CUVC control board as well as the T100, T300, T400 technology modules: The reference potentials are at electronics ground and are therefore connected with the drive converter ground, i.e. grounded. Setpoints from higher-level automation devices such as SIMATIC or SIMADYN D can be directly connected. Isolating amplifiers for analog inputs/outputs aren't absolutely required, but can be provided to suppress noise.
Isolating converters must be provided for the analog outputs of the CUVC control module if they are connected up through a distance of

- more than 4 m   when used as 0 ... $\pm$ 10 V signals,
- more than 100 m   when used as 0 ... 20 mA signals.

The following isolating amplifiers for analog I/O are available:

Des.	Order No.	Comment	Data I/O
TV1	6SX7010-0AC00	For analog inputs and outputs	0 to $\pm$ 10 V / 0 to $\pm$ 10 V
TV2	6SX7010-0AC16	For analog inputs and outputs	4 to 20 mA / 0 to 10 V
TV3	6SX7010-0AC02	For analog inputs	0 to $\pm$ 20 mA / 0 to $\pm$ 10 V
TV4	6SX7010-0AC03	For analog outputs	0 to $\pm$ 10 V / 0 to $\pm$ 20 mA
TV5	6SX7010-0AC04	For analog inputs and outputs	0 to + 10 V / 4 to 20 mA

Refer to the following diagram regarding the connections for the I/O of this isolating amplifier. The 24 V DC power supply voltage is floating, both with respect to the inputs as well as the outputs. The internal drive converter electronics power supply can be used for this purpose.

Strom-
versorgung

```
                    6        1
                  ┌─────────────┐
                    0 V    24 V
              5   │ +         + │   2
                  │      ◁      │
   Eingang        │             │        Ausgang
              4   │ -         - │   3
                  └─────────────┘
```

((Bild: Power supply, Input, Output))
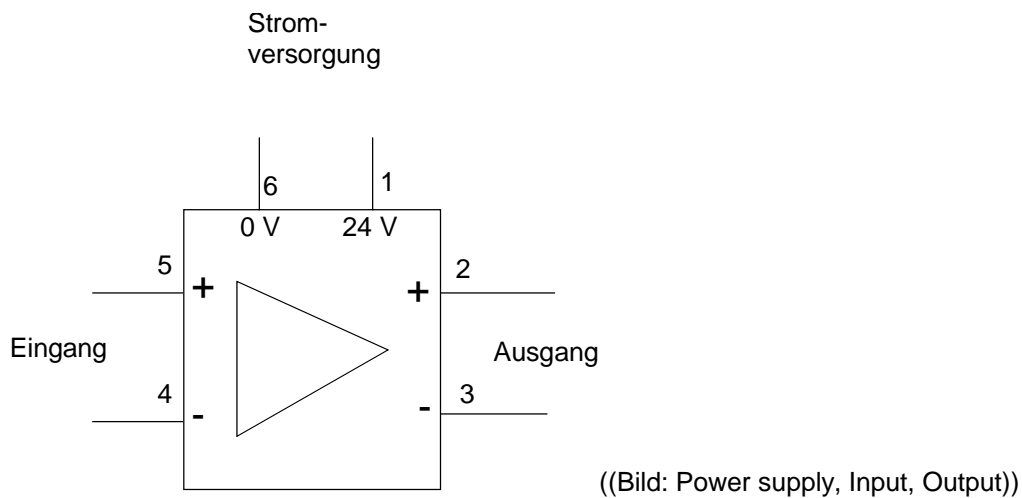
Terminal assignments of isolating amplifier TV1 to TV5

Digital tachometer interface DTI with Order No. 6SE7090-0XX84-3DB0

This adaption board includes inputs for a rotary pulse encoder for digital speed sensing. The encoder signals are processed, floating via opto coupler. The module is required,

- if in addition to signals with HTL logic (11 - 30 V), TTL logic signals (5 V) must be processed,
- if differential inputs are provided for effective noise signal suppression for signal cables more than 200 m long.

The module dimensions are: H x W x D = 95 x 160 x 48 mm.

An external 24 V power supply is required for this module. The power is oriented to the current demand of the encoder used. We recommend a 0.3 A power supply module (option).

Refer to Catalog DA65.10 (1998/99), Pages 6/67 and 6/68 for terminal assignments and connection diagrams for DTI.

The terminals of the DTI module are shown in the following table. Conductors with cross-sections from 0.5 to 2.5 mm² (inputs) and 0.5 to 1.5 mm² (outputs to CU2 or TSY) can be connected at the terminals.

Table: Terminals of the DTI digital tachometer adaptation module

Terminal	Function	Information
X401:		Terminals for 5 V TTL tachometer
1	Reference potential M	
2	Track A	
3	Track A, inverted	
4	Track B	
5	Track B, inverted	
6	Zero pulse	No evaluation
7	Zero pulse, inverted	No evaluation
8	Monitoring signal	No evaluation
9	Monitoring signal, inverted	No evaluation
10	5 V power supply	
X402:		Terminals for 15 ... 24 V HTL tachometer
1	Reference potential M	
2	Track A	
3	Track A, inverted	
4	Reference potential M	
5	Track B	
6	Track B, inverted	
7	Reference potential M	
8	Zero pulse	No evaluation
9	Zero pulse, inverted	No evaluation
10	Reference potential M	
11	Monitoring signal	No evaluation
12	Monitoring signal, inverted	No evaluation
13	Reference potential M	
14	15 V power supply	
X403:		Outputs to the CU2- or TSY module
1	Reference potential M	
2	Track A	
3	Track B	
4	Zero pulse	No evaluation
5	Monitoring signal	No evaluation
6	15 V power supply	
X404:		External 24 V power supply
1	Reference potential M24 external	
2	Power supply voltage P24 ext.	
3	Reference potential M24 PS T	
4	Supply voltage P24 PS T	
X405:		For future applications
1	Reference potential M5 PS T	Outputs can presently be used
2	Track A	to adapt the signal level of an HTL
3	Track A, inverted	tachometer to a 5 V TTL signal level
4	Track B	
5	Track B, inverted	
6	Zero pulse	
7	Zero pulse, inverted	
8	5 V power supply	
X80	Grounding point / screen ground	With cable lug for M4 screw
X81	Grounding point / screen ground	With cable lug for M4 screw

Analog tachometer interface ATI with Order No. 6SE7090-0XX84-3DF0

This adaption module is required for analog tachometers for tachometer voltages > 10 V up to max. 300 V. The speed actual value can be set coarsely and finely via potentiometers. The module dimensions are: H x W x D = 35 x 38 x 60 mm.
The terminals are suitable for conductor cross-sections of

- 0.2 to 4 mm² for solid conductors and
- 0.2 to 2.5 mm² for flexible conductors.

Refer to Catalog DA65.10 (1998/99), Page 6/66ATI for the terminal assignments and typical circuit configurations for ATI.

Comments:

DC tachometers should only be used, if customers expressly require these, or a motor with DC tachometer is too be used. For applications with DC tachometer, if possible, only use the control version "Speed control with V/Hz characteristic".

If a speed actual value encoder is required, a rotary pulse encoder is generally recommended in order to avoid offset- and calibration problems.

A rotary pulse encoder is required for high speed accuracies ≤ 1 % and/or high control quality, especially around zero speed.

Please note that 1LA5 motors are prepared so that a rotary pulse encoder can be mounted, but a DC tachometer cannot be mounted.

SCI1 interface module with Order No. 6SE7090-0XX84-3EA0
SCI2 interface module with Order No. 6SE7090-0XX84-3EF0

If, for certain customer requirement, the terminals on the CUVC basic electronics module are not sufficient, then a terminal expansion can be realized using the SCI 1 and/or SCI 2 interface modules. The following are available:

For SCI 1:   10 digital inputs with 24 V, via opto coupler,
              4 relay outputs, load capacity up to 250 V AC, 100 V DC, changeover contact,
              3 relay outputs, load capacity up to 250 V AC, 100 V DC, NO contact,
              1 digital output, 24 V DC,
              3 analog inputs, 0 to $\pm$ 10 V or 0 to $\pm$ 20 mA or 4 to 20 mA
              3 analog outputs, 0 to $\pm$ 10 V or 0 to $\pm$ 20 mA or 4 to 20 mA.

For SCI 2:   16 digital inputs with 24 V, via opto coupler,
              4 relay outputs, load capacity up to 250 V AC, 100 V DC, changeover contact,
              3 relay outputs, load capacity up to 250 V AC, 100 V DC, NO contact,
              5 digital outputs, 24 V DC.

In addition to one of these modules, a total of 2, i.e. 2 x SCI 1 or 2 x SCI 2 or SCI 1 + SCI 2 can be used. The connection to the basic drive converter electronics is established via fiber-optic cable to the SCB 1 communications module. This therefore provides "protective separation" to the drive converter in accordance with VDE 0160.
The SCI 1 or SCI 2 modules each require an external 24 V power supply, 24 V DC, 1 A.
If one or several SCI 1 or SCI 2 are used, then in addition, an SCB 1 is required. The fiber-optic cables are supplied with the modules and do not have to be ordered separately.
The module dimensions are:
SCI 1: H x W x D = 95 x 300 x 80 mm,
SCI 2: H x W x D = 95 x 250 x 80 mm.

The terminal assignments on the SCI 1 and SCI 2 modules are shown in the following tables. The significance is as follows, as for the terminals on the CUVC basic electronics module:

Digital inputs:
- H signal: +24 V, e.g. the voltage available at terminal -X427:A1 is switched-through to the digital input.
- L signal: 0 V (= reference potential M) is connected to the digital input or is left open-circuit.

Digital outputs:
- H signal: Relay pulled-in for a relay output or 24 V DC for a transistor output
- L signal: Relay dropped-out, for a relay output or 0 V DC for a transistor output

Table 2.3.7 terminal assignment of SCI 1

Terminal	Type	Signal level	Comment
X427			
A1	Power supply	+24 V DC	Auxiliary voltage for digital inputs
A2	Reference potential	M	Auxiliary voltage for digital inputs
A3	Digital input 6		
A4	Digital input 7		
A5	Digital input 8		
A6	Digital input 9		
A7	Digital input 10		
A8	Reference point		Reference point for digital inputs 6 - 10
A9	Reference potential	M	Auxiliary voltage for digital inputs
A10	Power supply	M	Connection for ext. power supply
A11	Power supply	M	Connection for ext. power supply
B1	Digital output 8	+24 V	Driver voltage for transistor
B2	Digital output 8		Collector output
B3	Digital input 1		
B4	Digital input 2		
B5	Digital input 3		
B6	Digital input 4		
B7	Digital input 5		
B8	Reference point		Reference point for digital inputs 1 - 5
B9	Power supply	+24 V DC	Auxiliary voltage for digital inputs
B10	Power supply	+24 V DC	Connection for ext. power supply.
B11	Power supply	+24 V DC	Connection for ext. power supply
X428			
1	Power supply	+10 V stab	For setpoint input, max 5 mA
2	Power supply	- 10 V stab	For setpoint input, max 5 mA
3	Analog input 1	0 to ± 10 V	Voltage input
4	Reference potential		For analog input 1
5	Analog input 1	0/4 to ± 20 mA	Current input, 250 Ω load resistor
6	Analog input 2	0 to ± 10 V	Voltage input
7	Reference potential		For analog input 2
8	Analog input 2	0/4 to ± 20 mA	Current input, 250 Ω load resistor
9	Analog input 3	0 to ± 10 V	Voltage input
10	Reference potential		For analog input 3
11	Analog input 3	0/4 to ± 20 mA	Current input, 250 Ω load resistor
12	Analog output 1	0 to ± 10 V	Max. 5 mA
13	Reference potential		For analog output 1
14	Analog output 1	0/4 to ± 20 mA	Max. 500 Ω load resistor
15	Analog output 2	0 to ± 10 V	Max. 5 mA
16	Reference potential		For analog output 1
17	Analog output 2	0/4 to ± 20 mA	Max. 500 Ω load resistor
18	Analog output 3	0 to ± 10 V	Max. 5 mA
19	Reference potential		For analog output 1
20	Analog output 3	0/4 to ± 20 mA	Max. 500 Ω load resistor

Table 2.3.7 Terminal assignment for SCI 1 (continued)

Terminal	Type	Signal	Comment
X429			
1	Binary output 1	NO contact	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
2	Binary output 1	NO contact	or　　　　250 V AC, 8 A
3	Binary output 2	NO contact	Load capacity with 24 V - 100 V, 10 mA – 2.4 A
4	Binary output 2	NO contact	or　　　　250 V AC, 8 A
5	Binary output 3	NO contact	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
6	Binary output 3	NO contact	or　　　　250 V AC, 8 A
7	Binary output 4	Changeover contact: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
8	Binary output 4	Ch. cont.: NC cont.	or　　　　250 V AC, 8 A
9	Binary output 4	Ch. cont.: NO cont.	
10	Binary output 5	Ch. cont: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
11	Binary output 5	Ch. cont.: NC cont.	or　　　　250 V AC, 8 A
12	Binary output 5	Ch. cont.: NO cont.	
13	Binary output 6	Ch. cont: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
14	Binary output 6	Ch. cont.: NC cont.	or　　　　250 V AC, 8 A
15	Binary output 6	Ch. cont.: NO cont.	
16	Binary output 7	Ch. cont: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
17	Binary output 7	Ch. cont.: NC cont.	or　　　　250 V AC, 8 A
18	Binary output 7	Ch. cont.: NO cont.	

((Bild: P24 V supply, internal or external, Output: Driver voltage, Output, Load, Reference potential))

SCI 1

P24 V Versorgung
intern oder extern

Ausgang:
Treiberspannung

Ausgang

Last

Bezugspotential

Digital output using transistors
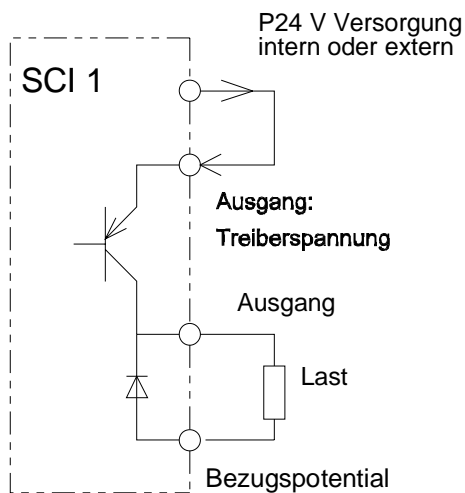
Transistor output as binary output:
The transistor outputs are available as driver outputs, where both the emitter- as well as the connector connections are fed out to terminals. The emitter connections can either be connected internally or to an external P24 V DC driver voltage. The (actual) collector output switches the connected load with respect to the reference potential. Refer to the example in the adjacent diagram.

The maximum permissible output current for these transistor outputs are:
20 mA (SCI 1) or 10 mA (SCI 2) for an internal driver voltage power supply, 100 mA for an external driver voltage power supply.

Table 2.3.2.8 terminal assignment for SCI 2

Terminal	Type	Signal level	Comment
X437			
A1	Digital input 9		
A2	Digital input 10		
A3	Digital input 11		
A4	Digital input 12		
A5	Digital input 13		
A6	Digital input 14		
A7	Digital input 15		
A8	Digital input 16		
A9	Reference potential	M	Reference point for digital inputs 6 - 16
A10	Power supply	M	Auxiliary voltage for digital inputs
A11	Power supply	M	Connection for ext. power supply
A12	Power supply	M	Connection for ext. power supply
B1	Digital input 1		
B2	Digital input 2		
B3	Digital input 3		
B4	Digital input 4		
B5	Digital input 5		
B6	Digital input 6		
B7	Digital input 7		
B8	Digital input 8		
B9	Reference potential	M	Reference point for digital inputs 1 - 8
B10	Power supply	+24 V DC	Auxiliary voltage for digital inputs
B11	Power supply	+24 V DC	Connection for ext. power supply.
B12	Power supply	+24 V DC	Connection for ext. power supply
X438			
A1	Digital output 11	+24 V	Driver voltage for transistor
A2	Digital output 11		Collector output
A3	Digital output 12	+24 V	Driver voltage for transistor
A4	Digital output 12		Collector output
A5	Power supply	P 24 V	Internal power supply for digital outputs
A6	Power supply	M	Internal reference voltage for digital outputs
B1	Digital output 8	+24 V	Driver voltage for transistor
B2	Digital output 8		Collector output
B3	Digital output 9	+24 V	Driver voltage for transistor
B4	Digital output 9		Collector output
B5	Digital output 10	+24 V	Driver voltage for transistor
B6	Digital output 10		Collector output
X439			
1	Digital output 1	NO contact	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
2			or 250 V AC, 8 A
3	Digital output 2	NO contact	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
4			or 250 V AC, 8 A
5	Digital output 3	NO contact	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
6			or 250 V AC, 8 A
7	Digital output 4	Changeover contact: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
8		Ch. cont.: NC cont.	or 250 V AC, 8 A
9		Ch. cont.: NO cont.	
10	Digital output 5	Ch. cont.: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
11		Ch. cont.: NC cont.	or 250 V AC, 8 A
12		Ch. cont.: NO cont.	
13	Digital output 6	Ch. cont.: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
14		Ch. cont.: NC cont.	or 250 V AC, 8 A
15		Ch. cont.: NO cont.	
16	Digital output 7	Ch. cont.: Common	Load capacity with 24 V - 100 V DC, 10 mA – 2.4 A
17		Ch. cont.: NC cont.	or 250 V AC, 8 A
18		Ch. cont.: NO cont.	

2.3 Operator control and visualization

The drive and inverter can always be controlled and visualized (HMI) via:
- the operator control and parameterization unit for local operator control,
- the control terminal strip for (conventional) operator control from the control room or remote control,
- communications via the serial interfaces.

These three possibilities will now be investigated in more detail.

2.3.1 Operator control via the local operator panel

Two operator panels are available,
- the standard operator panel: **P**ara**m**eterization **U**nit PMU,
- the user-friendly operator panel OP1S as option.

The converter and inverter always include the **parameterization unit PMU** as standard operator panel, refer to Fig. 2.3.1.1.
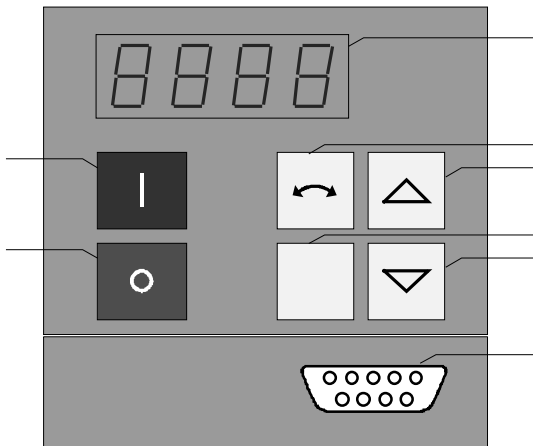
Fig. 2.3.1.1 Parameterization unit PMU as standard operator panel

The following functions can be executed using the parameterization unit PMU:
- the drive can powered-up and powered-down using the On/Off key,
- parameterization using the P- and the raise/lower key,
- internal setpoints can be entered and changed,
- reversing via the reversing key,
- setpoints/actual values as well as parameters and parameter values can be read on the four 7-segment displays.

Further, the parameterization unit PMU also has a sub-D miniature connector (X300).
This can be used to
- either connect a user-friendly OP1S operator panel,
- or to implement a serial connection, e.g. using SIMOVIS via a PC.

The USS protocol (Universal Serial Interface) is implemented in this basic drive converter interface SST1. Refer to Section 2.3.3. Refer to the following section for more detailed information about the serial interfaces.

The **user-friendly operator panel OP1S** as option, Fig. 2.3.1.2 has the same function keys as the parameterization unit PMU and the same functions can be implemented. Beyond this, OP1 also includes:

- LED displays for operator control and faults
- keys for inching (jogging)
- numerical keypad to directly select and change parameters
- display with 4 * 16 characters to display operating statuses, setpoints/actual values as well as parameters and parameter values.

The OP1S user-friendly operator panel can be ordered under Order No. 6SE7090-0XX84-2FK0. The OP1S can be located and mounted as follows:

- it can be directly inserted on the parameterization unit PMU (for higher-rating units from drive converter size E, this is only permissible for service purposes – not continuously!),
- it can be connected to the parameterization unit PMU via a cable, max. length 5 m (Order No. 6SX7010-0AB05) at the sub-D miniature connector,
- it can be connected via a cable, maximum 200 m long, either to the parameterization unit PMU or the control terminal strip (in this case an additional 5 V DC power supply is required! A commercially available simple power supply is suitable, $\geq$ 400 mA).

Fig. 2.3.1.2 User-friendly operator panel OP1S

With this last possibility, to connect the OP1 operator panel through a cable up to 200 m long, user-friendly remote control is possible, e.g. from a central control room.

Communications with the OP1 is established using the USS interface. As this is bus-capable, several drive converters can be addressed and controlled using one OP1S and the appropriate bus connections.

For normal applications, the parameterization unit PMU, provided in the basic drive, is adequate for start-up (commissioning) and service. It must be decided on a case-for-case basis whether the user-friendly OP1S operator panel is required. This is dependent, among other things, on what expectations the customer has regarding operator control and visualization (HMI). If several drives or inverters are to be controlled, then it makes sense to consider using a user-friendly OP1S operator panel. When required for commissioning or for operator control and visualization, the OP1S can be inserted at the individual drive units. This can be realized online.

2.3.2 (Remote) operator control via the control terminal strip on the CUVC control module

The type and number of the inputs/outputs provided as standard on the CUVC are shown in the following Table 2.3.1.

Type	No.	Comments
Digital I/O	4	Bi-directional I/O, should be parameterized as input or output
Digital inputs	3	24 V DC,
Analog inputs	2	0 - ± 10 V or 4 - 20 mA (250 Ω load resistor)
Analog outputs	2	0 - ± 10 V, max. 5 mA or 4 - 20 mA (250 Ω load resistor)
Input for temperature sensor	1	To sense the motor temperature via a KTY84 sensor or PTC thermistor
Input for digital tachometer	1	15 V signal level
RS485 interface	1	5 terminals, as an alternative to interface X300 on the parameterization unit PMU

Table 2.3.1 I/O available on the standard CUVC terminal strip

Details and terminal assignment with factory pre-assignments, refer to Catalog DA65.10 (1998/99), Pages 6/24 to 6/27.

If these inputs/outputs are not sufficient, then additional digital and analog I/O are available via the EB1 and EB2 expansion modules as well as via the serial I/O modules SCI 1 and SCI 2 in conjunction with the serial SCB1 communications module. For more detailed information on the terminal connections, refer to the previous Section 2.2: Expanded functionality using supplementary modules.

Connectors are provided for the standard control terminals, which are supplied loose with the drive converters. The incoming signal cables should be connected to the terminals of this connector. The connectors themselves are then plugged into the associated mating connector on the CUVC control module, as is shown in detail in the Instruction Manual.

In order to maintain EMC (Electromagnetic Compatibility) screened control cables must be used which are routed separately away from the power cables, with a minimum clearance of 20 cm between them. The screen must be connected to ground at both ends. The information, installation instructions and mounting specifications, provided in the Instruction Manual must be observed.

Cables/conductors with cross-sections from 0.14 mm² to 1.5 mm², finely-stranded, with end sleeves can be connected to the connectors. For the signal cables we recommend multi-core, screened cables with a cross-section of 0.5 mm².

At least 2 screen clamps and 4 cable ties are provided loose so that the signal cables can be correctly retained and routed.

Comments regarding the use of analog and digital inputs and outputs.

The reference potentials of the **analog and digital inputs/outputs** are at electronics ground and are therefore connected with the drive converter ground, i.e. grounded. Setpoint input signals and control commands for the digital inputs of higher-level automation units such as SIMATIC or SIMADYN D can be directly connected. Isolating amplifiers are not required, but however can be provided to suppress noise signals.

Isolating converters should be provided for **analog outputs** if they are connected-up over longer distances

- than 4 m   when used as 0 ... ± 10 V signals
- than 100 m   when used as 0 ... 20 mA signals.

The inputs/outputs can be used for all setpoints/actual values as well as for all functions, which are available or accessible via binectors or connectors. There are pre-assigned values, as specified in Catalog DA65.10 (1998/99), Pages 6/24 to 6/27.

Otherwise, the inputs/outputs can be individually assigned using the appropriate parameterization. The possibilities of assigning inputs/outputs is provided in the binector- and connector lists of the Compendium. The most important signals for assigning the inputs/outputs are shown in the following tables.

For the digital inputs this means:

- H signal: +24 V,   e.g. the voltage available at terminal -X101:1 is switched-through to the digital input.

- L signal: 0 V ,   e.g. the voltage available at terminal -X101:2 is connected to the digital input or is left open-circuit.

Signals available for digital inputs

Signal	Signal level	Parameter (Source ...)	Comment
ON/OFF1 command	H: On L: Off1 (Stop)	554	Power-off means that the drive decelerates along the down ramp and is powered-down at standstill
OFF 2	H: Run L: Off2	555, 556, 557	Pulses are inhibited and the drive is immediately powered-down (before first being decelerated down to zero speed)
OFF 3	H: Run L: Off3	558, 559, 560	Fast stop: Braking along the current limit (prerequisite: the drive has braking capability) and then powered-down
Inverter enable	H: Inverter enable L: Inverter inhibit	561	If this is not used, the inverter is automatically enabled via a sequence contr.
RFG enable	H: RFG enable L: RFG inhibit	562	Enables the ramp-function generator and sets the RFG output to "Zero". If this is not used, it is identical with the inverter enable
Start RFG	H: RFG enable L: RFG hold	563	Enable or stop ramp-function generator
Setpoint enable	H: SW enable L: SW inhibit	564	Enables the setpoint or sets the setpoint to zero; the actual setpoint is fed through the RFG (delayed). If this is not used, it is identical to inverter enable.
Acknowledge	H: Acknowledge L: Run	565, 566, 567	Acknowledgement is realized at the changeover from an L → H signal
Jogging 1, 2	H: Inching (jogging) On L: Inching (jogging) Off	568, 569	Inching (jogging) with the first or second inching (jogging) setpoint
Select clockwise rotating field	HL: Clockwise rotating field LH: Counter-clockwise rot. field	571, 572	2 inputs should be assigned "Select clockwise rotating field " and "Select counter-clockwise rotating field "
Select motorized potentiometer raise/lower	HL: Motor. pot. ↑ LH: Motor. pot. ↓	573, 574	2 inputs should be assigned with "Select motorized potentiometer raise " and "Select motorized potentiometer lower"
Ext. fault 1	H: No fault L: Fault	575	
Ext. fault 2	H: No fault L: Fault	586	This only becomes effective after pre-charging has been completed, suitable for monitoring the braking unit
Ext. alarm 1,2	H: No alarm L: Alarm	588, 589	
Enable techn. controller	H: Enable	U350	Inhibits or enables the technology controller (as free function block)

Table 2.3.2: Functions available for digital inputs

Comment: The "OFF 2", "OFF 3" and "Acknowledge" input signals can be effective from up to 3 different sources, independently and with the same priority. For example, with suitable parameterization, the acknowledge command can be received from the operator panel as well as via a digital input via a terminal or via a serial interface.

Signal	Signal level	Parameter (Source ...)	Comment
Changeover, function data set		576, 577	Possible to toggle between 4 function data sets (2 inputs are required). Can be changed over four times online or when ready: • up to 12 fixed setpoints • main- and supplementary setpoints • torque- and current limits • ramp-function generator data • characteristic data, technology controller • characteristic data, user-friendly RFG • characteristic data, wobble generator • 18 suppl. fixed setpoints for free blocks • times for 7 timers • positions for cam switching unit
Changeover, motor data set		578, 579	Possible to toggle between 4 motor data sets (2 inputs are required). Can be changed four times (only) when ready: • motor type and motor data • control version (V/Hz characteristic, vector control) • control parameters • characteristic data for the pulse encoders • motor temperature monitoring type • parameterizing WEA, KIP/FLN, restart-on-the-fly, droop, brake control • gating unit parameters such as pulse frequency, modulation depth, SIMOSOUND
Changeover, BICO data set		590	Possible to changeover between 2 BICO data sets, e.g. for changeover [local/remote control]
Synchronization	H: Syncr. enabled L: Syncr. inhibited	582	
Restart-on-the-fly	H: Restart-on-the fly-enabled L: Restart-on-the fly-inhibited	583	
Droop selection	H: Droop enabled L: Droop inhibited	584	
Controller enable	H: Controller enabled L: Controller inhibited	585	For speed controllers. For controller inhibit: no-load current flows in the motor, torque = zero. This is only possible with a speed actual value encoder, it is only practical for (vector)speed control.
Changeover, master/slave drive	H: Slave drive L: Master drive	587	Master drive: with closed-loop speed control, Slave drive: with closed-loop torque control
Main contactor checkback signal	H: MC closed L: MC open	591	

Table 2.3.2: Available functions for digital inputs (continued)

Signals available for digital outputs

A selection of messages/signals, which are available for digital outputs, are shown in the following table. The binector No. in brackets signify the same signal, but inverted. Additional signals are listed in the Compendium (binector list).

Message	Signal	Binector No.	Comment
MC control	H: Close MC	B 0124 (B 0125)	Controls a main contactor
Fault	H: No fault L: Fault	B 0106 (B 0107)	Group fault
Run	H: Run	B 0104 (B 0105)	
Ready to power-up	H: Ready to power-up	B 0100 (B 0101)	
Ready	H: Ready	B 0102 (B 0103)	Ready means, that: - drive converter is powered-up, - DC link voltage is present, - but the inverter is (still) inhibited.
OFF2	H: No OFF2 L: OFF2 present	B 0108 (B 0109)	Displays whether an OFF2 command is present
OFF3	H: No OFF3 L: OFF3 present	B 0110 (B 0111)	Displays whether an OFF3 (fast stop) command is present
Power-on inhibit	H: No power-on inhibit L: Power-on inhibit	B 0112 (B 0113)	Power-on inhibit available, if - fault present, - OFF command(s) present, - no (external) power supply available
Alarm	H: No alarm L: Alarm	B 0114 (B 0115)	Group alarm
Setpoint-actual value deviation	H: No deviation L: Deviation	B 0116 (B 0117)	Signal available, if an adjustable setpoint-actual value difference (P517) of the frequency/speed is present over a longer period of time (P518). The signal disappears when the setpoint-actual value difference has become smaller.
Comparison frequency / speed reached	H: f > compar.frequ L: f < compar.frequ	B 0120 (B 0121)	This signal indicates whether the frequency or speed lies above or below an adjustable fixed value (P512 with P513 as hysteresis), e.g. this can be used as a standstill signal.
Fault, undervoltage	H: No fault L: Fault	B 0122 (B 0123)	Signals DC link undervoltage
RFG active	H: RFG active L: RFG held	B 0126 (B 0127)	
Clockwise / counter-clockwise rotation	H: Clockwise rotating field L: Counter-clockwise rot. field	B 0128 (B 0129)	Signals whether the setpoint is requesting clockwise- or counter-clockwise rotating field
KIP / FLN active	H: KIP active	B 0130 (B 0131)	Indicates whether the kinetic buffering or flexible response function is active or the drive is in the standard mode.
Restart-on-the-fly active	H: Restart on the fly active	B 0132 (B 0133)	Indicates whether the restart-on-the-fly function is enabled, i.e. the drive converter is powered-up onto a motor which is still rotating.
Sync. reached	H: Sync. reached	B 0134 (B 0135)	Indicates whether synchronization has been achieved when synchronizing.
Alarm Sync. error	H: No alarm L: Alarm	B 0160 (B 0161)	Alarm, that synchronizing is not functioning.

Table 2.3.2.3: Functions available for digital outputs

Overspeed	H: No overspeed L: Overspeed	B 0136 (B 0137)	Indicates whether the frequency or speed lies above a selectable maximum value (P452 for RDF, P453 for LDF).
Fault, ext.1	H: No fault L: Fault	B 0138 (B 0139)	
Fault, ext.2	H: No fault L: Fault	B 0140 (B 0141)	
Alarm, external	H: No alarm L: Alarm	B 0142 (B 0143)	
Alarm I²t converter	H: No alarm L: Alarm	B 0144 (B 0145)	Signal is received if the drive converter I²t monitoring responds.
Fault, overtemp. converter	H: No fault L: Fault	B 0146 (B 0147)	Responds for a heatsink overtemperature condition, sensed using the temp. sensor
Alarm, overtemp. converter	H: No alarm L: Alarm	B 0148 (B 0149)	Refer to the previous comment.
Alarm, overtemp. motor	H: No alarm L: Alarm	B 0150 (B 0151)	Assumes that a motor is being used with PTC thermistors or KTY84 temperature sensors, which are evaluated in the drive converter.
Fault, overtemp. motor	H: No fault L: Fault	B 0152 (B 0153)	Refer to the previous comment.
Fault, motor stalled	H: No fault L: Fault	B 0156 (B 0157)	
Bypass contactor closed	H: Bypass contactor closed	B 0158 (B 0159)	This is used to control a bypass contactor (US) when powering-up an inverter on a DC link busbar (after the inverter DC link capacitors have been charged-up).
Pre-charging active	H: Pre-charging active	B 0162 (B 0163)	This signal is used to control a pre-charging contactor when powering-up an inverter on a DC link busbar (to charge-up the inverter DC link capacitors).

Table 2.3.2.3: Functions available for digital outputs (continued)

Analog inputs

The gain of analog inputs can be adapted. They can be used for the following functions:
- main- or speed setpoint
- supplementary frequency- or speed setpoint before and after the ramp-function generator
- supplementary speed setpoint after the ramp-function generator
- speed actual value for the analog tachometer and pulse encoder
- torque setpoint
- supplementary torque setpoints
- acceleration torques for pre-control (K0077)
- torque limiting, motoring and generating
- technological setpoints and actual values for the technology controller in the basic drive software

Additional possible actual value signals can be taken from the Compendium (connector list).

Analog outputs

The analog outputs can be adapted to the requirements by adjusting the offset and gain. All of those values, which are available as connectors, can be considered as output quantities. A small excerpt of the available quantities are specified in the following, which can be connected through to analog outputs. For instance, to display signals in the main control room or to trace optimization runs at start-up (commissioning). Three-phase quantities are always basic fundamental RMS values if not otherwise specified. Please refer to the Compendium (connector list) for other possible additional actual value signals.

Following significance: K xxxx :   Connector as single word, 16 bit

                                KK xxxx :   Connector as double word. 32 bit

Function	Connector
Output voltage (smoothed with 2 s)	K 0021
Output current (smoothed with 2 s)	K 0022
Output (smoothed with 30 ms)	K 0023
Motor torque (smoothed with 30 ms)	K 0024
Motor torque, not smoothed	K 0241
DC voltage (smoothed with 2 s)	K 0025
Motor utilization = motor temperature, calculated from I²t without taking account the cooling conditions	K 0244
Motor temperature for KTY sensor	K 0245
Drive converter temperature	K 0247
Motor speed (smoothed with 2 s)	KK 0020
Speed actual value from the pulse encoder	KK 0091
Frequency/speed actual value at the speed controller input	KK 0148
Frequency/speed setpoint at the speed controller input	KK 0150
Speed setpoint-actual value difference (= speed controller input)	KK 0152
Magnetizing current	K 0182
Active current actual value	K 0184
Output frequency of the Vdmax- or KIP controller	KK 0270
Actual main setpoint for frequency/speed	KK 0071
Act. setpoint at the ramp-function generator input after limiting and freq. suppress.	KK 0072
Frequency/speed setpoint at the ramp-function generator output	KK 0073
Frequency/speed setpoint at the ramp-function generator output after suppl. setp.	KK 0074
Actual setpoint for V/Hz open-loop control or closed-loop speed/frequency control (after limiting)	KK 0075
Torque (=integral)component at the speed/frequency controller output	K 0155
Actual torque setpoint	K 0153
Actual supplementary torque setpoint including pre-control	K 0164
Active current setpoint from the actual torque setpoint after limiting	K 0167
Technology controller output before limiting	K 0585
Technology controller output after limiting	K 0588
Setpoint-actual value difference at the technology controller input	K 0580
Instantaneous value, drive converter output current, phase U	K 0238
Instantaneous value, drive converter output current, phase W	K 0239

Table 2.3.2.4: Functions available for analog outputs

Additional terminals on the T300 and T100 technology modules

If the terminals available on the basic CUVC electronics module are not sufficient for the customers' requirements, and if a T300 or T100 technology module is required anyway for specific technological requirements, then it is possible to use the analog and digital I/O available on these technology modules. They can be partially used for drive converter-specific functions as listed in Tables 2.3.2.2, 2.3.2.3 and 2.3.2.4 and for the analog inputs. This is especially true for the T100 technology module. On the other hand, for the T300 technology module, the inputs/outputs can only be used with some restrictions, or not at all, for drive converter-specific functions.

Caution: If the technology module terminals are used for drive-converter-specific functions, then it should be checked whether there are sufficient terminals and I/O for technological functions. If in doubt, then it will be necessary to expand the number of terminals using EB1 or EB2 or SCI 1 and/or SCI 2 as well as SCB1.

The following can be used with the T100 technology module:
- 8 digital inputs,
- 5 digital outputs,
- 5 analog inputs,
- 2 analog outputs.

With the T300 technology module, it would possible, under certain circumstances, to use:
- 16 digital inputs,
- 8 digital outputs,
- 7 analog inputs,
- 4 analog outputs.

Comment: If the analog and digital I/O are to be used for T300, then a SE300 terminal block is required which is snapped onto an existing mounting rail.
Dimensions: W x H x D = 224 x 60 x 60 mm. The terminal block together with all of the associated feeder cables are part of the scope of supply of the technology module.

The terminal assignment of the technology modules can be individually taken from Catalog DA65.10 and the documentation on T100 and T300.

2.3.3 Operator control via the serial interfaces

The following are available as serial interfaces:

- an RS485 interface on the terminal strip or an RS232/RS485 interface via a 9-pin sub-D socket on the standard PMU operator control panel, with USS protocol
- CBP communications module with PROFIBUS DP
- peer-to-peer link

Which of these interfaces and which combinations are actually used, depends on the customers' requirements and the properties/characteristics of the available interfaces. The essential properties of these interfaces are shown in the following table.

Other combinations of these interfaces are also possible and practical, e.g.:
USS protocol for parameterization and service **and** peer-to-peer links for fast setpoint input.

Interface	USS protocol	PROFIBUS DP	Peer-to-peer
Suitable for	Automation, service and diagnostics (SIMOVIS)	Automation	Replaces analog connections between drives
Typical applications	Parameterization	Automation	Setpoint cascade
Supplementary requirements in the basic drive	None (only if potential isolation if required, then an SCB2 is necessary)	CBP communications module	SCB1 (with fiber-optic cable) SCB2 or T100 or T300 (with RS485)
Master required?	Yes, e.g. PC (SIMOVIS), CP524 (S5), CP340 (S7) or third-party PLC	Yes, e.g. IM308B (S5) CP342-5 (S7)	-
Physical interface	RS485 2 wire	RS485 2 wire	RS485 2/4 wire or fiber-optic cable (for SCB1)
Data transfer	From the master to the slave and back, one after the other for all slaves	From the master to the slave and back, one after the other for all slaves	From drive to drive or from one drive to many drives
Nodes (stations)	1 - 31	1 - 127 (with 4 repeaters)	Any number for point-to-point connections, 2 - 32 for a parallel circuit configuration (not with fiber-optic cables)
Process data which can be transferred (reference-actual values)	0 - 16 words	2 / 6 / 10 words	1 - 5 words
Read/write parameters	0 / 3 / 4 words	0 / 4 words	Not possible
Data transfer rates	9.6 / 19.2 / 38.4 kbaud	9.6 kbaud - 12 Mbaud	9.6 - 38.4 kbaud (fiber-optic cable) 9.6 - 187.5 kbaud (RS485)
Maximum distances	1200 m	3 x 1200 m (93.7 kbaud), 3 x 200 m (1500 kbaud), for 4 repeaters	200 m
Typical bus cycle time = time until the first node is addressed again	15 - 400 ms For 10 nodes, depending on the telegram length, at 38.4 kbaud	0.6 - 1.5 ms For 10 nodes, depending on the telegram length, at 12 Mbaud	--
Signal delay time from the first to the last node for peer-to-peer	--	--	15 - 100 ms For 10 nodes, depending on the telegram length, at 38.4 kbaud
Typical cycle time with the setpoint updated in the basic drive, for 10 nodes	15 - 400 ms + 5 ms, (+ 4 t_o) Dependent on the telegram length, for 38.4 kbaud	0.6 - 1.5 ms + 5 ms, (+ 4 t_o) Dependent on the telegram length, for 12 Mbaud	1.5 - 10 ms + 5 ms, (+ 4 t_o) Depending on the telegram length, for 38.4 kbaud

2.3.2.5 Essential characteristics of the available serial interfaces

2.4 Software functions

The subsequently listed functions can be used in the standard software.

2.4.1 Restart-on-the-fly circuit

Background

When the drive converter or inverter is powered-up „normally" it is assumed that the motor is at standstill and the drive converter is to accelerate the motor from standstill up to the setpoint speed. However, in many cases, this situation does not exist. For example, for a fan or blower drive, when the drive converter is powered-down, the air flowing through the fan or blower can cause it to rotate in any direction.

Using the restart-on-the-fly circuit, the drive converter can be powered-up when a single motor is already rotating. The restart-on-the-fly circuit does not function for group drives, if several motors are fed in parallel from a drive converter and these motors can asssume different speeds when the drive converter is powered-down. Thus, with the exception of a few special cases, **the restart-on-the-fly circuit can only be used for single-motors drives.**

Mode of operation

A differentiation should be made in this case between with and without speed encoders.

For **drives with speed encoders**:

Speed encoders are in this case:
- DC tachometers or incremental encoders for FC or VC,
- Encoder or, resolver for SC.

For induction motors, restart-on-the-fly operates as follows:
After the drive converter is powered-up, at the instantaneous rotating frequency, determined by the speed encoder, the voltage is ramped-up from zero up to the voltage which would occur under steady-state conditions at the associated frequency. The ramp-up rate corresponds to the main field time constant of the connected motor. This ramp-up sequence is used to excite the „squirrel-cage" induction motor, and is executed when the motor is under no-load conditions and no motor torque is generated. The drive is then changed-over into normal operation, V/f characteristic (V/Hz mode) or closed-loop speed/torque control.

For **drives without speed encoders, only for FC and VC**:

Initially, a „standstill test" is executed, i.e. a DC current is briefly impressed for approx. 1 s. This is used to identify as to whether the motor is stationary or is rotating at a speed > approx. 10% of the rated speed (in this case, for drives with low moments of inertia it can occur that the motors may have already been braked down to zero speed). If a standstill condition has been identified, this is then followed by a standard ramp-up.
However, if it has been identified that the motor is still rotating, then restart-on-the-fly at maximum frequency is started, whereby a search current (P369) which can be parameterized, is impressed. The frequency is then reduced at a specific rate (P370). If the frequency reaches the instantaneous speed, then this is identified by the subsequent field reduction, i.e. the voltage at the motor increases. The drive then changes over into standard operation, V/f characteristic (V/Hz mode) or closed-loop speed/torque control.

If the motor is not found, because it is rotating in the other direction, the search sequence is repeated in the other direction.

Caution:

> The restart-on-the-fly circuit without speed actual value transmitter (encoder) for FC and VC can only be used for induction motors. It **cannot be used** for permanent-magnet synchronous motors such as SIEMOSYN motors or reluctance motors.

Caution:

> If a rotating fan with a high moment of inertia is to be „found", but its direction of rotation is different than actually required, e.g. for a fan which is being driven in the opposite direction, then the drive must first brake regeneratively after the motor has been found. During the project clarification phase, take this possibility into account and if necessary, include the brake resistor option!

Activating the restart-on-the-fly circuit

For the **SC control version,** it is always assumed that there is a speed encoder, e.g. resolver or encoder for the 1FT6 and 1FK6 servomotors or incremental encoder for the compact 1PH6 and 1PA6 induction motors. In this case, the restart-on-the fly function is already included in the normal power-up sequence and it is not necessary to specially select or activate it. There is no difference between powering-up the motor when it is at a standstill or rotating.

For the **FC and VC control versions** on the other hand, the restart-on-the-fly circuit function must be activated via parameter P583. Further, the restart-on-the-fly circuit function can either be inhibited or enabled at each power-up command. It can either be enabled via a binary input or the serial interface for different enable conditions. The enable command for the restart-on-the-fly circuit corresponds to bit 23 of the 2nd control word.

The complete restart sequence duration until the full motor output is available is as follows for FC and VC:

- approx. 2 to 5 sec   for restart with speed encoder,
- approx. 3 to 10 sec for restart without speed actual value encoder,

dependent on the output and system conditions.

2.4.2 Automatic restart function, only for FC, VC

The automatic restart function powers-up the drive converter again after a power failure (this is sensed as DC link undervoltage) when the supply voltage returns. The drive is then ramped-up again to the setpoint.

The automatic restart function (WEA) is activated via parameter P366. The following functions can be set:

- Automatic restart is inhibited, the drive remains powered-down after a power failure, a fault message is present and must be acknowledged before the drive is powered-up again.

- After acknowledging the fault message, but no automatic restart; this is only realized using a new ON command.

- The drive is automatically powered-up after the line voltage returns and after a delay time (P367) which can be parameterized, has expired. This time must be selected to be at least as long as the motor run down time so that restarting is realized when the motor is stationary.

- Automatic restart after the line supply voltage returns in conjunction with the restart-on-the-fly circuit (refer to Section 2.4.1). Thus, the automatic restart can also be realized when the motor is still rotating. Further, the restart-on-the-fly circuit is activated after each standard power-up, but not after a power failure.

Caution: The power failure time is not monitored!

If the automatic restart is activated, **automatic restart is not only realized for brief power failures, but also after line supply faults, which can be of any duration**. This can, under certain circumstances, result in an undesirable restart, and possibly to an automatic restart when the supply voltage returns. This can result in serious damage. Thus, automatic restart should only be activated if subsequent damage can be absolutely excluded. Typical applications for activating the automatic restart are, for example, pump drives in unmanned stations if suitable monitoring systems are available.

The automatic restart function is only available for control versions FC and VC.

2.4.3 Kinetic buffering, only for control versions FC and VC

Background

Using the KIP kinetic buffering function, brief supply failures up to approximately 1 s can be buffered using electronic measures. In this case, the load must have a sufficient moment of inertia, i.e. it must have an adequate level of kinetic energy.

Mode of operation

When the power fails, which is sensed when the DC link voltage drops below 76% of the value under normal operating conditions (i.e. if $V_{DC\ link} < 0.76 * 1.35 * V_{supply} \approx V_{supply}$), then the drive converter frequency is reduced. This is realized in a controlled fashion, so that the motor, operated above synchronous speed, supplies power to cover the system losses of the drive converter and motor. The associated speed reduction must be taken into account. When the supply returns, i.e. the DC link voltage increases up to the nominal value of $1.35 * V_{supply}$, the drive changes over into standard operation, and the drive converter frequency is again ramped-up to the selected setpoint frequency.

A prerequisite for the correct functioning of the kinetic buffering is that the reduced DC link voltage can be maintained by the drive kinetic energy. This is possible as long as the motor speed does not fall below approx. 10 %. If this is not possible and the DC link voltage falls below a value of 60% of the normal value (= $0.6 * 1.35 * V_{supply} \approx 0.8 * V_{supply}$), the drive converter is tripped (powered-down) with the fault message „DC link undervoltage".

The **kinetic buffering function is suitable both for single-motor drives and group drives** (several motors connected in parallel to a drive converter).

On the other hand, **for multi-motor drives** (e.g. where several inverters are connected to a common DC link or there are several individual drive converters which are coupled as a sectional drive), **the kinetic buffering function is either not suitable or only suitable under certain conditions**. This is because there is the danger that individual drives could oppose one another.

Example: For a multi-motor drive, it may be sufficient to only activate the kinetic buffering function for the main drive (generally the highest rating drive and that with the highest moment of inertia); this is under the condition that the remaining drives have the same speed as the main drive and have a specific speed relationship to this main drive. Under certain circumstances, the kinetic buffering function for a multi-motor drive can only be centrally implemented using the common system control, and not decentrally using the kinetic buffering of the individual units.

Activating the kinetic buffering
The kinetic buffering function must be activated via parameter P379. The DC link voltage level where kinetic buffering is to be initiated, can be set between 65 to 86% of the value under standard operating conditions via parameter P380. 76% is pre-set in the factory.

Caution:
The kinetic buffering function is only practical for standard drive converters or systems with rectifier units, however **not for drive converters with regenerative feedback** (e.g. inverters with rectifier/regenerative feedback units ERE or cabinet units with regenerative feedback into the line supply). Reason: If the power fails during regenerative feedback, then the inverter can reach its stability limit (inverter shoot through), fuses could rupture and the drive could fail. The actual purpose of kinetic buffering, i.e. to buffer brief power failures cannot be guaranteed in cases such as these!

2.4.4 Flexible response FLN, only for FC and VC

Background

Uninterrupted operation is mandatory for specific production processes. For instance, in the textile industry, even if the drive fails for just fractions of a second, this can mean that the complete system must be run-down and run-up again with the corresponding production downtime.

On the other hand, sporadic power failures, e.g. resulting from short-circuit problems elsewhere, can be expected and not just in developing countries. Brief power outages such as these normally involve power failures (at the primary of the supply transformer) for a maximum of approx. 200 to 300 ms and on the low-voltage side (at the secondary of the supply transformer), the voltage is maintained at a specific level due to other loads such as directly-connected motors. Thus, during such brief outages, typically a minimum voltage of approx. 50% of the rated value is not fallen below. The flexible response function can be used for cases such as these to maintain production.

Mode of operation of the flexible response (FLN)

The flexible response function essentially means that the drive converter is not tripped for line supply dips up to 50% of the rated value (it senses a **DC link voltage** decrease down to 50% of the rated value).

The critical point is when the supply voltage returns after the brief outage. If the supply voltage returns too quickly, i.e. if it increases from 50% to 100% of the rated voltage in less than approx. 5 ms, then the appropriate current surge (to charge-up the DC link capacitors) can cause the line fuses to rupture or the DC link voltage can be charged-up to an inadmissibly high voltage. In both cases, the drive converter would fault trip. In order to prevent this, when using the flexible response function, **a line commutating reactor with 4 % u_K must be used** in the incoming supply feeder.

Activating flexible response FLN

Flexible response must be activated and enabled using parameter P379. This parameter is used to select which of the functions is effective: Either KIP (kinetic buffering) or FLN (flexible response). Both cannot be used simultaneously!

Caution:
The FLN function is only possible for standard drive converters or systems with rectifier units; However, **not for drive converters with regenerative feedback**, (e.g. inverters with rectifier/regenerative feedback units ERE or cabinet units with regenerative feedback). Reason: If the power fails during regenerative feedback, the inverter could reach its stability limit and the fuses could rupture which is the same as drive failure. The actual purpose of flexible response, which is to buffer brief power supply failures, cannot be guaranteed under these circumstances!

Configuring information regarding FLN

If FLN (flexible response) is used, then an external 24 V DC power supply is required for the drive converter or in inverter. The internal power supply, which is taken from the DC link voltage, is not sufficient for the flexible response function.

If a main contactor is used, then it is not permissible that it drops out when the drive power fails. Thus, an uninterruptable power supply is required to control the contactor.

Generally, when using FLN, the motor and/or the converter must be over-dimensioned with respect to conventional applications without flexible response. The following situations should be taken into account:

a) Applications with permanent-magnet synchronous motors (SIEMOSYN motors)

These motors cannot be used for field weakening. If they are to be used for flexible response, whereby the DC link voltage and therefore the maximum output voltage can dip down to 50 %, then they must be ordered with a winding design. However, the maximum speed and therefore the maximum frequency are reached at only 50% of the line voltage. This means twice the rated current with respect to a winding design for the full line supply voltage. The drive converter must be selected for the required current, which practically means that it must be over-dimensioned by a factor of 2. Under this pre-requisite, when the line supply voltage dips down to 50°%, the full output can be maintained without influencing production.

This is principally the same for reluctance motors.

b) Applications with standard induction motors

In this case, operation is possible with a reduced motor voltage during line supply dips. This means brief field-weakening operation of the motor down to 50 % of the rated field at maximum speed.

There are two principle versions:

On one hand, without having over-dimensioned the equipment, a brief speed dip can be taken into account when the supply voltage dips.

Example: An extruder drive for 20 kW at 1000 RPM has a 400 V supply with a 1LA5 207-6AA.. 22 kW motor and a 6SE7024-7ED20 drive converter for 22 kW.

If the line supply voltage was to dip down to 50% at the maximum speed, then the stall torque of the motor would drop down to 124 Nm, and therefore only approximately 86 Nm or 40% of the rated motor torque is available and no longer the full load torque of 191 Nm. This results in a brief speed reduction. However, such a speed reduction only occurs for speeds > 50%. The full load torque is always available at lower speeds.

A drive converter with vector control VC, which can handle the control required for the fast speed reduction is required in this case. The V/f characteristic control (V/Hz mode) for FC types is not adequate.

The other design is where the full output must be available for a line supply dip down to 50%. Example: The same extruder drive as before for 20 kW at 1000 for a 400 V supply voltage. In this case, a bigger motor is required so that the full load torque is available at the maximum speed taking into account the required stall torque. Thus, a 1LA6 280-6AA.. motor is required with 45 kW, whose stall torque at half the rated voltage is 252 Nm which means that it is still higher than the required load torque of 191 Nm. The maximum current for this particular case is approximately 90 A and a drive converter is required which can provide this peak current. This means a 6SE7027-2ED_0 drive converter with a rated output of 37 kW. Thus, for this application, the motor and drive converter must be significantly overdimensioned in contrast to the actually demanded drive outputs.

2.4.5 Synchronizing

Background

The synchronizing function is always required if motors are to be changed-over or „transferred" from one drive converter to another drive converter or to another three-phase system. A typical example is in the textile industry when motors or motor groups are run-up using a starting converter, and then changed-over to the operating converter after the starting converter has been synchronized to the operating converter. In this case, synchronizing means that the output voltages of the two drive converters are the same both as far as the amplitude and the phase position are concerned.

Mode of operation

A prerequisite for synchronization is that the two drive converters are equipped with the TSY synchronizing board. Refer to the information in Catalog DA65 for the required wiring. The synchronizing signals between the two drive converters are conditioned and processed on the TSY. Synchronization is realized as follows:
The drive converter determines the actual frequency of the reference converter which is to be synchronized to when the synchronizing command is received. The drive converter then ramps to this frequency. A low supplementary frequency is input, so that the phase positions of the two drive converter output voltages slowly drift away from one another. When it has been identified that the phase difference is zero, the supplementary frequency is withdrawn, and therefore the same phase position is maintained. The „synchronism reached" signal is output at a binary output of the TSY board. This signal can be used to change over the motors. It is possible to visualize and monitor the actual synchronizing process via the serial interface, monitoring parameter r388. Thus, synchronizing can be initiated and the motors changed-over via an automation unit.

Secondary conditions and prerequisites

Contactors must be provided between the drive converters and motors to changeover the motors. Changeover requires a finite time which is between approximately 50 and 60 ms. The phase position of the „permanent-magnet synchronous" motor may not drift away in this time. This is only possible if the drive has a sufficiently high moment of inertia and the load torque is not too high.
When synchronizing, it is assumed that the frequency of the drive converter to which the system is to be synchronized doesn't change during the synchronization operation which lasts several seconds. Synchronizing is only realized after having been previously requested with the synchronizing demand and not continuously.
(Continuous synchronization where the motor tracks the frequency- and speed of another drive converter is therefore not possible with the „synchronizing" function. This can only be implemented using the „angular synchronous control" function in conjunction with a T300 technology board.)
The **"synchronizing"** function is **only available** for the FC and VC control versions **if** the open-loop/closed-loop control type **"V/f open-loop control for textile applications"** is selected.
Thus, it is not possible to synchronize a standard induction motor with the usual control types „V/f characteristic" or „closed-loop frequency control" to the supply system (required when transferring the motor to the supply) using the „synchronizing" function. Presently, this can only be implemented using the T300 technology board (angular synchronous control). Refer to the information under Section 3.3.3 for the problems involved for fast synchronized motor transfer.

2.4.6 Technology controller

A technology controller is available in the basic drive converter software (from software release 1.2) for control versions FC and VC. This technology controller can be used to execute simple higher-level closed-loop control functions. Here are some of the typical applications:

- Closed-loop pressure control for an extruder,
- Closed-loop water level control for a pump drive,
- Closed-loop temperature control for a fan drive

and similar control tasks. For simple controls such as these, an additional T100 or T300 technology board is not required.

The sampling time of the technology control is 8x the sampling time set in P308. A technology controller sampling time of 9.6 ms is set in the factory.

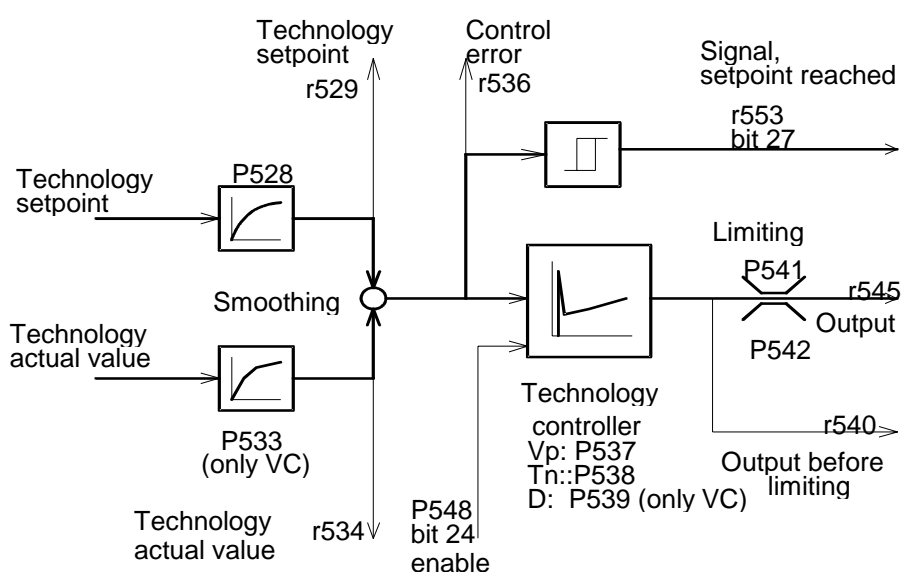The technology controller structure is shown in Fig. 2.4.1 below.

Fig. 2.4.1 Block diagram of the technology controller

The technology setpoints and actual values can be entered as internal values which can be parameterized, via analog inputs or via the serial interfaces. The amplitude can be continuously adapted with the appropriate parameterization.
The technology controller can be parameterized as P-, PI- or PID controller (PID controller only for VC, not for FC).

Visualization/monitoring values can be interrogated via the serial interface, and further they can

- either be switched (parameterized) to analog outputs just like the smoothed technology-setpoint-actual values and the control error as well as the technology controller output,

- or „connected" (parameterized) to binary outputs just like the „setpoint reached" signal (=bit 27 of the status word for the serial interface).

The technology controller enabling can be parameterized via a binary input or via a serial interface (=bit 24 of the control word).
The technology controller output can be used as speed setpoint, as supplementary speed setpoint or as torque setpoint.

Technology controller applications

Smooth changeover to the closed-loop technology control

In many applications, drives with a higher-level technology control are run-up with the technology control disabled. The technology control is enabled at the operating speed. The transition should be smooth, i.e. without a speed change.

Example: Starting an extruder
The empty extruder is ramped-up to the pre-selected speed. The extruder is then filled and heated up. When the required pressure has been achieved, closed-loop pressure control is selected (technology control) (Fig. 2.4.2).

Implementation using the technology controller:
A main speed setpoint as well as a technology setpoint and actual value are entered, depending on the practicality, via analog inputs, via a parameterizable internal (setpoint/reference) quantities or via an existing serial interface. The technology controller output is parameterized as supplementary speed setpoint (refer to Fig. 2.4.2).

As long as the technology controller output is inhibited (via the enable input, and as long as the control error of the technology quantities has not gone to zero), then the main speed setpoint is the only setpoint which is effective. The technology controller is enabled at the transition to technology process controlled operation. The main speed setpoint should still be present, unchanged. The technology setpoint is equalized by the technology controller which supplies a supplementary speed setpoint.

Prerequisite for a smooth transition into process-controlled operation: At the changeover instant, the technology actual value must be same as the technology setpoint. The „technology setpoint reached" signal can be used for this purpose, e.g. by logically interlocking it with the power-on command issued from the control room. The simplest case, as shown in Fig. 2.4.2, is implemented by actuating a switch which enables the technology controller when the „technology setpoint reached" signal is present for the first time. Alternatively, the technology controller can be enabled via an auxiliary contactor, which is controlled by the „technology setpoint reached" signal which then causes the auxiliary contactor to latch-in.
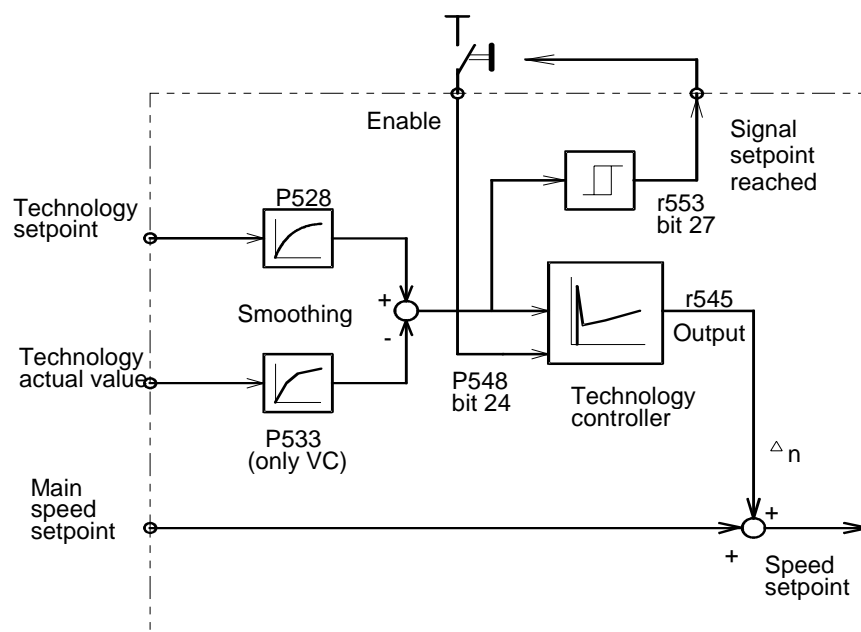

Fig. 2.4.2: Connecting-up the technology controller

Power limiting with a technological controller

For specific applications, the output must be able to be limited to defined values. For simple applications, this can be achieved using a fixed torque limit. The speed controller output, for control version VC in the closed-loop frequency or speed control (P163=3 or 4) represents the torque setpoint. If this is limited to a fixed value, in addition to an effective current limit, the maximum output is also limited corresponding to this maximum torque at the maximum operating speed.

In many cases, a permanently set torque limit is not sufficient to provide an effective power limit, e.g. the fact that the torque limit must be set appropriately high with a view to having a high breakaway torque can cause the maximum permissible output to be exceeded at high speeds. Also in cases, where the motor field weakening operation is used, an effective output limit can only be achieved using a fixed torque limit in specific cases. The following example of a drilling head drive shows just how effective an output limit can be in cases such as these, when used in conjunction with the technology controller.

Example: Output limit for a drilling head drive

A drilling head should be operated in a speed control range from 300 to 2500 RPM. In this case, a maximum torque of 1280 Nm should not be exceeded. The maximum output should also be limited to 132 kW, as otherwise the drilling head would wear too quickly. Thus, the motor torque must be limited to values in accordance with curve A-A-A, Fig. 2.4.3.
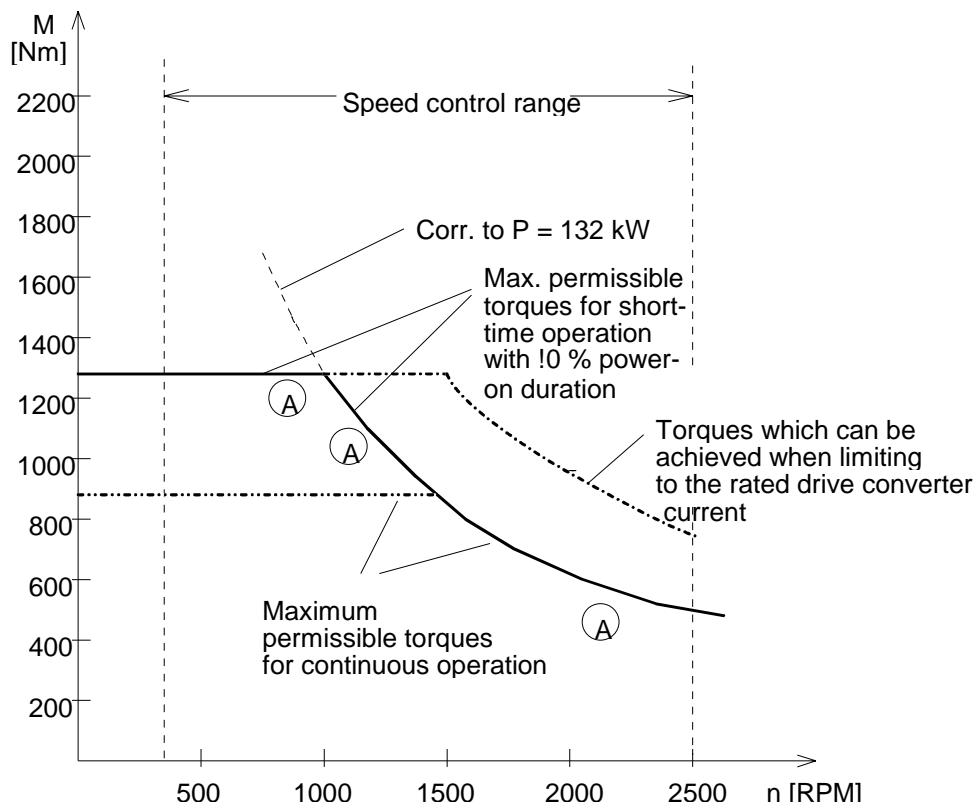

Fig. 2.4.3 Speed torque characteristics using a drilling head drive as example

For this case, it is recommended that a 4-pole motor is used which goes into the field-weakening mode above 1500 RPM. This is to ensure that there is sufficient stall torque at the uppermost field-weakening point at 2500 RPM. The 1LA6 316-4AA.. motor with 160 kW at 1485 RPM, 1030 Nm is suitable. The motor is adequate for this purpose, as the maximum torque of 1280 Nm is only briefly used (with reference to the thermal motor time constant!). However, not the inverter!

For the maximum torque which has to generated of 1280 Nm, at a 400 V supply voltage, a current of approximately 345 A is required. In this case, a 6SE7033-7EH20 drive converter is, for example, adequate. If the torque limit was to be set to a value corresponding to this 345 A, then the characteristic of the maximum torque with respect to speed would be as shown by the dotted lines in Fig. 2.4.3. Thus, the maximum output in the speed range from 1500 to 2500 RPM would lie significantly above the required maximum output of 132 kW.

An effective output limit can be achieved using the technology controller,which is re-parameterized as output limiter, refer to the following Fig. 2.4.4. In this case, the output actual value, which is calculated in the vector control, and which is available as (visualization) parameter r005, is compared with a permanently set setpoint. As long as the maximum 132 kW output is not reached, the technology controller output is at its upper limit, e.g. is at a value which corresponds to a torque of 1280 Nm. If the load torque increases and if the motor output reaches 132 kW, then the technology controller kicks-in and reduces the motor torque so that the 132 kW is not exceeded.

The closed-loop speed control is kept. A fixed value corresponding to 2500 RPM is entered as speed setpoint. Thus, the drive either operates at a full speed of 2500 RPM, or the speed controller is forced to the torque limit for larger load torques. The drive then operates with a maximum output of 132 kW and a maximum torque of 1280 Nm.
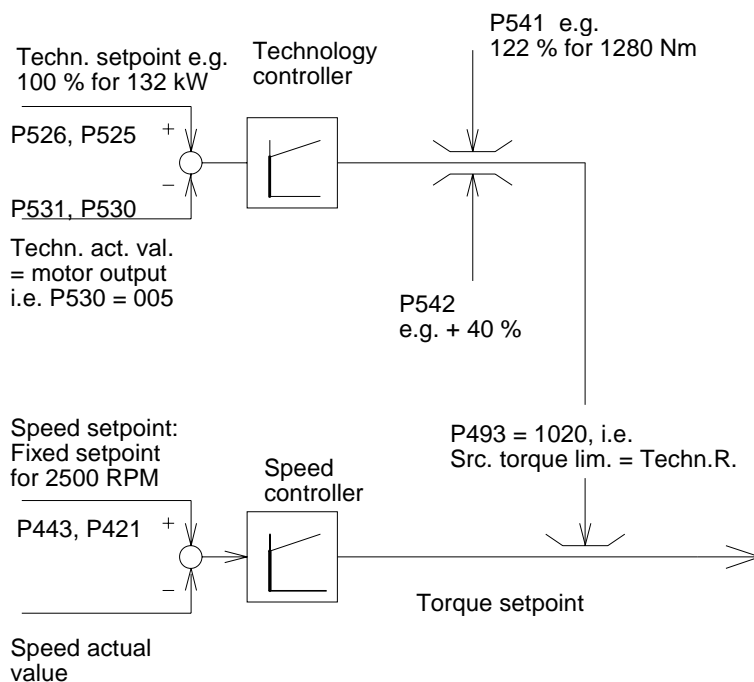
Fig. 2.4.4: Connecting-up the technology controller to limit the output

3 Design and description of the AC drive converter and inverter

Master Drives are available in the following versions
- as drive converter, i.e. including a rectifier to generate a DC link voltage,
- as inverter which can be connected to a common DC link voltage, generated using a DC link, which is either supplied from a rectifier unit (EE) or from a rectifier-regenerative feedback unit (ERE).

The plant/system conditions define which of these two solutions is selected. The following are valid as rough decision-making criteria:

AC drive converters should be selected for **single-motor drives**. Exception: If regenerative operation is required, this can only be implemented by combining, also for single-motor drives, an inverter with a rectifier/regenerative feedback unit or with an active front end.

For multi-motor drives, or also for **several** essentially **independent drives**, which however can be **spatially combined,** the **inverter solution** is recommended. In this case, the drives are connected through a **DC link**. This provides an especially space-saving design, as the switching devices, fuses and filters required on the line side are only required once, and that centrally. Further, for this solution, energy can be transferred between motoring and generating drives through the DC link. This means that regenerative feedback, if at all required under these conditions, only has to be provided once and that centrally.

3.1 Drive converter units

The drive converter units are available in three versions:

- as compact units in the low output range up to 37 kW,
- as chassis units in the output range, 45 to 200 kW,
- as cabinet units in the output range 45 to 200 kW and exclusively for higher ratings above 250 kW.

The technical data of the drive converter units are described in detail in Catalog DA65, and need not be listed again here.

The scope of the drive converter units is illustrated in Fig. 3.1.1. In this case, the compact- and chassis units only represent the shaded areas. For the compact- and chassis units, additional switching devices, fuses or line commutating reactors as well as additional components must be separately provided, i.e. mounted and connected-up. A main switch with input fuses, line commutating reactor with 2 % u_K and main contactor are only included as standard for the cabinet units. Additional components such as radio interference suppression filter, output filter etc. are optionally available.
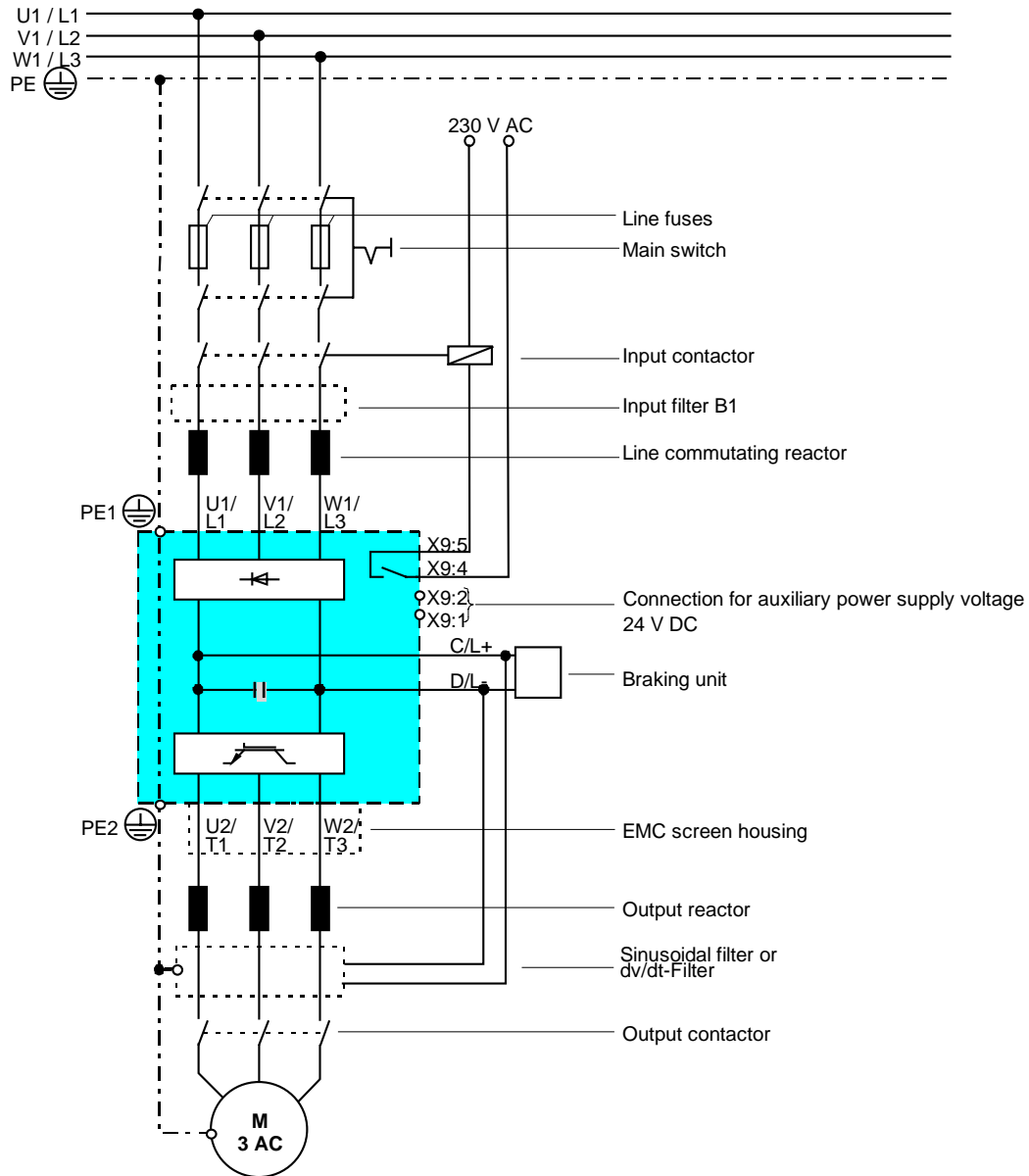
Fig. 3.1.1 Block diagram of a drive converter unit, sizes A to D

Connection to grounded and ungrounded line supply networks

Drive converters, sizes A to H, i.e. the compact- and chassis units up to 200 kW may only be connected to grounded supply networks in the basic version. The drive converters must be ordered with L20 if they are to be connected to ungrounded supply networks (IT supply networks). The reason is that the standard version includes a minimum radio interference function, consisting of discharge capacitors (to ground) on the line- and the DC link sides. When these units are connected to an IT supply network, these discharge capacitors are subject to an inadmissible voltage when a ground fault occurs (from experiences, these are not seldom occurances for IT supply networks). The L20 option means that these discharged capacitors are ineffective.

If older units (which were shipped by the beginning of 96) were ordered without the L20 option, and if they are to be retrofitted for connection to ungrounded supply networks (IT supply networks), the following capacitors must be removed:

To retrofit option L20 remove the capcitors:	on the board	for drive converters
C1 to C5	PEU	Compact units, sizes A to D
C5, C6	PCU	Chassis units, sizes E to H

For more recent drive converters (shipped since the beginning to middle of 1996), these capacitors are always included. It can be identified as to whether the unit is the standard version or the version with the L20 option as a result of a metal- or plastic disk, which establishes or interrupts the cable connection to ground. When retrofitting the standard units, the associated metal disk must be removed or replaced by a plastic disk.

Caution: When retrofitting the L20 option, or when changing-over, changes have to be made in the unit shipped from the factory. The unit must be basically disassembled and then re-assembled. Only qualified personnel may carry-out this work, and should only be made by an experienced Siemens specialist. Warranty cannot be accepted if this work was done unprofessionally.

The units must be appropriately identified after the retrofit!

Inverters for connection to a DC link voltage can be operated both in grounded as well as in ungrounded supply networks (IT supply network).

Which components for which application?

In the following text, it is shown which components must be used and when; both on the line- as well as on the motor sides. It should be noted that the information regarding line-side components is valid for the rectifier- and rectifier/regenerative feedback units (to supply a DC link). Also refer to Sections 3.2.3 and 3.2.4.

Input fuses.

Input fuses are always required.
They provide cable protection when a short-circuit develops. For this reason, especially for longer line supply feeder cables, they should be located as close as possible to the connection point to the line supply, i.e. at the beginning of the line feeder cable (and not at its end, i.e. at the drive converter input). The fuses may only be located in the drive converter if it can be assumed that the line feeder cable up to the drive converter has been routed so that it is short-circuit proof. Please refer to Catalog DA65 for the appropriate fuses for the individual units.
Fuses can also provide semiconductor protection. Alternatively, fast semiconductor fuses are listed in Catalog DA65, which provide both cable protection as well as semiconductor protection.
In this case, semiconductor protection only involves the protection of the line rectifier, i.e. the line-side diodes and thyristors. ***The IGBTs of the inverter cannot be protected by line-side fuses.***

Are cable protection fuses adequate or should semiconductor fuses be used?
The following should be considered. If a short circuit occurs **in front** of the line rectifier, the line-side semiconductors are not involved and in this case, semiconductor fuses are not necessary. If a short-circuit develops **after** the rectifier, i.e. in the DC link or in the inverter section, e.g. as a result of a defective IGBT, semiconductor fuses must be used to protect the line-side semiconductors. However, if such a short-circuit occurs in the DC link or in the inverter section, it can be assumed with a high level of certainty, that defective line-side semiconductors or IGBTs were the original cause of the short-circuit. Thus, the defective component must be replaced or the defect units replaced by a new unit. In the latter case, it is generally not important to replace the rectifier diodes in the defective unit which had to be replaced.

The following can be considered as a general rule:
If a defective unit is replaced, then generally it is sufficient to replace the cable protection fuses. This is especially true for low-output compact units.

On the other hand, if a fault develops and only the defective component is replaced, then it is recommended that the semiconductor fuses are also replaced. This is especially true for high-rating compact units and for chassis- and cabinet units.

Main switch

It must always be possible to switch the drive converter into a no-voltage condition (power-down). An additional main switch, or a switch already included in the installation can be used depending on the customers system and should be individually discussed with customers. If a main switch is required, this can either be a load disconnector with or without fuses or a fused load disconnector with fuses.

Main contactor

A main contactor must be provided if the customer requests a remote-controlled shutdown of the drive converter, e.g. from the main control room

As far as the drive converter is concerned, a main contactor is not mandatory, but is recommended for compact- and chassis units. If a main contactor isn't provided, when a fault develops with a short-circuited inverter, the charging resistors could burn - this only seldomly occurs. This will now be briefly explained:

When a drive converter is powered-up, the DC link capacitors are first charged-up via the pre-charging resistors. The bypass relay (compact units up to 37 kW) then closes and the thyristors of the line rectifier are triggered (chassis units up to 200 kW), whereby actual converter operation is then enabled.

If power is connected at the input of the drive converter without a main contactor **and** if the output is short-circuited, for instance in the DC link, for example as a result of a defective IGBT in the inverter, then a DC link voltage cannot be established. The bypass relay for the charging resistors is not energized and the line rectifier thyristors are not triggered. The charging resistors are continually under voltage in such a fault situation although a fault signal present. This is because the drive converter is not isolated from the line supply through a main contactor. After approximately 5 to 10 s, the pre-charging resistors are overloaded and interrupt the charging circuit. Under unfavorable conditions, arcing occurs which destroys the power section. This can be prevented by using a main contactor, which in this case, is opened as a result of the internally identified fault condition.

It can be assumed that this particular fault is so unlikely, that a main contactor cannot always be justified. If the short-circuit develops in the DC link (e.g. when an inverter becomes defective) in operation, then the input fuses blow and disconnect the line voltage. If the customer then simply changes the fuses without first checking-out the drive converter, and without removing the short-circuit, he must accept the risk of burning and destroying the pre-charging resistors. This is considered to be an acceptable risk if a main contactor is not used.

Line commutating reactor

A line commutating reactor is required for high system fault levels. On one hand it protects the drive converter itself from high harmonic currents and therefore overload, and on the other hand it limits harmonics to permissible values. Thus, line commutating reactors with 2 % u_K must be provided, if:

System fault level > 33 x rated drive converter output.

Refer to Section 3.6.3 for more detailed information.
Information regarding line-commutating reactors is provided in Catalog DA65 under drive converter components.

Radio interference suppression filter

Radio interference suppression filters are required, if, according to the EMC Law, the appropriate radio interference voltages must be observed in accordance with limiting value curve B (for residential areas) or A (for industrial environments). More detailed information is provided in Section 5 (being prepared) as well as in the document: „The significance of EEC Directives for electric drives and power electronics". Order No. E20001-P125-A515
Information regarding radio interference suppression filters is provided in Catalog DA65 under drive converter components.

Output reactors and output filter

Output reactors and dv/dt filters or sinusoidal filters are required in conjunction with long motor feeder cables, in order to limit capacitive re-charging currents caused by inverter commutation and to reduce voltage stressing of the motor winding. Which reactors and which filters are required in individual cases are described in detail in Section 3.7.4.

Output contactor

An output contactor is not mandatory. An output contactor should only be provided when a customer expressly requests it. An output contactor is for example required, if
- there is a bypass circuit,
- at EMERGENCY OFF the motor must be switched to a no-voltage condition, or
- a drive converter is to feed several motors which can be switched-in.

Generally, AC operated contactors are used as output contactors. Problems can occur if the contactors open at low motor frequencies < approx. 10 Hz, as these contactors are not suitable for interrupting quasi DC current. For single-motor drives with drive converter output contactors, if possible a leading auxiliary contact of the output contactor should be connected to a binary „inverter enable" input. In this case, when opened, the motor current is electronically interrupted by an inverter stop, and the contactor is not destroyed by „DC current".

3.2 Inverter connected to the DC link

3.2.1 General information

Use for multi-motor drives

In addition to drive converters which are connected to the three-phase line supply, inverters can also be used, which are connected to a DC voltage. This solution is especially advantageous for multi-motor drives, as illustrated in Fig. 3.2.1. The DC link is fed via a rectifier unit (in this case there is only one energy flow direction from the line supply to the DC link) or via a rectifier/regenerative feedback unit (this also permits regenerative feedback). The DC link voltage corresponds to the rectifier line supply voltage:

$$V_{DC} = 1.35 * V_{supply} \hspace{3cm} (3.2.1)$$
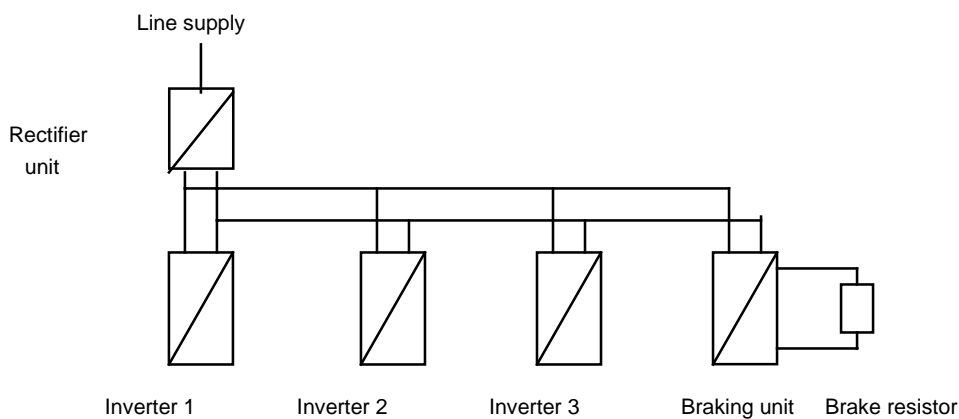
Fig. 3.2.1: Inverter units with rectifier unit and braking unit with brake resistor

If this DC link solution is selected, in comparison to single drive converters, the space requirement can be significantly reduced: Only one set of line-side fuses and switching devices including commutating reactors etc. are required and that centrally which permits an extremely space-saving design.

An additional advantage of this solution is that energy transfer via the DC link can be realized if one or several of the drives is regenerating. If regenerative power is occasionally present for a longer period of time, e.g. when all of the drives are simultaneously decelerated when the plant is being shutdown or after the emergency stop has been actuated, an additional braking unit can be provided (refer to Section 3.4.2), as shown in Fig. 3.2.1.

If the total power is frequently regenerative, or if regenerative operation is dominant, e.g. test stand drives for combustion engines, then it is recommended that a rectifier-/regenerative feedback unit is used instead of a rectifier unit. The rectifier/regenerative feedback unit feeds back the regenerative (braking) energy into the line supply thus permitting a high overall efficiency.

> **Comment:** Operation with a rectifier/regenerative feedback unit and braking unit simultaneously, e.g. in order to increase the available braking power, is generally not possible. The only possible solution would be to provide an additional braking unit together with the rectifier/regenerative feedback unit, so that the plant/system can be shutdown when a fault develops e.g. when the power fails. Up until now, such a combination has not be tested and should only be used after consulting ASI 1 A V.

Using inverter units for single-motor drives

For single-motor drives, inverters units must be used, if

- regenerative feedback is required   or
- 12-pulse supplies are to be used.

This is true, for example, for a winder drive, where higher regenerative powers occur, which are to be injected back into the line supply. A drive converter with regenerative feedback must be realized, as illustrated in Fig. 3.2.2, using an inverter, which is supplied via a rectifier/regenerative feedback unit.

Line supply connection

Rectifier/
regenerative
feedback unit
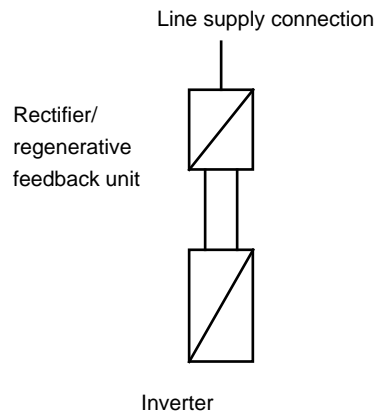
Inverter

Fig.: 3.2.2   Inverter unit with rectifier/regenerative feedback unit

For 12-pulse supplies, an inverter must be used, which is connected-up via 2 rectifier units, or for regenerative feedback, via two rectifier/regenerative feedback units. In this case, generally a three-winding converter transformer is required. Refer to Section 3.6.2 for more detailed information

3.2.2 Inverter units

The inverter units are identical with the appropriate drive converters when it comes to the outputs and currents which can be utilized. This can be seen as they have almost identical MLFBs (Order Nos.). The inverter units are engineered as far as the output is concerned, almost the same as for drive converters, i.e. as a function of the required drive data (also refer to the appropriate sections in the Engineering Manual for Motors).
The control versions are also defined as for the drive converters

The selection tables of the compact- and chassis units   refer to Catalog DA 65.1
    "   "   "   cabinet units   refer to Catalog DA 65.2.
Connecting-up, terminal strip   refer to Catalog DA 65

An inverter unit, as compact- or chassis unit, includes the following components as illustrated in Fig. 3.2.3 (only the shaded area!):

- IGBT inverter with associated DC link capacitors
- DC connecting panel
- Motor connecting panel
- Electronics box with control board
- Parameterizing and operator control panel
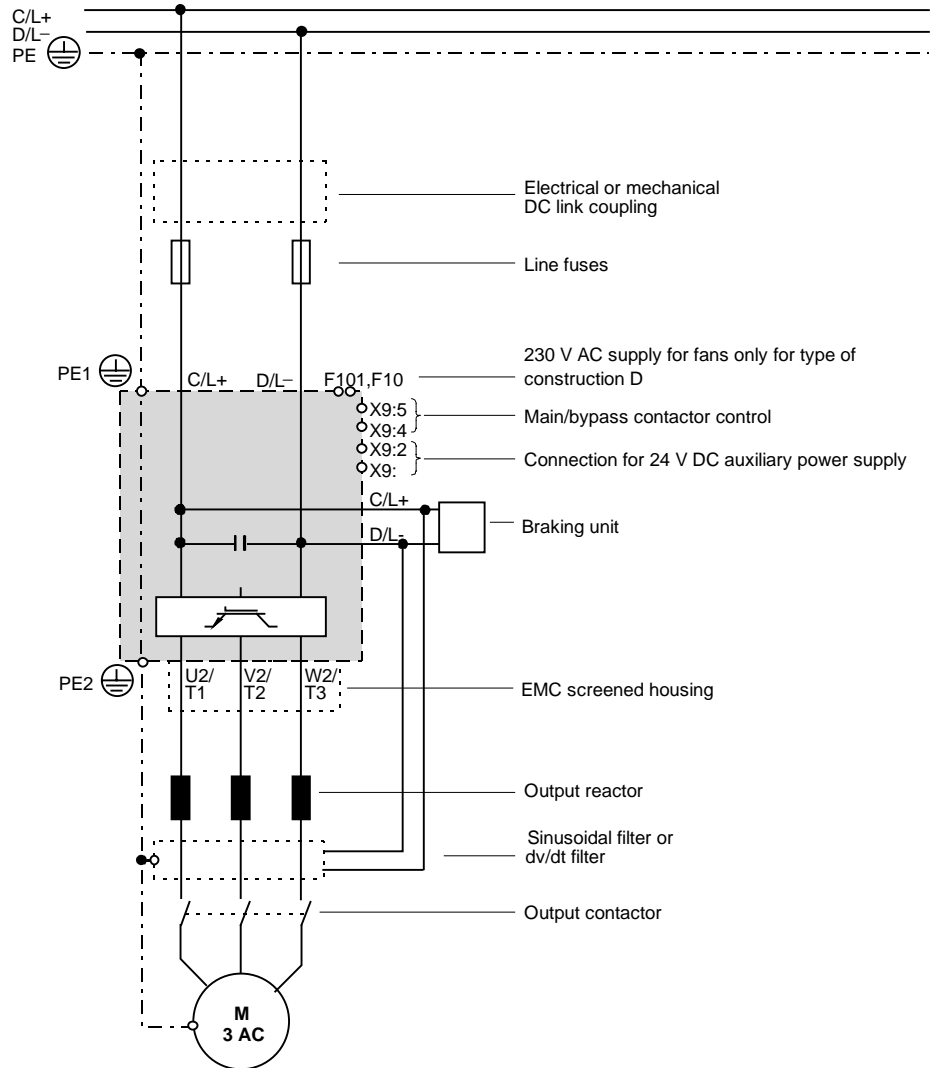
Fig. 3.2.3 Inverter design, sizes A to D

The output components such as output reactors, -filter or switchgear devices have the same selection criteria as for the drive converters, also refer to Sections 3.1 and 3.7.4. For the compact- and chassis units, these additional components must be mounted and connected-up in the cabinets. They are optional for cabinet units.

When connecting-up the inverters to a DC busbur, a decision must be made as to whether DC link fuses and switching devices should be provided.

When are fuses to the DC link bus required?

Fuses must always be provided between an inverter and the DC link connection if at least 2 inverters are operated from a DC link bus. Inverter fuses are not required only if an individual inverter is supplied from a rectifier unit or a rectifier/regenerative feedback with the same output. In this case, the same relationships exist as for a drive converter, whereby the inverter is protected by the line-side (cable protection) fuses.
Please refer to Catalog DA65 for the appropriate fuses.
For chassis units above 45 kW, the fuses can be ordered as option.

Which switching devices should be provided to the DC bus?

It can be assumed that the DC link bus is supplied from a rectifier unit or a rectifier/regenerative feedback unit, which charges-up the DC link capacitors of the inverters. As far as the inverters are concerned, it is not necessary to use switchgear, main switch or contactor. If switchgear is not used to connect the inverters to the DC link, the inverters are powered-up as long as the rectifier unit is powered-up. In this case, it is not possible to power-down individual inverters as only the complete system can be powered-down (shutdown).

On the other hand, if the customer requires that individual inverters must be able to be isolated from the DC bus and switched-in again, switchgear (switching devices) must be provided.
This can be necessary for the following reasons:
- Safety regulations of the various regulatory bodies must be maintained,
- Reserve units are to be used as required,
- Plant sections can be switched-in and -out as required,
- Repaired units can be switched-in again during operation.

If inverters are to powered-up and down **in operation**, then a pre-charging circuit for the DC link capacitors of the inverter must be provided, as illustrated in Fig. 3.2.3, and recommended in Catalog DA65.1. The contactor required in this case, can be controlled with the „control main/bypass contactor" signal from the inverter unit, terminal X9:4:5; refer to Fig. 3.2.2.
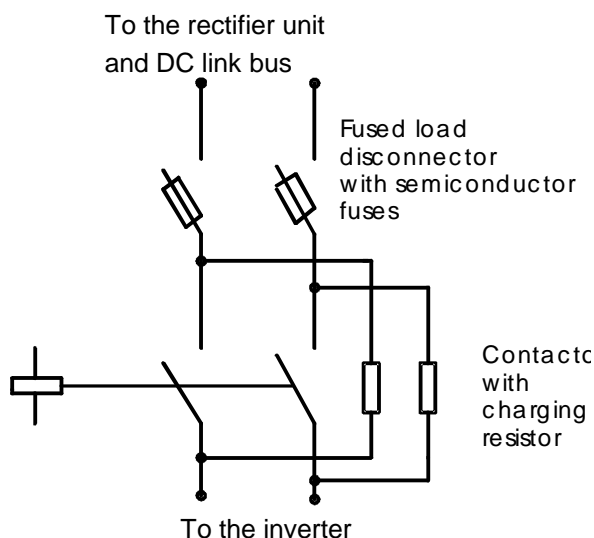
Fig. 3.2.3 Inverter coupling with isolator and pre-charging

However, it is recommended that the pre-charging circuit is supplemented as illustrated in the following diagram, Fig. 3.2.3 a.
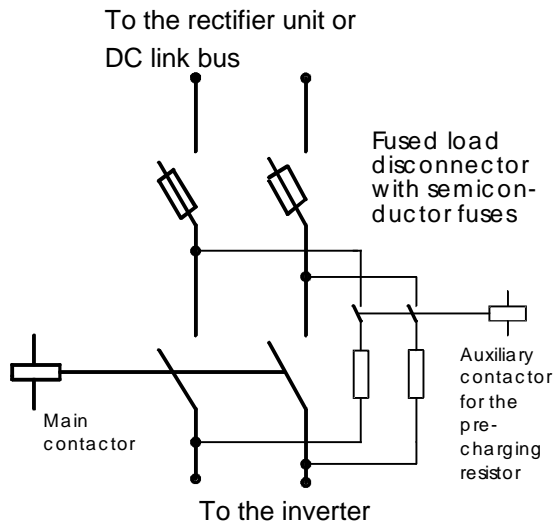
Fig. 3.2.3 a: Inverter coupling with isolating switch, main contactor and additional auxiliary contactor for pre-charging resistors

The additional auxiliary contactor has the task to disconnect the pre-charging resistors when a fault develops (short-circuit in the inverter). It should be controlled from a binary output of the inverter, which is parameterized with the „pre-charging active" signal. A 3TC44 auxiliary contactor can be used, which should then interrupt the following DC current

$$I_{Fault} = \frac{V_{DClink}}{2 * R_{pre-ch\,arg\,e}} = \frac{1,35 * V_{sup\,ply}}{2 * R_{pre-ch\,arg\,e}}$$

when a fault develops; refer to Catalog NS2. The pre-charging resistors $R_{pre-charge}$ have values between 2.7 and 10 Ω, refer to the information in Catalog DA65.

This additional auxiliary contactor is provided for the following reason:

If the main switch, shown in Fig. 3.2.3 was to be closed with a short-circuit condition in the connected inverter, then a DC link voltage would not be able to be established at the inverter. The main contactor would remain open, and voltage would be continuously applied to the pre-charging resistors which would mean that they would be overloaded. This could occur, if after the inverter fuses ruptured, the fuses were simply replaced, and the main switch closed without removing the short-circuit.

Inverter without pre-charging circuit

On the other hand, if it is **not necessary** to switch the inverters, **when operational**, to the live DC bus, then the fused load disconnector, shown in the upper part of Fig. 3.2.3, is adequate. In this case, **the fused load disconnector may only be closed**, if the DC link bus is at zero volts, i.e. **when the complete system is powered-down (shutdown).**

Practical arrangement of the individual inverters

If several inverters are operated from a DC link bus, then they cannot be randomly located. They must be arranged according to their particular output. This is practical and is also necessary for technical reasons.

If, for example, units with low and high outputs were to be randomly mixed as illustrated in Fig. 3.2.4 a, this would be unpractical from a mechanical perspective. The units with high outputs could also overload adjacent units having extremely low outputs due to high-frequency harmonic currents caused by commutation on the DC bus.

DC bus

Inverter 2.2

Inverter 45 kW

Inverter 2.2

Inverter 160

Inverter 2.2

Inverter 160

Inverter 45 kW
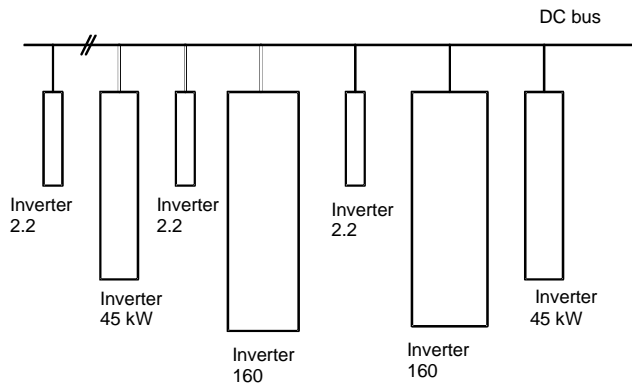
Fig. 3.2.4 a: Practical arrangement of a drive system with DC link bus

Thus, this system should be configured as illustrated in Fig. 3.2.4 b.

DC bus

Inverter 2,2

Inverter 2,2

Inverter 2,2

Inverter 45 kW

Inverter 45 kW

Inverter 160
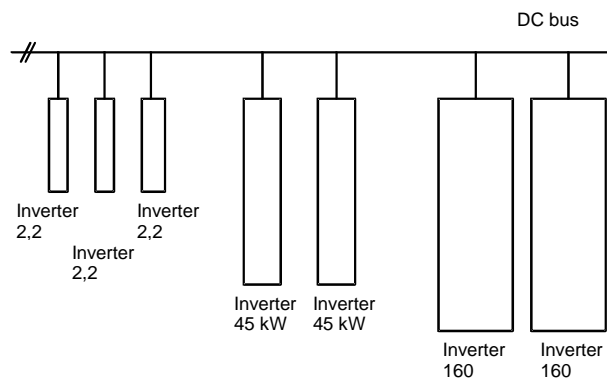
Inverter 160

Fig. 3.2.4 b: This configuration is practical and necessary for a system with DC link bus

When and why is a DC protective diode required?

If inverters with significantly differing outputs are operated on a common DC link bus, a DC protective diode must be provided, as illustrated in Fig. 2.3.5.
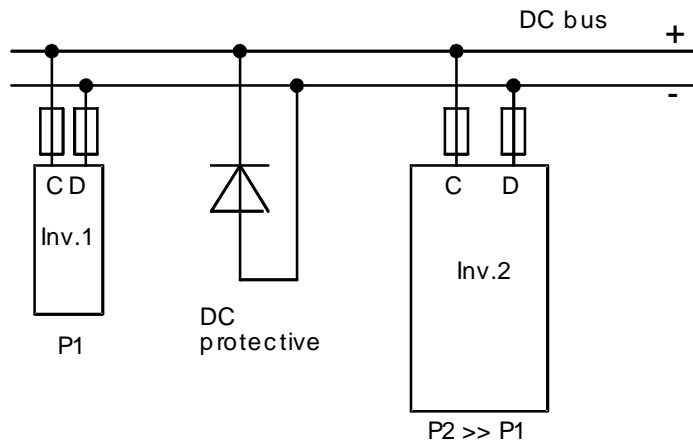
Fig. 3.2.5   Arrangement of the DC protective diode for inverters with different outputs connected to a common DC link bus

A protective diode is required for the following reason:
If the associated DC link fuses rupture due to a short-circuit within the (higher output) inverter INV2, then without a protective diode, the short-circuit (surge) current to be interrupted would be forced to flow through the free-wheeling diodes of the adjacent inverter, which could then damage it. If a protective diode is provided, when the fuse ruptures, this transient short-circuit current flows through the protective diode. This diode is adequately dimensioned to carry this current, so that no further damage occurs. Thus, the protective diode should prevent a fault in a higher output inverter from damaging other inverters with lower outputs. If a protective diode is required, it should be selected for the highest-output inverter and it should be connected as close as possible to the DC link connections of this inverter. For screw-in diodes, it is practical to mount the diode in a threaded bore in the negative DC link bus, which also establishes the electrical contact.
Refer to Catalog DA65.1 for the ordering information for the protective diode. The information is provided under components for inverters, e.g. on Page 4/15 for compact units, on Page 4/27 for chassis units, in the last column „free-wheeling diode at the DC bus"

The following table shows when a protective diode is required.

Independent of this, the following is always valid:

A protective diode is always required, if a braking unit is used in conjunction with a DC link.
If the P20 rating of the braking unit is greater than the output (rating) of the largest inverter, then a protective diode must be provided the same as for an inverter with an output of at least P20. The protective diode must be located as close as possible to the braking unit and this in turn must be located as close as possible to the largest inverter.

Supply voltage	A protective diode is **not** required, if the inverter is used in the following output ranges	A protective diode is required, if an inverter is used in the following output ranges
208 - 230 V	2.2 to 11 kW	2.2 to ≥ 15 kW
	4 to 22 kW	
380 - 460 V	2.2 to 15 kW	2.2 to ≥ 18.5 kW
	5.5 to 45 kW	5.5 to ≥ 55 kW
	18.5 to 90 kW	18.5 to ≥ 110 kW
	37 to 160 kW	37 to ≥ 160 kW
	45 to 250 kW	45 to ≥ 315 kW
	110 to 500 kW	110 to ≥ 630 kW
500 - 575 V	2.2 to 55 kW	2.2 to ≥ 75 kW
	11 to 110 kW	11 to ≥ 132 kW
	18.5 to 160 kW	18.5 to ≥ 200 kW
	37 to 250 kW	37 to ≥ 315 kW
	45 to 630 kW	45 to ≥ 710 kW
	75 to 1100 kW	
660 - 690 V	55 to 315 kW	55 to ≥ 400 kW
	90 to 1500 kW	

Table 3.2.1: Selection criteria for a DC protective diode

Comment:

In some cases, the inverter units cannot be graduated in the outputs as recommended in Fig. 3.2.4b. For example, this is not possible if the customer demands that the inverter units must be located in the same sequence in which the associated drives are mechanically arranged. This can result in an arrangement as illustrated in Fig. 3.2.4a (and in a similar fashion to that which was used): In this case, the same selection criteria for one or several DC protective diodes are valid as illustrated in Table 3.2.1.

For the arrangement according to Fig. 3.2.4a, assuming a line supply voltage of 400 V, the DC protective diodes must be assigned to the following:
inverter 45 kW (left) and to the two 160 kW inverters, due to their proximity to the 2.2 kW inverter.

However, for the arrangement according to Fig. 3.2.4 b, it would only be necessary to provide one DC protective diode to a 160 kW inverter unit. (an additional DC protective diode may have to be provided for a 45 kW inverter if the distance between the WR 2.2 kW inverter and the 45 kW inverter is low and on the other hand, the distance between the 45 kW inverter and the 160 kW inverter is higher).

Which DC currents occur?

To correctly select the rectifier units, the DC link current, which the individual inverters draw from the DC link, must be known. The average DC link current for each inverter unit can be determined in 2 different ways:

a) From the motor data at the associated load operating point

$$I_{DClink} = 1.35 * I_{Motor} * \cos\varphi_{Motor} * \frac{V_{Motor}}{V_{max}} * \frac{1}{\eta_{WR}}$$

V_{Motor} corresponds to the motor voltage at the instantaneous speed. The ration V_{Motor}/V_{max} changes depending on the parameterized V/f characteristic or the selected closed-loop control version; it changes from low values at zero speed (e.g. 4% as ohmic voltage drop at standstill) up to 1 at the rated motor speed.

b) From the mechanical power (shaft power) of the motor at the associated load operating point

$$I_{DClink} = \frac{P_{Motor}}{\eta_{Motor} * \eta_{WR}} * \frac{1}{V_{DClink}} = \frac{P_{Motor}}{\eta_{Motor} * \eta_{WR}} * \frac{1}{1.35 * V_{sup\,ply}}$$

Depending on which data is known, either one or the other formula can be used.

Comment: When an inverter is in the regenerative mode, the direction of the DC link current reverses, which is represented in the above formulas by a negative DC link current $I_{DC\,link}$: P_{Motor} becomes negative and $\varphi \rightarrow > 90°$, thus $\cos\varphi$ is also negative.

The DC link current, which flows at the inverter rated current in conjunction with a „standardized" (adapted) motor at the rated operating point, is specified in Catalog DA65.2 under „DC link current".

The above formulas are valid for the case where the DC link bus is fed via rectifier- or via rectifier/regenerative feedback units. In this case, the DC link voltage is identical to the rectified line supply voltage: $V_{DC\,link} = 1.35 \times V_{supply}$.

The situation is different when an active front end is used as rectifier unit. In this case, the DC link voltage lies above the rectified line supply voltage by a specific factor which can be parameterized:

$$V_{DC\,link} > 1.35 \times V_{supply}$$

The DC link current which then flows for each inverter unit is then lower by a specific factor, and more specifically in the ratio $1.35 \times V_{supply} / V_{DC\,link}$.

3.2.3 Rectifier unit

The rectifier unit supplies a common DC bus for the inverter units. It is always used if the power (energy) balance of the multi-motor drive group in operation is essentially motoring. If regenerative operation only briefly occurs, e.g. when the drive is quickly stopped (fast stop), it is recommended that a braking unit with brake resistor is additionally used. Also refer to Section 3.4.2.

A rectifier unit consists of:
- line supply connecting panel
- 6-pulse rectifier bridge with pre-charging
- Connecting panel for the DC link voltage

Low-output rectifier units, types B and C

For low outputs, types B and C, compact units from 15 to 55 kW, the rectifier comprises a diode bridge with pre-charging resistors as illustrated in Fig. 3.2.6.
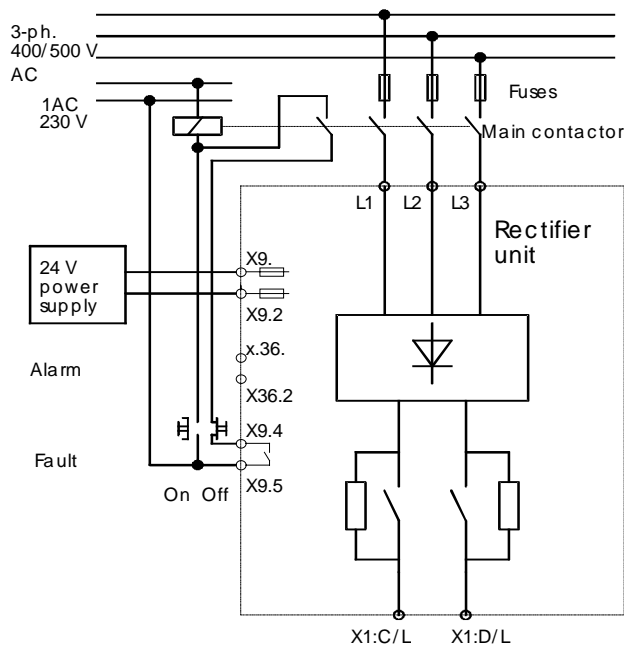
Fig. 3.2.6 Block diagram of the low-output rectifiers, types B and C.

After the rectifier unit has been powered-up, the output relay is initially de-energized (dropped-out), and the DC link capacitors of the inverters connected at the output, are charged via the pre-charging resistors within 1 to 2 seconds. The output relay then closes and bypasses the pre-charging resistors.

Fuses must be provided as close as possible to the supply point to protect the feeder cable and the rectifier units. Please refer to Catalog DA65.1 for the appropriate details.
Further, the unit **must be** electrically isolated from the line supply in order to protect the rectifier unit when a fault develops (with an internal fault signal at terminals X9:4.5). A main contactor can be used as illustrated in Fig. 3.2.6, which is controlled, latching, via an on/off button. Suitable switches are recommended in Catalog DA 65.1.

It is only possible to control the rectifier units via switching devices or via the terminals. The units are „dumb", which means that they cannot be controlled via a PMU parameterizing unit or via a serial interface.

In order to reduce harmonics fed back into the line supply, it is recommended that the rectifier units always have a line commutating reactor with a minimum of 2 % u_K (not shown in Fig. 3.2.6). The sum of the line feeder inductance and the inductance of the line commutating reactor must be at least 3% u_K.

A radio interference suppression filter may be additionally necessary in order to maintain the radio interference specifications in accordance with the EMC Law.

Further, an external 24 V DC power supply with $\geq$ 2 A must be provided. The 24 V DC power supply is fused in the rectifier unit.

Selecting the rectifier units

When selecting a suitable rectifier unit in this lower output range, it should be observed that the rated DC rectifier unit current must be equal to the sum of the rated DC currents of the connected inverter units:

$$I_{DClink\ EE} \quad \geq \quad I_{DClink\ inverter} \quad \text{for rectifier units, types B and C up to 37 kW}$$

If energy is transferred along via the DC link bus, which would result in a lower rectifier rating, this cannot be taken into account here, as otherwise the charging circuit could be overloaded.

Example:
For a multi-motor drive with 400 V supply voltage, ten inverters, 6SE7018-0TA10 with 2.2 kW, 6.1 A rated current, 7.3 A DC link current are connected to a DC link bus. As some of the drives operate regeneratively, instead of 10 x 2.2 = 22 kW, only 8 kW is required (rectifier unit rating).
However, the following is required: rectifier unit with $\geq$ 10 x 7.3 A = 73 A DC link current, i.e. 6SE7028-6EC85-0AA0 with 37 kW, 86 A rated DC link current.

Note: If additional inverter units are to be connected to a DC link at a later date, this should be taken into account when selecting the rectifier unit.

Medium-output rectifier units, type E.

For higher rectifier outputs:

    from 75 kW to 250 kW (400 V), up to 315 kW (500 V), up to 400 kW (690 V)
the power section of the rectifier units no longer comprises a diode bridge, but a fully-controlled
thyristor bridge; refer to Fig. 3.2.7.
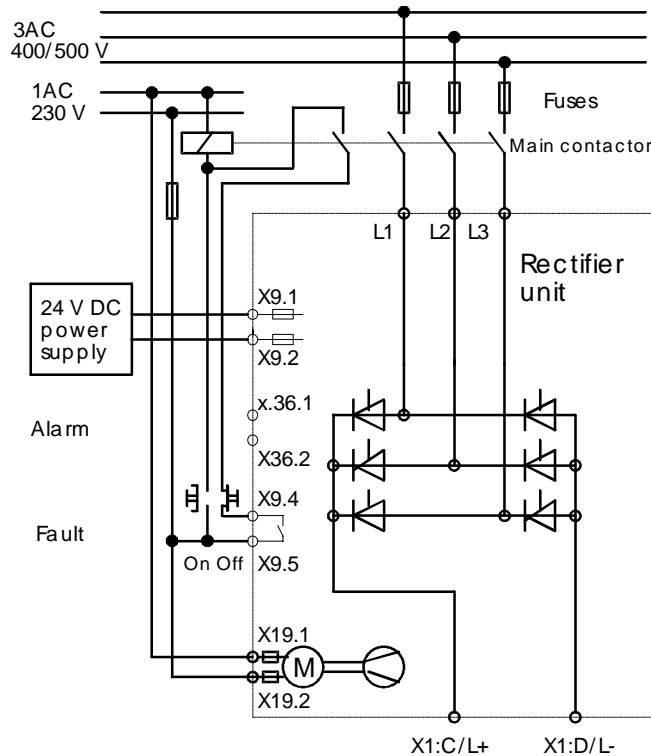
Fig. 3.2.7 Block diagram of the medium-sized rectifier units, Type E

A line-commutated gating unit controls the thyristors in the line-side converter. When the drive system
is powered-up, the DC link voltage is ramped-up from zero to the full, rectified line voltage within a
fixed time (this can be set between 1 s and 2 s). Under normal operating conditions, the thyristor bridge
acts just like a diode bridge. In this case, charging resistors are not required.

An external 24 V DC power supply with $\geq$ 2 A must be provided for correct operation. The 24 V DC
power supply is fused in the rectifier unit.

Further, a 230 V AC power supply $\geq$ 1 A is required for the fan.

A main contactor connected in series, as illustrated in Fig. 3.2.7, is not necessary to protect the rectifier
unit, but it is recommended, in order to prevent the system being accidentally powered-up, e.g. after a
fault has been acknowledged.

A fault signal can only be acknowledged by powering-down the unit or disconnecting the 24 V DC
power supply. Fuses must be located as close as possible to the supply point to protect the feeder
cable and the rectifier units. Appropriate information is provided in Catalog DA65.1.

In order to reduce harmonics fed back into the line supply, it is recommended that the rectifier units are
always connected to the supply through a line commutating reactor with at least 2 % u_K (not illustrated
in Fig. 3.2.7). The sum of the line supply feeder inductance and the inductance of the line commutating
reactor must be at least 3 % u_K.

It may be necessary to use an additional radio interference suppression filter in order to maintain the radio interference suppression regulations in accordance with the EMC law.
The rectifier units can only be controlled via switching devices or via terminals. The units are „dumb" which means that they cannot be controlled via a PMU parameterizing unit or via a serial interface.

Selecting the rectifier units
When selecting a suitable rectifier unit in this particular output range, it must be observed that the **instantaneous value** of the inverter-side DC link currents do not exceed the rated DC link current of the rectifier unit. This means that a rectifier unit can be selected, whose rated DC link current is lower than the sum of the rated DC link currents of the inverters. This is true, if several of the drives are not operating at their full output, or are operating regeneratively whereby energy is exchanged via the DC bus. However, for practical reasons the rectifier unit should not be selected too small; the rated DC link current of the rectifier unit should be a minimum of 30% of the sum of the rated DC link currents of the inverters. Thus, the following is valid:

$$I_{DClink\ EE} \geq (0{,}3 \ldots 1) * I_{DClink\ inverter} \qquad \text{for rectifier units size E and above, i.e. from 75 kW onwards}$$

Example:
For a multi-motor drive with 400 V supply voltage, 10 inverters 6SE7024-7TD20 with 22 kW, 47 A rated current, 55.9 A DC link current are connected to a DC link. For a specific load constellation, all drives can operate at full output. Thus, the following is required.
Rectifier unit with $\geq$ 10 x 55.9 A = 559 A DC link current, i.e.
6SE7036-1EE85-0AA0 with 250 kW, 605 A rated DC link current.

An additional example:
A plant with 6 centrifuges is realized as multi-motor drive. For a 400 V supply voltage, six inverters 6SE7032-1TG20 with 110 kW, 210 A rated current, 250 A DC link current are used. By suitably controlling the plant (the centrifuges are operated sequentially: A maximum of two centrifuges accelerate simultaneously, while at least one is braked) it is ensured that a maximum power of 40% of the total of the inverter ratings is drawn from the line supply. Under this prerequisite the following is valid:
The following rectifier unit is adequate with $\geq$ 0.4 x 6 x 250 A = 600 A DC link current, i.e.
6SE7036-1EE85-0AA0 with 250 kW, 605 A rated DC link current.

High-rating rectifier units, sizes H and K

The rectifier units in this output range

    400 to   800 kW at 400 V,

    450 to 1100 kW at 500 V,

    630 to 1500 kW at 690 V

also contain a fully-controlled thyristor bridge and the same is valid as for rectifier units, size E. Thus, the following is valid when selecting switching devices/switchgear, fuses, line commutating reactors and dimensioning the rectifier unit:

$$I_{DClink\ EE} \geq (0.3 \dots 1) * \quad I_{DClink\ inverter}$$

An external 24 V DC power supply with $\geq$ 2 A is also required. Further, a 230 V AC power supply with $\geq$ 3.3 A (type H) or $\geq$ 6.6 A (type K) for the fans.

These rectifier units have a microprocessor control, which is designed using the same principles as for the drive converter and inverter control: They have an identical electronics box with the CUR control board (open-loop and closed-loop control), where optional boards can be installed. These include the T100 or T300 technology board as well as interface boards such as the CB1 for communications via PROFIBUS SINEC L2 DP. Also refer to the following sections:

    2.2 Expanded functionality with supplementary boards and

    2.3 Operator control and visualization.

If a main contactor is to be used, it can be controlled, as for the drive converters, via contact X9:4,5 "main contactor control".

The rectifier unit can be controlled via

- parameterizing unit PMU,   or
- terminal strip,   or
- serial interface, either an RS485 interface with USS protocol, included in the basic unit, or optionally via PROFIBUS.

The rectifier units can also be controlled via a terminal strip, as illustrated in Fig. 3.2.8.
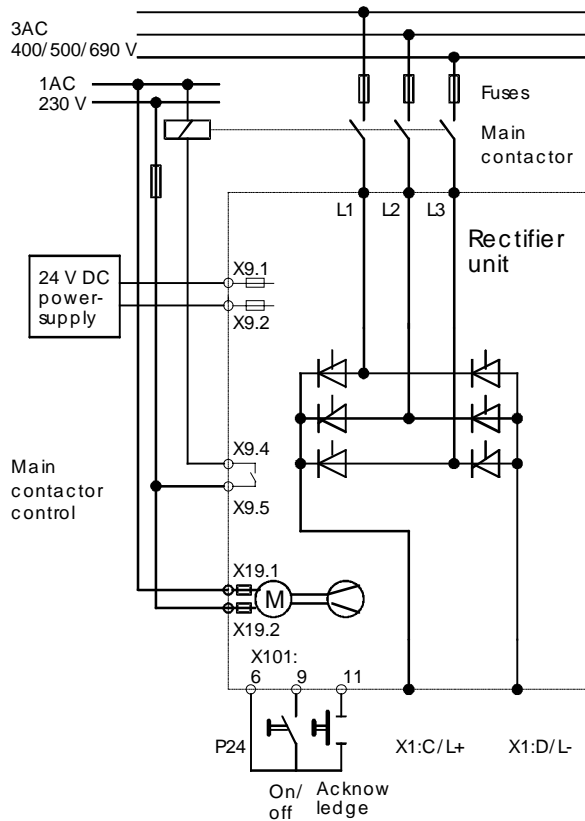
Fig. 3.2.8 *Controlling the rectifier units, size H and above, via terminal strip.*

All of the inputs and outputs are available at the terminal strip of the CUR board:

- 5 binary inputs
- 2 binary outputs
- 2 analog outputs
- 1 RS485 serial interface (alternatively available at connector X300 of the PMU).

The terminal assignment and the possible assignment of the binary and analog inputs/outputs are shown in the following tables.

If additional inputs/outputs are required, the SCI1 or SCI2 interface modules can be used in conjunction with the SCB1 communications board; also refer to Section 2.2.

Comment: The operator control, both via the PMU parameterizing unit as well as also via the terminal strip or the serial interfaces is essentially identical with that for the rectifier/regenerative feedback units. The following considerations are therefore also valid, with the exclusion of the rating-dependent data, for the rectifier/regenerative feedback units; also refer to the following section, Section 3.2.4.

Terminal	Function	Type	Comments
-X100			
1	RS485 interface	RS485 R+	
2	RS485 interface	RS485 R -	
3	RS485 interface	RS485 T+	
4	RS485 interface	RS485 T -	
5	RS485 interface	BS	
-X101			
6	+24 V	External 24 V supply	Max. 100 mA load capability
7	M	Ground for binary signals	
8	M	Ground for binary signals	
9	Binary input 1		The following is true for binary inputs:
10	Binary input 2		H signal: 13 V to 33 V
11	Binary input 3		L signal: -0.6 V to 3 V or
12	Binary input 4		input not connected (open-circuit)
13	Binary input 5		
-X102			
14	Analog output 1	0 to ±10 V, max 5 mA	
15	BS (ref. volt)	Reference potential	For analog outputs
16	Analog output 2	0 to ±10 V, max 5 mA	
-X104			
17	Binary output 1	NO contact	Relay contacts: max 50 V AC max 1 A (0.12 A) at
18	Binary output 1		
19	Binary output 2	NO contact	cosφ = 1 (0,4) or
20	Binary output 2		max. 30 V DC, max. 0.8 A

Table 3.2.1: Terminal connections for the rectifier units, from size H onwards

Terminal **-X9**	Function	Type
1	+ 24 V, max. 2 A	Auxiliary power supply
2	Reference potential	
3	Not assigned	
4	Main contactor control	NO contact, load capability
5	Main contactor control	230 V AC, 4 A

Table 3.2.2:   Terminal connections for main contactor control and the auxiliary power supply for rectifier units from size H onwards

For the analog and binary inputs and outputs, the functions can be provided in accordance with the following tables.

Functions for binary inputs

Can be assigned with	Signal	Pre-assignment via the factory setting	Comment
ON/OFF1 command	H: On L: Off1 (stop)	BE1: -X101:9	Power-off means: The line-side converter is ramped-down (for ERE: DC link discharged) within 2 s, with subsequent shutdown and pulse inhibit and the main contactor control contact opened.
OFF 2	H: Run L: Off2	BE2: -X101:10	Pulses are immediately inhibited and the „main contactor control" contact opened
Run-enable	H: Enable L: Inhibit	Not assigned	Identical with firing pulse enable. If this is not used, enabling is automatic via the sequence control
Acknowledge	L → H: Acknowledge L: Run	BE3: -X101:11	Acknowledge is realized when the signal changes L → H
Select, reserve/basic setting	H: Reserve setting L: Basic setting.	BE5: -X101:13	Possibility of selecting control inputs, e.g. changeover Terminal strip ↔ Serial interface
Inching 1	H: Inching on L: Inching off	Not assigned	From the ready status, this results in charging, the full DC link voltage is available after approx. 1 to 2 s
Inching 2	H: Inching on L: Inching off	Not assigned	Refer to the comment above
Select, Vd reduction	H: With Vd-reduction	Not assigned	The full rectified line supply voltage is not available as DC link voltage, but a lower value which is parameterized via P318
Select reserve data set	LL, LH, HL, HH	Not assigned	2 inputs are to be assigned, so that four data sets with different parameterization can be selected
Ext. fault 1	H: No fault L: Fault	Not assigned	
Ext. fault 2	H: No fault L: Fault	Not assigned	
Ext. alarm 1	H: No alarm. L: Alarm	Not assigned	
Ext. alarm 2	H: No alarm L: Alarm	Not assigned	
Master/slave changeover	H: Slave operation L: Master operation	Not assigned	For parallel rectifier- or rectifier/regenerative feedback units. Master operation: With internal DC link setpoint (master) Slave operation: With external DC link setpoint (slave)
Select, basic/reserve	H: Reserve setting L: Basic setting	Not assigned	
Main contactor checkback signal	H: Main contactor has pulled-in	Not assigned	To monitor the main contactor - if available - in the equipment control

Table 3.2.3: Functions available for binary inputs

Functions for binary outputs

Relay contacts are provided on the CUR boards for this purpose. The significance is as follows:

H signal: Relay pulled-in

L signal: Relay dropped-out

The signals, which are available for the binary outputs, are listed in the following table.

Message	Signal	Factory setting	Comment
Main contactor control	H: Close main contactor	-X9:4,5	To control a main contactor
Fault	H: No fault L: Fault	BA2: -X104:19,20	Group fault
Run	H: Run		
Ready to power-up	H: Ready to power-up		
Ready	H: Ready		Ready means that: - if a main contactor is provided, it is closed - the firing pulses are still inhibited.
OFF2	H: No OFF2 L: OFF2 present		Displays whether the OFF2 command is present
Power-on inhibit	H: No power-up inhibit. L: Power-up inhibit		Power-on inhibit is present, if - a fault is present, - OFF command(s) are present, - there is no (external) power supply.
Alarm	H: No alarm. L: Alarm		Group alarm
Setpoint-actual value deviation	H: No deviation L: Deviation		Signal is present, if an adjustable setpoint-actual value difference (P517) of the DC link voltage is available over a longer time period (P518). The signal is withdrawn when the setpoint-actual value difference becomes smaller.
Regenerative feedback ready	H: Regen. feedb. ready L: Reg.feedb.not ready		Only for rectifier/regenerative feedback units
Main contactor controlled	H: Main contactor closed L: Main contactor not closed		Extension contact for signal, main contactor control
Vd decreased	H: Vd decreased		Signals as to whether the DC link voltage is set to the specified value, i.e. is at a lower value than the fully rectified voltage
Motoring	H: Motoring L: Generating		Only for rectifier/regenerative feedback units; for rectifier units, the unit is always motoring.
Current limit active	H: Standard operation L: Operation at the current limit		If the drive is at the current limit, then under certain circumstances, the required DC link voltage cannot be maintained
Fault, external 1,2	H: Fault present		
Alarm, external	H: External alarm.		
Alarm I²t	H: Alarm L: No alarm		Alarm that the power module is presently overloaded.
Fault, power module overtemperatureT	H: Fault		Indicates that the heatsink temperature, sensed using a temperature sensor, has exceeded 95 °C.
Alarm, power module overtemperature	H: Alarm		Indicates whether the heatsink temperature, sensed using a temperature sensor, has exceeded 90°C.
Pre-charging active	H: Pre-charging active		Is present, as long as the DC link is charged after an ON command.

Table 3.2.4: Functions available for binary outputs

Analog inputs

There are no analog inputs. Setpoints can only be entered as parameter values. These include:

P318: The DC link voltage value, if, using the selection „decrease Vd", a value lower than the full rectified DC link voltge = 1.35 x line supply voltage) is to be set.

P486: DC link current setpoint for operation as slave-rectifier unit (or slave rectifier/regenerative feedback unit), if units are connected in parallel to increase the rating or there is 12-pulse operation.

Actual values for analog outputs.

All actual values, which are available via parameters, can be output at analog outputs.
These includes the values in the following table.

Function	Par
DC link voltage (as absolute value 1 HEX = 1 V)	r006
Line supply input voltage	r030
Input voltage at the regenerative bridge - only for rectifier/regenerative feedback units	r031
Supply frequency	r032
Firing angle of the line-side current converter for the range 0 to 165 °el	r033
DC link current setpoint	r034
DC link current actual value	r035
DC link voltage setpoint	r036
DC link voltage actual value (as a % of the rated value)	r037
Difference, setpoint actual value of the DC link voltage	r038

Table 3.2.5: Functions available for analog outputs

Connecting rectifier units in parallel to increase the rectifier rating

Only certain rectifier units may be connected in parallel. These are higher-rating units and are slightly different only as far as the control is concerned from those units which are only suitable for single operation, i.e. cannot be connected in parallel. This excludes the power section which is identical. Rectifier units which can be connected in parallel have a different order number than those units which cannot be connected in parallel.

A maximum of 2 or 3 rectifier units may be connected in parallel, but these units must be **identical**. In this case, one operates as master, and the other or the other two, as slave. Only the following units may be connected in parallel:

For 380 to 460 V line supply voltage:
6SE7041-3EK85-0A**D**0 with 630 kW, 1333 A rated DC link current,
6SE7041-8EK85-0A**D**0 with 800 kW, 1780 A rated DC link current.

For 500 to 575 V line supply voltage:
6SE7041-3FK85-0A**D**0 with 800 kW, 1285 A rated DC link current,
6SE7041-5FK85-0A**D**0 with 900 kW, 1464 A rated DC link current.
6SE7041-8FK85-0A**D**0 with 1100 kW, 1880 A rated DC link current.

For 660 to 690 V line supply voltage:
6SE7041-3HK85-0A**D**0 with 1000 kW, 1285 A rated DC link current,
6SE7041-5HK85-0A**D**0 with 1100 kW, 1464 A rated DC link current.
6SE7041-8HK85-0A**D**0 with 1500 kW, 1880 A rated DC link current.

Refer to Catalog DA65 for further technical data.

To realize a parallel circuit configuration, a standard unit must be combined with one or two parallel units with **identical ratings**.

Example:
Two rectifier units with 800 kW for a 400 V supply voltage are to be connected in parallel.
The following are required:
6SE7041-8EK85-0A**A**0 as master   +   6SE7041-8EK85-0A**D**0 as slave

The following would be required to connect three rectifier units in parallel:
6SE7041-8EK85-0A**A**0 as master   +   2 x 6SE7041-8EK85-0A**D**0 as slaves.

The following is valid: The slave units should be located to the left of the master unit. In order to ensure uniform load distribution between the master- and slave units, the following measures are required:
- Each rectifier unit must have a line commutating reactor of at least 2 % u_K connected in series.
- The feeder cables to the master- and slave units must be as symmetrical as possible. The same fuses and identical cable cross-sections with the same cable length must be used.

Under these prerequisites, the total available DC link current can be obtained as follows, taking into account the component tolerances of the rectifier unit EE:

$$I_{DC\ link\ total} = 0.9\ x\ \ \ (I_{DC\ link\ EE})$$

3.2.4 Rectifier/regenerative feedback unit ERE

The rectifier/regenerative feedback unit supplies a common DC bus for the inverter units, and can supply regenerative power back into the line supply. A rectifier/regenerative feedback unit is always recommended, if high regenerative powers occur for a multi-motor drive group or for a single drive, or if regenerative operation dominates. Also refer to the information in Section 3.4: Braking possibilities and regenerative operation, Table 3.4.1.

A controlled rectifier/regenerative feedback unit consists of:
- one supply connecting panel for the motoring and one for the generating thyristor bridges
- one 6-pulse thyristor bridge for the motoring thyristor bridge and one for the generating thyristor bridge
- parameterizing- and operator control unit (PMU)
- electronics box with the control board (open-loop and closed-loop control)
- connecting panel for the DC link voltage

The block diagram of the rectifier/regenerative feedback unit is illustrated in Fig. 3.2.9.
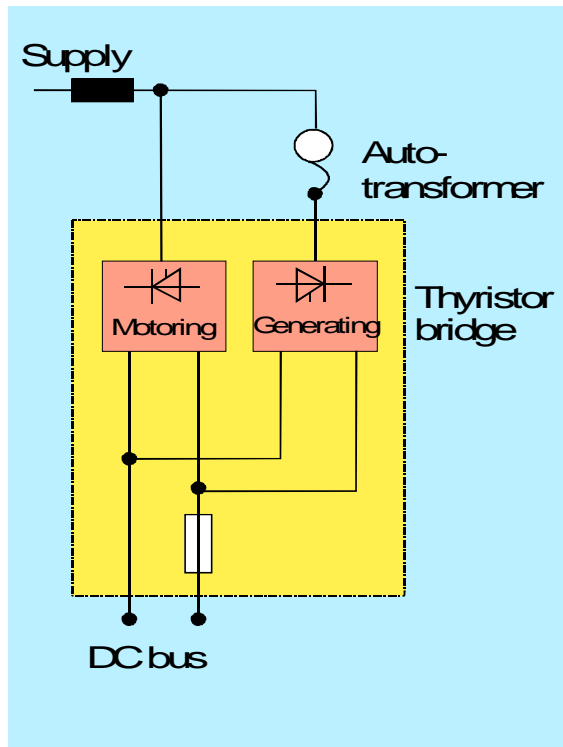
Fig. 3.2.9   Block diagram of the rectifier/regenerative feedback unit.

The unit is connected to the supply through a commutating reactor with $u_K = 4\%$. The inductance of the line commutating reactor must only be reduced for weak supply networks, if

$$S_{K\,supply} \leq 17 * S_{ERE}$$

(whereby $S_{K\,supply}$ = short-circuit rating of the line supply

S_{ERE} = rated apparent power of the rectifier/regenerative feedback unit, which is identical with its rated output (kW)),

The total short-circuit impedance, i.e. u_K, including the line commutating reactor, should not exceed 10% due to the inverter stability limit which must be maintained. However, we would like to point out, that regenerative feedback is problematical when used in conjunction with weak networks. A line

commutating reactor is only not required, when the equipment is fed from a stiff network, through a block transformer with at least 6% u_K. In this case, the block transformer rating must be adapted to the rated output of the rectifier/regenerative feedback unit.

Further, the regenerative bridge is supplied through an autotransformer. An autotransformer is required for the following reason:
When the unit is powered-up, the motoring thyristor bridge ramps-up the DC link voltage from 0 to the full value = 1.35 x supply voltage (as for a diode bridge). This voltage is also maintained in regenerative operation, i.e. when the unit is generating. The DC link voltage when generating is not reduced. In order that the full DC link voltage can also be maintained when generating, the regenerative (generating) or regenerative bridge must be supplied with a voltage of 120% of the supply voltage. To realize this, the regenerative thyristor bridge is supplied through an autotransformer.

Generally, the autotransformer is connected after the line commutating reactor, as shown in Fig. 3.2.9. The autotransformer should only be connected to the supply, i.e. in front of the line commutating reactor, for weak supply networks, i.e. if $S_{K\,supply}$ < approx. 25 * S_{ERE}.

The autotransformer is available in two versions:
- 25% power-on duration, if the average regenerative power is less than 25% of the rated motoring power
- 100% power-on duration, if regenerative operation predominates or is the actual operating mode.

When is it not necessary to use an autotransformer?
If an autotransformer is not to be used, the DC link voltage must be reduced, both in the regenerative feedback mode as well as when motoring. This means that the maximum motor voltage is limited to 80% of the line voltage. For example, for a 500 V supply, a rectifier/regenerative feedback unit for 500 V supply input voltage can be used which is parameterized so that a reduced DC link voltage of 540 V DC can be used. Thus, a DC link bus can be supplied, which can be used to supply inverter units with a maximum 400 V output voltage. The motors and inverter units must then be selected for the lower rated voltage.
Also a poorer line supply power factor must be assumed if an autotransformer is not used. When an autotransformer is used a (basic fundamental) power factor of $\cos\varphi_{(1)} \approx 1$, is obtained; when an autotranformer is not used, and the DC link voltage is reduced, this value deteriorates to $\cos\varphi_{(1)} \leq 0.8$.

Auxiliary power supplies, fuses and additional switching devices

An external 24 V DC power supply with ≥ 2 A output must be provided for correct operation. The 24 V DC power supply is fused in the rectifier/regenerative feedback unit.

Further, for the fans for units size E and above, a 230 V AC AC power supply with
> ≥ 1 A   for size E,
> ≥ 3.3 A for size H,
> ≥ 6.6 A for size K,

must be connected at terminals X19:1,2.

As far as the switching devices and main contactor are concerned, the same issues are valid as were described for the rectifier units (for sizes H and K).

A series main contactor is not absolutely necessary to protect the rectifier unit, however, it is recommended. Further, the rectifier/regenerative feedback unit must be fused. Refer to Catalog DA65 for the recommended fuses.

A rectifier/regenerative feedback unit can be connected as illustrated in 3.2.10.
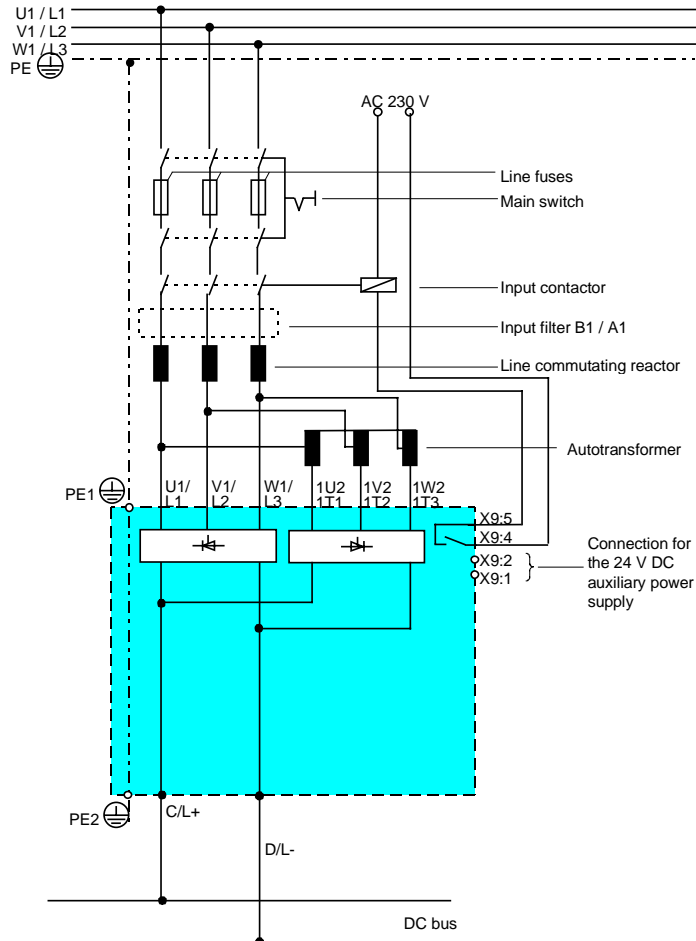
Fig. 3.2.10 Recommended connection for a rectifier/regenerative feedback unit

The unit is controlled just as for the rectifier units, from size H onwards, either via a parameterizing unit PMU, terminal strip or serial interface. Refer to the previous Section 3.2.3.

The rectifier/regenerative feedback unit is selected just the same as for rectifier units from size E or H onwards. Refer to the previous Section 3.2.3. When selecting a rectifier/regenerative feedback unit, the following is true:

$$I_{DClink\ ERE} \geq (0.3 \ldots 1) * \quad I_{DClink\ inverter}$$

Compare the appropriate dimension examples in Section 3.2.3.

Connecting rectifier/regenerative feedback units in parallel to increase the rectifier rating

In this case as well, only two or a maximum of three identical units having the same high output can be connected in parallel. These units which are suitable for connecting in parallel are:

For 380 to 460 V line supply voltages:
6SE7041-3EK85-1A**D**0 with 630 kW, 1333 A rated DC link current,
6SE7041-8EK85-1A**D**0 with 800 kW, 1780 A rated DC link current.

For 500 to 575 V line supply voltages:
6SE7041-3FK85-1A**D**0 with 800 kW, 1285 A rated DC link current,
6SE7041-5FK85-1A**D**0 with 900 kW, 1464 A rated DC link current.
6SE7041-8FK85-1A**D**0 with 1100 kW, 1880 A rated DC link current.

For 660 to 690 V line supply voltages:
6SE7041-3HK85-1A**D**0 with 1000 kW, 1285 A rated DC link current,
6SE7041-5HK85-1A**D**0 with 1100 kW, 1464 A rated DC link current.
6SE7041-8HK85-1A**D**0 with 1500 kW, 1880 A rated DC link current.

Refer to Catalog DA65 for additional technical data.

For a parallel configuraiton, one standard unit must be combined with one or two parallel units having the **same rating**.

Example:
2 rectifier/regenerative feedback units with 800 kW at 400 V supply voltage are to be connected in parallel. The following are required:
6SE7041-8EK85-1A**A**0 as master   +   6SE7041-8EK85-0A**D**0 as slave
                    + 2 x regenerative feedback transformer for master + slave.

The following would be required if three rectifier units were to be connected in parallel:
6SE7041-8EK85-1A**A**0 as master   +   2 x 6SE7041-8EK85-1A**D**0 as slave
                    + 3 x regenerative feedback transformer for master + slaves.

In this case, the following is valid: The slave units must be located to the left of the master unit. The following measures are required in order to achieve uniform load distribution between the master- and slave units:
* Each rectifier unit must have a series line commutating reactor of at least 2 % u_K.
* The feeder cables to the master- and slave units must be as symmetrical (balanced) as possible, and in this case, the same fuses and same cable cross-sections with the same cable length must be used.

Under these prerequisites, the total available DC link current, taking into account the component tolerances of the rectifier/regenerative feedback units is given by:

$$I_{DC\ link\ total} = 0.9\ x\ \ \ \ (I_{DC\ link\ ERE})$$

3.2.5 Controlled rectifier/regenerative feedback unit using transistor technology (Active Front End)

Instead of the line-commutated rectifier/regenerative feedback unit, as described in the previous Section 3.2.4, an Active Front End AFE can also be used.

The Active Front End is a converter at the input with the following characteristics:
- it is a self-commutated converter using IGBTs,
- sinusoidal line currents without the harmonic contents typical for line supplies, and therefore low harmonics and disturbances are fed back into the line supply,
- the supply power factor cos φ can be adjusted between 1 ... 0.8 inductive/capacitive
- suitable for both energy flow directions, i. e. motor- and generator operation,
- can be switched-off safely when the line supply fails; thus, when the line supply fails in regenerative operation, there are no commutation faults with the associated fuse rupture; this is due to the fact that IGBTs can be switched at any time, unlike thyristors
- line supply undervoltage conditions can be compensated by using voltage step-up operation.

The AFEs are presently available as cabinet units in the output range:

250 to 500 kW at 400 V   250 to 630 kW at 500 V   315 to 800 kW at 690 V

according to the catalog data DA 65.2, Section 7. We are presently working on connecting AFEs in parallel. Higher outputs up to twice those specified will be available from approximately the middle of 1997.

AFEs are mainly used:
- if the customer specifies that the harmonics fed back into the line supply must be extremely low; otherwise this can only be achieved using a 12-pulse rectifier unit or with harmonic filters,
- if the line supply is weak or prone to disturbances.

Mode of operation of the AFE

The AFE is essentially an inverter. As far as the power section is concerned, an AFE inverter is identical to an inverter unit having the same output.
Just like an inverter supplies a motor with sinusoidal currents (whereby the currents are smoothed by the leakage inductances of the motor winding), AFE feeds sinusoidal currents into the line supply (when the drive system is in the regenerative mode), or draws sinusoidal currents from the line supply (when the drive system is motoring). The AFE unit is connected to the line supply through an L-C-L line filter so that the line currents are sufficiently sinusoidal. This is shown in the block diagram illustrated in Fig. 3.2.11. Further, there is a charge circuit for the DC link capacitors.

When the unit is powered-up, the pre-charging contactor is first closed. The DC link capacitors are then charged up to approximately the peak value of the line supply voltage through free-wheeling diodes of the AFE inverter. The main contactor then closes. The AFE inverter then starts to clock and the DC link voltage increases to a value which is approximately 10 % higher than the peak line supply voltage. The AFE inverter then essentially operates as step-up controller. The DC link voltage must be slightly higher than the peak line supply voltage, so that the line supply currents are almost sinusoidal and do not manifest any harmonics, such as the 5th-, 7th, 11th, 13th etc., which are typical for line supplies.
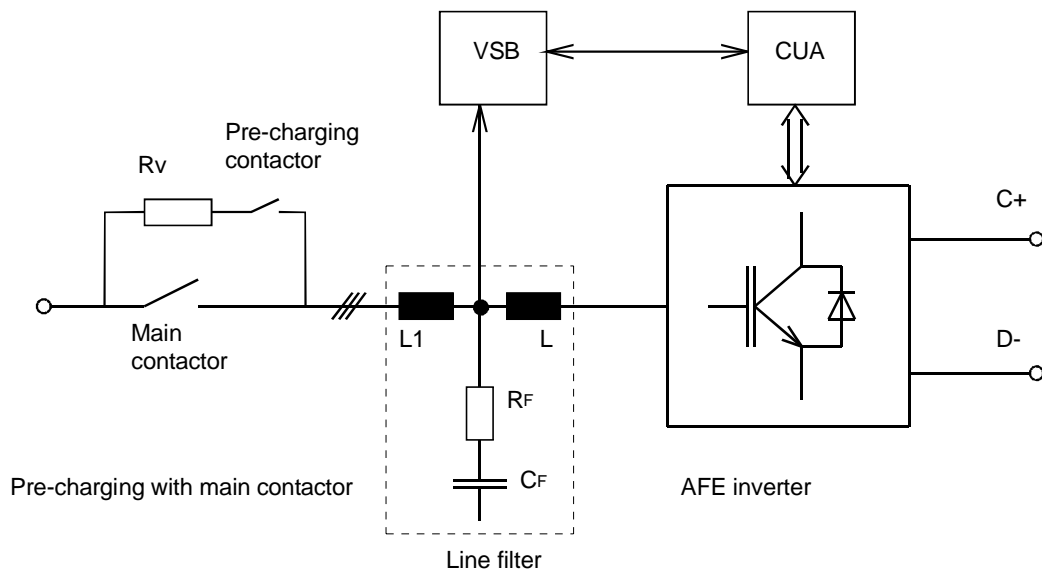
CUA: AFE control board
VSB: Line supply voltage sensing (voltage sensing board)
L1, L: Inductances, AFE filter
CF: Capacitance, AFE filter

Fig. 3.2.11   Block diagram of the Active Front End AFE

Control board CUA, which controls the IGBTs of the AFE, essentially includes
- a higher-level closed-loop DC link voltage controller, and
- a secondary, fast closed-loop phase current control.

The AFE has the task to provide a fixed, defined DC link voltage.

The control operates so that
- when the DC link voltage decreases to below the setpoint, the DC link voltage controller enters an additional (motoring) current component, which again charges-up the DC link,
- when the DC link voltages deviates to values greater than the setpoint, the DC link voltage controller enters an additional (regenerative) current component, which discharges the DC link.

Comment: With the present AFE software, the AFE can only be used with a line supply voltage. The AFE is therefore **not** suitable to generate an isolated supply network, i. e. to supply a load with a three-phase voltage system having a defined voltage and frequency, from an existing DC link voltage. In this case, another software (for isolated network operation) would be required, which is presently not available (and where we see no demand in the near future).

Information regarding the suitability of the AFE for weak supply networks.
The AFE was also designed for weak supply networks, and is therefore especially suitable for operation when connected to networks such as these. During brief line supply dips or brief line supply interruptions (power outages), the AFE attempts to remain operational and only switches-off when absolutely necessary.

The following is especially true: The AFE only switches-off, if
- the line supply voltage is less than 45 % of the rated line supply voltage for a minimum of 20 ms,
- an overcurrent condition has occurred (> 110 % of the maximum AFE current; practically this only occurs when extreme faults occur, e. g. short circuits or component failures, as normally the control limits the current to the maximum current),
- for DC link overvoltages (for $V_{DC\ link}$ > 820 V, 1020 V, 1220 V for voltage classes 400, 500, 690 V)
- when the DC link has an undervoltage condition (for $V_{DC\ link}$ < 76 % of the rectified rated line supply voltage).

When there is a brief line supply interruption, the AFE responds as follows:

If the line supply voltage drops (not below 45 %), the AFE control attempts to maintain the DC link voltage. This causes the line current to increase with (full) inverter loading. If the AFE control goes to the current limit, the DC link voltage dips (motoring) or increases (generating). If the permissible limits are exceeded, the AFE and therefore the drive converter shutdown with a fault condition.

Operator control capabilities.

As far as the operator control and control structure are concerned, the AFE are identical with the drive converter and inverter units. They have the same electronics box, however, with a different CUA control board. The AFE can be controlled via:
- PMU or OP1 operator control panel
- terminal strip
- serial interface, either via USS, which is installed in the basic drive converter, or via PROFIBUS with the additional CB1 communications board (option K10).

One should note, that specific inputs are only accessible via parameter; for example if the line supply power factor cos φ is to be set by the AFE. Thus, this can only be changed via the operator control panel or serial interface, however not via the terminal strip. The 2 analog inputs on the CUA module are used to transfer actual values (line supply voltage) and may not be used for any other purpose. Or put another way: The standard version of the AFE has no analog inputs i. e. without using additional terminal blocks!

The assignment of the terminal strip on the CUA control board is specified in the following table.

If other terminals are required for specific functions, an SCB1 or SCB2 communications board can be used in conjunction with an SCI1 or SCI2 interface module.

The possibilities of assigning binary and analog inputs/outputs are shown in the following tables.

Table: Terminal assignment of the standard AFE terminal strip

Terminal	Function	Type	Comment
-X100			
1	RS485 interface	RE485 R+	
2	RS485 interface	RE 485 R-	
3	RS485 interface	RE485 T+	
4	RS485 interface	RE 485 T-	
5	RS485 interface	Reference potential	Reference potential
6	Binary output 1	Reference contact	Internally assigned to control the
7	Binary output 1	NO contact	main contactor, and may not be used
8	Binary output 1	NC contact	for other purposes
-X101			
13	+ 24 V (150 mA)	For binary	
14	Reference potential	inputs/outputs	Reference potential for binary I/O
15	Reference potential, external	For 24 V DC supply	Reference potential for ext. 24 V supply
16	Binary input 1		H signal: 24 V (13 to 33 V)
17	Binary input 2		L signal: 0 V (-0.6 to 3 V)
18	Binary input 3		
19	Binary input 4		Pre-assigned 24 V ext monitoring
20	Binary input 5		
-X102			
25	No function		
26	No function		
27	Analog input 1	0 to ± 10 V	Assigned the line supply voltage signal
28	Reference potential		Reference potential
29	No function		
30	Analog input 2	0 to ± 10 V	Assigned the line supply voltage signal
31	Reference potential		Reference potential
32	No function		
33	Reference potential		Reference potential
34	Analog output 1	0 to ± 10 V	Can be loaded with ≤ 5 mA
-X9			
1	+ 24 V DC		External 24 V power supply
2	Reference potential		Reference potential
3	Not assigned		
4	Pre-charging contactor		
5	control		
6	Not assigned		
7	Fan		1-ph. 230 V AC fan supply
8	Not assigned		
9	Fan		

Functions available for binary inputs

Can be assigned to	Signal	Pre-assignment for the reserve setting	Comment
ON/OFF 1	L ➔ H: On L: Off 1	BE1: -X101/16	An **on command** closes the pre-charging contactor, charges the DC link, and after approx. 1 s closes the main contactor and enables the AFE pulses. An **Off1 command** inhibits the AFE pulses, opens the main contactor, the AFE goes into the ready to power-up condition, if there is no fault or off2
OFF 2	H: Run L: Off 2	BE2: -X101/17	**H signal:** Operating condition **Off2 command** inhibits the AFE pulses, opens the main contactor and the AFE goes into the power-on inhibit condition
Acknowledge	L ➔ H: Ackno. L: Run	BE3: -X101/18	L ➔ H: Acknowledge L signal: Operating condition
Ext. 24 V monitoring	H: 24 V avail. L: 24 V faulted	BE4: -X101/19	H signal: Operating condition L signal ➔ Fault F007
Select basic / reserve	H: Reserve L: Basic data set	BE5: -X101/20	**H signal:** The command d. (reserve) data set RDS2 become effective **L signal:** The commands of the RDS1 become effective, i. e. operator control mainly via the operator control panel
AFE inverter enable	H: Inverter enable L: Inverter inhibit		
Inching 1, 2	L ➔ H: On L: Off 1		The inching command is handled exactly the same as the ON/OFF 1 command
External fault	H: No fault L: External fault		H signal: Operating condition L signal ➔ Pulse inhibit, open main contactor, fault condition F036
Alarm, external 1, 2	H: No alarm L: External alarm		When alarms occur, alarm messages A015, A016 are output

Functions available for binary outputs

Message	Signal	Pre-assignment	Comment
Main contactor control	H: Close MC L: Open MC	On BA1: -X100 / 6,7,8	The wiring to control the main contactor may not be changed
Pre-charging contactor control	H: Close PCC L: Open PCC	On BA: -X9 / 4,5	The wiring to control the main contactor may not be changed
Ready to power-up	H: Ready to power-up		
Ready	H: Ready		Ready: Main contactor closed and DC voltage available, but AFE gating pulses still inhibited
Run	H: Run		
Fault	H: No fault L: Fault		The specified signal assignment is valid for the terminal strip. The signal assignment is inverted for the serial interface.
OFF 2 available	H: No OFF2 L: OFF2		
Power-on inhibit available	H: No power-on inhibit L: Power-on inhibit		The specified signal assignment is valid for the terminal strip. The signal assignment is inverted for the serial interface.
Alarm present	H: No alarm L: Alarm		The specified signal assignment is valid for the terminal strip. The signal assignment is inverted for the serial interface.
Setpoint-actual value deviation	H: No deviation L: Deviation		The demanded DC link voltage cannot be maintained.
Undervoltage fault	H: No fault L: Undervoltage fault		The DC link voltage condition is sensed. Refer to "Fault" regarding the signal assignment
Mot./ gen. operation	H: Gen. L: Mot.		
Current limiting active	H: Not active L: Active		Refer to "Fault" regarding the signal assignment
External fault 1, 2	H: No fault L: Fault		Refer to "Fault" regarding the signal assignment
External alarm	H: No alarm L: Alarm		Refer to "Fault" regarding the signal assignment
Alarm, I^2t AFE	H: No alarm L: Alarm		Refer to "Fault" regarding the signal assignment
Fault, AFE overtemperature	H: No fault L: Fault		The temperature is sensed using sensors on the heatsinks. Refer to "Fault" regarding the signal assignment
Alarm AFE overtemperature	H: No alarm L: Alarm		Refer to "Fault" regarding the signal assignment

Comment: The binary (relay) outputs, available in the standard unit, are assigned functions to control the main contactor and pre-charging contactor. If additional signals are to be used as binary outputs (via terminals) then an additional terminal block must be provided, e. g. option K41 or K45 in conjunction with K11 + K20.

Analog inputs

As already mentioned, the existing analog inputs on the CUA control board are used to transfer line voltage actual values, and may not be used for any other purpose. Further, no quantities are available which could be controlled via analog inputs. All of the setpoints or setting values are exclusively accessible via parameter. However, they can only be set via operator control panel or serial interface.

Analog outputs

All actual values, which are available via parameter, can be output at analog outputs. This includes the values shown in the following table.

Function	Par
AFE inverter after the filter ($\approx$ line current) basic fundamental	r004
Actual DC link voltage	r006
AFE utilization, based on the I^2t monitoring as a %	r010
Line voltage actual value, basic fundamental	r030
Line frequency	r032
Reactive power kVAr (setpoint) as a % of the maximum setpoint entered in P122	r123
DC link voltage reference value	r126
Maximum current setpoint, taking into account the I^2t monitoring	r174
Reactive current setpoint	r255
Reactive current actual value	r256
Active current setpoint	r263
Active current actual value	r264
Unsmoothed actual DC link voltage	r303
Modulation depth of the closed-loop control for the gating unit in %	r764

3.3 Calculating the efficiency of MASTERDRIVES VC units

Some significant changes have been made over previous Editions of the Engineering Manual on this subject, status February 1997. This has made it necessary to revise this section. The changes especially involved the following:

- Modified power sections for the chassis units up to 200 kW with the goal of reducing losses,
- developing complete drive converters as chassis units up to 400 kW, also with reduced total losses,
- developing units with water-cooling in addition to air-cooled units.

The following shows how the **drive converter- and inverter losses for any load points can be determined** from the shaft output P_W and the speed n of the motor. The calculation is based on the measured values, which were determined at the rated operating point during the type test. The losses at the particular load point are determined, by converting the measured values from the rated operating point to the load point.

The data on the losses refer to air-cooled units. They are also valid for water-cooled units having the same output, as these have the same electrical design and identical rated values. It may be necessary to additionally take into account the losses in the water cooling circuit (pump power for water circulating pumps etc.).

When calculating the drive converter efficiency it should be taken into account that the losses should be referred to the active drive converter output ($= P_W / \eta_M$ when motoring).

Losses at the rated drive converter current

The data on the losses at rated current (also refer to the data in Catalog DA65.10) are listed in Table 3.3-1 (compact- and chassis units) and Table 3.3-2 (cabinet units). The drive converter losses at the rated operating point of 50 Hz are specified. The pulse frequency is assumed to be 2.5 kHz, which is for VC set in the factory.

When determining the efficiencies at the rated operating point, it is assumed that the rated drive converter output is available, i.e. that the motor which is connected has a load which is equal to its rated output. In this case, a motor is assumed to have cos φ = 0.85 or above (as for standard induction motors with pole numbers up to 2p = 6).

The data, specified in Tables 3.3-1 and 3.3-2, are used to quickly determine the losses at the rated drive converter current. Additional data is required, as specified in the following, to determine the drive converter losses at any particular load point.

Data for compact- and chassis units

Voltage [V]	Rated motor output [kW]	MLFB (Order No.)	Losses at the rated operating point [kW]	Efficiency at the rated operating point %
230	2.2	6SE7021-1CA60	0.13	94.4
	3	6SE7021-3CA60	0.16	96.0
	4	6SE7021-8CB60	0.18	96.5
	5.5	6SE7022-3CB60	0.23	96.6
	7.5	6SE7023-2CB60	0.32	96.5
	11	6SE7024-4CC60	0.41	96.8
	15	6SE7025-4CD60	0.58	96.7
	18.5	6SE7027-0CD60	0.74	96.5
	22	6SE7028-1CD60	0.83	96.7
400	2.2	6SE7016-1EA61	0.11	96.3
	3	6SE7018-0EA61	0.12	96.9
	4	6SE7021-0EA61	0.16	97.0
	5.5	6SE7021-3EB61	0.16	97.6
	7.5	6SE7021-8EB61	0.21	97.6
	11	6SE7022-6EC61	0.34	97.3
	15	6SE7023-4EC61	0.47	97.3
	18.5	6SE7023-8ED61	0.60	97.2
	22	6SE7024-7ED61	0.71	97.1
	30	6SE7026-0ED61	0.85	97.5
	37	6SE7027-2ED61	1.06	97.4
	45	6SE7031-0EE60	1.18	97.6
	55	6SE7031-2EF60	1.67	97.2
	75	6SE7031-5EF60	1.95	97.6
	90	6SE7031-8EF60	2.17	97.8
	110	6SE7032-1EG60	2.68	97.7
	132	6SE7032-6EG60	3.40	97.6
	160	6SE7033-2EG60	4.30	97.5
	200	6SE7033-7EG60	5.05	97.7
	250	6SE7035-1EK60	7.10	97.3
	315	6SE7036-0EK60	8.20	97.6
	400	6SE7037-0EK60	10.2	97.5

Table 3.3.1   Losses and efficiencies of the drive converters (compact- and chassis units) at the rated output

Comment: The loss- and efficiency data only refer to the compact- or chassis units. Additional drive components, such as fuses, line commutating reactor, line filter, switchgear, output reactor, output filter etc. are not taken into account here!

Data for compact- and chassis units (continued)

Voltage	Rated motor output	MLFB (Order No.)	Losses at the rated operating point	Efficiency at the rated operating point
[V]	[kW]		[kW]	%
500	2.2	6SE7014-5FB61	0.10	96.7
	3	6SE7016-2FB61	0.11	97.2
	4	6SE7017-8FB61	0.12	97.7
	5.5	6SE7021-1FB61	0.16	97.6
	7.5	6SE7021-5FB61	0.21	97.6
	11	6SE7022-2FC61	0.32	97.5
	18.5	6SE7023-0FD61	0.59	97.2
	22	6SE7023-4FD61	0.69	97.2
	30	6SE7024-7FD61	0.87	97.4
	37	6SE7026-1FE60	0.91	97.8
	45	6SE7026-6FE60	1.02	97.9
	55	6SE7028-0FF60	1.26	97.9
	75	6SE7031-1FF60	1.80	97.8
	90	6SE7031-3FG60	2.13	97.8
	110	6SE7031-6FG60	2.58	97.8
	132	6SE7032-0FG60	3.40	97.6
	160	6SE7032-3FG60	4.05	97.7
	200	6SE7033-0FK60	5.80	97.3
	250	6SE7033-5FK60	6.80	97.5
	315	6SE7034-5FK60	8.3	97.5
690	55	6SE7026-0HF60	1.05	98.2
	75	6SE7028-2HF60	1.47	98.2
	90	6SE7031-0HG60	1.93	98.0
	110	6SE7031-2HG60	2.33	98.0
	132	6SE7031-5HG60	2.83	98.0
	160	6SE7031-7HG60	3.50	97.5
	200	6SE7032-1HG60	4.30	98.0
	250	6SE7033-0HK60	6.60	97.5
	315	6SE7033-5HK60	7.40	97.8
	400	6SE7034-5HK60	9.10	97.9

Table 3.3-1   Losses and efficiencies of the drive converters (compact- and chassis units) at the rated output (continued)

Comment: The loss- and efficiency data refer only to the compact- or chassis units. Additional drive components, such as fuses, line commutating reactor, line filter, switchgear, output reactor, output filter etc. are not taken into account here!

Cabinet unit data

(standard cabinets air-cooled, 6-pulse rectification, 1Q operation, without reactor)

Voltage	Rated motor output	MLFB (Order No.)	Losses at the rated operating point	Efficiency at the rated operating point
[V]	[kW]		[kW]	%
400	45	6SE7131-0EB61-3BA0	1.3	97.4
	55	6SE7131-2EC61-3BA0	1.9	96.8
	75	6SE7131-5EC61-3BA0	2.1	97.4
	90	6SE7131-8EC61-3BA0	2.4	97.5
	110	6SE7132-1ED61-3BA0	3.0	97.5
	132	6SE7132-6ED61-3BA0	3.6	97.5
	160	6SE7133-2ED61-3BA0	4.5	97.4
	200	6SE7133-7ED61-3BA0	5.2	97.6
	250	6SE7135-1EE62-3BA0	7.4	97.2
	315	6SE7136-0EG62-3BA0	8.6	97.4
	400	6SE7137-0EE62-3BA0	10.7	97.5
	500	6SE7138-6EG62-3BA0	16.0	97.0
	630	6SE7141-1EH62-3BA0	18.7	97.2
	710	6SE7141-3EJ62-3BA0	21.3	97.2
500	37	6SE7126-1FB61-3BA0	1.0	97.6
	45	6SE7126-6FB61-3BA0	1.2	97.6
	55	6SE7128-0FC61-3BA0	1.4	97.6
	75	6SE7131-1FC61-3BA0	1.9	97.7
	90	6SE7131-3FD61-3BA0	2.4	97.5
	110	6SE7131-6FD61-3BA0	2.8	97.6
	132	6SE7132-0FD61-3BA0	3.6	97.5
	160	6SE7132-3FD61-3BA0	4.3	97.5
	200	6SE7133-0FE62-3BA0	6.0	97.2
	250	6SE7133-5FE62-3BA0	7.0	97.4
	315	6SE7134-5FE62-3BA0	8.6	97.4
	400	6SE7135-7FG62-3BA0	12.5	97.1
	500	6SE7136-5FG62-3BA0	13.7	97.4
	630	6SE7138-6FG62-3BA0	16.1	97.6
	800	6SE7141-1FJ62-3BA0	20.1	97.6
	900	6SE7141-2FJ62-3BA0	23.1	97.6
	1000	6SE7141-4FL62-3BA0	25.7	97.6
	1100	6SE7141-6FL62-3BA0	29.4	97.5

Table 3.3-2   Losses and efficiencies of the drive converters (cabinet units) at rated output

Comment: The loss- and efficiency data refer to the cabinet unit including line commutating reactor and main switch with fuses.
Cabinet options, such as main contactor, line filter, output reactor, output filter etc. have not been taken into account here!

Cabinet unit data (continued)

Voltage	Rated motor output	MLFB (Order No.)	Losses at the rated operating point	Efficiency at the rated operating point
[V]	[kW]		[kW]	%
690	55	6SE7126-0HC61-3BA0	1.2	98.0
	75	6SE7128-2HC61-3BA0	1.6	98.0
	90	6SE7131-0HD61-3BA0	2.1	97.8
	110	6SE7131-2HD61-3BA0	2.5	97.9
	132	6SE7131-5HD61-3BA0	3.0	97.9
	160	6SE7131-7HD61-3BA0	3.8	97.8
	200	6SE7132-1HD61-3BA0	4.5	97.9
	250	6SE7133-0HE62-3BA0	6.9	97.4
	315	6SE7133-5HE62-3BA0	7.7	97.7
	400	6SE7134-5HE62-3BA0	9.3	97.8
	500	6SE7135-7HG62-3BA0	12.7	97.7
	630	6SE7136-5HG62-3BA0	15.1	97.7
	800	6SE7138-6HG62-3BA0	18.6	97.8
	1000	6SE7141-1HJ62-3BA0	23.3	97.8
	1200	6SE7141-2HJ62-3BA0	29.6	97.7
	1300	6SE7141-4HL62-3BA0	29.9	97.8
	1500	6SE7141-6HL62-3BA0	33.9	97.8

Table 3.3-2   Losses and efficiencies of the drive converters (cabinet units) at rated output (continued)

Comment: The loss- and efficiency data refer to the cabinet unit including line commutating reactor and main switch with fuses.
Cabinet options, such as main contactor, line filter, output reactor, output filter etc. have not been taken into account here!

3.3.1 Calculating the losses at any load point for compact- and chassis units

The drive converter losses consist of the following components:

- **Constant losses** V_{const} for the power supply, auxiliaries and IGBT gating

- **Rectifier losses** V_{re} on-state power losses and switching losses of the
                                                   line-side converter.

- **Inverter losses** V_{inv} on-state power and thermal losses of the inverter.

- **Switching losses** V_{sw} of the inverter as a function of the inverter pulse
                                                   frequency.

The **total losses** of the drive converter   V are obtained as follows:

$$V \ = \ V_{const} \ + \ V_{re} + V_{inv} + V_{sw} \qquad\qquad\qquad [3.3\text{-}1]$$

The loss components of the drive converter and inverter as well as the rectifier- and
rectifier/regenerative feedback units at the rated operating point are specified in the Tables 3.3-4 to
3.3-6. The following text will show you how to determine the losses at the particular operating point
from these values.

Individual loss data for compact- and chassis units

Voltage	Rated output	MLFB (Order No.)	I_n	V_{const}	V_{re}	V_{inv}	V_{sw} at 2.5 kHz
V	kW		[A]	[kW]	[kW]	[kW]	[kW]
230	2.2	6SE7021-1CA60	10.6	0.031	0.035	0.05	0.014
	3	6SE7021-3CA60	13.3	0.031	0.048	0.065	0.016
	4	6SE7021-8CB60	17.1	0.036	0.049	0.082	0.013
	5.5	6SE7022-3CB60	22.9	0.036	0.065	0.111	0.018
	7.5	6SE7023-2CB60	32.2	0.036	0.11	0.146	0.028
	11	6SE7024-4CC60	44.2	0.036	0.121	0.227	0.026
	15	6SE7025-4CD60	54	0.146	0.144	0.24	0.05
	18.5	6SE7027-0CD60	69	0.146	0.2	0.334	0.06
	22	6SE7028-1CD60	81	0.146	0.229	0.385	0.07
400	2.2	6SE7016-1EA61	6.1	0.031	0.018	0.053	0.008
	3	6SE7018-0EA61	8.0	0.031	0.023	0.055	0.011
	4	6SE7021-0EA61	10.2	0.031	0.033	0.081	0.015
	5.5	6SE7021-3EB61	13.2	0.036	0.034	0.063	0.027
	7.5	6SE7021-8EB61	17.5	0.036	0.048	0.097	0.029
	11	6SE7022-6EC61	25.5	0.036	0.068	0.196	0.04
	15	6SE7023-4EC61	34.0	0.036	0.101	0.279	0.054
	18.5	6SE7023-8ED61	37.5	0.146	0.099	0.295	0.06
	22	6SE7024-7ED61	47	0.146	0.13	0.334	0.1
	30	6SE7026-0ED61	59	0.146	0.164	0.45	0.09
	37	6SE7027-2ED61	72	0.146	0.212	0.592	0.11
	45	6SE7031-0EE60	92	0.135	0.24	0.66	0.145
	55	6SE7031-2EF60	124	0.16	0.32	1.00	0.19
	75	6SE7031-5EF60	146	0.16	0.39	1.14	0.26
	90	6SE7031-8EF60	186	0.16	0.48	1.17	0.36
	110	6SE7032-1EG60	210	0.38	0.50	1.40	0.40
	132	6SE7032-6EG60	260	0.41	0.65	1.78	0.56
	160	6SE7033-2EG60	315	0.53	0.82	2.35	0.6
	200	6SE7033-7EG60	370	0.53	1.01	2.72	0.79
	250	6SE7035-1EK60	510	1.09	1.32	3.59	1.1
	315	6SE7036-0EK60	590	1.1	1.57	4.13	1.4
	400	6SE7037-0EK60	690	2.4	1.85	4.4	1.55
	500	6SE7038-6TK60	860	1.3	-	8.5	2.1
	630	6SE7041-1TK60	1100	2.3	-	8.8	2.3
	710	6SE7041-3TK60	1300	2.3	-	9.6	2.6
	900	6SE7041-6TK60	1630	3.5	-	14.5	4.6 [*]

[*] If an interphase reactor chassis is used, 1 kW must be taken into account as interphase reactor losses

Table 3.3-3:   List of the individual losses at the rated operating point for compact- and chassis   units to calculate the total losses

Individual loss data for compact- and chassis units (continued)

Voltage	Rated output	MLFB (Order No.)	I_n	V_{const}	V_{re}	V_{inv}	V_{sw} at 2.5 kHz
V	kW		[A]	[kW]	[kW]	[kW]	[kW]
500	2.2	6SE7014-5FB61	4.5	0.036	0.012	0.042	0.01
	3	6SE7016-2FB61	6.2	0.036	0.018	0.04	0.016
	4	6SE7017-8FB61	7.8	0.036	0.018	0.046	0.02
	5.5	6SE7021-1FB61	11.0	0.036	0.027	0.069	0.028
	7.5	6SE7021-5FB61	15.1	0.036	0.04	0.099	0.035
	11	6SE7022-2FC61	22	0.036	0.057	0.179	0.048
	18.5	6SE7023-0FD61	29	0.146	0.109	0.235	0.1
	22	6SE7023-4FD61	34	0.146	0.099	0.325	0.12
	30	6SE7024-7FD61	46.5	0.146	0.13	0.434	0.16
	37	6SE7026-1FE60	61	0.135	0.16	0.555	0.15
	45	6SE7026-6FE60	66	0.135	0.18	0.72	0.165
	55	6SE7028-0FF60	79	0.16	0.22	0.79	0.23
	75	6SE7031-1FF60	108	0.16	0.33	1.10	0.31
	90	6SE7031-3FG60	128	0.41	0.33	1.21	0.45
	110	6SE7031-6FG60	156	0.41	0.41	1.27	0.71
	132	6SE7032-0FG60	192	0.5	0.56	1.60	0.94
	160	6SE7032-3FG60	225	0.53	0.67	2.12	0.98
	200	6SE7033-0FK60	297	1.08	0.84	2.88	1.2
	250	6SE7033-5FK60	354	1.2	1.19	3.21	1.4
	315	6SE7034-5FK60	452	1.2	1.32	4.53	1.55
	400	6SE7035-7UK60	570	1.3	-	5.9	1.7
	500	6SE7036-5UK60	650	1.4	-	6.7	1.9
	630	6SE7038-6UK60	860	2.2	-	7.2	2.2
	800	6SE7041-1UL60	1080	2.4	-	9.1	2.7
	900	6SE7041-2UL60	1230	2.6	-	10.9	3.2
	1000	6SE7041-4UQ60	1400	4.8	-	11.2	3 [*]
	1100	6SE7041-6UQ60	1580	5	-	12.8	3.5 [*]
690	55	6SE7026-0HF60	60	0.19	0.16	0.62	0.23
	75	6SE7028-2HF60	82	0.19	0.23	0.86	0.32
	90	6SE7031-0HG60	97	0.44	0.24	1.02	0.40
	110	6SE7031-2HG60	118	0.44	0.30	1.24	0.52
	132	6SE7031-5HG60	145	0.53	0.39	1.44	0.64
	160	6SE7031-7HG60	171	0.56	0.47	1.95	0.82
	200	6SE7032-1HG60	208	0.56	0.60	2.28	1.06
	250	6SE7033-0HK60	297	1.3	0.84	3.41	1.35
	315	6SE7033-5HK60	354	1.31	1.19	3.55	1.65
	400	6SE7034-5HK60	452	1.31	1.32	4.77	1.9
	500	6SE7035-7WK60	570	1.4	-	5.7	2.5
	630	6SE7036-5WK60	650	1.5	-	6.6	2.9
	800	6SE7038-6WK60	860	2.5	-	7.8	3.6
	1000	6SE7041-1WL60	1080	2.6	-	9.8	4.8
	1200	6SE7041-2WL60	1230	2.8	-	14.4	5.7
	1300	6SE7041-4WQ60	1400	5.6	-	12.2	4.8 [*]
	1500	6SE7041-6WQ60	1580	5.6	-	14.3	5.6 [*]

[*] If an interphase reactor chassis is used, 1 kW must be taken into account as interphase reactor losses

Table 3.3-3:   List of the individual losses at the rated operating point for compact- and chassis units to calculate the total losses (continued)

I)   Constant losses

The specified constant losses are valid for the basic drive converter without supplementary modules. If the units are ordered with supplementary modules, then the constant losses must be increased as follows.

Increasing the constant losses for		
	interface module CBP,CBC	+ 0.004 kW
	interface module SCB1	+ 0.001 kW
	interface module SCB2	+ 0.003 kW
	technology module T100	+ 0.013 kW
	technology module T300 (without encoder)	+ 0.017 kW
	technology module T400	+ 0.020 kW
	tachometer and synchronization module TSY	+ 0.004 kW

II)   Rectifier losses

The rectifier losses V_{re} are approximately proportional to the active output of the drive converter. The following is valid:

$$V_{GR} = V_{GR_N} \cdot \frac{P_W / \eta_M}{S_N \cdot \cos\varphi} = V_{GR_N} \cdot \frac{P_W / \eta_M}{\sqrt{3} * U_{Netz} * I_{UN} * 0{,}85} \qquad [3.3\text{-}2]$$

whereby:

$$P_W = \frac{M\,[\text{Nm}] \cdot n\,[\text{RPM}]}{9554}$$

motor shaft output at the load point being investigated

$V_{re\,N}$

the rectifier losses at the rated operating point, specified in Table 3.3-3

$$S_N = \sqrt{3} * U_N * I_{UM}$$

rated drive converter output in kVA,

$\cos\varphi$

power factor of an adapted motor at the rated operating point, assumed to be 0.85

η_M

motor efficiency at the load point being investigated.

I_{UN}

rated drive converter output current

The rectifier losses at the drive converter rated operating point $V_{re} = V_{re_N} \cdot \dfrac{P_W / \eta_M}{S_N \cdot \cos\varphi}$ and the rated

drive converter output current I_{UN} are specified in Table 3.3-3. The motor efficiency at the load point being investigated can be determined from the Tables under Section 3.3.8.

Caution: The rectifier losses V_{re} are eliminated, if only inverter units are being investigated which are connected directly to a DC link.

III)   **Inverter losses**

The inverter losses V_{inv} are approximately proportional to the drive converter output current. The following is valid:

$$V_{inv} = \frac{I}{I_{N_U}} \cdot V_{inv_N} \qquad \text{for } I \approx 0.2 \ ... \ 1.5 \ I_{N_U} \qquad \text{[3.3-3]}$$

whereby:

V_{inv_N} inverter losses at the rated operating point (refer to Table 3.3-3)

I motor current at the load point being investigated

I_{U_N} rated drive converter current

The motor current I (this is the same as the drive converter output current) is dependent on the load torque M_L.

The factor I / I_{Mn} (I_{Mn} = rated motor current) is best determined as shown in the following:

First determine, from Tables 3.3-4 and 3.3-5, the ratios

no-load current to rated current I_0 / I_{rated}

rated active current to rated current $I_{W\ N} / I_{M\ rated}$ of the motor

The load current can be calculated from load torque M according to the following formula:

$$\frac{Iload}{IM\,rated} = \sqrt{\left(\frac{I0}{IM\,rated}\right)^2 + \left(\frac{M}{M_N} * \frac{I_{W_N}}{IM\,rated}\right)^2} \quad \text{for operation at rated flux [3.3-4]}$$

For operation in the field-weakening mode ($f > f_n$) it should be observed, that the torque as well as the no-load current I_0 decrease approximately in the ratio f_n/f (f_n = rated motor frequency, f = drive converter output frequency):

$$\frac{Iload}{IM\,rated} = \sqrt{\left(\frac{I0}{IM\,rated} * \frac{fn}{f}\right)^2 + \left(\frac{M}{M_N} * \frac{f}{fn} * \frac{I_{W_N}}{IM\,rated}\right)^2} \quad \begin{array}{l}\text{for field-weakening operation}\\ \text{[3.3-5]}\\ \text{with } f > f\ n\end{array}$$

The thus determined motor current must be converted to the rated drive converter current in order to be able to determine the inverter losses in accordance with Equation [3.3-3].

Type	Pole No.				Type	Pole No.			
1LA5 **1MJ5**	2	4	6	8	**1LA6** **1MJ6**	2	4	6	8
050	70	74	96		**183**	36	41		
053	70	77	93		**186**		40	44	56
060	69	77	91		**206**	31		42	
063	68	81	82		**207**	31	41	36	51
070	56	78	76	83	**220**		37		45
073	60	71	73	78	**223**	26	37	36	42
080	60	74	79	85	**253**	28	35	34	38
083	47	71	82	90	**280**	28	35	34	37
090	60	74	72	83	**283**	25	33	33	36
096	47	70	73	70	**310**	31	34	33	44
106	45	70	70	72	**313**	30	33	32	43
107		65		70	**316**	26	27	35	40
113	37	51	65	67	**317**	22	31	34	39
130	55	50	55	63	**356**	23	31	33	41
131	52				**357**	20	30	32	40
133		53	57	64	**358**			34	41
134			54		**406**	23	32		
163	41	39	54	63	**407**	19	32	32	41
164	46			58	**456**	18	30	31	40
166	41	35	49	59	**457**	17	26	29	40
					1LA8				
					315	32	36	36	42
					317	30	36	36	42
					353	32	36		
					355	30	36	36	42
					357	30	35	36	42
					403	30	35	37	42
					405	30	35	36	42
					407	30	33	36	42
					453	30	35	37	44
					455	28	35	36	44
					457	26	33	36	44

Table 3.3-4:   No-load current of 1LA5 (1LA2), 1LA6, 1LA8 and 1MJ6 motors, specified as a % of the rated motor current

Type	Pole No.				Type	Pole No.			
1LA5 **1MJ5**	2	4	6	8	**1LA6** **1MJ6**	2	4	6	8
050	71	67	34		**183**	93	91		
053	71	64	37		**186**		92	90	83
060	72	64	41		**206**	95		91	
063	73	59	57		**207**	95	91	93	86
070	83	63	65	56	**220**		93		89
073	80	70	68	63	**223**	97	93	93	91
080	80	67	61	53	**253**	96	94	94	93
083	88	70	57	44	**280**	96	94	94	93
090	80	67	69	56	**283**	97	94	94	93
096	88	71	68	71	**310**	95	94	94	90
106	89	71	71	69	**313**	95	94	95	90
107		76		71	**316**	97	96	94	92
113	93	86	76	74	**317**	98	95	34	92
130	84	87	84	78	**356**	98	95	94	92
131	85				**357**	98	95	95	92
133		85	82	77	**358**			94	91
134			84		**406**	98	95		
163	91	92	84	78	**407**	98	95	95	91
164	89			81	**456**	98	95	95	92
166	91	94	87	80	**457**	98	97	96	92
					1LA8				
					315	95	93	93	91
					317	95	93	93	91
					353	95	93		
					355	95	93	93	91
					357	95	94	93	91
					403	95	94	93	91
					405	95	94	93	91
					407	95	94	93	91
					453	95	94	93	90
					455	96	94	93	90
					457	97	94	93	90

Table 3.3-5:   Active currents of 1LA5 (1LA2), 1LA6, 1MJ5 and 1MJ6 motors
for operation with rated torque
Specified as a % of the rated motor current

IV) Switching losses

The following is valid for the switching losses V_{SW}:

$$V_{Sch} = V_{Schn} \cdot \frac{f_p}{2,5\,kHz} * \frac{I_{Last}}{I_{Un}} * \frac{U_{Netz}}{U_{Tab}} \qquad \text{[3.3-6]}$$

whereby:

$V_{sw\,n}$ switching losses at the rated operating point at the line supply voltage specified in Table 3.3-3

f_p pulse frequency (= 3 kHz for FC, 2.5 kHz for VC or 5 kHz for SC, if not parameterized differently. For more detailed information refer to the comment below or Section 2.1 [being prepared]).

I_{load} load- or motor current; determined as in the previous section, refer to formulas [3.3-4] and [3.3-5].

I_{Un} rated drive converter current according to Table 3.3-3

U_{supply} line supply voltage, e.g. 400 V for units for a voltage range from 380 to 480 V

U_{tab} reference voltage, specified in Table 3.3-3, e.g. 400 V for units which can be operated between 380 V and 480 V.

Comment

For **50 Hz motors**, the pulse frequency f_p is obtained as follows, if not parameterized differently:

For	$f \leq 40$ Hz	$\rightarrow$	f_p 2.5 kHz at VC
For	40 Hz < f < 45 Hz	$\rightarrow$	space vector modulation with f_p = 2 kHz
For	45 Hz < f < 48 Hz	$\rightarrow$	edge modulation with f_p = 23 $*$ f $\approx$ 1070 Hz
For	48 Hz < f < 50 Hz	$\rightarrow$	edge modulation with f_p = 19 $*$ f $\approx$ 930 Hz
For	50 Hz < f < 62 Hz	$\rightarrow$	edge modulation with f_p = 19 $*$ f (field-weakening range)
For	62 Hz < f < 100 Hz	$\rightarrow$	edge modulation with f_p = 17 $*$ f (field-weakening range)

For **60 Hz motors**, the pulse frequency f_p is obtained as follows, if not parameterized differently:

For	$f \leq 48$ Hz	$\rightarrow$	f_p = 2.5 kHz at VC
For	48 Hz < f < 54 Hz	$\rightarrow$	space modulation with f_p = 2 kHz
For	54 Hz < f < 58 Hz	$\rightarrow$	edge modulation with f_p = 23 $*$ f $\approx$ 1290 Hz
For	58 Hz < f < 62 Hz	$\rightarrow$	edge modulation with f_p = 19 $*$ f $\approx$ 1140 Hz
For	62 Hz < f < 100 Hz	$\rightarrow$	edge modulation with f_p = 17 $*$ f (field-weakening range)
For	f > 100 Hz	$\rightarrow$	edge modulation with f_p = 9 $*$ f (field-weakening range)

V)   Calculation schematic

Example of a calculation for a pump drive:

Pump drive: $M \sim n^2$ for P_W = 120 kW and n = 1500 RPM

Drive converter: 6SE7032-6EG60 with 260 A, 400 V, VC version

Motor: 1LA6 313-4AA.. with P_N = 132kW, U = 400 V, n_N = 1485 RPM

                       I = 230 A, M = 849 Nm, I/I_0 = 33%, Iw/In = 94 % (Tables 3.3-4 and 3.3-5)

                       $\cos\varphi$ = 0.87, η_M = 0.95

Required: Drive converter losses and efficiency at

a) the configured output   **b) half load of a), i.e.**

   P = 120 kW at n = 1500 RPM   P = 120 kW / 2 = 60 kW at

$$n = \sqrt[3]{0,5} * 50\,Hz \approx 40\,Hz$$

whereby $\quad \dfrac{P}{P_{max}} = \dfrac{1}{2} = \left| \dfrac{n}{n_{max}} \right|^3$

Operating point a): P = 120 kW, n = 1500 RPM

- Torque at the load point:

$$M = \frac{P_W}{n} \cdot 9554 = \frac{120\,\text{kW}}{1500\,\text{RPM}} \cdot 9554 = 764\ \text{Nm} \qquad\qquad \text{M = 0.9} \cdot \text{M}_{N\ mot}$$

- Determine the motor current (from formula [3.3-4])

$$I = 230A * \sqrt{0,33^2 + (0.9*0.94)^2} = 209\,A \qquad\qquad I = 0.8 \text{ x } I_{conv}$$

- The following power losses are obtained:

V_{const_N} = 0.41 kW, $\qquad V_{re_N}$ = 0.65 kW,

V_{inv_N} = 1.78 kW, $\qquad \Delta V_{sw}$ = 0.56 kW $\qquad\qquad$ (from Table 3.3-3)

$$V_{GR} = 0,65\,\text{kW} \cdot \frac{120\,\text{kW}/0,95}{\sqrt{3}*400V*260\,A*0,85} = 0,54\,\text{kW} \qquad \text{acc. to formula [3.3-2]}$$

$$V_{inv} = 0.8 * 1.78\,\text{kW} = 1.42\,\text{kW} \qquad\qquad\qquad\qquad \text{acc. to formula [3.3-3]}$$

$$V_{Sch} = 0,56\,\text{kW} \cdot \frac{0,93kHz}{2,5kHz} * \frac{230\,A}{260\,A} * \left(\frac{400V}{400V}\right) = 0,18\,kW \qquad \text{acc. to formula [3.3-6]}$$

Total losses: V = 2.55 kW

Efficiency: $\qquad \eta = \dfrac{P_W/\eta_M}{(P_W/\eta_M)+\quad V} \approx \dfrac{120\,\text{kW}/0,95}{(120\,\text{kW}/0,95)+2,55\,\text{kW}} = 98,0\%$

Operating point b): P = 60 kW, n = 1200 RPM

Torque at the load point:
$$M = \frac{60\,\text{kW}}{1200\,\text{RPM}} \cdot 9554 = 478\,\text{Nm} \qquad M = 0.56 \cdot M_n$$

Determine the motor current (from the formula [3.3-4])

$$I = 230\,A * \sqrt{0,33^2 + (0,56 * 0,94)^2} = 143\,A \qquad I = 0.55 \times I_{conv}$$

- The following power losses are obtained:

V_{const_N} = 0.41 kW, $\qquad\qquad$ V_{re_N} = 0.65 kW,

V_{inv_N} = 1.78 kW, $\qquad\qquad$ V_{sw} = 0.56 kW $\qquad\qquad$ (from Table 3.3-3)

$$V_{re} = 0.65\,\text{kW} \cdot \frac{60\,\text{kW}/0,95}{\sqrt{3} * 400V * 260A * 0.85} = 0.27\,\text{kW} \qquad \text{acc. to formula (3.3-2)}$$

$$V_{inv} = 0.55 * 1.78\,\text{kW} = 0.98\,\text{kW} \qquad \text{acc. to formula (3.3-3)}$$

$$V_{Sch} = 0,56\,\text{kW} \cdot \frac{2,5\,kHz}{2,5\,kHz} * \frac{143\,A}{260\,A} * \left(\frac{400V}{400V}\right) = 0,31\,kW \qquad \text{acc. to formula (3.3-6)}$$

Total losses: $\qquad$ V = 1.97 kW

- Efficiency: $$\eta = \frac{P_W/\eta_M}{(P_W/\eta_M)+\quad V} \approx \frac{60\,\text{kW}/0,95}{(60\,\text{kW}/0,95)+1,97\,\text{kW}} = 97,0\,\%$$

3.3.2 Calculating the losses of additional components

The losses, specified under 3.3.1, only refer to the pure compact- or chassis unit. Additional components, such as output reactors, output filter or line commutating reactors have not been taken into account. The losses for these components must normally be taken into account when determining the drive efficiency.

Line commutating reactor losses

The losses $V_{ch\,n}$ of the line commutating reactors at the rated current on the line side can be taken from Catalog DA65.10 for 50 and 60 Hz line frequency. When converting to a specific load situation, it must be observed that the line commutating reactor losses reduced, as a first approximation, as a square-law with the line current (i.e. the drive converter output). Thus, the following is true for the losses:

$$V_{c.ch.} = V_{ch\,n} * \left(\frac{I\sup{ply}}{I_{ch\,n}} \right)^2$$

With $\quad I\sup{ply} \approx 1.15 * I_{Mot} * \cos\varphi * \dfrac{U_{Mot}}{U\sup{ply}} = \dfrac{1.15}{\sqrt{3}} * \dfrac{1}{U\sup{ply}} * P_W / \eta_{Mot}$

$$V_{K.ch.} = V_{ch\,n} * \left(\frac{1.15 * P_W / \eta_{Mot}}{\sqrt{3} * U\sup{ply} * I_{ch\,n}} \right)^2 \qquad\qquad [3.3\text{-}7]$$

whereby

P_W, η_{mot} $\qquad\qquad\qquad$ shaft output [kW], motor efficiency at the load point being investigated

$V_{ch\,n}$, $I_{ch\,n}$ $\qquad\qquad\qquad$ losses, rated line commutating reactor current under rated operating conditions, refer to Catalog DA65 under drive converter components.

Example: For the calculation example of a 120 kW pump drive under Section 3.3.1 V), a line commutating reactor is provided. The reactor is a 4EU2751-0UB00 type, with

$\qquad$ 253W$_{[50\ Hz]}$ / 275W$_{[60\ Hz]}$ $\qquad$ nominal power loss and
$\qquad$ 280 A $\qquad\qquad\qquad\qquad\qquad$ rated current

Thus, at the 120 kW and 60 kW load points, the reactor losses are given by

$$V_{c.ch.} = 253W * \left(\frac{1.15 * 120 / 0.95}{\sqrt{3} * 400 * 280} \right)^2 = 141W$$

at the 120 kW load point $\qquad\qquad\qquad\qquad\qquad$ or 35 W losses at the 60 kW load point.

Thus, the drive converter efficiencies are reduced

from $\quad$ 98.0 % to 97.89 % $\quad$ at the 120 kW load point $\qquad\qquad\qquad\qquad\qquad$ or
from $\quad$ 97.0 % to 96.94 % $\quad$ at the 60 kW load point.

Drive converter output reactor losses

The losses $V_{ch\,n}$ of the output reactors at rated current are specified in Catalog DA65.10. In order to calculate a specific load situation, the losses must be further segmented as follows

- iron losses, which are proportional to the pulse frequency and as a square-law to the supply voltage, and
- copper losses, which are a square-law to the output current.

The individual losses are specified in the following tables; for iron reactors (with $f_{max} \le 120$ Hz) and for ferrite reactors (with $f_{max} > 120$ Hz or for pulse frequencies > 3 kHz).

Table 3.3.3 Individual reactor losses

Rating	Reactor current	Reference voltage	Iron reactor	V Fe N	V Cu N	Ferrite reactor	V Fe N	V Cu N
kW	A	V	6SE70 - S87-1FE0	W	W	6SE70 - S87-1FF0	W	W
2.2	10.6	230	21-1C	18	33	21-1C	24	36
3	13.3	230	21-3C	18	33	21-3C	24	36
4	17.7	230	21-8C	23	45	21-8C	30	48
5.5	22.9	230	22-3C	29	51	22-3C	30	48
7.5	32.2	230	23-2C	23	45	23-2C	24	36
11	44.2	230	24-4C	29	51	24-4C	30	48
15	69	230	27-0C	33	61	27-0C	30	48
18.5	69	230	27-0C	33	61	27-0C	30	48
22	81	230	28-1C	43	68	28-1C	40	56
2.2	6.1	400	16-1E	29	51	16-1E	40	56
3	10.2	400	21-0E	29	51	21-0E	40	56
4	10.2	400	21-0E	29	51	21-0E	40	56
5.5	17.7	400	21-8E	34	61	21-8E	40	56
7.5	17.7	400	21-8E	34	61	21-8E	40	56
11	25.5	400	22-6E	42	68	22-6E	40	60
15	34	400	23-4E	43	87	23-4E	45	70
18.5	47	400	24-7E	65	125	24-7E	70	100
22	47	400	24-7E	65	125	24-7E	70	100
30	72	400	27-2E	43	87	27-2E	55	80
37	72	400	27-2E	43	87	27-2E	55	80
45	92	400	31-0E	65	125	31-0E	70	100
55	146	400	31-5E	75	145	31-5E	120	180
75	146	400	31-5E	75	145	31-5E	120	180
90	186	400	31-8E	100	200	31-8E	120	180
110	260	400	32-6E	100	200	32-6E	150	200
132	260	400	32-6E	100	200	32-6E	150	200
160	315	400	33-2E	125	245	33-2E	150	200
200	370	400	33-7E	130	250	33-7E	150	200
250	510	400	35-1E	150	310	35-1E	160	240
315	690	400	37-0E	200	420	37-0E	190	290
400	690	400	37-0E	200	420	37-0E	190	290
500	860	400	38-6E	250	490	38-6E	210	320
630	1100	400	41-1E	290	570			
710	1300	400	41-3E	340	670			
900	2x 860	400	38-6E (2x)	500	980			

Table 3.3.3 Individual reactor losses (continued)

Rating	Reactor current	Reference voltage	Iron reactor	$V_{Fe\,N}$	$V_{Cu\,N}$	Ferrite reactor	$V_{Fe\,N}$	$V_{Cu\,N}$
kW	A	V	6SE70 - S87-1FE0	W	W	6SE70 - S87-1FF0	W	W
2.2	6.2	500	16-2F	45	85			
3	6.2	500	16-2F	45	85			
4	17.5	500	21-5F	70	120			
5.5	17.5	500	21-5F	70	120			
7.5	17.5	500	21-5F	70	120			
11	25.5	500	22-2F	82	138			
18.5	34	500	23-4F	70	120			
22	34	500	23-4F	70	120			
30	47	500	24-7F	82	138			
37	61	500	26-0H	115	185			
45	82	500	28-2H	145	225			
55	82	500	28-2H	145	225			
75	125	500	31-2H	190	310			
90	125	500	31-2H	190	310			
110	171	500	31-7H	240	380			
132	225	500	32-3H	240	380			
160	225	500	32-3H	240	380			
200	297	500	33-0G	330	540			
250	354	500	33-5G	400	650			
315	452	500	34-5G	490	780			
400	570	500	35-7G	710	1130			
450	650	500	36-5G	760	1220			
630	860	500	38-6G	900	1450			
800	1200	500	41-2G	1260	2020			
900	1200	500	41-2G	1260	2020			
1000	2x 860	500	38-6G (2x)	1800	2090			
1100	2x 860	500	38-6G (2x)	1800	2090			

Table 3.3.3 Individual reactor losses (continued)

Rating	Reactor current	Reference voltage	Iron reactor	V Fe N	V Cu N	Ferrite reactor	V Fe N	V Cu N
kW	A	V	6SE70 - S87-1FE0	W	W	6SE70 - S87-1FF0	W	W
55	61	690	26-0H	130	170			
75	82	690	28-2H	160	210			
90	125	690	31-2H	220	280			
110	125	690	31-2H	220	280			
132	171	690	31-7H	270	350			
160	171	690	31-7H	270	350			
200	225	690	32-3H	270	350			
250	297	690	33-0G	380	490			
315	354	690	33-5G	460	590			
400	452	690	34-5G	560	710			
500	570	690	35-7G	810	1030			
630	650	690	36-5G	860	1120			
800	860	690	38-6G	1020	1330			
1000	1200	690	41-2G	1420	1860			
1200	1200	690	41-2G	1420	1860			
1300	2x 860	690	38-6G (2x)	2040	2660			
1500	2x 860	690	38-6G (2x)	2040	2660			

The reactor losses at a specific load point are approximately given by:

$$V_{ch} = V_{Cu\ ch} + V_{Fe\ ch}$$

whereby

$$V_{Cu\ ch} = V_{CuN} * \left(\frac{I_{Mot}}{I_{ch\ n}} \right)^2 \qquad\qquad\qquad\qquad [3.3 - 8]$$

with $V_{Cu\ N}$ copper losses according to Table 3.3.3
                I_{mot} motor current at the particular load point, refer to Equation [3.3-4] and [3.3-5]
                $I_{ch\ N}$ rated reactor current according to Table 3.3.3

$$V_{Fe\ che} = V_{FeN} * \frac{f}{f_{Mot}} * \left(\frac{U_{\ sup\ ply}}{U_{Tab}} \right)^2 \qquad \text{for iron reactors} \qquad [3.3 -9]$$

$$V_{FeDr} = V_{FeN} * \frac{f}{f_{Mot}} * \left(1 - \frac{1}{4} \frac{50Hz}{{}_{*}\ f_{Mot}} \right) * \left(\frac{U_{Netz}}{U_{Tab}} \right)^2 \qquad \text{for ferrite reactors} \qquad [3.3 - 10]$$

with $V_{fe\ N}$ iron losses according to Table 3.3.3
                f output frequency at the particular load point
                f_{mot} rated motor frequency, $f_{mot} \geq 50$ Hz
                U_{supply} line supply voltage, e.g. 460 V for drives for 380 - 460 V
                U_{tab} allocated line supply voltage, according to Table 3.3.3

Example:

For the calculation example of a 120 kW pump drive at 400 V under Section 3.3.1 V), an output reactor is provided. This is the iron reactor, type 6SE7032-6ES87-1FE0, with

    $V_{Cu\ N}$ = 200 W, $V_{Fe\ N}$ = 100 W   for a rated current of 260 A.

Thus, at the particular 120 kW and 60 kW load points, the reactor losses are given by

$V_{Cu\ ch}$ + $V_{Fe\ ch}$ = 200 W * (209 A / 260 A)² + 100 W = 229 W   at the 120 kW load point

$V_{Cu\ ch}$ + $V_{Fe\ ch}$ = 140 W   at the 60 kW load point

Thus, the drive converter efficiencies are reduced
from   98.0 % to 97.82 %   at the 120 kW load point   or
from   97.0 % to 96.77 %   at the 60 kW load point.

dv/dt filter losses

The $V_{dv/dt}$ losses of the dv/dt filters at rated current are specified in Catalog DA65.10. In order to convert to a specific load situation, the losses must be further segmented into

- voltage-dependent losses, and
- current-dependent losses.

The individual losses are specified in the following tables.

Table 3.3.4 Individual dv/dt filter losses

Rating	dv/dt filter rated current	Reference voltage	dv/dt filter	V (~U²) N	V (~I²) N
kW	A	V	Order No.	W	W
2.2	6.2	400	6SE7016-2FB87-1FD0	20	80
3	15	400	6SE7021-5FB87-1FD0	30	120
4	15	400	6SE7021-5FB87-1FD0	30	120
5.5	15	400	6SE7021-5FB87-1FD0	30	120
7.5	15	400	6SE7021-5FB87-1FD0	30	120
11	22	400	6SE7022-2FC87-1FD0	35	135
15	34	400	6SE7023-4FC87-1FD0	35	135
18.5	47	400	6SE7024-7FC87-1FD0	45	155
22	47	400	6SE7024-7FC87-1FD0	45	155
30	60	400	6SE7026-0HE87-1FD0	50	180
37	82	400	6SE7028-2HE87-1FD0	70	230
45	120	400	6SE7031-2HS87-1FD0	90	300
55	170	400	6SE7031-7HS87-1FD0	120	360
75	170	400	6SE7031-7HS87-1FD0	120	360
90	230	400	6SE7032-3HS87-1FD0	120	380
110	300	400	6SE7033-0HS87-1FD0	160	540
132	300	400	6SE7033-0HS87-1FD0	160	540
160	350	400	6SE7033-5HS87-1FD0	180	620
200	450	400	6SE7034-5H S87-1FD0	210	740
250	570	400	6SE7035-7HS87-1FD0	300	1000
315	650	400	6SE7036-5HS87-1FD0	360	1140
400	860	400	6SE7038-6HS87-1FD0	450	1350
500	860	400	6SE7038-6HS87-1FD0	450	1350

Comment: dv/dt filters can only be provided up to a specific rating, corresponding to the table; however, not for higher ratings where 2 inverters are connected in parallel. Reason: For these high ratings, when single-motor drives are used, Siemens motors with an increased insulation capability are available, where dv/dt filters are not necessary. On the other hand, for high drive converter outputs for group drives (where several low output motors are connected in parallel to the drive converter), where dv/dt filters are required due to the motor voltage stressing, we recommend that instead, the motors connected in parallel are distributed over 2 or more lower output drive converters. dv/dt filters are available for this configuration. These drive converters are then identically controlled.

Table 3.3.4 Individual dv/dt filter losses (continued)

Rating	dv/dt filter rated current	Reference voltage	dv/dt filter	V (~U²) N	V (~I²) N
kW	A	V	Order No.	W	W
2.2	6.2	500	6SE7016-2FB87-1FD0	30	70
3	6.2	500	6SE7016-2FB87-1FD0	30	70
4	15	500	6SE7021-5FB87-1FD0	40	110
5.5	15	500	6SE7021-5FB87-1FD0	40	110
7.5	15	500	6SE7021-5FB87-1FD0	40	110
11	22	500	6SE7022-2FC87-1FD0	50	120
18.5	34	500	6SE7023-4FC87-1FD0	50	120
22	34	500	6SE7023-4FC87-1FD0	50	120
30	47	500	6SE7024-7FC87-1FD0	60	140
37	61	500	6SE7026-0HE87-1FD0	70	160
45	82	500	6SE7028-2HE87-1FD0	80	220
55	82	500	6SE7028-2HE87-1FD0	80	220
75	125	500	6SE7031-2HS87-1FD0	110	270
90	125	500	6SE7031-2HS87-1FD0	110	270
110	171	500	6SE7031-7HS87-1FD0	130	350
132	225	500	6SE7032-3HS87-1FD0	130	370
160	225	500	6SE7032-3HS87-1FD0	130	370
200	297	500	6SE7033-0HS87-1FD0	180	520
250	354	500	6SE7033-5HS87-1FD0	220	580
315	452	500	6SE7034-5HS87-1FD0	270	680
400	570	500	6SE7035-7HS87-1FD0	380	920
450	650	500	6SE7036-5HS87-1FD0	450	1050
630	860	500	6SE7038-6HS87-1FD0	540	1260
55	61	690	6SE7026-0HE87-1FD0	77	153
75	82	690	6SE7028-2HE87-1FD0	100	200
90	125	690	6SE7031-2HS87-1FD0	130	260
110	125	690	6SE7031-2HS87-1FD0	130	260
132	171	690	6SE7031-7HS87-1FD0	160	320
160	171	690	6SE7031-7HS87-1FD0	160	320
200	225	690	6SE7032-3HS87-1FD0	167	333
250	297	690	6SE7033-0HS87-1FD0	233	467
315	354	690	6SE7033-5HS87-1FD0	267	533
400	452	690	6SE7034-5HS87-1FD0	317	633
500	570	690	6SE7035-7HS87-1FD0	433	867
630	650	690	6SE7036-5HS87-1FD0	500	1000
800	860	690	6SE7038-6HS87-1FD0	600	1200

Comment: dv/dt filters are only available up to the ratings listed in the table above. For larger units with 2 inverters connected in parallel, an adapted dv/dt filter (with half of the total rated current) can be used for each of the partial inverters. However, this is only permissible if an interphase reactor is not used.

Example:

For the calculation example for 120 kW pump drive at 400 V under Section 3.3.1 V) a dv/dt filter is provided. This is the 6SE7033-0HS87-1FD0 filter with

$V_{(\sim I^2)\,N}$ = 540 W, $V_{(\sim U^2)\,N}$ = 160 W for a 300 A rated current.

Thus, at the investigated 120 kW and 60 kW load points, the filter losses are given by:

$V_{(\sim I^2)} + V_{(\sim U^2)}$ = 540 W * (209 A / 300 A)² + 160 W =   422 W   at the 120 kW load point

$V_{(\sim I^2)} + V_{(\sim U^2)}$ = 540 W * (143 A / 300 A)² + 160 W =   283 W   at the 60 kW load point

Thus, the drive converter efficiency is reduced
from   98.0 % to 97.66 %   at the 120 kW load point   or
from   97.0 % to 96.55 %   at the 60 kW load point.

Sinusoidal filter losses

The losses V_{sin} of the sinusoidal filter at rated current are specified in Catalog DA65. In order to convert to a specific load situation, the losses must be further segmented into

- voltage-dependent losses, and
- current-dependent losses.

The individual losses for the sinusoidal filters which are presently available, are specified in the following tables.

Table 3.3.5 Individual sinusoidal filter losses

Rating	Sinusoidal filter rated current	Reference voltage	Sinusoidal filter	V ($\sim U^2$) N	V ($\sim I^2$) N	
kW	A	V	Order No.	W	W	
2.2	6.1	400	6SE7016-1EA87-1FC0	40	110	
3	10	400	6SE7021-0EB87-1FC0	55	145	
4	10	400	6SE7021-0EB87-1FC0	55	145	
5.5	18	400	6SE7021-8EB87-1FC0	70	180	
7.5	18	400	6SE7021-8EB87-1FC0	70	180	
11	26	400	6SE7022-6EC87-1FC0	80	220	
15	34	400	6SE7023-4EC87-1FC0	110	290	
18.5	47	400	6SE7024-7EC87-1FC0	130	370	
22	47	400	6SE7024-7EC87-1FC0	130	370	
30 (29)	72	400	6SE7027-2ED87-1FC0	160	440	
37 (35)	72	400	6SE7027-2ED87-1FC0	160	440	
45 (43)	100	400	6SE7031-0EE87-1FH0	120	330	
55 (55)	140	400	6SE7031-5EF87-1FH0	170	430	
75 (51)	140	400	6SE7031-5EF87-1FH0	170	430	***)**
90 (65)	140	400	6SE7031-5EF87-1FH0	170	430	
110 (74)	186	400	6SE7031-8EF87-1FH0	210	540	
132 (91)	186	400	6SE7031-8EF87-1FH0	210	540	
160 (111)	260	400	6SE7032-6EG87-1FH0	250	650	
200 (130)	260	400	6SE7032-6EG87-1FH0	250	650	
2.2	6.2	500	6SE7016-2FB87-1FH0	55	145	
3	6.2	500	6SE7016-2FB87-1FH0	55	145	
4	15	500	6SE7021-5FC87-1FH0	80	220	
5.5	15	500	6SE7021-5FC87-1FH0	80	220	
7.5	15	500	6SE7021-5FC87-1FH0	80	220	
11	22	500	6SE7022-2FD87-1FH0	110	290	
18.5	34	500	6SE7023-4FE87-1FH0	130	370	
22	34	500	6SE7023-4FE87-1FH0	130	370	
30	47	500	6SE7024-7FE87-1FH0	160	440	
37	61	500	6SE7026-1FE87-1FH0	120	330	
45	80	500	6SE7028-0FF87-1FH0	170	430	
55	80	500	6SE7028-0FF87-1FH0	170	430	
75	125	500	6SE7031-3FG87-1FH0	210	540	
90	125	500	6SE7031-3FG87-1FH0	210	540	
110	160	500	6SE7031-6FG87-1FH0	250	650	

*) This combination isn't considered to be practical due to the drive converter de-rating which is required. Refer to the following comment.

Comment: The following must be observed when using sinusoidal filters:

- When using sinusoidal filters, the drive converter output voltage is limited to 85 % of the line voltage (for 380 to 460 V line supply voltage) or to 90 % of the line supply voltage (for 500 to 575 V line voltage). This means that the motor and inverter have to be appropriately overdimensioned at any specific shaft output in comparison when the full line supply voltage can be utilized at the rated operating point.
- For a line supply voltage of 380 V to 460 V, when sinusoidal filters are used, the pulse frequency must be set to 6 kHz. For drive converters with these supply voltages, from 75 kW onwards, the permissible rated current must be reduced by 25 %.

Both effects, the reduction of the maximum output voltage and the possibly required reduction in the drive converter output current, can signify that the achievable drive converter output has to be significantly reduced. This lower achievable output, when sinusoidal filters are used, is specified in brackets in the first column of the table for line supply voltages of 400 V and 500 V.

Example:

For the calculation example of the 120 kW pump drive at 400 V under Section 3.3.1 V) a sinusoidal filter is provided.

However, this is no longer the previously used "132 kW drive converter" 6SE7032-6EG60, as this can now only provide an output of approximately 91 kW. This is due to the reduced output voltage (85 %) and the rated output current, which is reduced to 75 % (due to the 6 kHz pulse frequency and the thus increased switching losses). Thus, a "200 kW drive converter" is required.
6SE7033-7EG60. As a result of the lower maximum output voltage, the motor current is increased at the 120 kW load point, from 207 A to approx. 245 A.

The drive converter losses are then given by

V_{conv} = 3.1 kW (η = 97.6 %)   at the 120 kW load point

V_{conv} = 2.18 kW (η = 96.7 %)   at the 60 kW load point

The 6SE7032-6EG87-1FH0 sinusoidal filter is required with

$V_{(\sim I^2)\,N}$ = 650 W, $V_{(\sim U^2)\,N}$ = 250 W at a rated current of 260 A.

Thus, at the investigated 120 kW and 60 kW load points, the filter losses are:

$V_{(\sim I^2)}$ + $V_{(\sim U^2)}$ = 650 W * (245 A / 260 A)² + 250 W =   827 W   at the 120 kW load point

$V_{(\sim I^2)}$ + $V_{(\sim U^2)}$ = 650 W * (143 A / 260 A)² + 250 W =   447 W   at the 60 kW load point

Thus, the drive converter efficiency is reduced
from   97.6 % to 96.95 %   at the 120 kW load point   or
from   96.7 % to 96.0 %   at the 60 kW load point.

Losses associated with the line supply radio interference suppression filter

Generally, the radio interference suppression filter losses are so low, that they can be neglected when determining the efficiency. In order to provide a "full story", the filters, which are presently available, are specified in the following table.

Table 3.3.6 Radio interference suppression filters: Losses

Rating	Radio interference suppression filter rated current	Reference voltage	Radio interference suppression filter	V (~I²) N
kW	A	V	Order No.	W
2.2	12	230	6SE7021-0ES87-0FB1	10
3	18	230	6SE7021-8ES87-0FB1	15
4	18	230	6SE7021-8ES87-0FB1	15
5.5	36	230	6SE7023-4ES87-0FB0	10
7.5	36	230	6SE7023-4ES87-0FB0	10
11	80	230	6SE7027-28ES7-0FB0	20
15	80	230	6SE7027-2ES87-0FB0	20
18.5	80	230	6SE7027-2ES87-0FB0	20
22	120	230	6SE7031-0ES87-0FA0	35
2.2	12	400	6SE7021-0ES87-0FB1	10
3	12	400	6SE7021-0ES87-0FB1	10
4	12	400	6SE7021-0ES87-0FB1	10
5.5	18	400	6SE7021-8ES87-0FB1	15
7.5	18	400	6SE7021-8ES87-0FB1	15
11	36	400	6SE7023-4ES87-0FB0	10
15	36	400	6SE7023-4ES87-0FB0	10
18.5	80	400	6SE7027-2ES87-0FB0	20
22	80	400	6SE7027-2ES87-0FB0	20
30	80	400	6SE7027-2ES87-0FB0	20
37	80	400	6SE7027-2ES87-0FB0	20
45	120	400	6SE7031-0ES87-1FA0	35
55	160	400	6SE7031-5ES87-1FA1	40
75	160	400	6SE7031-5ES87-1FA1	40
90	190	400	6SE7031-8ES87-1FA0	40
110	350	400	6SE7033-2ES87-1FA1	50
132	350	400	6SE7033-2ES87-1FA1	50
160	350	400	6SE7033-2ES87-1FA1	50
200	600	400	6SE7036-0ES87-1FA1	80
250	600	400	6SE7036-0ES87-1FA1	80
315	600	400	6SE7036-0ES87-1FA1	80
400	1000	400	6SE7041-0ES87-1FA1	150

Comment: If a radio interference suppression filter is used, then a line commutating reactor having at least 2 % u_K is always is required.

Example:

For the calculation example of a 120 kW pump drive at 400 V under Section 3.3.1 V), a radio interference suppression filter is provided. This is the 6SE7033-2ES87-0FA1 filter with

$V_{(-I^2)\ N}$ = 50 W,   at a rated current of 350 A.

Thus, at the investigated 120 kW and 60 kW load points, the filter losses are given by:

$V_{(-I^2)}$ < 50 W * (209 A / 350 A)² W =   18 W   at the 120 kW load point

$V_{(-I^2)}$ < 50 W * (143 A / 350 A)² W =   8 W   at the   60 kW load point

Thus, the drive converter efficiency is practically not influenced.

Comment: As simplification, it has been assumed in this case, that the line current is the same as the motor current, which is basically the case for these particular load situations. For the line current which actually flows, referred to the motor current, refer to Section 3.2.

Other losses

These include losses in the switchgear (switching devices), and if available, losses in the main contactors, main circuit-breakers, fuses, feeder cables. These are generally extremely low and can be taken into account as a lump sum, i.e. 0.1 to 0.2 % of the rated drive converter output. These losses only have to be evaluated more precisely in extreme cases, e.g. for extremely long motor- or line supply feeder cables, whereby the (copper) losses cannot be neglected.

3.3.3 Cabinet unit losses
The individual cabinet unit losses are specified in the following.

These are made up as follows:

V_{const} constant losses, independent of the load

$V \sim I_{supply}{}^2$ thermal losses on the line side, especially caused by the line commutating reactor and are given by:

$$V_{I^2 Netz} = V_{I^2 Netz\ Tab} * \left| \frac{P_W / \eta_M}{S_N \cdot \cos\varphi} \right|^2 = V_{I^2 Netz\ Tab} * \left(\frac{P_W / \eta_M}{\sqrt{3} * U_{Netz} * I_{UN} * 0{,}85} \right)^2 \qquad \text{[3.3-10]}$$

V_{re} rectifier losses, calculated as follows

$$V_{GR} = V_{GR\ Tab} \cdot \frac{P_W / \eta_M}{S_N \cdot \cos\varphi} = V_{GR\ Tab} \cdot \frac{P_W / \eta_M}{\sqrt{3} * U_{Netz} * I_{UN} * 0{,}85} \qquad \text{[3.3-11]}$$

V_{inv} inverter losses, calculated as follows

$$V_{inv} = \frac{I}{I_{N_U}} \cdot V_{inv_N} \qquad \text{for } I \approx 0.2 \dots 1.5\ I_{N_U} \qquad \text{[3.3-12]}$$

V_{sw} switching losses in the inverter, calculated as follows

$$V_{Sch} = VSch\ Tab * \frac{f_p}{2{,}5\ kHz} * \frac{ILast}{IU_n} * \left| \frac{UNetz}{UTab} \right|^2 \qquad \text{[3.3-13]}$$

$V_{\sim I^2\ mot}$ I^2R losses at the drive converter output, calculated as follows

$$V_{\sim I^2 Mot} = V_{\sim I^2 Tab} * \left| \frac{I_{Mot}}{I_{UN}} \right|^2 \qquad \text{[3.3 - 14]}$$

Individually:

I_{mot} motor current at the particular load point, refer to Equation [3.3-4] and [3.3-5]

$$P_W = \frac{M\,[\text{Nm}] \cdot n\,[\text{RPM}]}{9554}$$

motor shaft output at the particular load point

$V_{re\,N}$ the rectifier losses, specified in Table 3.3-7, at the rated operating point

$$S_N = \sqrt{3} * U_N * I_{UM}$$

rated drive converter output in kVA,

$\cos \varphi$ power factor of an adapted motor at the rated operating point, assumed to be 0.85

η_M motor efficiency at the particular load point

I_{UN} rated drive converter output current

$V_{inv\,tab}$ inverter losses at the rated operating point (refer to Table 3.3-7)

I_{mot} motor current at the load point being investigated, refer to the formulas [3.3-4] and [3.3-5].

$V_{sw\,tab}$ switching losses at the rated operating point for the line supply voltage specified in Table 3.3-7

f_p pulse frequency. Refer to the comments below.

I_{Un} rated drive converter current according to Table 3.3-3

U_{supply} line supply voltage, e.g. 400 V for drive converters for a voltage range from 380 to 460 V

U_{tab} reference voltage, specified in Table 3.3-7, e.g. 400 V for drive converters which can be operated between 380 V to 460 V.

Comment

For **50 Hz motors**, if not otherwise parameterized, the pulse frequency f_p is as follows:

For			
For	$f \le 40$ Hz	$\rightarrow$	$f_p = 2.5$ kHz
For	40 Hz $< f <$ 45 Hz	$\rightarrow$	space vector modulation with $f_p = 2$ kHz
For	45 Hz $< f <$ 48 Hz	$\rightarrow$	edge modulation with $f_p = 23 * f \approx 1070$ Hz
For	48 Hz $< f <$ 50 Hz	$\rightarrow$	edge modulation with $f_p = 19 * f \approx 930$ Hz
For	50 Hz $< f <$ 62 Hz	$\rightarrow$	edge modulation with $f_p = 19 * f$ (field-weakening operation)
For	62 Hz $< f <$ 100 Hz	$\rightarrow$	edge modulation with $f_p = 17 * f$ (field-weakening operation)

For **60 Hz motors**, if not otherwise parameterized, the pulse frequency f_p is as follows:

For			
For	$f \le 48$ Hz	$\rightarrow$	$f_p = 3$ kHz at FC, or 2.5 kHz at VC
For	48 Hz $< f <$ 54 Hz	$\rightarrow$	space vector modulation with $f_p = 2$ kHz
For	54 Hz $< f <$ 58 Hz	$\rightarrow$	edge modulation with $f_p = 23 * f \approx 1290$ Hz
For	58 Hz $< f <$ 62 Hz	$\rightarrow$	edge modulation with $f_p = 19 * f \approx 1140$ Hz
For	62 Hz $< f <$ 100 Hz	$\rightarrow$	edge modulation with $f_p = 17 * f$ (field-weakening operation)
For	$f >$ 100 Hz	$\rightarrow$	edge modulation with $f_p = 9 * f$ (field-weakening operation)

Table 3.3-7: Individual cabinet unit losses 1Q, 6-pulse

Voltage	Rated output	MLFB (Order No.)	I_{UN}	V_{const}	$V_{\sim I^2 supply}$ 50 Hz	V_{re}	V_{inv}	V_{sw} at 2.5 kHz	$V_{\sim I^2 motor}$
[V]	[kW]		[A]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
400	45	6SE7131-0EB61-3BA0	92	0.155	0.1	0.24	0.66	0.145	
	55	6SE7131-2EC61-3BA0	124	0.19	0.1	0.32	1.1	0.19	
	75	6SE7131-5EC61-3BA0	146	0.16	0.15	0.39	1.14	0.26	
	90	6SE7131-8EC61-3BA0	186	0.2	0.19	0.48	1.17	0.36	
	110	6SE7132-1ED61-3BA0	210	0.35	0.19	0.5	1.56	0.4	
	132	6SE7132-6ED61-3BA0	260	0.41	0.25	0.65	1.73	0.56	
	160	6SE7133-2ED61-3BA0	315	0.48	0.25	0.82	2.35	0.6	
	200	6SE7133-7ED61-3BA0	370	0.53	0.25	1.01	2.62	0.79	
	250	6SE7135-1EE62-3BA0	510	1.09	0.33	1.32	3.56	1.1	
	315	6SE7136-0EE62-3BA0	590	1.1	0.4	1.57	4.13	1.4	
	400	6SE7137-0EE62-3BA0	690	2.4	0.5	1.85	4.4	1.55	
	500	6SE7138-6EG62-3BA0	860	2.45	0.45	2.5	8.5	2.1	
	630	6SE7141-1EH62-3BA0	1120	2.5	0.55	4.55	8.8	2.3	
	710	6SE7141-3EJ62-3BA0	1300	3.15	0.75	5.2	9.6	2.6	
500	37	6SE7133-0FB61-3BA0	61	0.145	0.08	0.16	0.47	0.145	
	45	6SE7133-0FB61-3BA0	66	0.215	0.1	0.18	0.54	0.165	
	55	6SE7133-0FC61-3BA0	79	0.2	0.1	0.22	0.67	0.21	
	75	6SE7133-0FC61-3BA0	108	0.2	0.1	0.29	1	0.31	
	90	6SE7133-0FD61-3BA0	128	0.53	0.15	0.33	1.04	0.35	
	110	6SE7133-0FD61-3BA0	156	0.44	0.19	0.41	1.3	0.46	
	132	6SE7133-0FD61-3BA0	192	0.51	0.19	0.56	1.7	0.64	
	160	6SE7133-0FD61-3BA0	225	0.53	0.25	0.67	2.05	0.8	
	200	6SE7133-0FE62-3BA0	297	1.03	0.25	0.84	2.78	1.1	
	250	6SE7133-5FE62-3BA0	354	1.2	0.25	1.19	3.16	1.2	
	315	6SE7134-5FE62-3BA0	452	1.2	0.33	1.32	4.43	1.32	
	400	6SE7135-7FG62-3BA0	570	1.3	0.45	3.15	5.9	1.7	
	450	6SE7136-5FG62-3BA0	650	1.4	0.45	3.25	6.7	1.9	
	630	6SE7138-6FG62-3BA0	860	2.22	0.45	4.03	7.2	2.2	
	800	6SE7141-1FJ62-3BA0	1080	2.4	0.57	5.33	9.1	2.7	
	900	6SE7141-2FJ62-3BA0	1230	2.6	0.57	5.83	10.9	3.2	
	1000	6SE7141-4FN62-3BA0	1400	4.8	0.75	5.95	11.2	3	1.0
	1100	6SE7141-6FN62-3BA0	1580	5.7	0.75	6.65	12.8	3.5	1.0

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Table 3.3-7: Individual cabinet unit losses 1Q, 6-pulse (continued)

Voltage	Rated output	MLFB (Order No.)	I_{UN}	V_{const}	$V_{\sim I^2\ supply}$ 50 Hz	V_{re}	V_{inv}	V_{sw} at 2.5 kHz	$V_{\sim I^2\ motor}$
[V]	[kW]		[A]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
690	55	6SE7133-0HE61-3BA0	60	0.24	0.1	0.16	0.51	0.19	
	75	6SE7133-0HE61-3BA0	82	0.19	0.13	0.23	0.74	0.31	
	90	6SE7133-0HE61-3BA0	97	0.44	0.17	0.24	0.85	0.4	
	110	6SE7133-0HE61-3BA0	118	0.44	0.17	0.3	1.07	0.52	
	132	6SE7133-0HE61-3BA0	145	0.53	0.17	0.39	1.27	0.64	
	160	6SE7133-0HE61-3BA0	171	0.56	0.3	0.47	1.65	0.82	
	200	6SE7133-0HE61-3BA0	208	0.56	0.29	0.51	2.08	1.06	
	250	6SE7133-0HE62-3BA0	297	1.3	0.33	0.81	3.11	1.35	
	315	6SE7133-5HE62-3BA0	354	1.31	0.33	1.16	3.25	1.65	
	400	6SE7134-5HE62-3BA0	452	1.31	0.45	1.32	4.32	1.9	
	500	6SE7135-7HG62-3BA0	570	1.4	0.45	3.2	5.15	2.5	
	630	6SE7136-5HG62-3BA0	650	1.5	0.45	3.7	6.55	2.9	
	800	6SE7138-6HG62-3BA0	860	2.5	0.55	4.15	7.8	3.6	
	1000	6SE7141-1HJ62-3BA0	1080	2.6	0.56	5.54	9.8	4.8	
	1200	6SE7141-2HJ62-3BA0	1230	2.8	0.7	6	14.4	5.7	
	1300	6SE7141-4HN62-3BA0	1400	5.6	0.78	6.6	12.12	4.8	1.0
	1500	6SE7141-6HN62-3BA0	1580	5.7	0.84	7.62	14.14	5.6	1.0

Calculation example for a constant torque drive with a speed control range of 1:5

Compressor drive: M = const: for P_W **= 600 kW** at **690 V** and n **= 1000 RPM**

Drive converter: 6SE7138-6HG62-3BA0 with 800 kW, 860 A, 690 V

Motor: 1LA8 457-6PM7. with P_N = 770 kW, U = 690 V, n_N = 993 RPM
(motor with increased insulation strength, therefore a dv/dt filter is not required)
I = 770 A, M = 7405 Nm, I/I_O = 30%, Iw/In = 95 % (Tables 3.3-4 and 3.3-5)
$\cos\varphi$ = 0.87, η_M = 0.97

Required: Losses and efficiency of the drive converter for

a) configured output 600 kW at 1000 RPM   **b) operation at 50 % speed**

Operating point a): P = 600 kW, n = 1000 RPM

- Torque at the load point:

$$M = \frac{P_W}{n} \cdot 9554 = \frac{120\,\text{kW}}{1500\,\text{RPM}} \cdot 9554 = 764\,\text{Nm} \qquad \text{M} = 0.774 \cdot \text{M}_{\text{N mot}}$$

- Determine the motor current (using formula [3.3-4])

$$I = 770\,A * \sqrt{0{,}3^2 + (0{,}774*0{,}95)^2} = 612\,A \qquad I = 0.71 \times I_{\text{conv}}$$

- The following power losses are obtained:

V_{const_N} = 2.5 kW, $V_{\sim I^2 \text{ supply}}$ = 0.55 kW, V_{re_N} = 4.15 kW,

V_{inv_N} = 7.8 kW, ΔV_{sw} = 3.6 kW   (from Table 3.3-7)

$$V_{I^2 \text{ sup } ply} = 0.55\,\text{kW} * \left(\frac{600\,\text{kW} / 0.97}{\sqrt{3} * 690V * 860\,A * 0.85} \right)^2 = 0.28\,kW \quad \text{acc.to formula[3.3-10]}$$

$$V_{re} = 0{,}65\,\text{kW} \cdot \frac{120\,\text{kW}}{150\,\text{kW} \cdot 0{,}87 \cdot 0{,}95} = 0{,}63\,\text{kW} \qquad \text{acc.to formula[3.3-11]}$$

$$V_{inv} = 0.71 * 7.8\,\text{kW} = 5.54\,\text{kW} \qquad \text{acc.to formula[3.3-12]}$$

$$V_{Sch} = 3{,}6\,\text{kW} \cdot \frac{0{,}93\,kHz * 612\,A}{2{,}5\,kHz * 860\,A} = 0{,}95\,kW \qquad \text{according to formula [3.3-13],}$$

Total losses: V = 12.23 kW

Efficiency: $$\eta = \frac{P_W / \eta_M}{(P_W / \eta_M) + V} \approx \frac{600\,\text{kW} / 0{,}97}{(600\,\text{kW} / 0{,}97) + 12{,}23\,\text{kW}} = 98{,}1\%$$

Operating point b): P = 300 kW, n = 500 RPM

The torque and motor current at 25 Hz remain the same. Thus, the following losses are obtained:

$$V_{I^2 \sup ply} = 0.57 kW * \left(\frac{300kW/0,95}{\sqrt{3} * 690V * 860A * 0.85} \right)^2 = 0.074 kW \qquad \text{acc.to formula[3.3-10]}$$

$$V_{re} = 4.15\,\text{kW} \cdot \frac{300\,\text{kW}/0.95}{\sqrt{3} * 690V * 860A * 0.85} = 1.50\,\text{kW} \qquad \text{acc.to formula[3.3-11]}$$

$$V_{inv} = 0.71 * 7.8\,\text{kW} = 5.54\,\text{kW} \qquad \text{acc.to formula[3.3-12]}$$

$$V_{Sch} = 3,6\,\text{kW} \cdot \frac{2,5 kHz * 612\,A}{2,5 kHz * 860\,A} = 2,56\,kW \qquad \text{according to formula [3.3-13],}$$

Total losses: V = 12.17 kW

Efficiency: $\eta = \dfrac{P_W/\eta_M}{(P_W/\eta_M) + \quad V} \approx \dfrac{300\,\text{kW}/0,95}{(300\,\text{kW}/0,95) + 12,17\,\text{kW}} = 96,2\,\%$

Efficiencies of 4Q drive converters with rectifier/regenerative feedback units ERE

The losses when motoring can be determined just as for 1Q drive converters. However, the losses of the autotransformers must be taken into account. When motoring, these are only the iron losses of the transformers, which can be assumed to be 30 % of the transformer losses specified in Catalog DA65.1. The full transformer losses are only involved when generating, whereby the full regenerative feedback current flows via the transformer.

Example: For the compressor drive investigated above, instead of the 1Q drive converter, a drive converter with regenerative feedback and a 25 % power-on duration transformer (25 % duty cycle) is used; i.e. the 6SE7138-5HG62-4BA0-Z drive converter   Z = L94.
For this converter, analog to the 800 kW rectifier regenerative feedback unit, an auto transformer is used with a 14.8 kW power loss at the rated operating point. The iron losses represent 4.44 kW, and the drive converter losses are appropriately increased. The drive converter efficiency is then given by

$$\eta = \frac{P_W/\eta_M}{(P_W/\eta_M) + \quad V} \approx \frac{600\,\text{kW}/0,97}{(600\,\text{kW}/0,97) + 12,23\,\text{kW} + 4,44\,\text{kW}} = 97,4\,\% \qquad \text{at the 600 kW load point}$$

$$\eta = \frac{P_W/\eta_M}{(P_W/\eta_M) + \quad V} \approx \frac{300\,\text{kW}/0,95}{(300\,\text{kW}/0,95) + 12,17\,\text{kW} + 4,44\,\text{kW}} = 94,9\,\% \qquad \text{at the 300 kW load point}$$

3.3.4 Losses of the rectifier units EE

As the losses of the rectifier units are generally significantly lower than the losses of the inverter unit(s), which are supplied, the losses of the rectifier units can be determined with sufficient accuracy (for determining the total system losses) as follows:

$$V_{EE} = V_{EErated} * \frac{P_{DClink}}{P_{EErated}} = V_{EErated} * \frac{P_{shaft}/\eta_{Motor}}{1.35 * U_{sup\,ply} * I_{DClink\,EE}}$$ [3.3 - 15]

Whereby:

$V_{EE\,rated}$ losses in the EE (rectifier unit) at the rated operating point according to the data in Catalog DA65.1, Section 7

P_{shaft}, η_{motor} mechanical shaft output and efficiency of the motors connected to the inverter units at the particular load points

$I_{DC\,link\,EE}$ rated DC link currents of the rectifier unit according to the data in Catalog DA65.1, Section 7

3.3.5 Losses of the rectifier/regenerative feedback units ERE

The losses of the rectifier/regenerative feedback units can be determined, in the same way as for the rectifier units. However, in this case the losses of the line-side autotransformer for the regenerative feedback bridge must be taken into account. In this case it should be observed, that when motoring, no power flows via this transformer, so that in this case only its iron losses have to be taken into account. Thus, different losses are obtained for motoring and generating as well as regenerative feedback operation, as specified in the following.

Losses when motoring:

$$V_{ERE} = V_{ERE\,rated} * \frac{P_{shaft}/\eta_{Motor}}{1.35 * U_{\sup ply} * IDC_{ERE}} + 0.3 * V transformer \qquad [3.3 - 16a]$$

Losses when generating and for regenerative feedback:

$$V_{ERE} = V_{ERE\,rated} * \frac{P_{shaft}/\eta_{Motor}}{1.35 * U_{\sup ply} * I_{DClink\,ERE}} + V_{transf.} * \left(0.3 + 0.7 * \left[\frac{P_{shaft} * \eta_{Motor}}{1.35 * U_{\sup ply} * I_{DClink\,ERE}} \right]^{2} \right) \qquad [3.3 - 16b]$$

Whereby:

$V_{ERE\,rated}$	ERE losses at the rated operating point according to the data on the losses in Catalog DA65.1, Section 8
P_{shaft}, η_{motor}	mechanical shaft output and efficiency of the motors connected to the inverter units at the particular load points
$I_{DC\,link\,ERE}$	rated DC link currents of the rectifier/regenerative feedback unit according to the data in Catalog DA65.1, Section 8
$V_{transformer}$	data on the losses for the auto transformers according to the data in Catalog DA65.1, Section 15

3.3.6 Losses of the active front end units AFE

The active front end units AFE, are as far as the power section is concerned, are identical to the inverters having the same rated current. However it should be noted, that for AFE, the DC link voltage is at least 10 % higher than for converters without AFE. This results in higher switching losses. Thus, the devices are clocked with the full pulse frequency in the inverter, even at the rated frequency. Further, the line filter losses must be taken into account, which essentially correspond with the losses of a 4 % uK reactor. Thus, the losses of the active front end unit AFE are given by:

V_{const} constant losses, independent of the load, identical with the constant losses in the Tables 3.3-3 and 3.3-7

V_{filter} I^2t losses in the line filter, calculated according to

$$V_{Filter} = V_{Filter\,Nenn} * \left| \frac{\Sigma\,(P_W / \eta_M)}{\sqrt{3} * U_{Netz} * I_{AFE}} \right|^2 \qquad\qquad \text{[3.3-10]}$$

V_{AFE} AFE on-state losses, calculated according to

$$V_{AFE} = \frac{P_W / \eta_M}{\sqrt{3} * U_{Netz} * I_{AFE}} * V_{WR\,Tab} \qquad\qquad \text{[3.3-12]}$$

V_{sw} AFE switching losses, calculated according to

$$V_{Sch} = V_{Sch\,Tab} * \frac{3kHz}{f_{P\,Tab}} * \frac{\Sigma\,(P_W / \eta_M)}{\sqrt{3} * U_{Netz} * I_{AFE}} * 1{,}2 * \left| \frac{U_{Netz}}{U_{Tab}} \right|^2 \qquad\qquad \text{[3.3-13]}$$

Whereby:

$$P_W = \frac{M\,[\text{Nm}] \cdot n\,[\text{RPM}]}{9554}$$

         motor shaft output (and of motors for several inverters) at the particular load points

η_M motor efficiency (efficiency of the motors) at the particular load point.

I_{AFE} rated current (line current) of the AFE

V_{AFE} on-state losses of the AFE, determined from the on-state losses of the inverters with the same current ratings, according to Tables 3.3-3 and 3.3-7

$V_{inv\ tab}$	inverter losses at the rated operating point (refer to Table 3.3-3 and 3.3-7)
$V_{sw\ tab}$	switching losses of the inverter with the same current rating according to Tables 3.3-3 and 3.3-7 at the line supply voltage specified in these tables
$f_{P\ tab}$	inverter pulse frequency specified in Tables 3.3-3 and 3.3-7
U_{supply}	line supply voltage, e.g. 400 V for drive converters for a voltage range from 380 to 460 V
U_{tab}	reference voltage specified in Tables 3.3-3 and 3.3-7, e.g. 400 V for drive converters, which can be operated between 380 V and 460 V.

Example:

A drive converter with AFE is to be used for the 600 kW drive at 690 V investigated in Section 3.3.3. This is the 800 kW drive converter with Order No. 6SE7138-6HK62-5BA0. This includes, both on the line side as the well as on the output side, an inverter chassis for 800 kW corresponding to the chassis unit 6SE7041-1UL60; also refer to the individual losses in Table 3.3-3.

The inverter losses are given by (due to the increased DC link voltage in conjunction with AFE, also at 600 kW, the full pulse frequency is used to clock the devices):

2.5 kW + 5.54 kW + 2.56 * 1.2 kW = 11.11 kW   at the 600 kW load point
2.5 kW + 5.54 kW + 2.56 * 1.2 kW = 11.11 kW   at the 300 kW load point

The appropriate AFE losses are:

For the 600 kW load point

V_{const} = 2.5 kW

$$V_{filter} = 840W * \left(\frac{600/0.97)}{\sqrt{3}*690V*774A} \right)^2 = 376W$$

$$V_{AFE} = \frac{600kW/0,97}{\sqrt{3}*690*860A} * 7,8kW = 4,7kW$$

$$V_{Sch} = 3,6\,\mathrm{kW} * \frac{3\,kHz}{2,5\,kHz} * \frac{600\,kW}{\sqrt{3}*690V*860A} * 1,2 * \left(\frac{690V}{690V} \right)^2 = 3,03\,kW$$

Thus, the total losses are 21.72 kW, and the efficiency is therefore reduced to 96.6 % (from 98.1 %).

For the 300 kW load point, the appropriate total losses are obtained of 18.43 kW; the efficiency therefore goes down to 94.4 % (from 96.2 %).

3.3.7 Drive converter efficiency characteristics for drives with M = const. and with M ~ n²

The efficiencies for standard drive converters, i.e. 1Q operation, are specified in the following Fig. 3.3. These characteristics are approximately valid for the drive converters over the complete output range for supply voltages 400 V, 500 V and 690 V, and can be assumed as rough values to quickly determine the approximate efficiency. The following assumptions are made:

- 50Hz motors are used,
- at the 50 Hz rated operating point, the motor and the drive converter are utilized according to their rated currents,
- no "loss-producing" options have been taken into account such as input- or output reactors or filter.

If these conditions are not available, and especially if the motor or drive converter, or both are only utilized in partial load operation, then it can be assumed that the efficiencies are less than indicated in the diagram. In all of these cases, the losses should be individually determined according to previous Sections 3.3.1 to 3.3.6.

Wirkungsgrad
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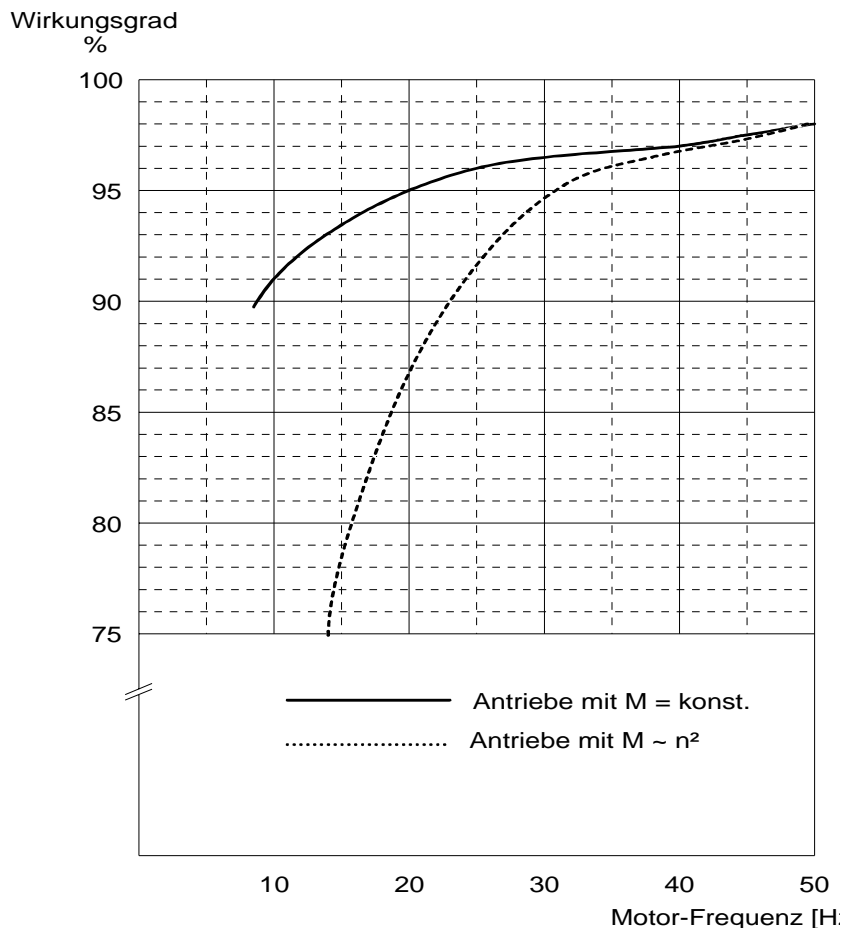
Fig. 3.3 Characteristic of the-
drive converter
efficiency as a func-
tion of the motor
speed and the motor
frequency

Antriebe mit M = konst.
Antriebe mit M ~ n²

Motor-Frequenz [Hz]

3.3.8 Motor efficiency data for full- and partial load operation

The efficiencies of standard Siemens 1LA5, 1LA6, 1LA8 motors, are specified in the following tables for 25, 50, 75 and 100 % of the rated motor torque and at frequencies of 12.5, 25, 37.5 and 50 Hz. The efficiencies must be interpolated for all other load situations.

This efficiency data is valid both for 1LA2 motors having the same output and pole number as well as for the appropriate EEx d motors. The efficiencies of force-ventilated 1PQ motors are, especially at low speeds, less, as the cooling- and friction losses are higher than for non-ventilated 1 LA motors.

Motor efficiencies in %

Motor		2p	= 2			2p	= 4			2p	= 6			2p	= 8		
1LA	M/Mn %	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz
1LA5 080	25	38	55	59	60	24	43	53	56	16	29	39	45				
	50	52	65	69	70	39	57	64	67	27	44	53	58				
	75	51	66	71	72	39	58	66	70	23	47	57	63				
	100	42	64	71	73	30	54	64	69	15	40	55	62				
1LA5 083	25	52	63	66	66	32	49	57	60	17	33	43	49				
	50	59	70	73	74	44	60	67	69	28	47	56	62				
	75	55	70	75	76	40	60	68	72	28	50	60	65				
	100	45	66	73	76	30	54	65	71	20	44	57	65				
1LA5 090	25	44	60	64	63	31	49	56	62	20	36	46	52	14	32	41	49
	50	57	69	72	73	46	61	67	70	33	51	59	64	24	45	56	61
	75	53	69	73	74	44	63	70	73	30	53	62	68	16	46	57	64
	100	42	66	73	75	35	58	68	73	24	47	60	67	10	34	52	60
1LA5 096	25	53	67	70	69	34	51	59	63	24	43	51	58	16	37	47	56
	50	62	74	76	78	48	63	69	73	38	56	63	68	27	51	61	67
	75	58	73	77	78	47	64	71	75	33	55	65	70	26	51	61	68
	100	48	69	76	78	34	61	70	74	33	49	62	68	11	41	56	64
1LA5 106	25	54	68	70	70	38	58	65	68	28	46	56	59	23	47	55	61
	50	64	74	77	78	54	68	73	76	41	59	67	69	36	56	65	69
	75	62	74	78	79	52	68	73	76	39	60	69	73	29	53	64	69
	100	56	72	77	79	41	65	73	76	35	56	67	72	10	41	57	64
1LA5 107	25					47	63	68	71					25	48	57	64
	50					57	71	75	78					37	59	68	72
	75					54	70	76	78					35	58	68	73
	100					43	66	74	78					20	52	64	70
1LA5 113	25	66	74	75	73	56	69	73	74	40	56	63	67	33	50	60	64
	50	70	78	80	80	64	74	79	80	52	66	71	75	45	61	69	72
	75	66	77	80	81	60	74	79	81	47	66	73	76	38	60	69	73
	100	58	74	79	81	50	71	77	80	32	62	75	76	30	53	65	71
1LA5 130	25	53	65	67	66	57	70	74	74	36	58	64	67	30	49	60	64
	50	65	73	76	76	67	76	80	81	53	67	72	76	45	62	69	73
	75	63	75	77	80	64	76	80	82	50	67	74	77	43	63	71	75
	100	55	73	78	80	57	74	80	82	37	64	72	77	26	58	68	74
1LA5 131	25	57	70	72	71												
	50	68	77	79	80												
	75	66	78	80	82												
	100	60	75	80	82												
1LA5 133	25					58	73	75	75	44	61	67	69	36	54	62	67
	50					69	78	81	82	57	69	74	78	49	65	71	75
	75					67	78	81	83	55	70	76	79	46	65	73	77
	100					62	76	81	83	44	67	75	79	32	61	71	76

Motor efficiencies in % (continued)

Motor 1LA	M/Mn %	2p = 2				2p = 4				2p = 6				2p = 8			
		12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz
1LA5 134	25									50	65	70	72				
	50									61	73	76	79				
	75									58	72	78	80				
	100									50	70	77	80				
1LA5 163	25	64	74	76	73	69	77	79	78	51	66	71	73	46	62	68	72
	50	71	79	81	82	74	80	83	84	63	73	79	81	56	70	75	78
	75	70	80	82	84	71	80	83	85	62	74	79	82	52	69	76	79
	100	63	77	82	84	66	79	83	85	56	73	79	82	40	65	74	78
1LA5 164	25	68	76	77	75									50	65	70	70
	50	74	81	83	83									59	73	77	80
	75	73	81	84	85									56	72	78	81
	100	69	80	84	85									48	69	77	80
1LA5 166	25	71	79	79	77	74	80	81	80	58	71	75	76	58	71	75	77
	50	78	84	85	84	76	83	85	86	67	77	81	83	63	76	80	82
	75	76	83	86	86	74	82	85	86	65	78	82	84	58	74	80	82
	100	72	82	85	87	69	80	84	86	60	76	81	84	48	70	78	81
1LA5 183	25	79	83	82	82	73	80	81	83								
	50	82	86	87	87	76	84	87	88								
	75	79	86	88	88	77	85	87	89								
	100	76	85	88	89	73	84	87	89								
1LA5 186	25					74	82	83	84	72	80	82	83	64	76	79	80
	50					79	85	88	88	75	83	86	87	71	80	84	86
	75					77	85	88	89	72	82	86	88	68	80	84	86
	100					76	84	88	89	65	80	85	87	61	78	83	86
1LA5 206	25	80	83	83	82					72	80	82	83				
	50	83	87	88	88					76	84	87	88				
	75	82	88	89	89					74	83	87	88				
	100	79	87	89	90					69	82	86	88				
1LA5 207	25	82	84	84	84	77	83	84	84	75	82	83	84	65	77	80	81
	50	84	88	89	88	80	86	88	89	78	85	87	88	71	80	85	86
	75	83	88	90	90	79	86	89	90	76	84	87	89	67	80	84	87
	100	80	88	90	91	76	85	88	90	70	82	86	88	59	77	83	86
1LA6 220 1LA6 223	25	87	89	88	86	84	88	89	87	82	87	88	88	75	83	85	85
	50	89	91	91	90	87	91	92	92	84	90	91	92	78	86	89	90
	75	87	90	91	90	84	91	92	93	80	89	91	92	72	84	88	90
	100	84	89	90	90	78	88	91	92	70	85	90	91	66	80	86	89
1LA6 253	25	90	91	90	88	87	90	90	89	84	88	89	89	79	85	87	87
	50	91	93	93	92	89	92	93	93	85	90	92	92	82	87	90	91
	75	89	92	93	92	86	92	93	93	81	89	92	93	78	87	90	91
	100	86	91	92	92	81	90	92	93	70	86	90	92	62	83	88	90
1LA6 280	25	91	92	91	89	88	90	90	88	87	90	91	90	83	88	89	89
	50	92	94	94	93	91	93	94	93	88	92	93	93	85	90	92	93
	75	90	93	94	93	90	93	94	94	85	91	93	94	81	89	92	93
	100	87	92	93	93	86	92	94	94	78	89	92	93	69	86	90	92
1LA6 283	25	92	93	92	90	88	90	90	88	87	90	91	90	83	88	89	89
	50	93	95	95	94	91	93	94	93	88	92	93	93	85	90	92	93
	75	91	94	95	94	90	93	94	94	85	91	93	94	81	89	92	93
	100	88	93	94	94	86	92	94	94	78	89	92	93	69	86	90	92

Motor efficiencies in % (continued)

Motor		2p	= 2			2p	= 4			2p	= 6			2p	= 8		
1LA	M/Mn %	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz	12.5 Hz	25 Hz	37.5 Hz	50 Hz
1LA6 310	25	92	92	90	87	90	91	91	90	87	90	91	90	84	89	90	89
	50	94	95	94	92	92	94	94	94	89	92	94	93	87	91	93	93
	75	93	95	95	94	91	94	95	95	86	92	93	94	84	91	93	94
	100	91	94	95	94	89	93	95	95	80	90	92	93	79	89	92	93
1LA6 313	25	92	92	90	87	90	91	91	90	87	90	91	90	84	89	90	89
	50	94	95	94	92	92	94	94	94	89	92	94	93	87	91	93	93
	75	93	95	95	94	91	94	95	95	86	92	93	94	84	91	93	94
	100	91	94	95	94	89	93	95	95	80	90	92	93	79	89	92	93
1LA6 316	25	94	94	93	90	92	93	93	92	89	91	92	91	86	90	91	90
	50	95	96	95	94	93	95	95	95	90	93	94	94	88	92	94	94
	75	94	96	96	95	92	95	96	95	89	93	94	95	86	92	94	94
	100	91	95	96	95	90	95	95	95	84	91	94	94	80	90	92	93
1LA6 317 **1LA6 318**	25	94	94	93	90	92	93	93	92	89	91	92	91	86	90	91	90
	50	95	96	95	94	93	95	95	95	90	93	94	94	88	92	94	94
	75	94	96	96	95	92	95	96	95	89	93	94	95	86	92	94	94
	100	91	95	96	95	90	95	95	95	84	91	94	94	80	90	92	93
1LA8 315 **1LA8 317**	25	95	95	94.5	93.5	93	94	94.4	94	91.5	93	93.7	93.7	88	91.6	92.6	93
	50	95	96	96.3	96	93.8	95.6	96	96.2	92.4	94.8	95.6	95.8	90	93.6	94.7	95.3
	75	93.5	95.8	96.4	96.4	92	95.2	96.1	96.4	90	94.2	95.5	96	87.6	92.9	94.6	95.5
	100	94	94.7	96	96.2	88	94	95.5	96.1	87	92.5	94.6	95.5	84	90.8	93.5	94.8
1LA8 353 **1LA8 355** **1LA8 357**	25	95.8	95.7	95.1	94	94.7	95.3	95.2	94.7	92	93.5	93.9	93.7	90	92.5	93.1	93.2
	50	96	96.9	97	96.3	95	96.4	96.7	96.6	93.6	95.4	95.9	96	91.8	94.4	95.3	95.9
	75	95	96.7	97	96.8	93.6	96	96.7	96.8	92.6	95.3	96.1	96.4	90	94.1	95.3	95.9
	100	93	96	96.6	96.7	93	95	96.1	96.5	89.6	94.4	95.7	96.2	87	92.5	94.5	95.5
1LA8 403 **1LA8 405** **1LA8 407**	25	96	96	95.4	94.3	94.9	95	94.9	94	92.3	93.4	93.5	93	90	92.4	92.9	92.9
	50	96.5	97	97	96.5	95.6	96.6	96.6	96.3	93.9	95.4	95.8	95.7	92.6	94.8	95.4	95.6
	75	95.6	97	97.2	97	94.7	96.4	96.8	96.8	93	95.5	96.1	96.2	91.6	94.8	95.7	96.1
	100	94	96.3	97	97	92.3	95.7	96.5	96.7	90.4	94.6	95.7	96.1	89	94	95.3	95.9
1LA8 453 **1LA8 455** **1LA8 457**	25	96	96	95.5	94.5	95	95.3	94.9	93.9	94	94.8	94.8	94.4	91.4	93	93.5	95.4
	50	96.7	97.2	97.1	96.7	96	96.7	96.7	96.3	95	96.3	96.6	96.5	93.4	95.3	95.8	95.9
	75	96.1	97.2	97.4	97.2	95.4	96.2	97	96.8	94	97.2	96.7	96.9	92.7	95.3	96.1	96.4
	100	94.5	96.7	97.1	96.1	94	96.2	96.7	96.8	91.6	95.4	96.3	96.7	90	94.5	95.7	96.2

3.3.9 Practical ways of the measuring the drive converter losses within the framework of a customer acceptance

Also refer to the ZVEI brochure:
"Determining the efficiency of drive converters."

This brochure can be ordered from: Z V E I
                                              FV Elektrische Antriebe
                                              Stresemannallee 19
                                              60596 Frankfurt/M.

Background:

If a drive converter manufacturer specifies a specific efficiency for the drive converter, and therefore guarantees it, it is often necessary to be able to prove and confirm the guaranteed values within the scope of customer acceptance tests.

There is only one practical possibility of determining the efficiency of a drive (drive converter + motor). This is the differential method. All of the other methods, which are also described in the following text, are either eliminated due to accuracy reasons, or because they cannot be implemented for large-rating drives.

Differential methods

For the differential methods, **the losses from the difference of the drawn (electrical) power and output (mechanical) power are determined**. Using this method, all of the drive losses, i.e. the drive converter- and motor losses can be determined with the required accuracy. This method is not suitable to only determine the drive converter losses.

Consequence: If the customer demands a proof of the losses and the efficiency, then it must be agreed with him, that the **system efficiency** (comprising the drive converter and motor) is determined using the method described above. Other methods to measure the drive converter losses cannot be applied in practice.

Additional, but not practical methods:

1. Calorimetric measurement of the drive converter losses:

Due to the resources required, this is not practical for Master Drives drive converters.
With this method, the thermal energy, generated in the drive converter is measured, and the power loss defined. The complete drive converter is thermally sealed, and the power loss is dissipated in a defined fashion through a cooling medium (e.g. air) and measured.

2. Direct measurement of only the <u>drive converter</u> losses from the drive converter input- and output power

This measurement can be made with low associated costs. However, it is problematical due to the demanded measurement accuracy, and is basically unusable for drive converter efficiencies which exceed 95 %.

Example:

A drive converter draws 100 kW and outputs 95 kW. The losses are therefore 5 kW. If the measurement inaccuracy of the active powermeter (wattmeter) used is only ± 0.5 %, then for a 100 kW measurement, an uncertainty of ±0.5 kW is obtained, both at the input- as well as the output. However, a measurement uncertainty of 2 × ± 0.5 kW represents a measuring tolerance of 20 % referred to 5 kW of losses!

According to VDE 0558 T1, Point 5.8.14, Table 5, the efficiency, determined using direct measurement may not deviate by more than $0.2 \times (1-\eta)$, i. e. the losses, determined using the differential measurement technique, must be able to be determined with 20 % accuracy. Put another way: A measurement is only considered to be correct, if the determined losses are incorrectly measured by a max. of 20 %. In case of doubt, the measured losses can be corrected by 20 % as a result of the tolerances of the measuring equipment used.

For the measuring equipment and PTs and CTs available today, these specified sensing accuracy's of the losses can only be achieved for efficiencies up to approx. 95 %. The interrelationships are described in detail in the ZVEI brochure mentioned before.

If efficiencies exceeding 95 % are expected, which is the case for Master Drives drive converters, **then the direct measurement makes no sense**. The main reason for this is the output voltage which is not sinusoidal (square wave voltage blocks with high rates-of-rise of 500 V / µs and above). This means that there is a high level of uncertainty especially when measuring the drive converter output. Under these prerequisites ($\eta \geq 97$ %), under certain circumstances, a direct measurement might provide efficiencies of $\eta > 1$ "; it is also possible that a lower efficiency is "incorrectly measured", i.e. it was measured to be lower than it really is.

Summary: Direct measurement

It is not possible to directly determine the drive converter efficiency by measuring the input- and output power for drive converters (with $\eta \geq 95$ %). If the customer still demands this type of measurement, you must explain the interrelationships and background. Of course these explanations are also valid for third-party drive converters.

3. Determining the drive converter losses from the individual losses

The individual losses, i.e. the constant-, rectifier-, on-state- and switching losses are measured. The sum of these individual losses provides the drive converter losses.

Individual loss measurements such as the (and they can only so executed) are made during development, and when the drive converter is **type tested** in the factory. The drive converter in this case is specifically prepared as the required measuring quantities in series units are not easily accessible. **Thus, this type of measurement cannot be used for customer acceptance purposes.**

When **practically calculating the losses for a specific load**, as a result of the measured values during the type test, the individual losses are specified at the rated operating point of the drive converter. The measured values can be converted, as shown in the previous Sections 3.3 and onwards, for any operating point.

Thus, this method is only **suitable for calculating the losses**, based on existing measured values. On the other hand, it is **not** suitable for determining the losses using measurements, within the scope of a customer acceptance test.

3.4 Braking and regenerative operation

General information

When is a braking function absolutely required?

Regenerative operation (braking) is generally requried for the following cases:

- **System-related**
    - for cranes and elevators when the load is lowered,
    - for roller-table drives when reversing,
    - for stretching machines in the foil- and fiber industry,
    - for test bay drives when testing combustion engines,
    - for unwinders,
    - for traversing drives.

- **Defined braking of high moments of inertia**
    - for high-inertia drives such as centrifuges and fans/blowers when braking

Further, a braking function should be considered for **dynamic operation**. In practice, it has been shown, that for certain applications, drives which generally do not have to be braked, should still be provided with a braking function.
In this case, it involves drives with high up to extremely high moments of inertia, typically fan/blower drives. Under steady-state operating conditions, these drives are always motoring. However, for transitional sequences, braking may be required. In this case, **2 typical situations** can be considered:

a) The customer specifies that the drive **must be braked**, under an emergency situation, **within a specified time**.

b) **Satisfactory operating characteristics** should be achieved also during stabilization- and speed setpoint changes.

The latter point will now be explained using as an example a ramp-up sequence when the speed setpoint is changed. As shown in the following Fig. 3.4.0, the speed overshoots (shown in the characteristic) when the controller is conventionally optimized (e.g symmetrical optimum).
Regenerative operation is briefly required to equalize the setpoint after the overshoot. If regenerative operation is not possible, this setpoint equalization can only be realized using the load torque and the intrinsic drive losses. For high moments of inertia and low load torques, this can take a considerable amount of time (dotted characteristic in Fig. 3.4.0).
In this case, the drive is de-coupled from a closed-loop control perspective, which makes it difficult to achieve optimum operation if the speed is frequently changed. As an alternative, the controller could be set so that the new speed is achieved without overshoot, which is practically not possible for large drives.The three possible speed characteristics are shown in Fig. 3.4.0. The same is essentially true when reducing the speed.
The load itself defines the transition characteristics if regenerative feedback and a pulsed resistor are not used.
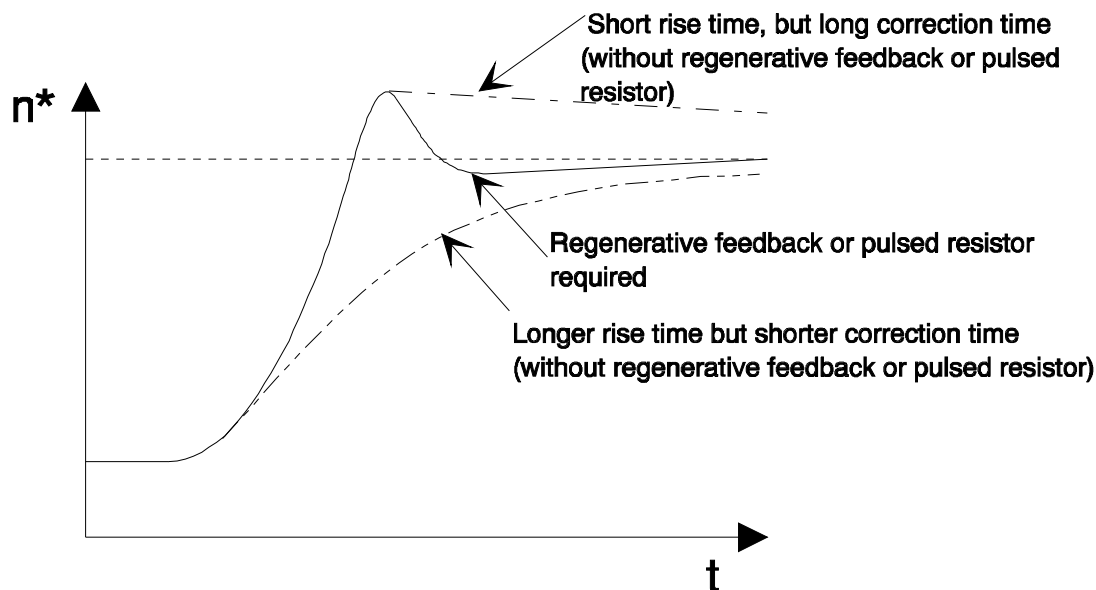
Fig. 3.4.0: Speed characteristics for a setpoint step

Before a decision is made not to use any braking, for example, for fan drives with high moments of inertia, this should be discussed with the customer. The customer should be made aware that under certain circumstances, the control behavior could be unsatisfactory at speed setpoint changes.

Which braking torques can be achieved by the standard drive converter alone?

Excluding the **DC current braking function**, where the drive can only be braked down to zero speed when it is powered-down, then braking generally means equipping the drive converter with a **pulsed resistor** or with **regenerative feedback**. As this makes the drive converter more expensive, if possible it should be attempted to just use the standard drive converter. (without pulsed resistor and without regenerative feedback). This is essentially true for fan- and pump drives as well as for extruders, reciprocating compressors and other applications. For the standard drive converters, regenerative torques and therefore regenerative power is only possible in so much that the drive converter and motor losses are not exceeded. The drive converter losses in the vicinity of the no-load point (M ≈ 0) generally lie between 0.5 and 1 % of the rated drive converter output; the motor losses in the vicinity of the rated speed and at M ≈ 0, are between 1 and 2 % of the rated motor output. This means, that **with the standard drive converter (without pulsed resistor, without regenerative feedback) and without DC current braking at rated speed, a maximum braking torque of only approx. <u>1 .... 3 % of the rated motor torque can be achieved</u>.**

The possible braking torque increases, with decreasing speed, in the following ratio

$$(1...3 \ \%) \ \cdot \frac{n_n}{n} \ for \ n \ < \ n_n .$$

The following engineering information should be observed so that disturbance-free operation is still achieved in spite of high moments of inertia but without using supplementary braking functions.

Engineering note: <u>Braking without regenerative feedback and pulsed resistor</u>

a. Set the **ramp-function generator down ramp,** par. P464, to a sufficiently high value so that the speed decreases as a result of the load torque, so that active braking is not required.

b. Set the **ramp-function generator rounding-off time,** e.g. par. P468, to higher values (up to 30% of the ramp-up/ramp-down time). This means that when a lower frequency setpoint is entered, the transition into no-load or slight regenerative operation is „smooth". This „overvoltage" shutdown will not occur during regenerative operation.

c. Activate the Vd_{Max} controller, par. P377. The ramp-down is slowed if the maximum permissible DC link voltage is reached.

d. For **vector control VC** (closed-loop frequency-, speed-, torque control): Limit the regenerative setpoint to an appropriately low value using par. P498.

Which braking type is used for which application?

For 6SE70/71 AC drive converters, the following braking types can be considered (with the exception of a mechanical brake mounted on a motor which will not be considered here):

- DC current braking in conjunction with induction motors for the FC (frequency control) and VC (vector control) control versions
- Resistor braking, only for 1FT6 servomotors with SC control version (servo control)
- Pulsed resistor
- Regenerative feedback into the line supply with line-commutated regenerative thyristor converter
- Regenerative feedback into the line supply as active front end, i.e. as regenerative converter with IGBTs

To select the suitable braking type, the essential characteristics are briefly listed in the following table. Detailed explanations follow in the subsequent text.

Type	DC current braking	Resistor braking	Pulsed resistor	Regenerative feedback with thyristor converter	Regenerative feedback with active front end
Suitable for	Only braking	Only braking	Braking and brief regenerative operation.	Braking and regenerative operation	Braking and regenerative operation
Used for	Individual units with induction motors	Individual units with SC and servomotors	Individual units and DC link bus	Individual units and DC link bus	Individual units and DC link bus
Braking torques which can be achieved	Good up to satisfactory, only for low-output motors	Can be adapted to the required braking power	Can be adapted to the required braking power.	Can be adapted up the full regenerative braking power	Full regenerative braking power
Require-ments	Only software, no hardware requirements	Supplementary resistors and contactors	Additional hardware: chopper and resistors	Additional hardware: Rectifier/regenerative feedback unit	Additional hardware, highest costs
Special advantages	No supplementary requirements	Independent of the line supply	Independent of the line supply, low extra costs if $P_{gen.} \ll P_{mot.}$	Excellent overall efficiency	Good overall efficiency, low harmonics fed back into the line supply, suitable for weak, disturbance-prone line supplies
Recom-mended	Only if braking is required and the braking torque is sufficient	Only if braking down to standstill is required	If sporadic braking energy occurs	If higher regenerative powers occur	For higher regenerative powers in conjunction with weak, disturbance-prone line supplies
Availability	Immediately	Can be immediately retrofitted	Immediately	Immediately	Presently available up to 800 kW infeed power

Table 3.4.1: Overview of the braking possibilities

3.4.1 DC current braking

DC current braking can only be used for induction motors. (For permanent-magnet synchronous motors, e.g. SIMOSYN motors or for servomotors for SC, a DC current cannot be impressed due to the magnetic field induced by the voltages. Further, for permanent-magnet synchronous motors without damping cage, if a DC current was to be impressed, braking torques would not be generated, only oscillating torques. For 1FT6 servomotors, resistor braking is the equivalent to DC current braking; also refer to the comments provided in 3.4.1 b).

The DC current braking function is included as standard in the basic drive converter software. When this function is selected (using par. 372), it is activated with the command „OFF3" (equals fast stop). The sequence is indicated in the following table:

Section	Activities	Comments
1	Enter OFF3 command	Activates the DC current braking function
2	OFF3 ramp-down time of the RFG expires, fast stop is initiated	OFF3 ramp-down time: par. 466 (0.1 to 999.9 s). The motor runs down along the fast stop down ramp to the frequency for the start of braking.
3	The RFG reaches the frequency for start of braking, the inverter enable is withdrawn, and the DC current braking is activated after the de-energization time has expired	Frequency at the start of braking: Par. 375 (0.1 to 300 Hz), defines, in conjunction with the OFF3 ramp-down time, the braking time along the fast stop ramp until DC current braking is initiated. This requires a braking function (pulsed resistor, regenerative feedback or load torque). If DC braking is to be used immediately, the frequency at the start of braking must be set sufficiently high. In this case, Section 2 is bypassed, and DC current braking starts immediately after Section 1 and after the de-energization time has expired (par. 371)
4	DC current braking with adjustable DC current	Braking time: Par. 374 (0.1 to 99.9 s), Braking current: Par. 373 (20 to 400 % of $I_{n\ motor}$)
5	After the braking time has expired: the inverter is no longer enabled and the „open main contactor" command is output	Motor is in the no-current condition

Table 3.4.2: DC current braking timing

Braking torques which can be achieved using DC current braking

Which braking torques can actually be achieved using DC current braking? In this case, the current- and torque characteristics of the motors for direct starting or for on-line operation of the motors are required. This data is provided in Catalogs M10 and M11, and can also be inquired from the motor factories.

The following is always valid, as long as the motor magnetic field is lower than the nominal value, i.e. for DC current braking at all speeds above the (low) slip frequency or practically over the complete speed control range with the exception of zero speed:

$$M_{brake} \sim I_{brake}^2$$

This is because at the specified speed and DC current (i.e. stator frequency = 0), and the thus specified motor impedance, the torque generated is given by:

$M \sim \Phi * I$ whereby in this case: $\qquad \Phi \sim I_{brake}$

At low speeds close to the rated slip frequency, the braking torque increases to higher values, e.g. to twice the rated torque if 200% rated current is entered as braking current at twice the rated slip frequency. The braking torque is further decreased at still lower speeds down to motor standstill.

Example: For a certain motor, e.g. 1LA5130-4CA.. with 5.5 kW, 1450 RPM, the torque is to be determined which is required to brake down to standstill at 500 RPM. A magnetic DC field is obtained in the motor when a DC current is entered. With respect to this spatially stationary magnetic field, the rotor rotates with a slip frequency of

$$fs = \frac{n}{60} * p = \frac{500\ RPM}{60} * 2 = 16\frac{2}{3}\ Hz$$

This corresponds to the point designated by A for direct on-line operation in Fig. 3.4.1.
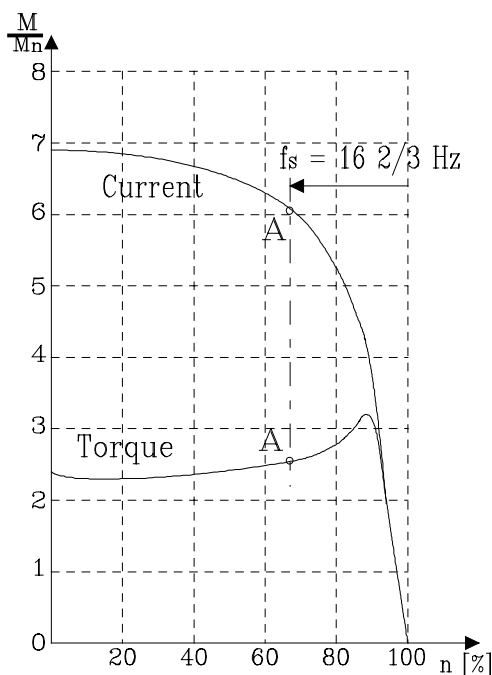
Fig. 3.4.1 Current- and torque characteristics when operating the motor direct online

In this case, 260% of the rated motor torque is obtained at 610% of the rated motor current. If a braking current is specified, then for the speed being considered, 500 RPM, the braking torque is given by:

$$\frac{M_{brake}}{M_n} = \frac{2,6}{6,1^2} * \left| \frac{I_{brake}}{I_n} \right|^2 = 0,07 * \left(\frac{I_{brake}}{I_n} \right)^2$$

or: for a braking current which is the same as the rated motor current, a braking torque of only 7% of the rated motor torque is obtained at 500 RPM. The actual achievable braking torques as a function of the DC braking current and speed, are specified in the subsequent Fig. 3.4.2 for:

        motor outputs up to approx. 3 kW,

        motor outputs from approx. 4 kW to approx. 15 kW and

        motor outputs from approx. 22 kW
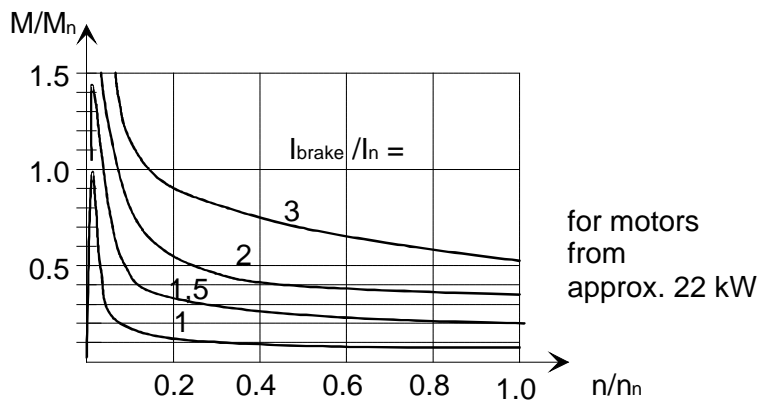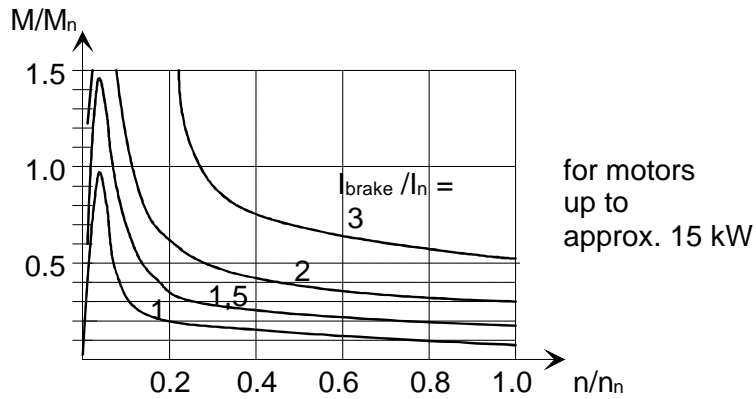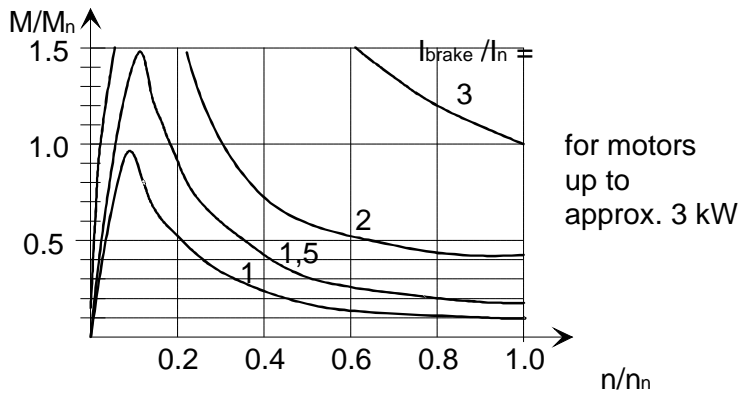
Fig. 3.4.2 Approximate values for the achievable braking torques with DC current braking

The following general comments can be made:

The lower the motor output, then the higher are the achievable braking torques at the specified braking current. The reason for this is that smaller motors have a higher (%) ohmic resistance in the stator and rotor, which is then reflected in the relatively high slip values. Even for these low-rating motors, a DC braking current close to twice the rated motor current must be provided in order to achieve braking torques of at least 30% to 50% of the rated motor torque above approximately 40% of the rated speed. For motors above approximately 30 kW, a braking current of approx. 250% to 300% of the rated motor current is required to achieve braking torques of at least 50% of the rated motor torque at speeds above approximately 15% of the rated speed.

The basic characteristics of the braking torques appears to make DC current braking suitable, especially for pumps and fans, whereby the load torque decreases as a square of the speed. In this case, the drive is braked from high speeds with a sufficiently high load torque. At lower speeds, the load torque almost completely disappears, but the DC current braking becomes increasingly effective.

Caution: Take into account the peak currents which are permissible for the drive converter which you selected! If you intend to use DC current braking up to 300% of the rated motor torque for your particular drive application, then this is only possible if the drive converter can actually output this current. Under certain circumstances, this can mean that the drive converter must be significantly overdimensioned. For standard applications, i.e. without having to overdimension the drive converter as far as DC current braking is concerned, it can be generally assumed, that the permissible DC currents are approximately 150% of the rated motor current.

Permissible braking times

Finally some comments regarding motor temperature rise as a result of DC current braking. When using DC current braking, the complete braking energy is dissipated as power loss in the motor. If, for example, the rated motor current is specified as braking current, then DC current braking does not cause higher motor losses than in standard operation; in fact they can even be somewhat lower due to the lower iron losses. The fact that all of the braking energy is dissipated in the motor as power loss (temperature rise), makes it irrelevant for the motor temperature rise, however, what is decisive is the time, the current and the speed.

The interrelationship between the specified braking current as a multiple of the rated motor current to the permissible braking times is specified in Fig. 3.4.3. In this case, it is assumed that DC braking is used when the motor is in the warm condition. For instance, when braking with 300% rated motor current, braking can last up to approx. 22 s; when braking with the rated motor current, this time can be extended up to over 100 s.

When sporadically using the braking times with braking currents which are significantly higher than the rated motor currents, according to Fig. 3.4.3, it should be noted that an adequate recovery time is provided before the next braking operation is initiated. On the other hand, if DC braking is used regularly within a load duty cycle, then this can be taken into account as explained in the Engineering Manual for Motors, in the section, load duty cycles. For the DC current braking phase, instead of the load torque, a value of

$$M_{equivalent} = \frac{I_{brake}}{I_n} * M_n$$

must be used.
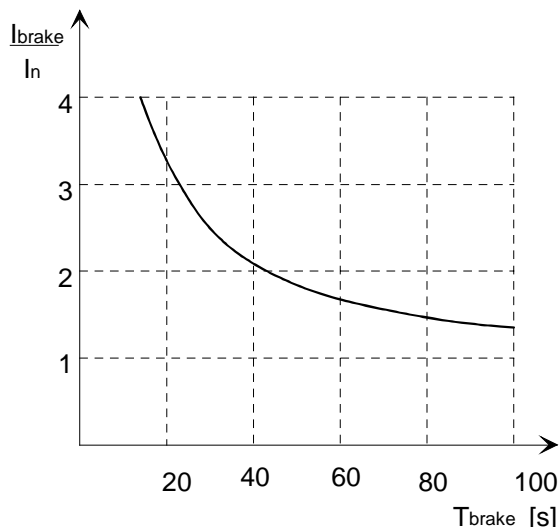
Fig. 3.4.3   Approximate values for permissible braking times
when using DC current braking with the motor
in the warm condition, as a function of the specified
DC current.

3.4.1.1 Resistor braking in conjunction with 1FT6 servomotors

For permanent-magnet servomotors, a voltage is induced at the specified speed as a result of the permanent magnets in the stator. Thus, if the stator winding is short-circuited, either directly or through a resistor, then the internal winding resistance limits the current and a braking torque is generated which can be used to brake the motor down to zero speed. The braking torques which can be achieved in this fashion are roughly the same as the rated motor torque. Refer to Section 2.7 of the Engineering Manual for Motors for more detailed information regarding the braking torques, deceleration time and recommended brake resistors.

This type of resistor braking can be used, if the motors must be immediately shutdown if a line supply fault develops, or the converter develops a fault. This would be necessary to limit subsequent damage. The control devices such as changeover contactors must be separately provided, mounted and wired.

3.4.2 Pulsed resistor with braking units and load resistors

The regenerative (braking) energy is converted into heat using the pulsed resistor. To realize this, a braking unit (equals DC controller or chopper) is located in the DC link as illustrated in Fig. 3.4.4. The braking unit chopper switches a resistor with a specific pulse-period interval (mark-to-space ratio) corresponding to the regenerative power to be dissipated. The chopper control depends on the DC link voltage. The brake resistor is only effective, if the DC link voltage has increased above the rectified line supply voltage due to the regenerative mode, i.e. not in the standard, motoring mode.
Two or more braking units can be connected in parallel to increasing the braking power.
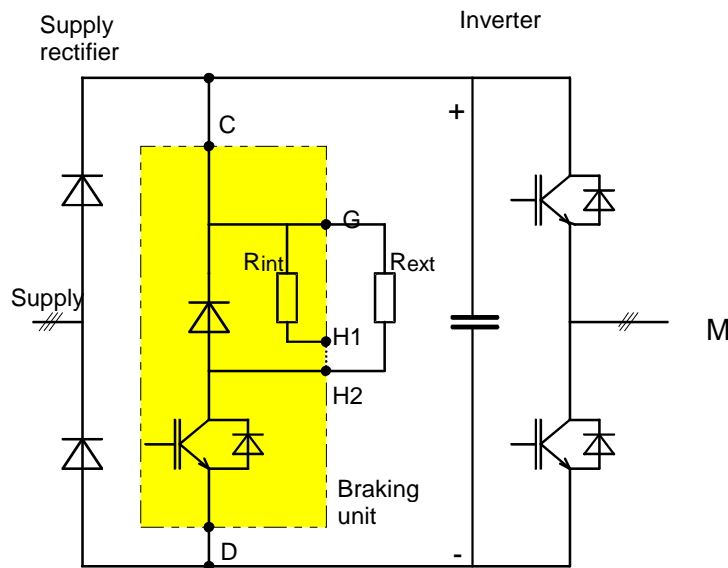
Fig. 3.4.4 Drive converter with additional braking unit and brake resistor

The pulsed resistor is an autonomous unit, and can be retrofitted to a drive converter. The braking units are suitable for:

- individual drive converters as well as
- multi-motor drives connected to a common DC link .

Braking unit(s) as well as external load resistors must be separately ordered for compact- and chassis units. For cabinet units they can be optionally ordered together with the equipment. The braking units must be mounted as close as possible to the drive converter $\leq$ 3 m, and connected at the drive converter DC link or as close as possible to the inverters. The braking units are available in three sizes: 0, 1 and 2.

Braking units with internal load resistor, only for sizes 0 and 1
For braking units with braking powers up to 20 kW, an internal load resistor is provided. Thus, only a relatively low braking energy can be dissipated. If an external load resistor is provided, then the braking energy which has to be dissipated is significantly higher. The maximum braking power for internal and external load resistors is the same. This maximum braking power for an internal brake resistor can only be used for approximately 1/8 of the time of that for an external brake resistor.
Caution: Either only the internal load resistor or only the associated external load resistor may be used, but not both simultaneously! If only the external load resistor is used, jumper H1-H2 must be removed as shown in Fig. 3.4.4.

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Braking units without internal load resistor, for size 2
For the higher braking powers from 50 to 200 kW, no internal load resistors are included and an external load resistor must always be provided. In this case, each braking unit is assigned a load resistor, dependent on the supply voltage.

Caution: A braking unit may only be operated with the associated external load resistor due to the protection- and monitoring electronics! Other combinations are not permitted.

Mounting the external load resistors
The external load resistors have degree of protection IP20. They must be installed and mounted so that they are protected, from for example, conductive dust deposits. It is not permissible to mount them outdoors, and they must always be mounted in a cabinet or in a switchgear room. The lower load resistors up to 10 kW are suitable for both roof-section- and wall mounting. The larger load resistors are suitable for wall- or floor mounting.
Sufficient air circulation must be guaranteed due to the relatively high levels of power which have to be dissipated by the load resistors. They should be mounted separately, away from drive converter power sections (danger of excessive temperature rise!). The maximum permissible distance between a load resistor and braking unit is 50 m.

What happens if the permissible braking power of the braking units is exceeded?
The braking units with or without load resistor are designed for a specific load duty cycle, and can only accept a limited braking power within a specified time. If these values are exceeded as far as the load requirements are concerned, then the electronic monitoring function of the braking unit causes the chopper firing level to be reduced when the maximum braking energy of the braking units has been reached. The braking energy dissipated in the load resistor then goes to 0, and the DC link voltage quickly increases due to the regenerative energy present and the drive converter or the system with the DC link overvoltage condition is shutdown. This is the same as a failure of the drive (system).

Monitoring the braking units.
The braking units include a fault relay which is included in the monitoring chain.
Terminals: X38:4,5, 60 V load capability, NO contact. Contact closed: No fault.
This fault relay responds when the braking unit is overloaded or when the chopper is defective, e.g. a defective chopper transistor. It also responds when the heatsink temperature of the braking unit exceeds a specific level.
External load resistors also include an overtemperature contact (NC contact, the contact opens when an overtemperature situation develops), which should also be included in the fault circuit.

Fusing (protecting the braking units).
The braking units do not have any internal fuses. They must be fused using the fuses specified in Catalog DA65.1 Fuses are not required only if a braking unit is connected to a single drive converter unit **and** if the P20 power rating of the braking unit approximately coincides with the rated converter output. In this case, the braking unit is fused via the line-side drive converter fuses.

Caution: These fuses do not rupture if a chopper transistor becomes defective, whereby the current is limited by the brake resistor. **In order that the brake resistors do not burn when such a fault develops**, the power feed must be interrupted which is realized using a fault contact of the chopper. If the drive converter has a main contactor, it is sufficient to loop the chopper fault contact into the general fault circuit. Also refer to the connecting-up examples in the Instruction Manual of the brake units. Otherwise, for instance, when using braking units for a DC link bus, it might be necessary to provide a separate contactor for the braking units.

Special issues for braking units connected in parallel.
Generally, several braking units can be connected in parallel to the DC link. In this case, each braking unit must have its own resistor (it is not possible to connect-up the load resistors themselves in parallel!).
Due to the various tolerances, it may occur that for low regenerative powers, not all of the braking units operate simultaneously, but only those with the lower response threshold. If these braking units then trip due to overload, the DC link voltage rises until the response threshold of the next braking units is reached. This means that the full braking power is still available.
Thus, when braking units are connected in parallel, their fault relays should also be connected in parallel (and not in series!), as otherwise the fault of an individual braking unit would result in a fault of the complete system. However, when an overtemperature contact of an external load resistor responds, it must shutdown the associated braking unit. Otherwise (for example, if a chopper resistor becomes defective), the associated load resistor would be continuously connected to the DC link voltage, and the load resistor could burn.
Caution: As braking units with an internal load resistor only have a group fault signal, and not an additional overtemperature signal, the fault outputs may not be connected in parallel. **Thus, it only makes sense and is only permissible if braking units are connected in parallel when external load resistors are used.**

The braking powers which can be achieved when external load resistors are used will now be discussed. The braking powers which can be achieved using internal load resistors will be specified after this.

Braking powers which can be achieved using the pulsed resistor option with an external load resistor and selecting the suitable pulsed resistor devices for specified load duty cycles.

The braking units are available in the following power levels as listed in the following table.

Voltage range	braking power for 20 s					
208 V to 230 V	5 kW	10 kW	20 kW	----	----	----
380 V to 460 V	5 kW	10 kW	20 kW	50 kW	100 kW	170 kW
500 V to 575 V	5 kW	10 kW	20 kW	50 kW	100 kW	200 kW
660 V to 690 V	----	----	20 kW	50 kW	100 kW	200 kW

Table 3.4.3: Available braking powers in conjunction with an external load resistor

The data of the individual braking units with the associated brake resistors are listed together with the Order Nos. in the following tables 3.4.4 and 3.4.5.

Braking unit		Brake resistor			
Order No.	Size	Order No.	Technical data		
			Power P_{20} (kW)	Rated voltage (V)	Resis-tance (Ω)
6SE7021-6CS87-2DA0	0	6SE7021-6CS87-2DC0	5	208 to 230	20
6SE7018-0ES87-2DA0	0	6SE7018-0ES87-2DC0	5	380 to 460	80
6SE7016-4FS87-2DA0	0	6SE7016-4FS87-2DC0	5	500 to 575	124
6SE7023-2CA87-2DA0	1	6SE7023-2CS87-2DC0	10	208 to 230	10
6SE7021-6ES87-2DA0	0	6SE7021-6ES87-2DC0	10	380 to 460	40
6SE7021-3FS87-2DA0	0	6SE7021-3FS87-2DC0	10	500 to 575	62
6SE7026-3CA87-2DA0	1	6SE7026-3CS87-2DC0	20	208 to 230	5
6SE7023-2EA87-2DA0	1	6SE7023-2ES87-2DC0	20	380 to 460	20
6SE7022-5FA87-2DA0	1	6SE7022-5FS87-2DC0	20	500 to 575	31
6SE7022-1HA87-2DA0	1	6SE7022-1HS87-2DC0	20	660 to 690	44.4
6SE7028-0EA87-2DA0	1	6SE7028-0ES87-2DC0	50	380 to 460	8
6SE7026-4FA87-2DA0	1	6SE7026-4FS87-2DC0	50	500 to 575	12.4
6SE7025-3HA87-2DA0	1	6SE7025-3HS87-2DC0	50	660 to 690	17.8
6SE7031-6EB87-2DA0	2	6SE7031-6ES87-2DC0	100	380 to 460	4
6SE7031-3FB87-2DA0	2	6SE7031-3FS87-2DC0	100	500 to 575	6.2
6SE7031-1HB87-2DA0	2	6SE7031-1HS87-2DC0	100	660 to 690	8.9
6SE7033-2EB87-2DA0	2	6SE7033-2ES87-2DC0	170	380 to 460	2.35
6SE7032-5FB87-2DA0	2	6SE7032-5FS87-2DC0	200	500 to 575	3.1
6SE7032-1HB87-2DA0	2	6SE7032-1HS87-2DC0	200	660 to 690	4.45

Table 3.4.4: Selection table for braking units with external brake resistors

Braking unit			External load resistor	
Size	Dimensions in mm H x W x D		Power P_{20} (kW)	Dimensions in mm H x W x D
0	425 x 45 x 350		5	145 x 540 x 360
1	425 x 90 x 350		10	145 x 540 x 360
2	425 x 135 x 350		20	302 x 485 x 430
--	--		50	302 x 485 x 740
--	--		100	602 x 485 x 740
--	--		200	1322 x 485 x 740

Table 3.4.5: Dimensions of the braking units and external load resistors

The braking powers, specified in Tables 3.4.4 and 3.4.5 above, can be utilized in conjunction with the associated external load resistors for 20 s. However, a minimum no-load interval of 70s is then required. The standard load duty cycles which can be achieved with the pulsed resistor in conjunction with an external load resistor are illustrated in Fig. 3.4.5.
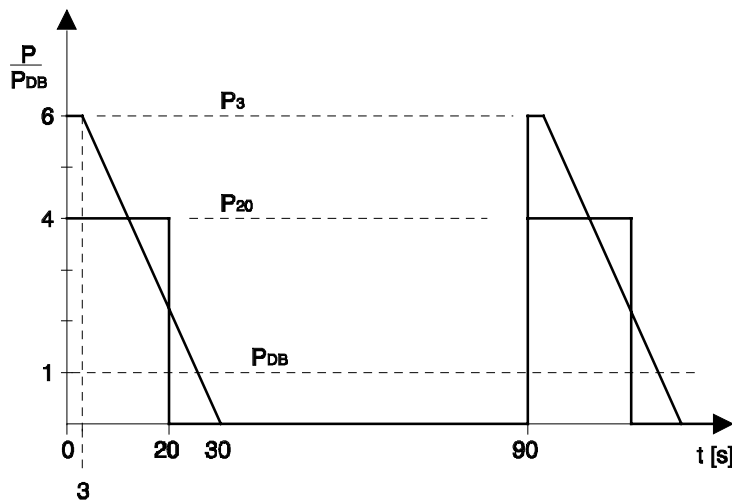
Fig. 3.4.5   Standard load duty cycles for a pulsed resistor
with an external load resistor

Meanings:

P_{DB} =   Permissible continuous output

$P_{20} = 4 * P_{DB}$ =   Permissible peak output for 20 s which is identical with
the power data in Table 3.4.4 above

$P_3 = 6 * P_{DB}$ =   Peak output when the chopper is fully controlled

Comment: The peak power $P_3 = 6 * P_{DB}$ can be fully used for 12 s, if this is immediately followed by a 70 s no-load interval; also refer to the 3rd dimensioning example. As „3-second power", it may only be used for 3 s, if this is immediately followed by a braking power which linearly decreases within 27 s, as shown in Fig. 3.4.5.

The **response threshold** to activate the braking unit and the **thus associated DC link voltage which occurs when braking with a pulsed resistor,** is specified in Table 3.4.6.

Rated voltage [V]	Reponse threshold [V]	Comments
208 V to 230 V	387	
380 V to 460 V	774 (673)	774 V is the factory setting. For rated supply voltages from 380 V to 400 V, the response threshold can be reduced to 673 V to reduce the motor voltage stressing. However, the achievable peak power is reduced by the ratio: The peak power/P20 is then no longer 1.5/1 but only 1.13/1.
500 V to 575 V	967 (841)	967 V is the factory setting. For a rated supply voltage of 500 V, the response threshold can be reduced to 841 V to reduce the motor voltage stressing. However, the achievable peak power is reduced by the ratio: The peak power/P20 is then no longer 1.5/1 but only 1.13/1.
660 V to 690 V	1158	

Table 3.4.6 Response threshold of the braking units

Two typical load cases are taken into account for the load duty cycles in accordance with Fig. 3.4.5:
- load duty cycles, where a periodically constant braking power is required, e.g. for a crane drive where the load is periodically lowered,
- load duty cycles, where the braking power linearly decreases from a peak value to zero, e.g. for a centrifuge drive, which is periodically accelerated and braked.

For load duty cycles which deviate from those specified above, the following must be ensured,
a)   for any 90 s time interval, the average braking power is less than the permissible continuous power of the braking unit,
b)   the peak braking power is less than 600% of the continuous braking unit power.

When selecting a suitable pulsed resistor device, it is recommended to proceed as follows for defined load duty cycles:

For periodic load duty cycles with a load cycle duration ≤ 90 s:
    The required braking power is determined within the load duty cycle $P_{brake} = f(t)$
    The average braking power is determined within the load duty cycle.
    A braking unit is selected in accordance with the selection table 3.4.4 above, whose 20s rating P20 is at least 450 times greater than the average value of the determined braking power.
    Independent of this, it must be ensured, that the required peak braking power can be absorbed, i.e. a braking unit must be selected whose 20 s rating P20 is at least 67% (88% for a reduced response threshold according to the comments in Table 3.4.6) of the required peak power in the load duty cycle, in accordance with Table 3.4.4.

For periodic load duty cycles with a load cycle duration (>90 s) and for sporadic braking:

The required braking power P_{brake} = f(t) is determined

A 90 s time segment is selected, so that in this time segment the highest average value of the required braking occurs.

The average value of the braking power within this time segment is determined.

A braking unit is selected in accordance with selection Table 3.4.4 above, whose 20s rating is at least 450 times greater than the average value of the required braking power in this time segment. Independent of this, it must be ensured that the required peak braking power at any instant in time (also outside the particular time sector) must be able to be absorbed, i.e. a braking unit must be selected whose 20 s rating P20 in accordance with Table 3.4.4 is at least 67% (88% for a reduced response threshold according to the comments in Table 3.4.6) of the required peak output in the load duty cycle.

Dimensioning examples

Example 1

For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in the following Fig. 3.4.6.
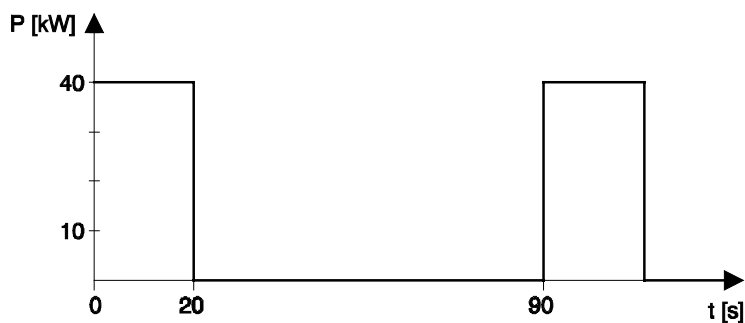
Fig. 3.4.6 Required braking power for example 1

This corresponds to the standard load duty cycle in accordance with Fig. 3.4.5. A braking unit with a 20 s rating P20 of at least 40 kW is suitable. Thus, the following is necessary:

Braking unit 6SE7028-0EA87-2DA0 with P20 = 50 kW,

together with the external load resistor 6SE7028-0ES87-2DC0

Example 2

For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in the following Fig. 3.4.7.
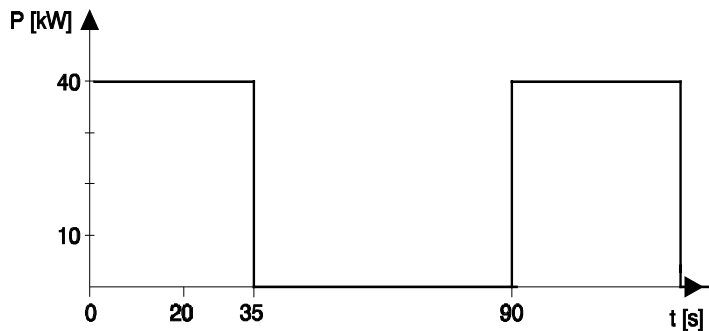
Fig. 3.4.7 Required braking power for example 2

In this case, the average braking power is given by: 40 kW ∗ 35 s / 90 s = 15.6 kW. The braking unit required must have a 20 s rating P20 of at least 4.5 ∗ 15.6 = 70.2 kW. Thus, the following is required:
Braking unit 6SE7031-6EB87-2DA0 with P20 = 100 kW,
together with an external load resistor 6SE7031-6ES87-2DC0.

Comment:
Alternatively, 2 braking units can be used; one with 50 kW and one with 20 kW, connected in parallel. In this case, the following would be required:
Braking units:
 6SE7028-0EA87-2DA0 with 50 kW with load resistor 6SE7028-0ES87-2DC0,
+ 6SE7023-2EA87-2DA0 with 20 kW with load resistor 6SE7023-2ES87-2DC0.
It must be decided on a case for case basis, which of these alternatives - 1 braking unit with 100 kW or 2 braking units with 50 + 20 kW or generally; 1 braking unit or 2 braking units with an overall lower total power. The most favorable solution must be decided on a case-for-case basis. In this case, the criteria is the space required and the associated costs.

Example 3

For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in the following diagram 3.4.8.
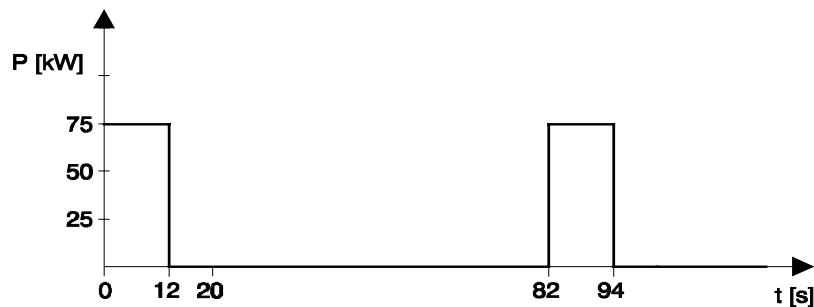
Fig. 3.4.8 Required braking power for example 3

In this case, the average braking power is given by: 75 kW ∗ 12 s / 82 s ≈ 11 kW. The required braking unit must have a 20 s rating P20 of at least 4.5 ∗ 11 = 50 kW. The condition: Peak power ∗ 0.67 ≥ P20 is also fulfilled. Thus, the following is required:
Braking unit 6SE7028-0EA87-2DA0 with P20 = 50 kW,
together with an external load resistor 6SE7028-0ES87-2DC0.

Example 4

For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in the following Fig. 3.4.9.
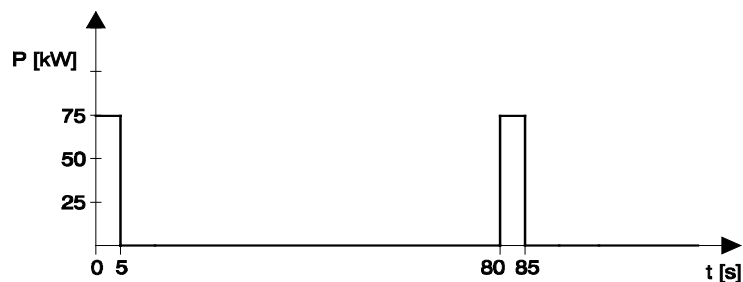
Fig. 3.4.9 Required braking power for example 4

In this case, the average braking power is given by: 75 kW ∗ 5 s / 80 s ≈ 4.7 kW. The required braking unit must have a 20 s rating P20 of at least 4.5 ∗ 4.7 = 21.2 kW. However, a braking unit with P20 ≥ 50 kW is required as a result of the condition: Peak power ∗ 0.67 = 75 kW ∗ 0.67 = 50 kW ≤ P20:
Braking unit 6SE7028-0EA87-2DA0 with P20 = 50 kW,
together with an external load resistor 6SE7028-0ES87-2DC0.

Example 5

For a 400 V supply voltage, a pulsed resistor is required as illustrated in the load duty cycle requirements in the following Fig. 3.4.10. For example, when a crane lowers a load which then must be braked. As the load duty cycle is > 90 s, a time segment of 90 s must be selected, in which the average of the required braking power reaches a maximum.
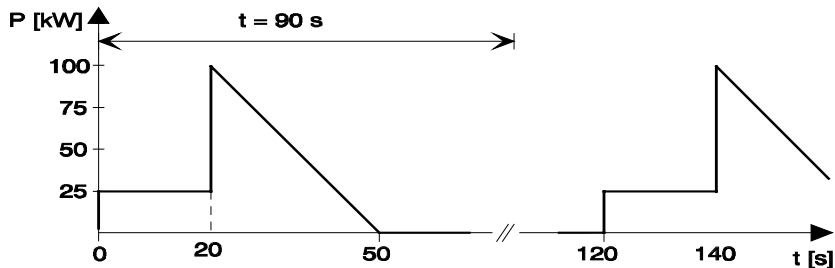
Fig. 3.4.10 Required braking power for example 5

This is clearly the case in the time segment shown in Fig. 3.4.10. In this case, the average braking power: (25 kW * 20 s + 100 kW/2 * 30 s) / 90 s = 22.2 kW. A braking unit is required with $P20 > 4.5 * 22.2 = 100$ kW. Thus, peak powers of 100 kW can be handled. The following braking unit is required: 6SE7031-6EB87-2DA0 with P20 = 100 kW,
together with an external load resistor 6SE7031-6ES87-2DC0.

Example 6

For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in the following Fig. 3.4.11.
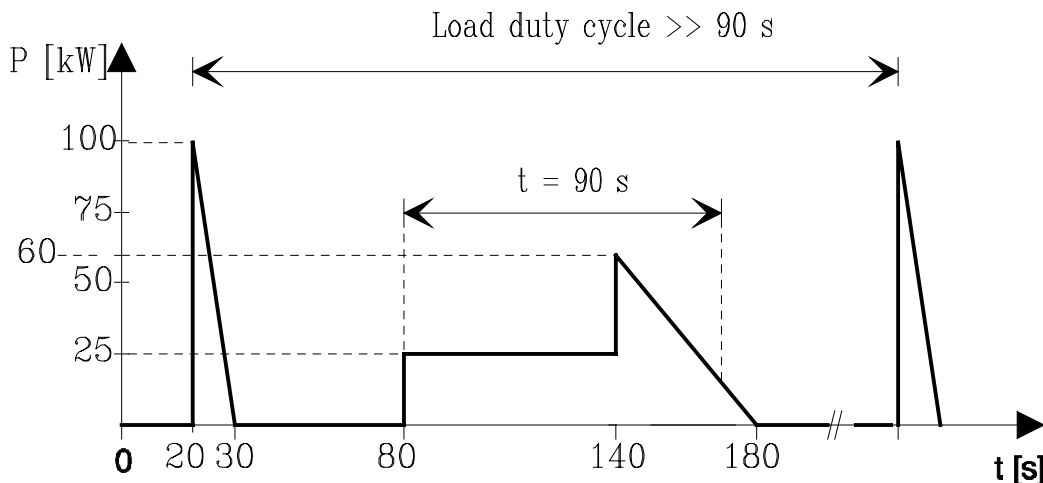
Fig. 3.4.11 Required braking power for example 6

As the load duty cycle is > 90 s, a time segment of 90 s must be selected in which the average of the required braking power reaches a maximum. This is the case in the time segment identified in Fig. 3.4.11. In this case, the average braking power is given by: [25 kW * 60 s + (60 +15 kW)/2 * 30 s] / 90 s = 29.2 kW. A braking unit is required with:
P20 > 4.5 * 29.2 = 131 kW. Thus, the peak power of 100 kW can be handled. The following braking unit is required:
6SE7033-2EB87-2DA0 with P20 = 200 kW,

together with an external load resistor 6SE7033-2EB87-2DA0.

Alternatively, 2 braking units can be used here; one with 100 kW and one with 50 kW, connected in parallel. The following would be required:
Braking units: 6SE7031-6EB87-2DA0 with 100 kW with load resistor 6SE7031-6ES87-2DC0
        6SE7028-0EA87-2DA0 with 50 kW with load resistor 6SE7028-0ES87-2DC0

Also observe the comment to example 2.

Example 7
For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in the Fig. 3.4.12.
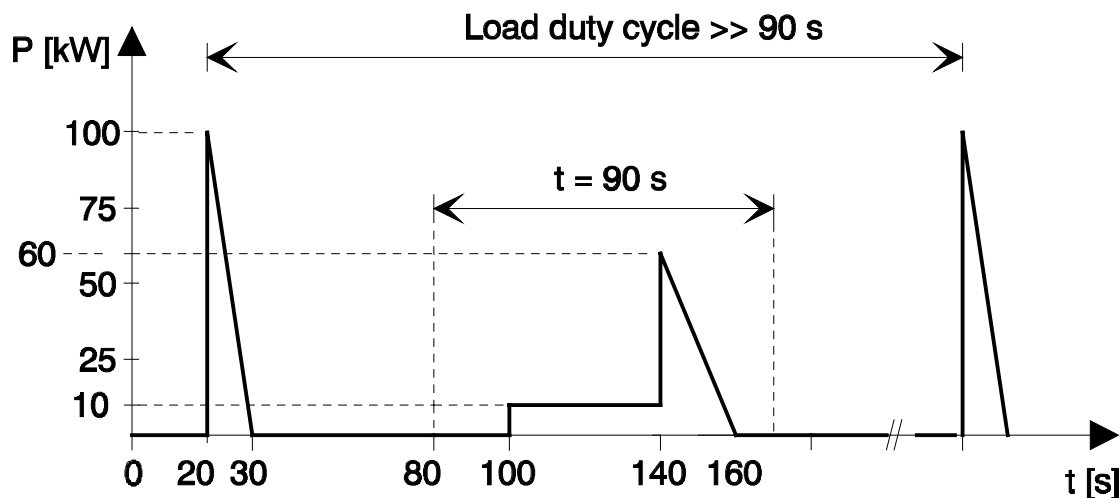
Fig. 3.4.12 Required braking power for example 7

As the load duty cycle is > 90 s, a time segment of 90 s must be selected in which the average of the required braking power reaches a maximum. This is the case in the time segment identified in Fig. 3.4.12. In this case, the average braking power: [10 kW * 40 s + (60 kW)/2 * 20 s] / 90 s = 11 kW. A braking unit is required with at least:
P20 > 4.5 * 11 = 50 kW. Thus, the peak power of 100 kW cannot be handled. The following is required:
P20 ≥ 0.67 * 100 kW = 67 kW. Thus, the following is required: Braking unit 6SE7031-6EB87-2DA0 with P20 = 100 kW,
together with an external load resistor 6SE7031-6ES87-2DC0.
Alternatively, 2 braking units can be used here; one with 50 kW and one with 20 kW connected in parallel. The following would be required:
Braking units: 6SE7028-0EA87-2DA0 with 50 kW, with load resistor 6SE7028-0ES87-2DC0
        6SE7023-2EA87-2DA0 with 20 kW, with load resistor 6SE7023-2ES87-2DC0

Also refer to the comment to example 2.

Pulsed resistor option: Braking powers which can be achieved using the internal load resistor and selecting the suitable pulsed resistor devices for specified load duty cycles

For the internal resistor, the possible continuous power is relatively low. For continuous operation, it corresponds to approximately 2.8 % of the 20 s rating P20, and therefore only approx. 12.5 % of the energy which can be dissipated using an external load resistor. However, it must be checked and ensured that if one or several braking units with internal load resistor are accommodated in a cabinet, that the power loss can also be dissipated.

The standard load duty cycle, illustrated in Fig. 3.4.13, is valid for braking units with internal load resistor.
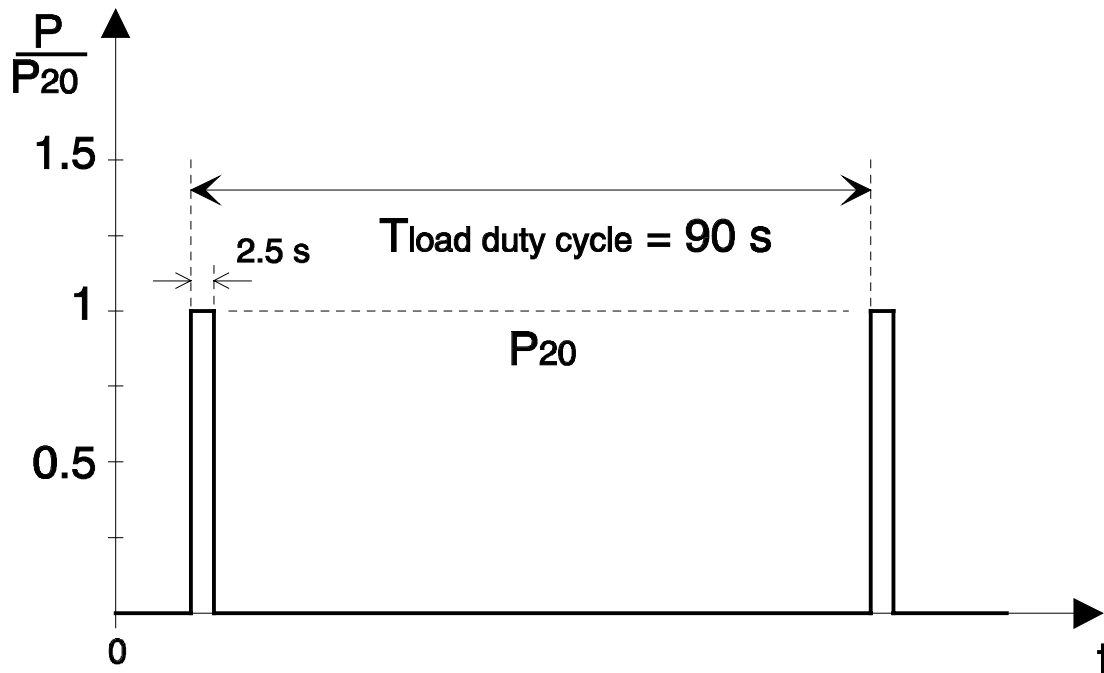
Fig. 3.4.13 Standard load duty cycle for an internal load resistor.

The P20 power can therefore be utilized for 2.5 s with a 90 s load duty cycle duration. The peak power of 1.5 * P20 (1.13 * P20 with a reduced response threshold according to the comments in Table 3.4.6) - can be used for 1.7 s when the chopper is fully-controlled. Thus, the internal load resistor is generally only suitable for braking within a time period of < 2.5 ...5 s.

When selecting a suitable pulsed resistor device **for only an internal load resistor**, we recommend to proceed as follows for a specified load duty cycle:

For periodic load cycles with a load duty cycle duration ≤ 90 s:
   The required braking power is determined within a load duty cycle.
   The average braking power is determined within the load duty cycle.
   A braking unit is selected, whose 20 s rating P20 according to Table 3.4.4 is at least 36 times as large as the average determined braking power.
   Independent of this, it must be guaranteed that the required peak braking power can be absorbed, i.e. a braking unit must be selected whose 20 s rating P20 is at least 67% (88% for a reduced response threshold according to the comments in Table 3.4.6) of the required peak power in the load duty cycle in accordance with Table 3.4.4.

For periodic load duty cycles with a load duty cycle duration >90 s and for sporadic braking:

A time sector of 90 s is selected in which the highest average value of the required braking power occurs.
The average braking power is determined within this time sector.
A pulsed resistor is selected according to the above selection Table 3.4.4, whose 20 s rating P20 is at least 36 times larger than the average required braking power in this time sector.
Independent of this, it must be guaranteed that the required peak braking power at any particular instant in time (also outside the time sector being investigated) can be absorbed, i.e. a braking unit must be selected whose 20 s rating P20 is at least 67% (88% for a reduced response threshold in accordance with the comments in Table 3.4.6) of the required peak power in the load duty cycle according to Table 3.4.4.

Dimensioning examples

Example 8
For a 400 supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in Fig. 3.4.14. In this case, only the internal load resistor should be used.
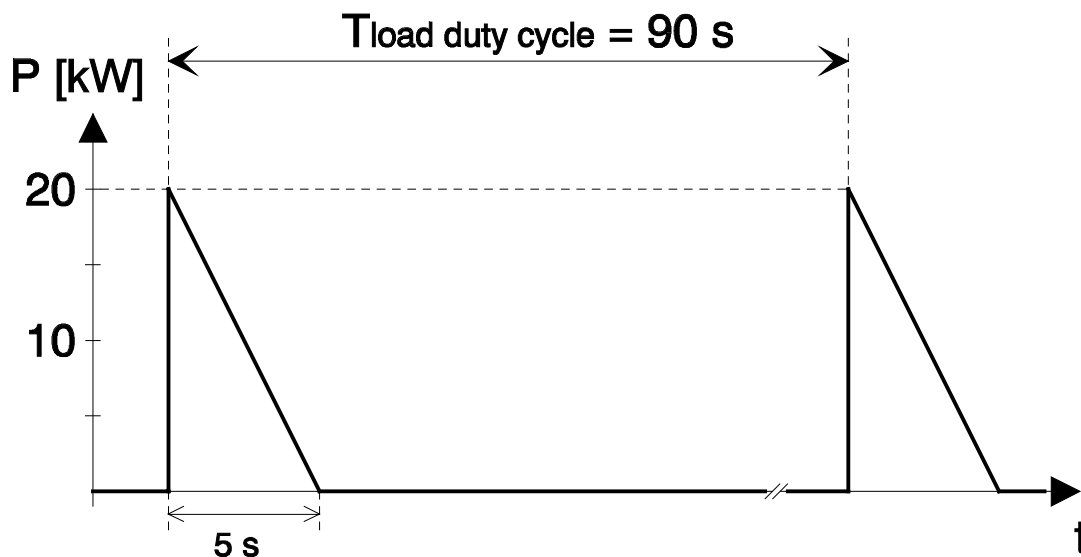
Fig. 3.4.14 Required braking power for example 8

In this case, the average braking power is: 20 kW/2 * 5 s / 90 s ≈ 0.55 kW. The required braking unit must have a 20 s rating P20 of at least 36 * 0.55 = 20 kW. Thus, the following braking unit is required: 6SE7023-2EA87-2DA0 with P20 = 20 kW.

Example 9

For a 400 V supply voltage, a pulsed resistor is required with the load duty cycle requirements illustrated in Fig. 3.4.15. In this case, only the internal load resistor should be used.
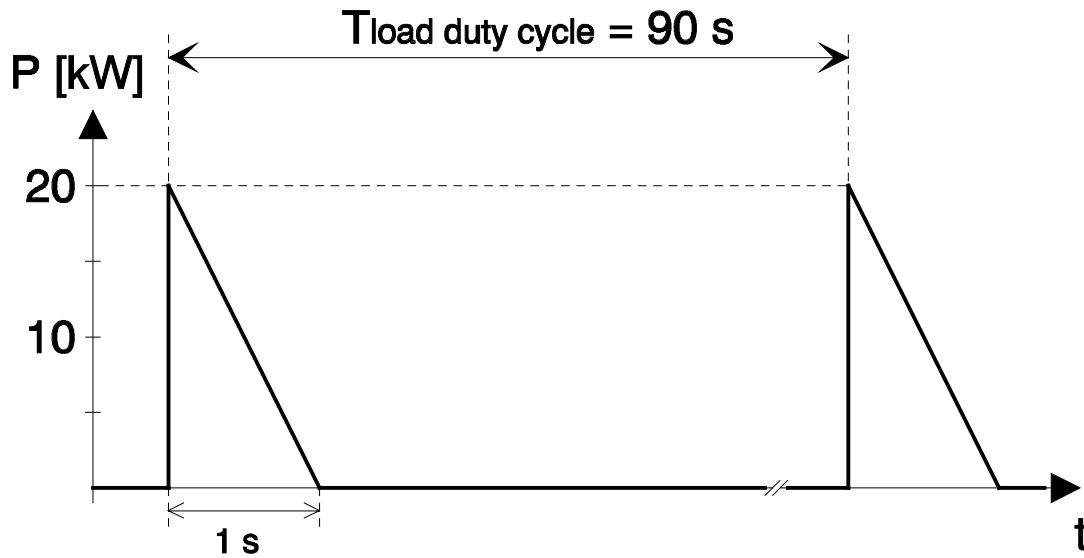
Fig. 3.4.15 Required braking power for example 9

In this case, the average braking power is: 20 kW/2 * 1 s / 90 s $\approx$ 0.11 kW. The required braking unit must have a 20 s rating P20 of at least 36 * 0.11 = 4 kW. Thus, the 20 kW peak power cannot be handled. The following is required:

P20 $\geq$ 0.67 * 20 kW = 13.3 kW. Thus, braking unit 6SE7023-2EA87-2DA0 with P20 = 20 kW.

3.4.3 Regenerative feedback into the line supply using a thyristor bridge

Using the regenerative feedback function with thyristor bridges, the full drive converter power, which is available for motoring, can also be fed back into the line supply. It consists of a bridge which ramps-up the drive converter DC link voltage at power-on, and remains fully controlled. When motoring, the power flows through this bridge. The regenerative feedback bridge is connected in an anti-parallel configuration with this first bridge and is connected through an autotransformer to the line supply. Regenerative feedback is possible in conjunction with the rectifier/regenerative feedback unit (ERE) both for single-motor drives as well as for multi-motor drives with several inverters connected to a common DC bus. Also refer to the information under Section 3.2. Thus, if regenerative feedback is required for a single-motor drive, then an inverter (which can also be connected to a DC bus) should be combined with an associated rectifier/regenerative feedback unit, as shown in Fig. 3.4.16.
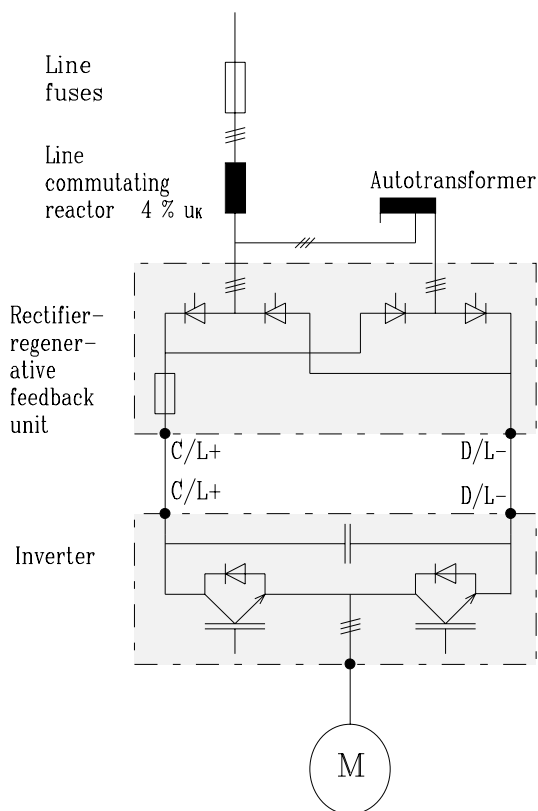
Fig. 3.4.16 A single-motor drive with regenerative feedback consisting of a rectifier/regenerative feedback unit and inverter

Line input fuses, a line commutating reactor and an autotransformer are also required. The autotransformer is used to step-up the input voltage of the regenerative feedback bridge. The rating of the rectifier/regenerative feedback unit is dependent on the inverter output. The same is true for the line input fuses and the line commutating reactor. For the autotransformer, a 25% duty ratio is sufficient, if the average value of the braking power or regenerative power is less than 25% of the rated output when motoring. This should be the case for most applications. An autotransformer with 100% duty ratio normally only has to be used for cases where the regenerative- or generator operation is predominant or is always the operating mode; for example, for motor test stands in the automobile industry or for wind-driven generators.

Please refer to Section 3.2 for additional details on the inverters as well as the rectifier- and rectifier/regenerative feedback units.

Caution! Regenerative feedback using the rectifier/regenerative feedback unit should only be used with stable, reliable supply networks. In regenerative operation, for line supply failures > 2 ms, the inverter can "shoot through" and the fuses can rupture. Thus, for drives which are supplied through a contact system e.g. rail-guided vehicles, contact jumping must be avoided or a redundant supply must be used. If a stable, disturbance-free supply cannot be guaranteed, then the pulsed resistor function should be used as described in Section 3.4.1.2.

3.4.4 Regenerative feedback with active front end

Instead of the line-commutated rectifier/regenerative feedback as mentioned in the previous section, an active front end AFE can be used.

An active front end is an input converter with the following characteristics:
* it is a self-commutated converter with IGBTs,
* supplies sinusoidal line currents with an adjustable cos φ (cos φ = 1 to 0.8 capacitive or inductive) without the typical harmonics for line supplies and therefore low noise is fed back into the line supply,
* it is suitable for both power-flow directions, i.e. motoring and generating,
* it can actively shutdown when the supply fails therefore the inverter does not „shoot through" and the fuses do not rupture when the supply voltage fails in regenerative operation,
* supply undervoltages can be compensated using voltage step-up operation.

The active front end devices are still in the development phase. Precise data and more detailed information are presently not available. The availability dates and a detailed description will be announced.

3.6 Harmonics, 6- and 12-pulse supplies

The subsequent descriptions only refer to low-frequency harmonic voltages and currents up to a maximum of 5 kHz, which converters feed back into the line supply. The high-frequency harmonics which are generally handled under EMC (electromagnetic compatibility) or radio interference suppression are not discussed here. They are handled in Section 7 (being prepared).
Further, the harmonics considered here refer to standard drive converters and systems with rectifier units and rectifier/regenerative feedback units, i.e. when (at least) a three-phase supply is being used through a diode bridge (standard converter and rectifier units) or a fully-controlled thryristor bridge (rectifier/regenerative feedback units). This is not true for drive converters with active front end which can essentially supply sinusoidal line currents. For more detailed information, refer to the previous Section 3.4.4.

3.6.1 6-pulse harmonics

Background and prerequisites

Users of variable-speed drives as well as power supply companies (US: utility companies) are increasingly requiring statements to be made regarding the **harmonic characteristics** of variable-speed drives in order to evaluate the compatibility of the equipment with the line supplies.
The harmonic levels which have to be maintained and the valid regulations/specifications will be discussed in more detail under Section 3.6.3.

For 6-pulse supplies, essentially only uneven harmonic currents and voltages, which are not a multiple of three, occur on the line side with the following harmonic Order Nos.

$$\nu = 5, 7, 11, 13, 17, 19, 23, 25, ...$$

So-called inter-harmonics with other frequencies, whose order numbers differ from these values, do not occur for MASTER DRIVES and need not be taken into account.

The harmonic characteristics of the drive converter are defined by the distortion factor (DF).

Investigations carried-out on MASTER DRIVES drive converters have shown that the amplitudes of the harmonic currents are essentially dependent on the drive converter smoothing elements (line commutating reactors, DC link reactors for regenerative feedback, DC link capacitors). This means, that the subsequently used characteristics to specify the line-side harmonic currents (diagrams 3.6.1 to 3.6.4) are only valid for 6SE70 and 6SE71 drive converters. The characteristics <u>cannot</u> be used to define the harmonics of competitors equipment. This is because, although competitors may apply the same converter principles, under certain circumstances, smaller smoothing elements may be used.

When determining harmonic voltages, it is assumed that there are no parallel resonance effects in the line supply, in the range of the harmonic numbers ν of the harmonics (from $\nu = 5$ to $\nu = 25$). This is always the case if there are **no** non-inductive compensation capacitors available in this line supply.

Caution: if non-choked (non-inductive) capacitors are installed in the line supply for reactive power compensation, then there is a good chance that even at relatively low frequencies, resonance effects will occur, which can be excited by the harmonics generated by the drive converter. Thus, we urgently recommend that non-choked capacitors are <u>not</u> used in conjunction with drive converter loads. In this case, only choked capacitors (inductor-capacitor units) should be used!

The magnitude of the harmonic currents is dependent on the inductance due to the line supply, which is assumed to be sinusoidal (e.g. generator in the power station) up to the drive converter connection point - refer to Fig. 3.6.1.
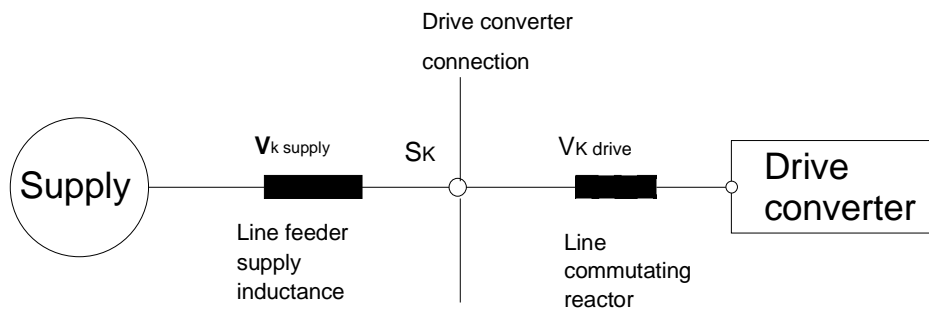
Fig. 3.6.1: Line supply configuration when connecting a drive converter

The lower the line feeder inductances, then the higher the harmonic currents. Either the short-circuit voltage of the line supply feeder inductance or the fault level at the drive converter connecting point S_K is required to specify the line supply characteristics.

The following relationship exists between $u_{K\ supply}$ of the line feeder inductance and the short-circuit rating S_K:

$$S_K = \frac{1}{V_{K\ sup\ ply}} * S_{driveconverter}$$

with $\quad V_{K\ supply}\quad =\quad$ short-circuit voltage of the line feeder cable so that the rated drive converter current flows,

$\quad S_{drive\ converter} = \sqrt{3} * V * I_{drive\ converter}\ =$ rated drive converter apparent output

Thus, the line feeder inductance can be calculated when the fault level at the drive converter connecting point is known.

If a line commutating connector with 2 % u_K or 4 % u_K is used, the reactor inductance plays a significant role in smoothing the line currents and therefore in reducing the line current harmonics. If a line commutating reactor is not to be used, then this is only permissible with an appropriately lower fault level at the supply location. For more detailed information, refer to Section 3.6.3.

The PFAD program can be used to calculate the line-side harmonic currents and voltages. The harmonic currents and voltages as well as the distortion factor are thus calculated for a specified load point, for a known fault level at the feeder location. This is true for both a direct connection to the line supply as well as supply through a (block) transformer.

On the other hand, the line-side harmonic current and voltages can also be calculated using the following calculation sheets and using the normalized characteristics (refer to Figs. 3.6.2 to 3.6.5) depending on the line-supply configuration (short-circuit rating).

The following secondary conditions are used as basis for these characteristics:

For Fig. 3.6.2:

$S_{conv.} / S_K$ = approx. 1 / 22 ... 37   without line commutating reactor   or

$S_{conv.} / S_K$ = approx. 1 / 45 ...55   for a line commutating reactor with 2 % u_K or

$S_{conv.} / S_K$ = approx. 1 / 400 ... > 1000   for a line commutating reactor with 4 % u_K

For Fig. 3.6.3:

$S_{conv.} / S_K$ = approx. 1 / 28 ... 35   without line commutating reactor   or

$S_{conv.} / S_K$ = approx. 1 / 80 ... 120   for a line commutating reactor with 2 % u_K

Comment: These harmonic relationships are still permissible for the nominal operating point ($I_d \approx 1.25 \times I_G$) for chassis- and cabinet units from 45 kW, size E, and higher. Also refer to the information under Section 3.6.3.

For Fig. 3.6.4:

$S_{conv.} / S_K$ = approx. 1 / 40 ...50   without commutating reactor   or

$S_{conv.} / S_K$ = approx. 1 / 500   for a line commutating reactor with 2 % u_K

Comment: These harmonic relationships for the nominal operating point ($I_d \approx 1.25 \times I_G$) are still permissible for compact units up to 37 kW; however, they are not suitable for chassis- and cabinet units above 45 kW. Also refer to the information provided under Section 3.6.3.

For Fig. 3.6.5:

$S_{conv.} / S_K$ = approx. 1 / 80 ...120   without line commutating reactor.

Comment: These harmonic relationships are not permissible at the nominal operating point ($I_d \approx 1.25 \times I_G$) for all units. For this line supply configuration, $S_K > 50 * S_{conv}$, a line commutating reactor is required. Also refer to the information under Section 3.6.3.

We recommend that you contact ASI 1 A V if specific harmonic values have to be maintained, and where the calculation using the calculation sheets shows that the specified limit values have been reached or exceeded.

Calculation procedure

The line harmonic current I_ν/I_n as a function of the DC link current I_{DC}/I_n is illustrated in Figs. 3.6.2 to 3.6.5 (I_n: rated drive converter current).

Starting from the shaft output and the drive frequency, and taking into account the motor-, drive converter- and line data, those quantities are calculated, which are required to read the harmonic currents from diagrams 3-1.1 to 3-1.4. The significance of the quantities used in the characteristics can be taken from the calculation sheet. The efficiencies of the motor and drive converter are still required for the calculation.

The harmonic currents I_ν/I_n read from the characteristics at the nominal operating points I_{DC}/I_n are then entered in Table 3-1 of the calculation sheet. From these values, using the specified formulas, the absolute values of the harmonic currents, the harmonic voltages and the percentage component of the harmonic voltage with respect to the line supply voltage are then calculated.

Further, the **relative harmonic distortion** (distortion factor, D.F.) can be calculated from the sum of the square roots of the individual harmonic voltages:

$$D.F. = \frac{\sqrt{3 \cdot \sum_{n=5}^{n=25} U_\nu^2}}{V_1} \cdot 100 \ [\%]$$

with V_ν = νth order harmonic voltage

   V_1 = basic fundamental of the line supply voltage

The distortion factor (D.F.) is occassionally used by users of variable-speed drives to evaluate whether the drive can be connected to the line supply.

The harmonic currents and voltages as well as the distortion factor can be calculated for **another voltage level** using Table 3-2 of the calculation sheets.

When making the calculation in the calculation sheets, it is assumed that you know the fault level S_{k1} at the drive converter connection point. However, if you do not know this value, but fault level S_{k2} of a higher voltage level as well as the transformer data which couples both voltage levels, then the fault level S_{k1} can be calculated as follows:

$$S_{K1} = \frac{S_T}{u_k + \dfrac{S_T}{S_{k2}}}$$

with S_T = transformer rating

   u_k = per unit short-circuit rating of the transformer

   S_{k2} = fault level of the higher voltage level
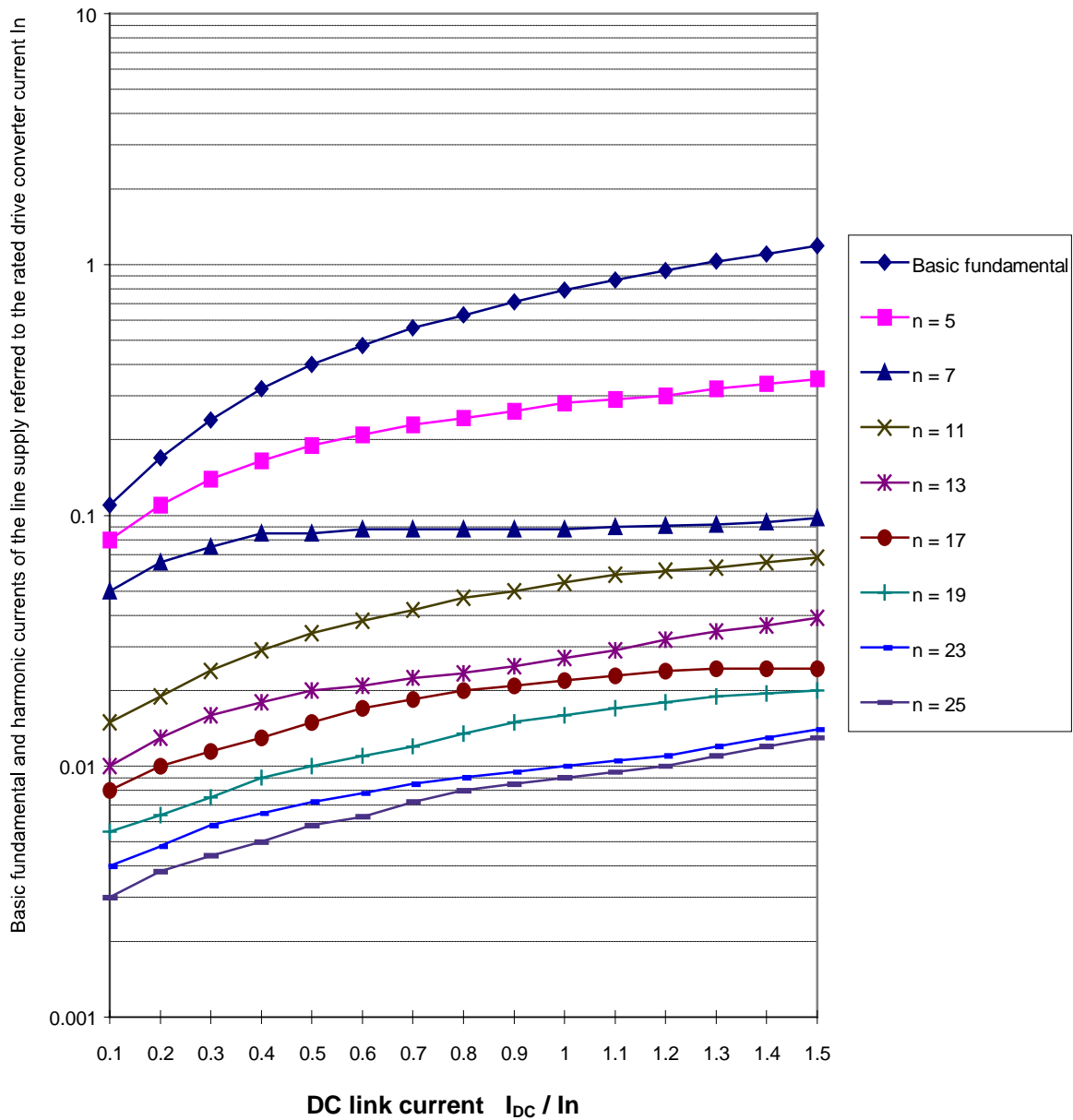
Fig. 3.6.2: Line harmonic current I_v/I_n as a function of the DC link current I_{DC}/I_n

I_n: Rated drive converter current

Secondary condition:
$S_{conv.} / S_K$ = approx. 1 / 22 ... 27   without line commutating reactor   or
$S_{conv.} / S_K$ = approx. 1 / 45 ... 55   for a line commutating reactor with 2 % u_K or
$S_{conv.} / S_K$ = approx. 1 / 400 ... > 1000   for a line commutating reactor with 4 % u_K
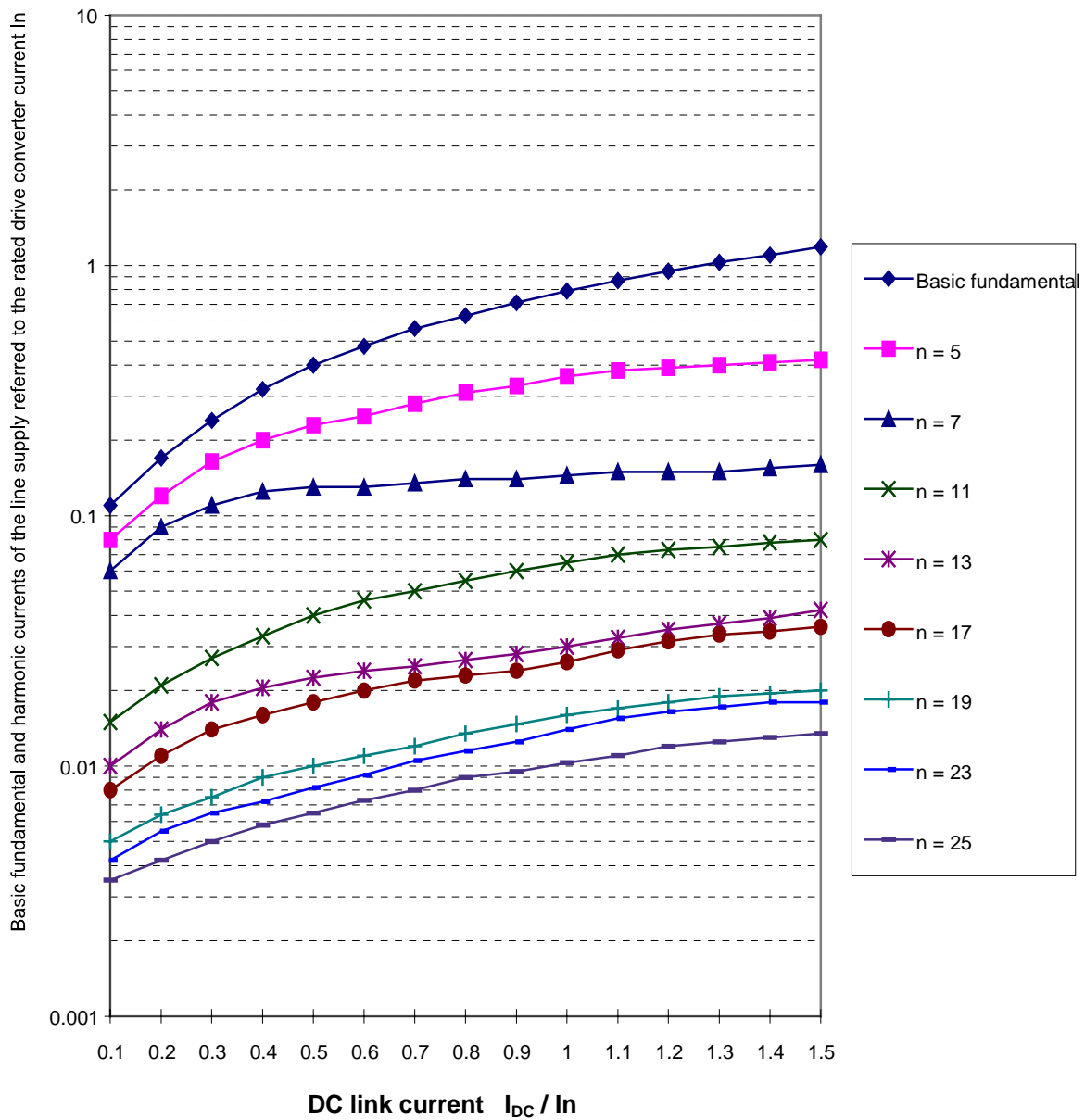
Fig. 3.6.3: Line harmonic current I_v/I_n as a function of the DC link current I_{DC}/I_n

I_n: Rated drive converter current

Secondary condition:

$S_{conv.} / S_K$ = approx. 1 / 28 ... 35   without line commutating reactor   or

$S_{conv.} / S_K$ = approx. 1 / 80 ... 120   for a line commutating reactor with 2 % u_K
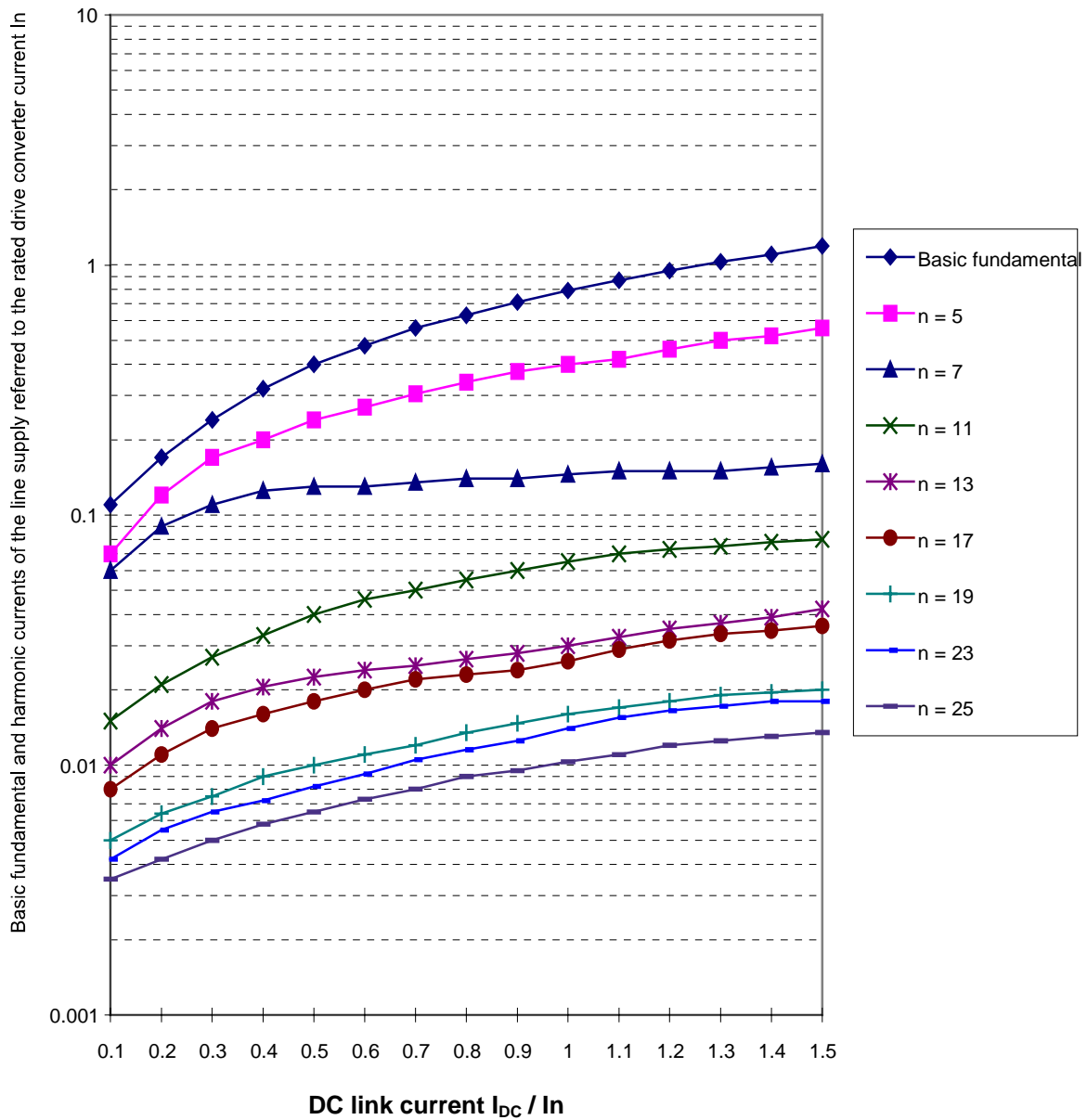
Fig. 3.6.4: Line harmonic current I_v/I_n as a function of the DC link current I_{DC}/I_n

I_n: Rated drive converter current

Secondary condition:

$S_{conv.} / S_K$ = approx. 1 / 40 ...50   without line commutating reactor   or

$S_{conv.} / S_K$ = approx. 1 / 500   for a line commutating reactor with 2 % u_K
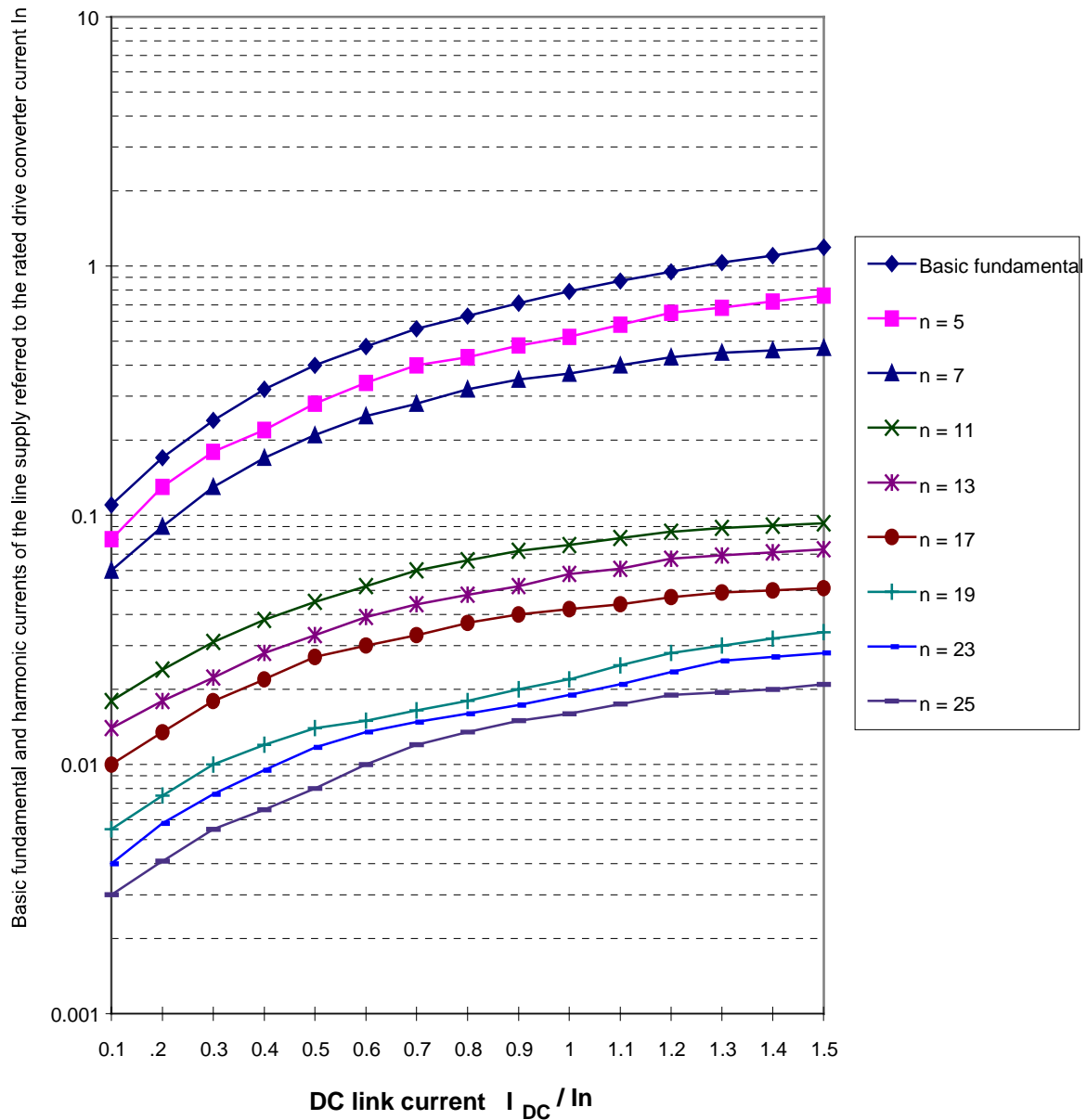
Fig. 3.6.5: Line harmonic current I_v/I_n as a function of the DC link current I_{DC}/I_n

I_n: Rated drive converter current

Secondary condition:
$S_{conv.} / S_K$ = approx. 1 / 80 ...120   without line commutating reactor.

Calculation sheets

Line-side current- and voltage harmonics for SIMOVERT P drives

Motor

Motor Order No.: 1LA_____

Shaft output at the nominal operating point P_N = _____ kW
at f_N = _____ Hz
Motor frequency at the nominal operating point f = _____ Hz

Shaft output of the motor at the nominal operating point:
$P_N \cdot f/f_N$ for constant-torque drives
$P_N \cdot (f/f_N)^3$ for fans and pumps P_W =_____kW

Motor efficiency at the operating point: η_M =_____

Drive converter

Drive converter Order No.: 6S_____

Rated supply voltage: U_{N1} =_____V

Rated drive converter current: I_n =_____ A

Efficiency of the drive converter at the
nominal operating point: η_U =_____

DC link voltage:
V_d = 1.35 x V_{N1} = 1.35 x _____ V U_d =_____ V

DC link current at the nominal operating point:
$$I_{DC} = \frac{P_W \times 10^3}{V_d \cdot \eta_M \cdot \eta_U} = \underline{\hspace{1cm}} \times 10^3 / (\underline{\hspace{1cm}} \times \underline{\hspace{1cm}} \times \underline{\hspace{1cm}}) =$$

I_{DC} =_____ A

Per unit operating point:
I_{DC}/I_n = _____ / _____ I_{DC}/I_n = _____

Line supply

Supply voltage of the
transformer secondary: U_{NT} = _____ V

Supply fault level at
the transformer connecting point: S_{K1} = _____ MVA

Line reactance referred to V_{NT}:
$$X_{N1} = \frac{V^2_{NT}}{S_{K1} \cdot 10^6} = (\underline{\hspace{1cm}})^2 / (\underline{\hspace{1cm}} \times 10^6) \qquad X_{N1} = \underline{\hspace{1cm}} \Omega$$
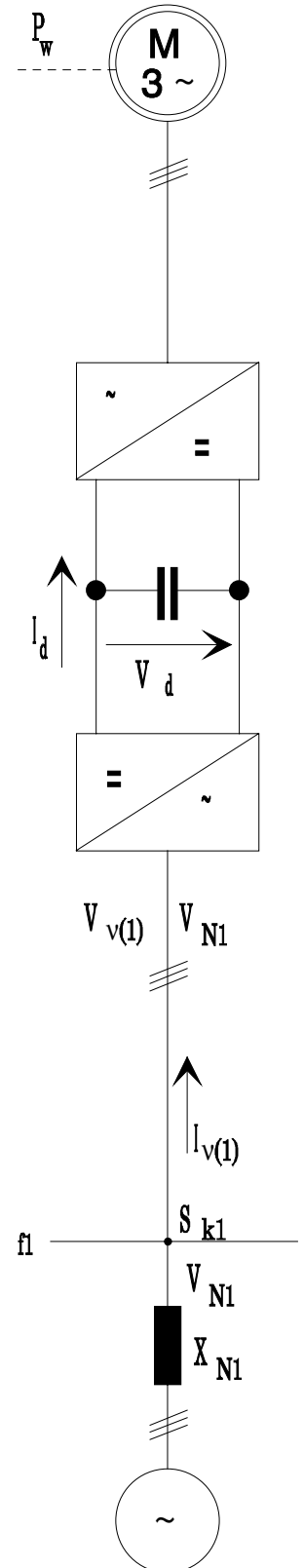
Harmonic Order No. ν	Harmonic current I_n referred to I_ν / I_n	Harmonic current $I_{\nu(1)} = I_n \times I_\nu / I_n$	Harmonic voltage $V_{\nu(1)} = \nu \times X_{N1} \times I_{\nu(1)}$	$V^2_{\nu(1)}$	Percentage component of the harmonic voltage at V_{N1} $u_{\nu(1)} = V_{\nu(1)} \times \sqrt{3} \times 100 / V_{N1}$
5		A	V	V^2	%
7		A	V	V^2	%
11		A	V	V^2	%
13		A	V	V^2	%
17		A	V	V^2	%
19		A	V	V^2	%
23		A	V	V^2	%
25		A	V	V^2	%

Table 3.6.1: νth order harmonic currents and voltage,

- **Distortion factor**: $\qquad$ $V^2_{\nu(1)} =$ _____ V^2

$$D.F. = \frac{\sqrt{3 \cdot \sum_{\nu=5}^{\nu=25} V^2_{\nu(1)}}}{V_{N1}} \cdot 100 \; [\%] = (\sqrt{3} \times 100 \times \underline{\qquad}) / \underline{\qquad} = \underline{\qquad} \%$$

- **νth order harmonic currents and voltages, at voltage level V_{N2}**

Supply voltage of the
higher-level voltage: $\qquad V_{N2} =$ _____ V

Fault level: $\qquad S_T =$ _____ MVA

Short-circuit rating: $\qquad u_k =$ _____

Ratio:

$\ddot{u} = V_{N2} / V_{NT} =$ _____ / _____ $\Rightarrow \quad \ddot{u} =$ _____

Fault level of the supply at voltage level V_{N2}:

$$S_{K2} = \frac{S_T \cdot S_{K1}}{S_T - (u_k \cdot S_{K1})} =$$

_____ x _____ / (_____ - _____ x _____)

$\Rightarrow \quad S_{K2} =$ _____ MVA

Line reactance referred to V_{N2}:

$$X_{N2} = \frac{V^2_{N2}}{S_{K2} \cdot 10^6} = (\underline{\qquad})^2 / (\underline{\qquad} \times 10^6)$$

$\Rightarrow \quad X_{N2}$ _____ Ω
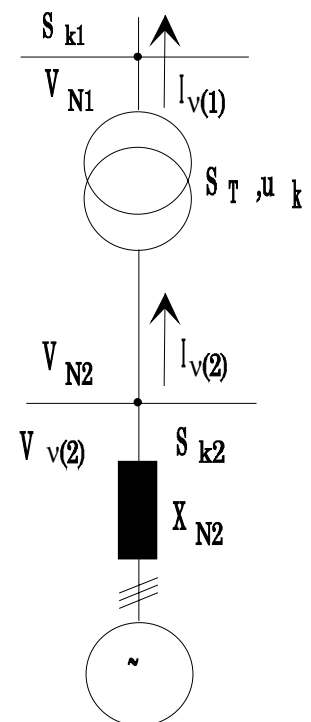
Order No. of the harmonics ν	Harmonic current $I_{\nu(2)} = I_{\nu(1)} / ü$	Harmonic voltage $V_{\nu(2)} = \nu$ x X_{N2} x $I_{\nu(2)}$	$V^2_{\nu(2)}$	Percentage component of the harmonic voltage at V_{N1} $u_{\nu(2)} = U_{\nu(2)}$ x $\sqrt{3}$ x 100 / U_{N2}
5	A	V	V^2	%
7	A	V	V^2	%
11	A	V	V^2	%
13	A	V	V^2	%
17	A	V	V^2	%
19	A	V	V^2	%
23	A	V	V^2	%
25	A	V	V^2	%

Table 3-2: **Relative harmonic distortion**

- **Distortion factor**: $\Rightarrow$ $V^2_{\nu(2)} = \underline{\qquad} \; V^2$

$$D.F. = \frac{\sqrt{3 \cdot \sum_{\nu=5}^{\nu=25} V^2_{\nu(2)}}}{V_{N2}} \cdot 100 \; [\%] = (\sqrt{3} \text{ x } 100 \text{ x } \underline{\qquad}) / \underline{\qquad} = \underline{\qquad} \%$$

$$D.F. = \underline{\qquad} \%$$

Calculation sheet - example

Line-side current- and voltage harmonics for SIMOVERT P drives

Motor

Motor Order No.:	1LA **6223-6**.......with **30 kW**
Shaft output at the operating point	P_N = **26** kW **F, contr.range 1:3**
at	f_N = **50** Hz
Motor frequency at the operating point:	f = **45** Hz

Shaft output of the motor at the operating point:

$P_N \cdot f/f_N$ for constant torque drives **26·45/50** kW

$P_N \cdot (f/f_N)^3$ for fans and pumps P_W = **23.4** kW

Motor efficiency at the operating point: η_M = **0.916** **(Sec. 4.5)**
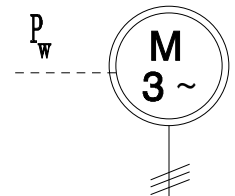
Drive converter

Drive converter Order No.:	**6SE7026-0ED.0**
Rated supply voltage:	V_{N1} = **400** V
Rated drive converter current:	I_n = **59** A
Drive converter efficiency at the op. point:	η_U = **0.98 (Section 4.6)**

DC link voltage:

V_d = 1.35 x V_{N1} = 1.35 x **400** V $\Rightarrow$ V_d = **540** V

DC link current at the operating point:

$$I_{DC} = \frac{P_W \times 10^3}{V_d \cdot \eta_M \cdot \eta_U} = \quad \textbf{23.4} \times 10^3 / (\textbf{540} \times \textbf{0.916} \times \textbf{0.98}) =$$

$\Rightarrow$ I_{DC} = **48** A

Per unit operating point:

I_{DC} / I_n = _**48**/ **59** $\Rightarrow$ I_{DC} / I_n = **0.81**

Line supply

Supply voltage of the
transformer secondary: V_{NT} = **400** V

Fault level of the supply at
the transformer connecting point: S_{K1} = **4** MVA

Line reactance referred to V_{NT}:

$$X_{N1} = \frac{V^2_{NT}}{S_{K1} \cdot 10^6} = (\textbf{400})^2 / (\textbf{4} \times 10^6) \qquad \Rightarrow \qquad X_{N1} = \textbf{40} \text{ m}\Omega$$

With $S_{K1}/S_{conv.} \approx 100 / 1$ a line commutating reactor of 2% uK is used thus the following is obtained acc. to Fig. 3-1.2 3-1.2 $\Rightarrow$ $\Rightarrow$ $\Rightarrow$
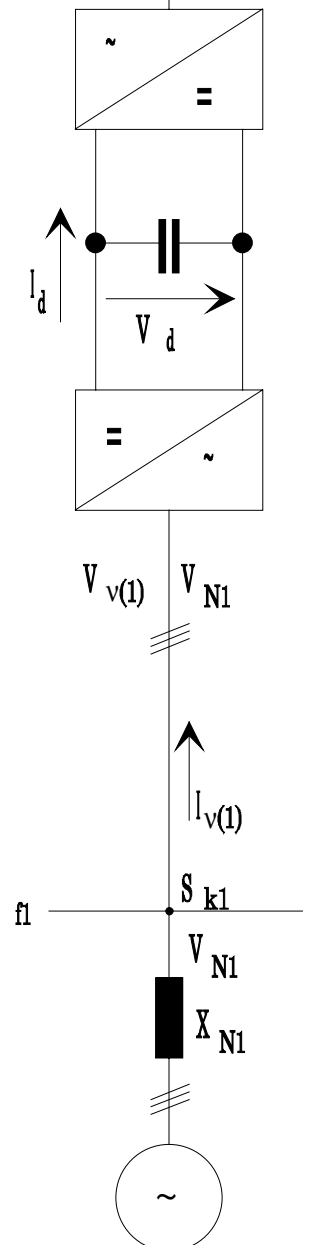
Harmonic Order No. ν	Harmonic current I_G referred to I_ν / I_n	Harmonic current $I_{\nu(1)} = I_n \times I_\nu / I_n$	Harmonic voltage $V_{\nu(1)} = \nu \times X_{N1} \times I_{\nu(1)}$	$V^2_{\nu(1)}$	Percentage component of the harmonic voltage at V_{N1} $u_{\nu(1)} = V_{\nu(1)} \times \sqrt{3} \times 100 / V_{N1}$
5	**0.31**	**18.3 A**	**3.66 V**	**13.4 V^2**	**1.58 %**
7	**0.14**	**8.26 A**	**2.31 V**	**5.35 V^2**	**1.00 %**
11	**0.055**	**3.25 A**	**1.43 V**	**2.04 V^2**	**0.62 %**
13	**0.0265**	**1.56 A**	**0.81 V**	**0.66 V^2**	**0.35 %**
17	**0.023**	**1.36 A**	**0.92 V**	**0.86 V^2**	**0.40 %**
19	**0.0135**	**0.80 A**	**0.61 V**	**0.37 V^2**	**0.26 %**
23	**0.0115**	**0.68 A**	**0.63 V**	**0.39 V^2**	**0.27 %**
25	**0.009**	**0.53 A**	**0.53 V**	**0.28 V^2**	**0.23 %**

Table 3-1: νth order harmonic currents and voltage

- **Distortion factor** $\Rightarrow$ $V^2_{\nu(1)} =$ **23.35** V^2

$$D.F. = \frac{\sqrt{3 \cdot \sum_{\nu=5}^{\nu=25} V^2_{\nu(1)}}}{V_{N1}} \cdot 100 \; [\%] = (\sqrt{3} \times 100 \times \mathbf{4.83}) / \mathbf{400} = \quad \mathbf{2.1} \%$$

- **νth order harmonic currents and voltages at voltage level V_{N2}**

Supply voltage of the higher-level voltage: $V_{N2} =$ **6000** V

Transformer rating: $S_T =$ **250** kVA

Fault level: $u_K =$ **0.06**

Ratio

$\ddot{u} = V_{N2} / V_{NT} =$ **6000** /**400** ➡ $\ddot{u} =$ **15**

Fault level of the supply at voltage level V_{N2}:

$$S_{K2} = \frac{S_T \cdot S_{K1}}{S_T - (u_k \cdot S_{K1})} = \mathbf{0.25} \times \mathbf{4} / (\mathbf{0.25} - \mathbf{0.06} \times \mathbf{4})$$

$$\Rightarrow \quad S_{K2} = \mathbf{100} \text{ MVA}$$

Line reactance referred to V_{N2}:

$$X_{N2} = \frac{V^2_{N2}}{S_{K2} \cdot 10^6} = (\mathbf{6000})^2 / (\mathbf{100} \times 10^6)$$

$$\Rightarrow \quad X_{N2} = \mathbf{0.36} \; \Omega$$

Harmonic Order No. ν	Harmonic current $I_{\nu(2)}$ $= I_{\nu(1)}/\ddot{u}$	Harmonic voltage $U_{\nu(2)} = \nu$ $\times X_{N2} \times I_{\nu(2)}$	$U^2{}_{\nu(2)}$	Percentage component of the harmonic voltage at V_{N1} $u_{\nu(2)} = V_{\nu(2)} \times \sqrt{3} \times 100 / V_{N2}$
5	**1.22 A**	**2.2 V**	**4.84 V²**	**0.063 %**
7	**0.55 A**	**1.39 V**	**1.92 V²**	**0.040 %**
11	**0.217 A**	**0.86 V**	**0.74 V²**	**0.025 %**
13	**0.104 A**	**0.49 V**	**38.4 V²**	**0.014 %**
17	**0.091 A**	**0.41 V**	**0.24 V²**	**0.012 %**
19	**0.053 A**	**0.36 V**	**0.13 V²**	**0.010 %**
23	**0.045 A**	**0.37 V**	**0.14 V²**	**0.011 %**
25	**0.035 A**	**0.315 V**	**0.10 V²**	**0.009 %**

Table 3-2: **Harmonic distortion**

- **Distortion factor**   :   ➡ $V^2{}_{\nu(2)}$ = **8.49** V²

$$D.F. = \frac{\sqrt{3 \cdot \sum_{\nu=5}^{\nu=25} V_{\nu(2)}^2}}{V_{N2}} \cdot 100 \; [\%] = (\sqrt{3} \times 100 \times \mathbf{2.91}) / \mathbf{6000} = \mathbf{0.084} \%$$

$$D.F. = \mathbf{0.084} \%$$

3.6.2 12-pulse harmonics

If the harmonics are to be significantly reduced for large variable-speed AC drives, this can be effectively achieved by using circuit configurations with higher pulse numbers. A **12-pulse drive converter circuit has significantly lower harmonics** than a 6-pulse design (refer to Fig. 3.6.6). This requires two 3-phase line supplies with a 30° electrical shift between them. A 2 x three-phase AC system can be achieved from a three-phase system by using, for example, a three-winding transformer. One of the windings on the drive converter side (= secondary side) is connected in a star circuit configuration and the other in a delta-circuit configuration. Dy5Dd0 and Dy11Dd0 are the usual vector groups used. When both of the secondary windings are equally loaded, 12-pulse harmonics are generated at the primary. The basic fundamental of the phase current improves as the low-frequency harmonics, 5th and 7th order are significantly reduced (refer to Fig. 3.6.7).

6-pulse harmonic currents
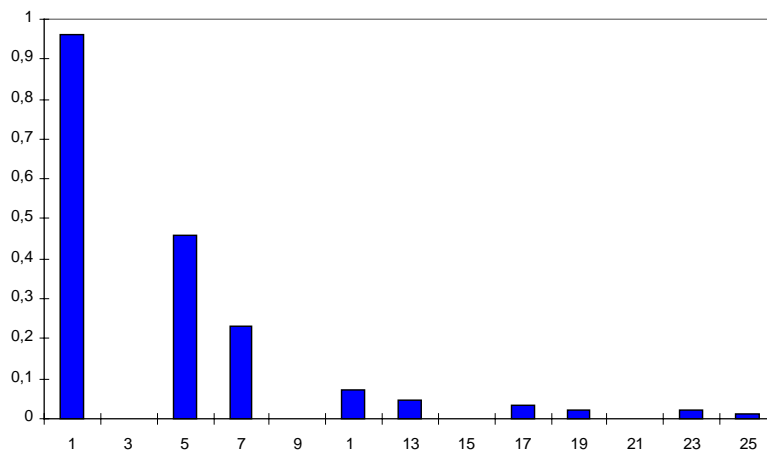
12-pulse harmonic currents
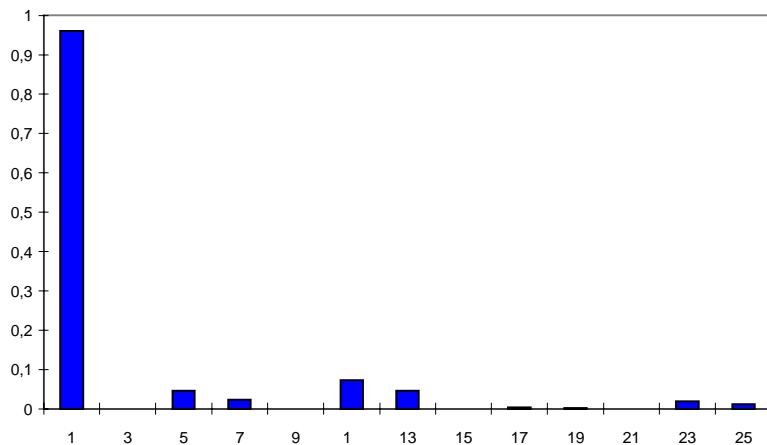
Fig. 3.6.6: Comparison of the line-harmonic currents for a 6-pulse and 12-pulse drive converter input circuit at the rated drive output

Principle of the 12-pulse supply

Three-winding transformer
e.g. Dy5Dd0

Incoming rectifier

Voltage DC link

Inverter

INV

AC motor

M
3 ~
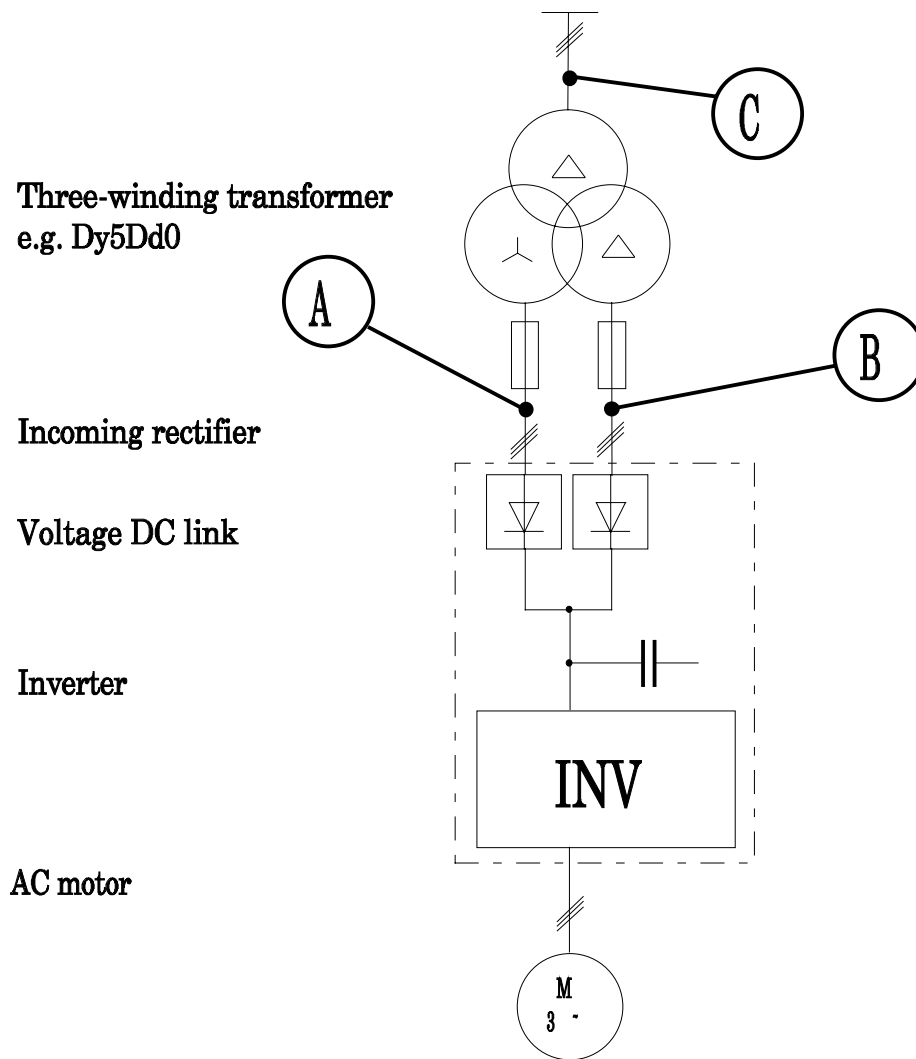
Idealized current characteristics
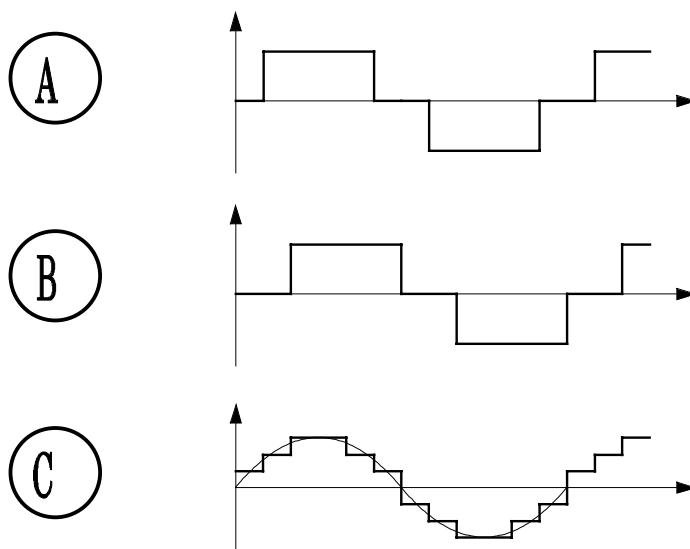
Fig. 3.6.7: Idealized current characteristics for a 12-pulse supply

From a pure theoretical standpoint, harmonics, orders 5, 7, 17, 19, 23, 25 etc. are completely compensated at the primary of the drive converter transformer as a result of the 12-pulse supply. However, in practice, low components of these harmonics are still present due to the slight but unequal load distribution in the two input converters. This is as a result of tolerances in the components and the transformer. However, it has been shown that it can be assumed that the values are approximately 10% of those of a 6-pulse supply and that with adequate accuracy.

If there is a 12-pulse supply, then only the relationships on the line side, i.e. at the transformer primary, are of interest. To calculate the harmonics fed back into the line supply, you can proceed as specified in the previous section, Section 3.6.1:

$\Rightarrow$ The harmonic currents are determined for the particular load using Figs. 3.6.2 to 3.6.5. (These currents have a 50% amplitude at the drive converter side and therefore in the transformer secondary windings).

$\Rightarrow$ The harmonic currents, orders 11, 13, 23, 25 are used, unchanged; only 10% of the, harmonic currents, Orders 5, 7, 17, 19 are taken and are used to calculate the harmonic currents and voltages as well as the distortion factor at the transformer primary.

Note: The motor still only has a **three-phase supply** also for 12-pulse rectifier circuits. Thus, only motors with three winding phases can be used with SIMOVERT P drive converters. Reason: The torque ripple <u>cannot</u> be further reduced using two three-phase windings as for SIMOVERT A. The „12-pulse circuit" term when used in conjunction with SIMOVERT P refers exclusively to the line supply side!

Implementing the 12-pulse supply

A 12-pulse supply is not possible with converter units, as these only have a 6-pulse input rectifier. Instead of this, **also for single-motor drives**, inverters must be used. They are supplied with the necessary DC link voltage via two rectifier/regenerative feedback units. These rectifier- or rectifier/regenerative feedback units must be connected at both secondary windings of the drive converter transformer, Fig. 3.6.8.
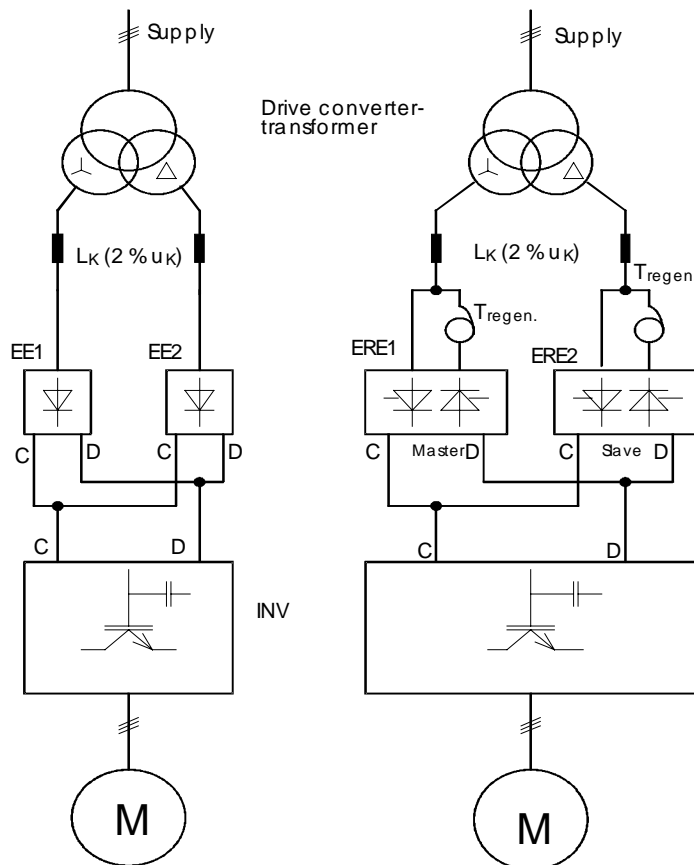
Fig. 3.6.8: *12-pulse supply with rectifier units EE (left) and rectifier/regenerative feedback units E/R-E for a single-motor drive (right).*

For 12-pulse operation, the two drive converter input systems must be connected through a three-winding drive converter transformer. This transformer, which supplies 2 three-phase systems displaced through 30° electrical, must be additionally ordered.

Normally, line commutating reactors L_K with 2 % u_K are required for uniform load distribution in the two incoming branches. A line commutating reactor is not required if a double-tier transformer is used as drive converter transformer with a rating which is adapted to the drive converter output, and which has a minimum u_K of 6%.

When ERE (rectifier/regenerative feedback units) are used, autotransformers T_{regen} are required, which are used to step-up the input voltage by 20% for the ERE regenerative bridge. These autotransformers are not required if the drive converter transformer output windings have additional winding taps, with a 20% higher output voltage. For example, when the drive converter is connected to a 400 V supply, the

drive converter transformer output windings must have an additional winding tap for
1.2 x 400 V = 480 V. The drive converter transformer is in this case somewhat more expensive.

Comment:

If the 12-pulse supply is realized using rectifier/regenerative feedback units, then these operate in master-slave operation. Communications between the two rectifier/regenerative feedback units is established via a connecting cable and an interface adapter which must be additionally ordered under the following Order No.:
6SE70-0XX85-1TA : (= cable + 2 x (CUR- and SST adapter).
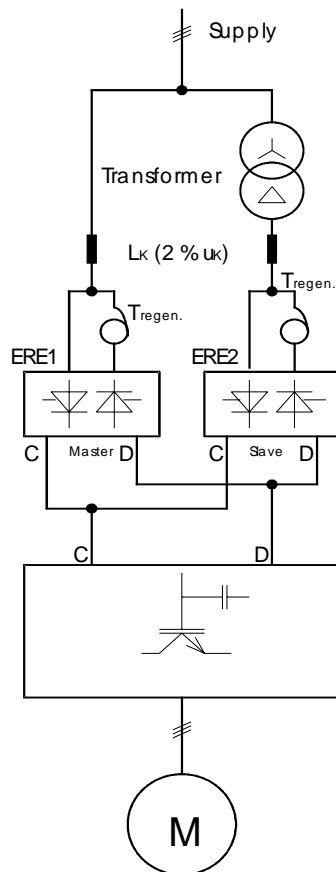
A more favorably-priced solution is possible if the rectifier/regenerative feedback units have a 12-pulse connection to the existing low-voltage supply. In this case, only a basic transformer with half the total rating is required for a partial system, as illustrated in Fig. 3.6.9. In this case, the current controllers of the two input bridges ERE1 and ERE2 are used to ensure equal load- and current distribution.

Fig. 3.6.9: 12-pulse supply with rectifier/regenerative feedback units ERE for a single-motor drive when connected to a low-voltage supply network

When using **rectifier units EE with low outputs up to size E,** a 12-pulse supply **must always be realized using a three-winding drive converter transformer.** This is also the case, if, for the connection to the low-voltage supply, a voltage ratio of 1:1 is required.
The power cable from the drive converter transformer to the two rectifier units EE must have the same cross-section and same length, so that the best possible load equalization is obtained.
As far as the two secondary windings of the converter transformer are concerned, they should be as symmetrical as possible. It is extremely important that the no-load voltages of these two secondary windings do not differ by more than 0.5%. To obtain uniform current distribution line commutating reactors with 2 % u_K are absolutely necessary.

3.6.3 Guidelines for deciding which harmonics fed back into the line supply are permissible and which are not

Which line supply harmonics are admissible and which are not? What measures are required in order to reduce possible harmonics fed back in to the supply?

- in this case, a differentiation should be made between the effects on the drive converter itself, i.e. for which harmonics is operation of the drive converter itself, in danger, and
- effects on other loads which are connected to the same supply.

3.6.3.1 Permissible harmonics and harmonic currents to protect a drive converter or an inverter connected to a common DC link

As described under Section 3.6.1, harmonic currents increase as the total feeder inductance decreases including a possibly existing line commutating reactor. If the harmonic currents exceed specific values relative to the (basic fundamental) rated current, the input rectifier (including fuses!) as well as the DC link capacitors of the drive converter or inverter could be thermally overloaded.
The drive converter and rectifier units are designed so that they can be connected to a supply using line commutating reactors with 2% u_k without any danger

- 500 x fault level S_k (in comparison to the drive converter output) for compact units up to 37 kW (sizes A to D),
- 100 x fault level S_k (in comparison to the drive converter output) for chassis- and cabinet units from 45 kW onwards (from size E).

To illustrate this, the relationships will now be investigated in more detail using the following Fig. 3.6.10.
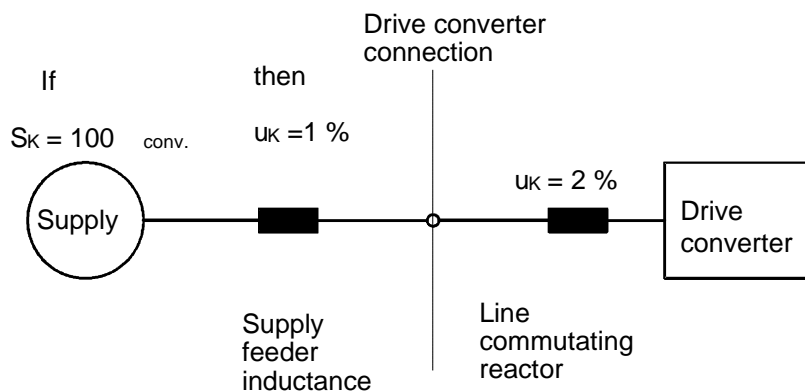
Fig. 3.6.10: Line supply configuration for a fault level 100 x rated drive converter output

Thus, the line feeder inductance, for a supply fault level of 100 x rated drive converter output, has a relative short-circuit voltage of $u_k = S_{conv.}/S_k = 1/100 = 1\%$,
referred to the rated output or the rated impedance of drive converter $S_{conv.}$

with $S_{conv.} = \sqrt{3} * V_{supply} * I_{conv.}$

The harmonic currents are limited by the total inductance comprising the line commutating reactor and the line feeder inductance. If you wish to eliminate a line commutating reactor for the higher-rating units (chassis- and cabinet units from 45 kW), then the line feeder inductance must be appropriately higher, i.e. its relative short-circuit voltage must have a value of at least 3 % u_k. This is the same as the requirement that the supply fault level is less than the 33 x rated drive converter output. The same is true for compact units for outputs up to 37 kW.

The question as to whether a line commutating reactor is required **to protect the drive converter** and if yes, which one, can be answered depending on the fault level using the following table:

Compact units up to 37 kW	Chassis- and cabinet units above 45 kW	
$S_{k\,supply} / S_{conv.} =$	$S_{k\,supply} / S_{conv.} =$	
≤ 45	≤ 33	Line commutating reactor <u>not</u> required
$> 45 ... 500$	$> 33 ... 100$	Line commutating reactor with 2 % u_k required
> 500	> 100	Line commutating reactor with 4 % u_k required

For $S_{conv.}$ the following should be inserted:
- the rated drive converter output when connecting a single unit to the supply,
- the sum of the rated drive converter outputs when several individual drive converters are connected to the same supply under the prerequisite that they are powered-up and as an average are operated with a minimum of 50% of their rated output,
- the rated output of the rectifier unit(s) if one (or several) multi-motor drives with common DC link are used.

If one or several drive converters are fed through a transformer, then the relevant supply fault level $S_{k\,supply}$ at the transformer secondary is given by:

$$S_{k\,\text{sup}\,ply} = \frac{S_{transformer}}{u_{k\,transformer} + \dfrac{S_{transformer}}{S_{k\,HV}}}$$

whereby
$S_{transformer}$ = transformer rating

$u_{k\,transformer}$ = transformer short-circuit voltage as an absolute value, e.g. 0.06 at 6%

$S_{k\,HV}$ = fault level at the transformer primary

In practice, you can proceed as follows:
- If you do not know the line configuration for the individual drive converters, i.e. the supply fault level at the drive converter connection point, it is always recommended to connect a line commutating reactor in front of the drive converters. Generally, a 2 % u_k reactor is sufficient.
- If several individual drive converters were planned for a specific system, which would have required separate line commutating reactors (as well as switchgear/switching devices, contactors, fuses, ...), then it could be more favorable from a cost and space standpoint to use inverters which are then connected to a common DC link. In this case, only one line commutating reactor is required (with the associated switchgear).

3.6.3.2 Permissible harmonics and harmonic currents as far as other loads which are connected to the same supply

In this case, „other loads" are loads which require, as far as possible, a sinusoidal supply, for example, motors which are directly connected to the supply. Such loads can be disturbed by harmonics generated by drive converters. For instance, this can result in significant supplementary motor losses due to inadmissibly high line harmonic voltages. The harmonics must therefore be limited to permissible values. This can be realized by using

- a suitable line commutating reactor,
- a 12-pulse supply,
- special filter circuits for extreme cases
  (also refer to Catalog K, Order No. E50001-K1600-A111-A19).

Comment: If individual drive converters or several converters are exclusively fed through a block transformer having approximately the same rating, and there are no other loads, then the harmonic voltages **at the low-voltage side** of the transformer are of no significance. The permissible harmonics must then be maintained at the **transformer primary**.

Which Directives are valid for the various permissible harmonics? Although increasing harmonization can be seen within Europe, the regulations still differ from country to country. Thus, the regulations for the following countries

Germany,   USA/Canada,   England

will be discussed but not in considerable detail.

Germany

Here, the following regulations should be observed:

DIN VDE 0160

These regulations are valid for „erecting power equipment with electronic devices". It refers to operating drive converters from **industrial supply networks**, and is considered to be generally binding when using all types of drive converters in Germany.
Note: Presently, attempts are being made to replace this by a Euro Standard (pr EN 50178).

As far as low-frequency harmonics are concerned, the following is defined in DIN VDE 0160:

Commutating dips:

The instantaneous deviation of the line AC voltage from the instantaneous fundamental, caused by commutating dips, may only be a maximum of 20% of the peak value of the basic fundamental.
For MASTER DRIVES drive converters, it can be assumed that the line supply voltage is either rectified using a diode bridge or a thyristor bridge which, at least in motor operation (rectifier operation) is fully controlled, and thus behaves like a diode bridge. In this case, the commutation (if „overlapping commutation" is actually present), always takes place close to the natural firing instant (at $\alpha \approx 0°$). A commutating voltage dip of ≥ 20 % of the peak supply voltage can in this case be practically excluded. (commutating voltage dips such as these are typical for fully-controlled thyristor bridges with firing angles close to $\alpha \approx 90°$). VDE 0160 does not specify any special measures for this requirement, and therefore a line commutating reactor is not required.

Permissible harmonic voltages:

The basic harmonic content must be at least 99.5 %, i.e. the harmonic content as

$$D \cdot F \cdot = \frac{1}{V_1} * \sqrt{\sum_{v \geq 5} \left(V_v \right)^2}$$

(also designated as distortion factor D.F.) may be a maximum of 10 % of the basic fundamental, referred to all harmonics which occur. Further, the harmonic voltages up to the 25th harmonic may not exceed the values specified in the following table. In this case, it should be taken into account that the specified level may not be exceeded when **all** of the connected drive converters are in operation. If several drive converters are connected to a supply, then their component harmonic voltages must be added!

Order No. n	5	7	11	13	17	19	23	25
Maximum permissible harmonic voltages	5 %	5 %	5 %	5 %	4,5 %	4 %	3,5 %	3,2 %

Table 3.6.3.1: Permissible voltage harmonics in accordance with DIN VDE 0160

If these harmonic voltages were to actually have this magnitude, then up to the 25th harmonic, a distortion factor of 12.6 % would be obtained.

We have made no comment about the magnitude of the harmonic currents; they can be calculated from the line inductance and the harmonic voltages.

The permissible harmonic voltages are relatively high and the required values are generally maintained, if a line commutating reactor is provided in accordance with the criteria specified in Section 3.6.3.1. The harmonic calculation in accordance with Section 3.6.3.1 or 3.6.3.2 or the PFAD EDP program can be used to determine whether the permissible values are maintained.

General comments to the remaining specifications in DIN VDE 0160

DIN VDE 0160 assumes (which should also be considered as recommendation wherever possible), that the total drive converter rating is a maximum of 1% of the fault level at the connection point with a view to other loads. From experience, a line commutating reactor of 2 % u_k or 4% u_k, is adequate to ensure that the specified level is not exceeded and other loads are not inadmissibly influenced.

In practice, what does this actually mean - $S_{fault\ level} > 100 * S_{drive\ converter}$? If one assumes that the supply is generally realized through a transformer from the medium- or high voltage line supply, then the actual fault level at the drive converter connection point is given by:

$$S_K \approx 15 ... 25 * S_{transformer} , \qquad if \qquad u_{k\ transformer} = 4 ... 6 \%.$$

Thus, the recommended maximum drive converter load is:

$$S_{conv.} < 0.15 ... 0.25 * S_{transformer} ,$$

i.e. the connected drive converter load should only be 15 to 25% of the total available supply power, the remaining line load should consist of „linear" loads such as motors which do not cause any harmonics.

On the other hand, if the supply load essentially consists of drive converters and the remaining linear loads are in comparison neglible (e.g. < 20%), then, even if line commutating reactors are provided, significant voltage harmonics occur with a d.f. > 10%. From experience these can disturb other loads, e.g. PLCs. Under these conditions, harmonics can only be reduced to acceptable values using interphase transformer circuits, which are generally expensive and complicated. For cases such as these, it would be better to use separate transformers for the supplies, a (higher rating) for the drive converter load, a (lower rating) for the other, generally sensitive loads, as illustrated in Fig. 3.6.11. This has, under certain circumstances, the advantage that line commutating reactors can be eliminated, if the transformer u_k, i.e. its leakage inductance, is sufficiently high. This can therefore represent a significant cost saving.

In order to be able to realize separate supplies for the drive converter and for the other linear load, if the drive converter power dominates, this demands a well conceived power supply design. Thus, issues such as these should be carefully considered in the initial phase when designing the complete installation. Motto: If possible, use a dedicated supply for higher drive converter outputs!

For fault level:
For low fault levels, the following configuration is:
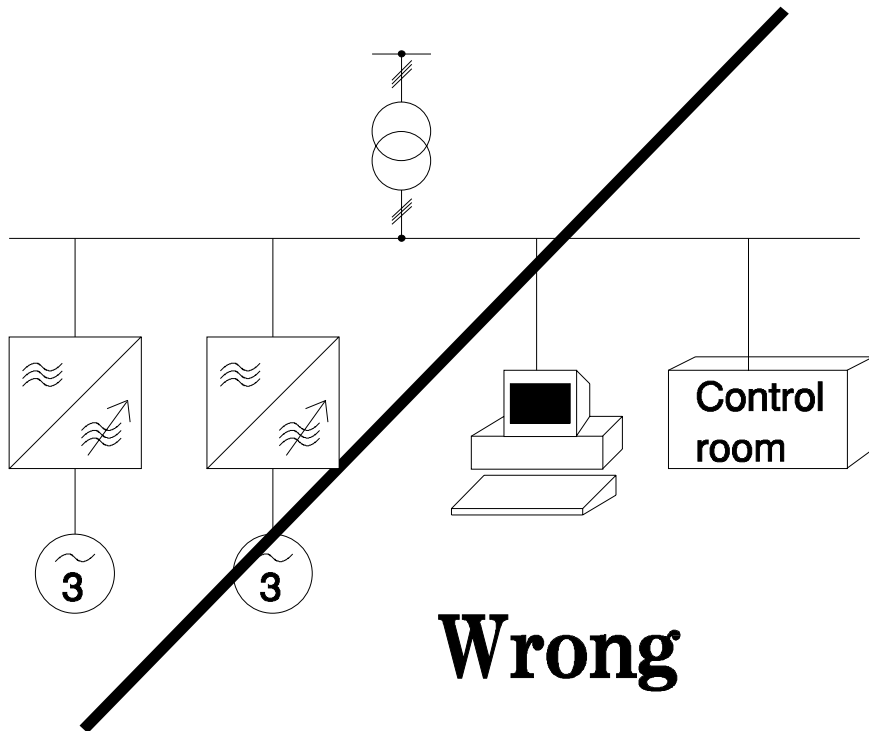
Fig. 3.6.11a: Unpractical drive converter configuration/connection

To mutually de-couple the loads:
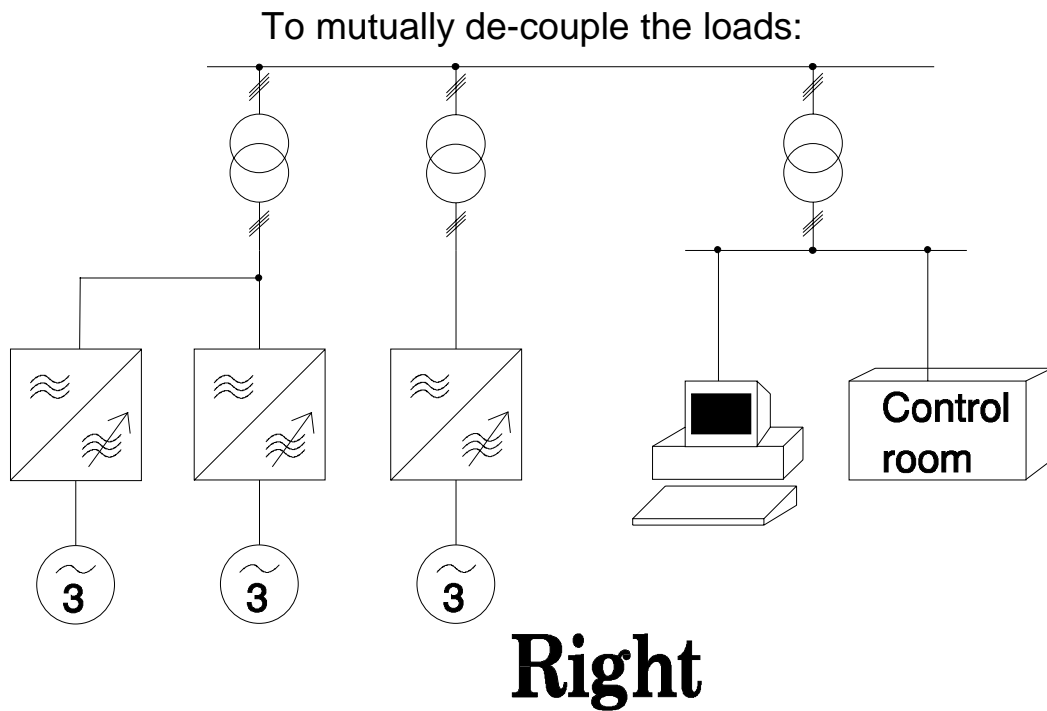
Fig. 3.6.11b: Practical connection of the drive converters

European Standard EN 60 555 (DIN VDE 0838 Part 2)

This standard limits harmonics, which are caused by „domestic equipment and similar electrical equipment". Thus, it also includes low-output drive converters, which are used in residential areas on the low-voltage supply network, e.g. in a small workshop, as water circulating pumps in a high-rise building etc.

Essentially EN 60 555 is **not** meant for exclusively commericial applications. However, it is not always possible to utilize this clause. This is because the „Conditions for connection to the low-voltage network", Edition 1993, of the Vereinigung Deutscher Elektrizitätswerke - VDEW - (German Utility Body), specify, under Paragraph 8.3, the following: Equipment, used commercially for work or agricultural purposes, can be connected, if a standard is not available, and **if they maintain the limiting values specified in DIN VDE 0838 (EN 60 555)**".

According to this Standard, individual devices may inject current harmonics up to a certain magnitude into the line supply, as specified in the following table 3.6.3.2.

Harmonic Order No. ν	5	7	11	13	$15 \leq n \leq 39$
Maximum permissible harmonic currents	1.14 [A]	0.77 [A]	0.33 [A]	0.21 [A]	$0.15 * \dfrac{15}{n} \ [A]$

Table 3.6.3.2:   Permissible harmonics in accordance with EN 60 555 Part 2 (DIN VDE 0838 Table 1) for connection to 220/380 V-, 230/400 V-, 240/415 V line supplies

If this value is to be maintained, this means in practice that, for example, the smallest drive converter (6.1 A rated current when connected to 400 V), the 5th current harmonic must be limited to less than 18% of the rated current. This is possible, as can be seen in the results under 3.6.1, if a line commutating reactor is used, and a certain tolerance is acceptable. For larger units and higher rated currents, EN 60 555 cannot be maintained by just using a line commutating reactor. In this case, filter circuits and harmonic interphase transformer, as described in Catalog K (Order No. E50001-K1600-A111-A19) would be required.

Comments:
These standards are tailored to low-rating loads, which generally lie below the output range of MASTER DRIVES. Presently, an attempt is being made to change the validity range and to extend them up to higher outputs, up to load currents of approximately 100 A. Of course the permissible level must be adapted.
If problems occur in household networks, in conjunction with EN 60 555, i.e. in the generally accessible public supply networks, then a reference should be made to the preliminary standard EN V 61000 Part 2-2 as well as to the „basics to evaluate line harmonics" (also refer below).

EN V 61000 Part 2-2 (VDE 0839 Part 2-2)

This involves a European Draft standard, which came into force in March 1993 and is initially valid for 3 years, i.e. up to 3/1996. Depending on the experience which is gained during this transition time (during which time the associated national standards can be retained), this standard could become generally valid, possibly with some modifications, from 1996 onwards. The standard **handles „compatibility level for lower-frequency cable-borne noise ... in public low-voltage networks".** Drive converters and other loads, which are connected to public low-voltage networks, may not be negatively affected by the level specified in this Draft standard. The harmonic voltages generated by the drive converters themselves must of course remain below this level. As shown in the subsequent table with the compatibility levels, the values for the 5th and 7th harmonics are almost identical with those of DIN VDE 0160, while they are lower for the higher-frequency harmonics.

Harmonic Order No. ν	5	7	11	13	17	19	23	25	> 25
Maximum permissible harmonic voltage.	6 %	5 %	3.5 %	3 %	2 %	1.5 %	1.5 %	1.5 %	$0.2 + 0.5 * \dfrac{25}{n}$ %

Table 3.6.3.3: Voltage harmonics in accordance with EN V 61000 Part 2-2

If harmonic voltages actually do occur with the specified magnitude, then a distortion factor of 9.6% would be obtained up to the 25th harmonic.

Basics to evaluate harmonics. Edition 1992.
These are guidelines for permissible harmonic levels which are to be maintained on the public low-voltage supply network from the perspective of the power company (power utility company). This was published by the Vereinigung Deutscher Elektrizitätswerke - VDEW - e.V (Germany regulatory body). They are based on the values specified in EN V 61000 Part 2-2 in accordance with the above Table 3.6.3.3, which are to be maintained at the connection points in the public supply network. Corresponding to the guidelines, it can be evaluated to what level individual loads can use this, as a function of their registered power data.

USA/Canada

Standard IEEE 519 (IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems) is the valid standard. The following is specified for the PCC (point of common coupling):

Commutating dip

The commutating dip as a percentage of the **instantaneous** (basic fundamental) supply voltage may not exceed the following values:

10 %   for special applications (sensitive loads such as are found in hospital clinics and airports),
20 %   for general applications,
50 %   for applications where special agreements have been made.

Comment: As the commutating dips are not referred to the peak of the sinusoidal basic fundamental voltage as for VDE 0160, but are referred to the actual instantaneous value, generally this requirement cannot be fulfilled by just using a line commutating reactor which would then have to be always provided.

Permissible harmonic voltages

The permissible voltage harmonic level is oriented to the application and the ratio between the supply fault level and the maximum power drawn (averaged over 15 or 30 minutes) in accordance with the following table 3.6.3.4.

Ratio, fault level/max. power drawn	Permissible level for each voltage harmonic	Typical users
10	2.5 - 3 %	Special customers with special agreements/ contracts
20	2.0 - 2.5 %	1 - 2 large power users
50	1.0 - 1.5 %	A few users with high power demands
100	0.5 - 1 %	15 - 20 users with medium power demands
1000	0.05 - 0.1 %	Many users with low power demands

Table 3.6.3.4: Permissible voltage level per user in accordance with IEEE 519

The distortion factor in the voltage, caused by an individual unit, may be a maximum of 3 %. The total distortion factor, i.e. when several units are connected at the PCC, may not exceed 5%. This is valid for line supply voltages up to 69 kV.

Permissible harmonic currents

In addition to the harmonic voltages which must be maintained, the harmonic currents must also be limited to permissible values. These levels are specified in the following Table 3.6.3.5.

Ratio fault level/ max. power drawn	n = 5.7	n = 11.13	n = 17.19	n = 23.25	n > 25	Distortion Faktor $\frac{1}{I_1} * \sqrt{I_v^2}$
< 20	4 %	2.0 %	1.5 %	0.6 %	0.3 %	5 %
20 - 50	7 %	3.5 %	2.5 %	1.0 %	0.5 %	8 %
50 - 100	10 %	4.5 %	4 %	1.5 %	0.7 %	12 %
100 - 1000	12 %	5.5 %	5 %	2.0 %	1.0 %	15 %
> 1000	15 %	6.0 %	6 %	2.5 %	1.4 %	20 %

Table 3.6.3.5:   Permissible harmonic currents in accordance with IEEE 519 as a % of the maximum current drawn at the PCC (averaged over 15 or 30 min)

England, including Australia

In this case, Engineering Recommendation G.5/3: "Limits for Harmonics in the United Kingdom Electricity Supply System", Classification C must be taken into account.

The loads are sub-divided into 3 categories:

Category 1 (Stage 1):
These are units up to a rating of
- 12 kVA for 6-pulse supply on the 415 V supply
- 130 kVA for 6-pulse supply from the 6.6 kV- or 11 kV supply
- 250 kVA for 12-pulse supply from the 6.6 kV- or 11 kV supply

These units can be connected to the public supply network without any restrictions. There are no special measures required to reduce the harmonics.

Category 2 (Stage 2):
This involves equipment with a higher rating than that of category 1. They may only be connected to the public supply, if
- the distortion factor at each PCC of the supply before connecting a new unit must have a value of $\leq$ 3.75 % (when connected to a 415 V supply) or $\leq$ 3 % (when connected to a 6.6 kV- or 11 kV supply), **and if**
- the permissible harmonic currents, specified in Table 3.6.3.6, are not exceeded for each individual unit.

Connected to	$\nu = 5$	$\nu = 7$	$\nu = 11$	$\nu = 13$	$\nu = 17$	$\nu = 19$
415 V	56 A	40 A	19 A	16 A	5 A	6 A
6.6 kV or 11 kV	10 A	8 A	7 A	6 A	2 A	1 A

Table 3.6.3.6: Permissible harmonic currents for each individual unit for category 2 equipment

Comment: In accordance with these permitted harmonic currents, drive converters with rated currents above approx. 200 A or approx. 150 kVA can no longer be directly operated from the 415 V supply, e.g. 12-pulse line supplies must be used.

Category 3 (Stage 3):
This category involves equipment where the criteria according to Category 2 are not fulfilled, e.g. that units > 150 kVA are to be operated directly from the 415 V supply. This is only possible in exceptional cases, after prior discussions with the power company and after it is guaranteed, either by making precise calculations or measurements, that the distortion factor at any PCC does not exceed 5 % (when connected to a 415 V supply) or 4% (when connected to 6.6 kV- or 11 kV supply).

3.7 Effects on the converter supply: Additional current- and voltage stressing and the required filter measures

The drive converter supplies at its output, a voltage which consists of voltage blocks with the amplitude of the DC link voltage. The rate of rise dv/dt of these voltage blocks is extremely steep and is determined by the switching speed of the IGBT used. Minimum switching times range from 0.08 to 0.1 µs. For a DC link voltage of $V_{DC\ link} = 1.35 * V_{supply}$ voltage rates of rise of up to

$$dv/dt \geq 690 * 1.35\ V\ /\ 0.1\ µs \approx 10\ kV/µs \quad \text{for a 690 V supply voltage, are obtained}$$

If an output filter is not provided, and especially for long motor feeder cables, this results in additional stressing, both in the drive converter (additional current spikes) as well as in the motor (increased voltage stressing which can damage the motor winding insulation). Both of these effects will now be separately discussed.

3.7.1 Additional current loading of the drive converter as a result of long motor cables

Motor cables have a specific capacitance. The longer the cable, the higher the resulting cable capacitance. These capacitances are re-charged at each commutation. This involves a charging current of the cable capacitances which is superimposed on the actual motor current, refer to Fig. 3.7.1.
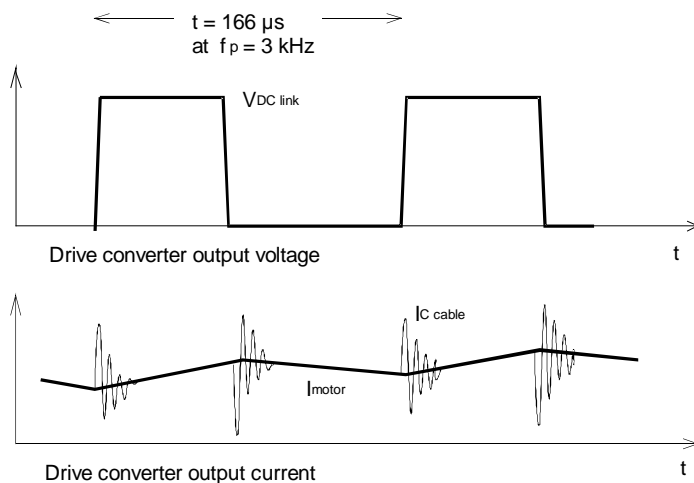
Fig. 3.7.1 Instantaneous values of the drive converter output voltage and current

The drive converter must, in addition to the motor current, also supply these capacitive re-charging currents, which decay after approx. 1 µs. The amplitudes of these capacitive re-charging currents are higher, the higher the cable capacitance, and thus the longer the cable. Smoothing reactors or filters must be provided at the drive converter output, so that it is not fault tripped due to overcurrent when long motor feeder cables are used. Also refer to Section 3.7.4.

3.7.2 Increased voltage stressing of the motor

If motors are fed through longer cables, then increased voltage levels are obtained at the motor terminals due to steep voltage increases at the drive converter output (high rate of rise). Thus, the motor not only sees the voltage blocks with the DC link voltage amplitude (= 1.35 x of the line voltage), but brief, maximum peak values up to almost twice this value. Fig. 3.7.2 briefly explains how these voltage peaks occur.
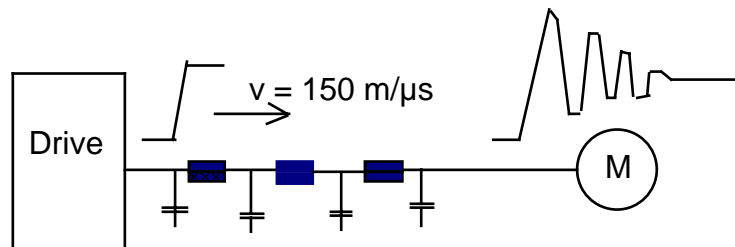
Fig. 3.7.2 Motor feeder cable and voltage characteristics at the drive converter output and at the motor

The high rate of rise of the voltage at each commutation (i. e. 6000 times per second in each phase for a 3000 Hz pulse frequency) at the drive converter output can be considered to be a moving wave. It is propagated along the motor feeder cable with a speed of approx. 150 m/µs (≈ half the speed of light). The characteristic impedance suddenly changes at the motor:

$$(R_{W\ motor} \approx 10\ ...\ 20 \times R_{W\ cable}).$$

Thus, the moving voltage wave received from the drive converter is reflected back to the drive converter and then back to the motor again etc. The initiated stabilization sequence decays to the steady-state value, e. g. the DC link voltage, after approx. 1 µs. This results in the motor voltage characteristic illustrated in the righthand half of Fig. 3.7.2. The maximum motor voltage in rated operation, i. e. under load, taking into account full voltage reflection, is given by:

$$\hat{V}_{motor} \approx 1.9 * V_{DC\_link} = 2.6 * V_{supply}$$

During brief transient operations, e. g. when braking with a pulsed resistor, or at the end of an acceleration phase, the DC link voltage can also reach higher values with appropriately higher voltage stressing at the motor. The maximum peak voltages at the motor terminals, which would be present if there were no smoothing- or filter measures, are summarized in the following table.

Supply voltages	Peak motor voltage under standard operating conditions	Sporadic peak motor voltages during equalization
230 V	600 V	735 V
400 V	1040 V	1470 V
460 V	1200 V	1470 V
500 V	1300 V	1840 V
575 V	1500 V	1840 V
690 V	1800 V	2200 V

Table 3.7.1　　Voltage spikes occurring at the motor due to voltage reflections
*　　　　　　　for cable lengths > 10 m without any filters*

The prerequisite for maximum voltage reflection is that the voltage rise at the drive converter output is shorter than the propagation time of the moving voltage wave from the drive converter to the motor:

Full reflection, if
$$\Delta t \; < \; t_{prop.} \; = \; \frac{l_{cable}}{\textsf{v}}$$

The voltage rise time Δt for the IGBT used is approximately 0.08 to 0.1 μs. Thus, the critical cable length, above which full voltage reflection occurs, is given by:

$$l_{cable} \; > \; \textsf{v} * \Delta t = 150 \; \frac{m}{\mu s} * 0,1 \; \mu s \; = \; 15 \; m$$

This means that the full voltage reflection already occurs at very low cable lengths from 10 to 15 m, i.e it must always be assumed that they are present.

Please refer to the following literature for more detailed information on this subject:

Berth, M., Eberhardt, M., Kaufhold, M., Speck, J., Auinger,H.: Elektrische Belastung und Ausfallverhalten der Wicklungsisolierung von Asynchronmaschinen bei Umrichterspeisung. Elektrie 8/9 (1995) S. 336-344.

Hentschel, E., Niedermeier, K. Schäfer, K.: Beanspruchung der Wicklungsisolation von Drehstrommaschinen. etz Bd. 114 (1993) H. 17 S. 1074-1077.

Persson, E.: Transient Effects in Applications of PWM Inverters to Induction Motors. IEEE Transactions on Industrial Applications, Vol. 28, No. 5, September/October 1992.

Bunzel, E., Graß, H.: Spannungsbeanspruchung von Asynchronmotoren im Umrichterbetrieb. etz Bd. 114 (1993) Heft 7-8 S. 448-458.

3.7.3 Measures to reduce voltage stressing

If measures should be, or have to be implemented to reduce the increased voltage stressing, then output reactors and output filters can be used. These will now be discussed individually:

3.7.3.1 Output reactors
Output reactors limit the capacitive output currents and additionally reduce the voltage rate of rise after the reactor with increasing cable length. The following reactors can be used:

- Iron reactors, if the drive converter output has frequencies ≤ 120 Hz. In this case, the maximum pulse frequency is limited to 3 kHz.

- Ferrite reactors, if the drive converter output frequencies are > 120 Hz or if the pulse frequency is set to values > 3 kHz. In this case, the maximum pulse frequency is limited to 6 kHz.

The Order Nos. as well as the technical data of these output reactors can be taken from Catalog DA 65.1.

3.7.3.2 dv/dt filters

dv/dt filters reduce the voltage rate-of-rise to values of dv/dt $\leq$ 500 V/µs. This means that the capacitive re-charging currents are significantly reduced. Further, the voltage spikes occurring at the motor are reduced to a maximum of approximately

$$1.3 \times V_{DC\ link} = 1.76 \times V_{supply}\ \text{for normal operation}$$

The basic circuit diagram of the dv/dt filter is illustrated in the following Fig. 3.7.3.

dv/dt filters, as shown in Fig. 3.7.3, comprise a filter reactor L_{Fi} and filter capacitors C_{Fi}. The decoupling capacitors C_{limit} in conjunction with the diode bridge limit the instantaneous value of the output voltage of the dv/dt filter, and therefore the motor voltage so that it cannot exceed approximately 130 % of the DC link voltage.
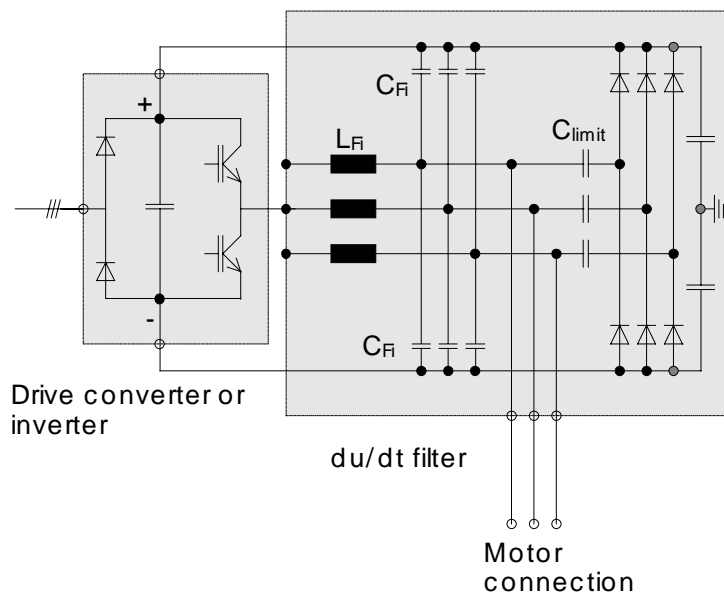
Fig. 3.7.3: Block diagram of a dv/dt filter

The maximum permissible pulse frequency is limited to 3 kHz so that the dv/dt filter is not overloaded. For the same reasons, the motor feeder cable should not exceed a specific length. For more detailed information, refer to the following Sections, especially Table 3.7.4.1, and Catalog DA 65.

The Order Nos. as well as the technical data for the dv/dt filters can be taken from Catalog DA 65.

Information when using dv/dt filters:

The pulse frequency should be set to values $\leq$ 3 kHz.
For compact units up to 37 kW, sizes A to D, dv/dt filters with the (present) product status A may **only** be used for grounded line supplies. From version B, they can only be used with grounded- and non-grounded supply networks
For chassis- and cabinet units $\geq$ 45 kW, from size E, dv/dt filters can be used both for grounded as well as for non-grounded line supplies (IT supply networks). Observe the appropriate instructions and information in the relevant Instruction Manuals.

3.7.3.3 Sinusoidal filters

Sinusoidal filters represent the most complex and expensive filter technique. They use LC filters, which supply a practically sinusoidal voltage at the output. They are tuned for a pulse frequency of 6 kHz (230 V to 460 V supply voltage) or 3 kHz (500 V to 575 V supply voltage) and can only be used at these pulse frequencies.

When using sinusoidal filters, the drive converters or inverters are only operated with sinusoidal modulation or space vector modulation. This means that the drive converter output voltage, and therefore the motor voltage, are limited to a maximum of 85 % (90 % at 500 V) of the line supply voltage. This must be taken into account when engineering and dimensioning a drive system. For drives using standard 1LA motors, this means that the drive converter and motor have to be over-dimensioned by 15 % (10 % at 500 V) over operation without sinusoidal filter.

Operation with a sinusoidal filter is only permissible for motor feeder cable lengths, specified in Catalog DA 65 (250 m up to and exceeding 1000 m depending on the power and cable type). Otherwise, undesirable resonance effects could occur and the sinusoidal filter could be overloaded.

The Order Nos. as well as the technical data for the sinusoidal filters can be taken from Catalog DA 65.1.

Information when using sinusoidal filters:

The pulse frequency must be permanently set to 6 kHz (380 V to 460 V) or 3 kHz (500 V to 575 V).

Sinusoidal filters can be used for both grounded as well as non-grounded line supplies (IT supply networks). The appropriate instructions should be observed in the relevant Instruction Manual.

3.7.4 Measures which are required due to increased voltage stressing

3.7.4.1 Measures to reduce inadmissibly high re-charging currents for long motor feeder cables (to protect the drive converter)

Inadmissibly high re-charging currents must be prevented in order to protect the drive converter. This is primarily realized using output reactors. The appropriate information has already been provided in Catalog DA65.1, Page 3/12, but for the sake of completeness will also be repeated here. These values are valid for worst case conditions. For specific secondary conditions, for example, the drive converters are operated at 400 V and not at 460 V as in the worst case situation, then more favorable conditions are obtained, which are now discussed.

It should be observed, that the specified cable lengths refer, for motors connected in parallel at the drive converter output, to the total cable lengths, i. e. the sum of all the cables. For example, if 6 motors are connected in parallel directly at the drive converter output, and the motors are located 80 m away from the drive converter, then the total cable length is 6 x 80 = 480 m. In this case, appropriate filter measures must be provided.
The following measures can be taken if the overall cable length exceeds the maximum permissible value due to the fact that more motors are connected in parallel:
- either a central cable should be used between the drive converter to where the motors are located and from there cables routed to the individual motors (including the individual motor protection).
- or the motors are combined in groups and are distributed over 2 or 3 appropriately lower-rating drive converters, so that the maximum total cable lengths for the individual drive converters are not exceeded.

For short motor feeder cables, additional measures such as output reactors or output filters are not required. This is valid for the values up to those specified in the following Table 3.7.2.

Table 3.7.2 Permissible cable lengths for standard drive converters without output reactors or filters

Maximum cable lengths as standard			
Output	Rated voltage	Unscreened cables	Screened cables
To 4 kW	208 to 575V	50 m	35 m
5.5 kW	208 to 575V	70 m	50 m
7.5 kW	208 to 575V	100 m	67 m
11 kW	208 to 575V	110 m	75 m
15 kW	208 to 575V	125 m	85 m
18.5 kW	208 to 575V	135 m	90 m
22 kW	208 to 575V	150 m	100 m
20 to 200 kW	380 to 575V	150m	100 m
250 to 710 kW	380 to 460V	200 m	135 m
250 to 1500 kW	500 to 690V	150 m	100 m

For longer cable lengths, output reactors can be provided. Thus, the values specified in the following tables can be achieved. One should observe, that depending on the cable length, it may be necessary to connect 2 or 3 output reactors in series.

Table 3.7.3 Maximum permissible cable lengths when drive converter output reactors are used

Maximum cable lengths which can be connected when a reactor is used							
Number of reactors in series →		1	2	3	1	2	3
Drive converter/ inverter frame size	Rated voltage						
		Non-screened cables			Screened cables		
To 4 kW	208 to 575V	150 m	1)	1)	100 m	1)	1)
5,5 kW	208 to 575V	200 m	1)	1)	135 m	1)	1)
7,5 kW	208 to 575V	225 m	450 m	1)	150 m	300 m	1)
11 kW	208 to 575V	240 m	480 m	1)	160 m	320 m	1)
15 kW	208 to 575V	260 m	520 m	1)	175 m	350 m	1)
18,5 kW	208 to 575V	280 m	560 m	1)	190 m	375 m	1)
22 kW	208 to 575V	300 m	600 m	900 m	200 m	400 m	600 m
20 to 200 kW	380 to 575V	300 m	600 m	900 m	200 m	400 m	600 m
250 to 710 kW	380 to 460V	400 m	800 m	1200 m	270 m	530 m	800 m
250 to 630 kW	500 to 690V	300 m	600 m	900 m	200 m	400 m	600 m
710 to 1100 kW 2)	500 to 575V	300 m	450 m	600 m	200 m	300 m	450 m
800 kW	660 to 690V	300 m	600 m	900 m	200 m	400 m	600 m
900 to 1500 kW 2)	660 to 690V	300 m	450 m	600 m	200 m	300 m	450 m

1) Not possible

2) 2 parallel reactors are used with half the rated current

For longer cable lengths, dv/dt filters can be alternatively used. However, due to the high costs involved, they should only be used if they are absolutely necessary to protect the motor winding; also refer to the comments in Section 3.7.4.2. This allows cable lengths, specified in the subsequent table to be used. One should observe, that, depending on the cable length, one or 2 additional output reactors may be required.

Table 3.7.4 Maximum cable lengths when a dv/dt filter is used

Cable lengths which can be connected when a dv/dt filter is used						
Drive converter / inverter rated current	dv/dt filter	dv/dt filter and reactor	dv/dt filter and 2 reactors 2)	dv/dt filter	dv/dt filter and reactor	dv/dt filter and 2 reactors 2)
	Non-screened cables			Screened cables		
to 22A	150 m	1)	1)	100 m	1)	1)
to 370A 4)	150 m	300 m	450 m	100 m	200 m	300 m
to 225A 5)	150 m	300 m	450 m	100 m	200 m	300 m
510 to 860A 4)	150 m	375 m	1)	100 m	250 m	1)
297 to 860A 5)	150 m	375 m	1)	100 m	250 m	1)
From 990 A 6)	3)	3)	3)	3)	3)	3)

1) Not possible

2) Voltage limiting is no longer effective for line supply voltages > 500 V.

3) Presently not available.

4) Rated line supply voltage, 380 to 460V

5) Rated line supply voltage, 500 to 690V

6) Rated line supply voltage, 380 to 690V

For long cable lengths, sinusoidal filters can be alternatively used. However, due to the high costs involved they should only be used, for example, in hazardous locations, or where they are specified by the customer. Also refer to the comments in Section 3.7.4.2. Extremely long motor feeder cables may only be possible if sinusoidal filters are used.

The cable lengths, specified in the following table, can be achieved when sinusoidal filters are used. Please observe that sinusoidal filters are only available for drive converter outputs up to a maximum of 132 kW and for supply voltages up to a maximum of 575 V.

Table 3.7.5 Maximum cable lengths when sinusoidal filters are used

Cable lengths which can be connected when sinusoidal filters are used				
Output	380 to 460 V	500 to 575 V	380 V to 460 V	500 to 575 V
	Non-screened cables		Screened cables	
To 4 kW	250 m	350 m	170 m	250 m
5.5 kW	320 m	475 m	210 m	320 m
7.5 kW	400 m	550 m	270 m	400 m
11 kW	500 m	700 m	330 m	500 m
15 kW	600 m	900 m	400 m	600 m
18.5 kW to 132 kW	A	B	0,67 • A	A

$A = 600\ m + 7.5 • (P_{[kW]} - 15)\ m$ $B = 900\ m + 10 • (P_{[kW]} - 15)\ m$

P: Rated drive converter or inverter output in kW

Determining the permissible length of motor feeder cables as a function of the individual system parameters with an accuracy of 15% <u>without any safety reserves</u>

As already mentioned, the permissible cable lengths, specified in Tables 3.7.2 to 3.7.5 are valid for worst case conditions and under certain basic assumptions regarding the cable cross-sections. If these assumptions are not fulfilled then longer (or shorter) cable lengths can be obtained on a case for case basis.

The following factors influence the maximum cable length:

- the ratio between the drive converter/inverter output current and the rated motor current(s)
- line supply voltage
- cable type and cross-section
- maximum load current

Generally, longer cable lengths are possible, if

- the motor output is less than the drive converter output (lower-rating motors have higher leakage inductances),

- the maximum possible line supply voltage is not present, e. g. at 400 V, whereby the drive converters are suitable for line supply voltages up to 460 V,

- if cables with a lower cross-section are used (cables with lower cross-sections have lower capacitance values and have a higher damping effect due to their higher resistance),

- the drive converter overload current is not utilized, e. g. if the current limiting is parameterized to the rated drive converter current or less (using the torque limiting).

The maximum permissible cable lengths are obtained as shown in the following.

Permissible cable lengths l$_{permissible}$ when feeding a motor (single-motor drive) without an output reactor between the drive converter / inverter and motor:

Factors, which influence the cable length:

- ratio between the drive converter / inverter output current and the rated motor current(s)

- line supply voltage

- cable type and cross-section

$$l_{permissible} = l_{\max N} \bullet \frac{I_{VN}}{I_{MotN}} \bullet \frac{V_{V\max}}{V_{supplyN}} \bullet \left| 0.5 + 0.5 \frac{A_{reference}}{A_{configured}} \right|$$

Maximum permissible cable lengths l$_{permissible}$ when feeding 2 motors without an output reactor between the drive converter / inverter and motors:

$$l_{permissible} = l_{\max N} \bullet \frac{I_{VN}}{I_{MotN}} \bullet \frac{V_{V\max}}{V_{supplyN}} \bullet \frac{1}{2} \left| 0.5 + 0.5 \frac{A_{reference}}{2 \bullet A_{configured}} \right|$$

An output reactor must always be used if more than 2 motors are connected to the drive converter output.

Terminology and formulas:

l$_{permissible}$: Maximum permissible cable length without any safety reserve (distance between the motor and drive converter) — in m

l$_{maxN}$: Maximum permissible cable length according to Table 3.7.2 — in m

I$_{VN}$: Rated drive converter/ inverter current — in A

I$_{MotN}$: Rated motor current or currents of all the motors — in A

V$_{supplyN}$: Configured rated line supply voltage — in V

V$_{Vmax}$: Maximum rated drive converter supply voltage values refer to Table 3.7.6 — in V

A$_{reference}$: Reference cross-section of the drive converter and inverter values refer to Table 3.7.7 — in mm^2

A$_{configured}$: Configured motor cable cross-section — in mm^2

n: Number of motor cables to the separate motors

Maximum permissible cable lengths I$_{permissible}$ when feeding a motor (single-motor drive) with an output reactor between the drive converter / inverter and motor:

Factors which influence the cable length:

- ratio between the drive converter / inverter output current and the rated motor current(s)
- line supply voltage
- maximum load current
- cable type and cross-section

$$l_{permissible} = l_{\max N} \bullet \frac{I_{VN}}{I_{MotN}} \bullet \frac{V_{V\max}}{V_{supplyN}} \bullet \left| 5.76 - 3.5 \bullet \frac{I_{V\max}}{I_{VN}} \right| \bullet \left(0.5 + 0.5 \frac{A_{reference}}{A_{configured}} \right)$$

Maximum permissible cable lengths I$_{permissible}$ when feeding a motor group (multi-motor drive) with an output reactor between the drive converter / inverter and motors:

$$l_{permissible} = l_{\max N} \bullet \frac{I_{VN}}{I_{MotN}} \bullet \frac{V_{V\max}}{V_{supplyN}} \bullet \left| 5.76 - 3.5 \bullet \frac{I_{V\max}}{I_{VN}} \right| \bullet \frac{1}{n} \left(0.5 + 0.5 \frac{A_{reference}}{n \bullet A_{configured}} \right)$$

An output reactor must be used if more than 2 motors are connected at the drive converter output.

Terminology and formulas:

I$_{permissible}$: Maximum permissible cable length without any safety reserve   in m
          (distance between the motor and drive converter)

I$_{maxN}$:   Maximum permissible cable length according to Table 3.7.3   in m

I$_{VN}$:   Rated drive converter/ inverter current   in A

I$_{Vmax}$:   Maximum configured load current of the drive converter/inverter   in A

I$_{MotN}$:   Rated motor current or currents of all the motors   in A

V$_{supplyN}$: Configured rated line supply voltage   in V

V$_{Vmax}$:   Maximum rated drive converter supply voltage   in V
          values refer to Table 3.7.6

A$_{reference}$: Reference cross-section of the drive converter and inverter   in mm^2
          values refer to Table 3.7.7

A$_{configured}$: Configured motor cable cross-section   in mm^2

n: Number of motor cables to the separate motors

Maximum permissible cable lengths I$_{permissible}$ when feeding a motor (single-motor drive) with dv / dt filters between the drive converter / inverter and motor:

Factors which influence the cable length:
- line supply voltage
- cable type and cross-section

$$l_{permissible} = l_{\max N} \bullet \frac{V_{V\max}}{V_{supplyN}} \bullet \left| \, 0.5 + 0.5 \frac{A_{reference}}{A_{configured}} \, \right|$$

Maximum permissible cable lengths I$_{permissible}$ when feeding a motor group (multi-motor drive) with a dv/dt filter between the drive converter/inverter and motors:

$$l_{permissible} = l_{\max N} \bullet \frac{V_{V\max}}{V_{supplyN}} \bullet \frac{1}{n} \bullet \left| \, 0.5 + 0.5 \frac{A_{reference}}{n \bullet A_{configured}} \, \right|$$

Terminology and formulas:

I$_{permissible}$: Maximum permissible cable length without any safety reserve in m
(distance between the motor and drive converter)

I$_{maxN}$: Maximum permissible cable length according to Table 3.74 in m

V$_{supplyN}$: Configured rated line supply voltage in V

V$_{Vmax}$: Maximum rated drive converter supply voltage in V
values refer to Table 3.7.6

A$_{reference}$: Reference cross-section of the drive converter and inverter in mm^2
values refer to Table 3.7.7

A$_{configured}$: Configured motor cable cross-section in mm^2

n: Number of motor cables to the separate motors

Maximum permissible cable lengths l_permissible when feeding a motor (single-motor drive) using a sinusoidal filter between the drive converter / inverter and motor:

Factors which influence the cable length:
- line supply voltage
- cable type and -cross-section

$$l_{permissible} = l_{max\,N} \bullet \frac{V_{V\,max}}{V_{supplyN}} \bullet \left|\, 0.5 + 0.5\frac{A_{reference}}{A_{configured}} \,\right|$$

Maximum permissible cable lengths l_permissible when feeding a motor group (group drive) using a sinusoidal filter between the drive converter / inverter and motors:

$$l_{permissible} = l_{max\,N} \bullet \frac{V_{V\,max}}{V_{supplyN}} \bullet \frac{1}{n} \bullet \left(0.5 + 0.5\frac{A_{reference}}{n \bullet A_{configured}} \right)$$

Terminology and formulas:

$l_{permissible}$: Maximum permissible cable length without any safety reserve   in m
            (distance between the motor and drive converter)

l_{maxN}:   Maximum permissible cable length according to Table 3.7.5   in m

$V_{supplyN}$: Configured rated line supply voltage   in V

V_{Vmax}:   Maximum rated drive converter supply voltage   in V
            values refer to Table 3.7.6

$A_{reference}$: Reference cross-section of the drive converter and inverter   in mm^2
            values refer to Table 3.7.7

$A_{configured}$: Configured motor cable cross-section   in mm^2

n: Number of motor cables to the separate motors

Table 3.7.6: Maximum rated drive converter supply voltage V$_{vmax}$
for drive converters and inverters:

Available or configured line supply voltage		V$_{Vmax}$ which can be used
3-ph. 208V to 230V AC or	280V to 310V DC incl. +15%	3-ph. 230V AC or 310V DC
3-ph. 380V to 460V AC or	510V to 620V DC incl. +15%	3-ph. 460V AC or 620V DC
3-ph. 500V to 575V AC or	675V to 780V DC incl. +15%	3-ph. 575V AC or 780V DC
3-ph. 660V to 690V AC or	890V to 930V DC incl. +15%	3-ph. 690V AC or 930V DC

Table 3.7.7: Reference cross-sections according to VDE 0298 Part 2
and 40° ambient temperature

I load	A reference	I load	A reference
≤ 15 A	2.5 mm²	≤ 150 A	95 mm²
≤ 20 A	4 mm²	≤ 170 A	120 mm²
≤ 26 A	6 mm²	≤ 195 A	150 mm²
≤ 36 A	10 mm²	≤ 225 A	185 mm²
≤ 48 A	16 mm²	≤ 260 A	240 mm²
≤ 65 A	25 mm²	≤ 290 A	300 mm²
≤ 80 A	35 mm²	≤ 580 A	2 x 300 mm²
≤ 95 A	50 mm²	≤ 1160 A	4 x 300 mm²
≤ 120 A	70 mm²	≤ 1740 A	6 x 300 mm²

In this case, either the rated drive converter current or a lower value, if the drive converter current limiting is set appropriately low enough, should be used as I load.

3.7.4.2 Measures to reduce inadmissibly high motor voltage stressing for long motor feeder cables (to protect the motor winding)

For the motors used, it should be checked as to whether the winding insulation could be damaged as a result of the voltage stressing in accordance with Section 3.7.2, especially Table 3.7.1. It can then be decided whether a filter is required. However, the measures described in the previous Section 3.7.4.1, are always required to protect the **drive converter**. The measures defined in this Section are therefore only required if they go beyond the measures required in Section 3.7.4.1.

Special motors, for example Siemosyn- or reluctance motors or 1FT6 servomotors and 1PH6 compact induction motors are designed for drive converter operation. It can always be assumed that their winding insulation is designed so that the increased voltage stressing can be handled without any additional filter measures. Thus, for these motors, no special filter measures are required, **under the assumption**, that the line supply voltage is not higher than the rated motor voltage.

Standard induction motors must be especially evaluated, i. e. conventional squirrel-cage induction motors.

Measures for Siemens 1LA5 and 1LA6 motors

For line supply voltages up to 500 V:
No special filter measures are required to reduce the voltage level. The motor winding insulation can handle the additional voltage stressing up to a line supply voltage of 500 V.

For line supply voltages > 500 V to 690 V:
In this case, **at least one** dv/dt filter is required.

Measures for Siemens 1LA8 motors

For 1LA8 motors the same is essentially true as for 1LA5 and 1LA6 motors; a dv/dt filter is required for line supply voltages > 500 V. However, these motors are available in a **special version with increased insulation strength**, whereby a dv/dt filter is not required for line supply voltages of 690 V. These motors have a somewhat lower output, compared with 1LA8 motors with standard windings. The motors with increased insulation strength have an M at the 9th position of the Order No. You will find technical data on these motors in Catalog M 19 and in the Engineering Manual for Motors.

Example: 1LA8 315-4P**M**8. with 225 kW rated output with increased insulation strength.
As a comparison: 1LA8 315-4PB8. with 250 kW rated output for the standard winding.

We recommend that, up to a line supply voltage of 500 V, motors with standard winding are used; for higher line supply voltages, especially at 690 V, we recommend motors with increased insulation strength.
The torque utilization factors and the motor-drive converter assignments for both motor versions are specified in the Engineering Manual for Motors.

Measures for Siemens 1LA1 motors

This generally involves motors with an increased insulation strength. No additional measures are required to reduce the voltage stressing.

Measures for third-party motors

It can be assumed, that motors from established European manufacturers such as ABB or AEG have similar characteristics to Siemens motors so that the same measures are required and are adequate as far as winding stressing is concerned. If in doubt, the motor manufacturer should be asked.
At this point, the question should be asked as to which standards the motors should fulfill. DIN VDE 0530 Part 1 Sheet 2 from April 1993, corresponding to IEC 34-17 (Report) is decisive. In this case, it can be assumed that in drive converter operation, the winding lifetime is not significantly reduced if the following limit values are maintained:

$$\hat{U} < 1000 \text{ V}; \qquad dV/dt < 500 \text{ V/μs."}$$

If these values are to be maintained, then dv/dt filters would be required. As can be seen from the measures required for Siemens motors, their insulation system is significantly better than that actually demanded by DIN VDE 0530. However, this cannot be assumed for all motor manufacturers. This is especially true for motor manufacturers in eastern Europe, Asia and South America, and caution is advised if the motors are to be fed from drive converters. In some cases, even a dv/dt filter for 400 V supply voltages may not be adequate so that sinusoidal filters must be used.

3.7.4.3 Operating explosion-protected 1MJ6 and 1MJ2 motors from SIMOVERT MASTERDRIVES 6SE70 and 6SE71 drive converters

For variable-speed drives in hazardous locations, it is recommended that 1MJ6 and 1MJ2 squirrel-cage motors are used with EEx d flameproof degree of protection. For these motors, in some cases, special measures are required to reduce the voltage; also refer to the information in the Engineering Manual for Motors, Chapter 1, Section 1.5.

4 Engineering information

4.1 Which motors for which applications?

For a specific drive case, it is first necessary to find the most suitable motor. When connected and supplied from MASTERDRIVES VC, there are a multitude of different motor types available, with the exception of the 1FT6 and 1FK6 servomotors. The following information should make it easier to select the correct motor. Several characteristics of the motors will be referred to, which will now be briefly explained:

Non-ventilated: No fan or fan blades, cooling via convection

Self-cooled: Cooling with a shaft-mounted fan which rotates with the motor speed, e. g. for 1LA5/6

Separately ventilated: Cooled by a fan, driven by a separate motor, which is then independent of the motor speed

Detailed information about these and many other motor characteristics and properties can be taken from the following brochure:
Low-voltage three-phase motors - Engineering Documentation - Technical Descriptions:
Catalog M10###1991   Order No. E20002-K1710-A101-A1.

1LA5, 1LA6, 1LA7, 1LA8 and 1LA1 standard motors

The preferred standard motors are the well-proven 1LA5, 1LA6, 1LA7, 1LA8 and 1LA1 squirrel-cage motors as listed in Catalog M11 (1998). Also refer to the Engineering Documentation in Catalog M10. Engineering using these motors is discussed in detail in the Engineering Manual for Motor.

These standard motors are recommended for, among others, the following reasons:

- unified output range from < 0.1 kW up to over 1500 kW,
- unified voltage range, 230 V to 690 V,
- manufactured in high unit quantities and therefore favorable-priced,
- simplified stocking as they can be universally used, not only for variable-speed drives,
- high IP54 degree of protection as standard,
- compact enclosure for tough operating conditions and restricted mounting space.

These standard motors can be operated together with the MASTERDRIVES VC drive converters. Also refer to the information provided in Section 2.1.

In order to fully utilize the control dynamic performance, even at speeds close to zero ($\geq$ 2 RPM) or for high speed holding accuracy, a tachometer or angular encoder can be mounted. The motors can be optionally supplied with a mounted pulse encoder with 1024 pulses/revolution. You'll find detailed information about this in the technical information included with the M19 price list in the new edition of the M11 Catalog, Edition 1998.

Thus, it makes a lot of sense to also use these motors for all drive applications. If special conditions apply, it may be more favorable to use special motors or other motor types. This will now be discussed.

1LA9 squirrel-cage motors

These motors are special designs of the standard 2- and 4-pole motors. They are available with the following characteristics/features:

Versions with an **extended voltage range** for outputs from 0.09 to 18.5 kW
This means that special windings are possible with rated frequencies other than 50/60 Hz.

Versions with **increased output** for outputs from 26 to 53 kW
In comparison to comparable 1LA5 motors, up to 40 to 50 % higher outputs can be achieved, when fully utilized to temperature rise class F.

Versions with **increased efficiency** for outputs from 18.5 to 37 kW
In comparison to comparable 1LA5 motors, the efficiencies increase by 1.2 to 1.3 percentage points (2-pole motors) and by 1.7 to 2 percentage points (4-pole motors).

Refer to Catalog M19 for additional information on these motors.

Force-ventilated motors

In addition to the non-ventilated 1LA6 and 1LA8 motors, separately-ventilated 1PQ6 and 1PQ8 motors can be used (analog to 1LA6 and 1LA8).
We recommend that a separately-ventilated motor is selected instead of a standard non-ventilated motor for 2 reasons:

- to utilize the high, permissible stall (standstill) torque which might mean that a smaller frame size can be used than for a non-ventilated motor with a high speed control range; also refer to the permissible torque characteristic according to Fig. 4.2,

- the fan noise, which under certain circumstances can be significant at high speeds above approx. 2200 RPM can be reduced, if motors with pole numbers 2p ### 4 are used in field weakening or with 87 Hz characteristic.

The drive can be engineered as for non-ventilated motors; also refer to the Engineering Manual for Motors. In this case, if no other comments are made regarding the individual motors, one can assume that there is a speed control range of 1:2.

Note: Separately-ventilated motors must be fused and monitored just like a fixed-speed drive.
Refer to Catalog M19 for additional information on these motors.

Open-circuit ventilated motors 1LL8, degree of protection IP23

These 1LL8 motors are separately-ventilated induction motors with squirrel-cage rotor, open-circuit ventilation and with a lower IP23 degree of protection. They are therefore smaller than comparable 1LA8 motors. Additional essential features include:
- output range, 315 to 1250 kW,
- supply voltages, 400 V to 690 V,
- rated speeds, 750 to 3000 RPM,
- frame sizes, 315 to 450,
- IP23 degree of protection.

Thus, one can consider using these motors in the output range up to 1250 kW, if mounting space is restricted, and if the relatively low IP23 degree of protection doesn't represent a problem. Refer to the data and information in Catalog M19 for engineering suitable drives.

Wound-rotor motors (US: slipring motors)

Wound-rotor motors can be connected and operated from a drive converter with the sliprings short-circuited. They then behave and have the characteristics of a squirrel-cage motor. However, it can be problematical to use wound-rotor motors when fed from drive converters for the following reasons:

- The winding temperatures in the rotor should not reach a level so that the winding insulation is destroyed (this is significantly less critical for squirrel-cage motors as they do not use rotor winding insulation). Thus, a higher torque rating is required than for squirrel-cage motors due to the supplementary motor losses. If the manufacturer's data isn't available, we recommend that the outputs which can be utilized, specified in the Engineering Manual for Motors, is reduced by 20 %. The characteristics for high-rating slipring motors, which have a special winding in the rotor are especially critical. Especially high supplementary rotary losses can occur as a result of the skin effect, which can make it necessary to reduce the output by up to 40 %.

- Due to the slipring brushes, slipring motors are far less maintenance-free and rugged than squirrel-cage induction motors. Especially at partial loads, very high brush wear can occur, due to the inadequate "lubrication" of the carbon brushes.

For these reasons, slipring motors should not be considered for new drive applications. However, if a customer expressly wishes to use a slipring motor, as he has an existing motor, then it can be used.

Siemens slipring motors have the type designations 1LS3 and 1LS6 and have outputs between 1.3 kW and 405 kW at rated speeds from 750 to 1500 RPM. Additional information and data can be taken from Catalog M12, Pages 59 - 84.

Compact 1PA6 three-phase induction motors

These are 4-pole, separately-ventilated squirrel-cage induction motors, which are derived from main spindle motors. The essential characteristics/properties are:

- output range, 4 to 215 kW,
- supply voltages, 400 V and 480 V, 200 V for Japanese projects
- rated speeds, 400 to 2900 RPM,
- maximum speeds in the field-weakening range up to 9000 RPM (up to 14 kW) or 5000 RPM (from 90 kW),
- rated torques, 22 to 1145 Nm,
- frame sizes, 100 to 225
- IP55 degree of protection
- lower dimensions and lower shaft heights than standard 1LA5/6 motors with the same output,
- incremental encoder integrated as standard for speed- and position sensing,
- low moment of inertia,
- excellent smooth running characteristics, even at the lowest speeds.

Thus, you can consider using these motors in the output range up to 160 kW, for:

- high speeds > 3000 RPM, which is not possible using standard 1LA5/6 motors,
- if a high control dynamic performance is required with acceleration times which, for standard 1LA5/6 motors would mean that it would be necessary to significantly over-dimension the drive converter,
- if mounting space is restricted, which would exclude the use of standard 1LA5/6 motors.

The compact three-phase induction motors and engineering drives with these motors are described in detail in the Engineering Manual for Motors. Also refer to Catalog DA65.3 (1998).

Compact 1PL6 three-phase induction motors

These are 4-pole, separately-cooled squirrel-cage induction motors similar to 1PA6, but open-circuit ventilated and with a lower IP23 degree of protection. Thus, they are significantly more compact than the 1PA6 motors. Essential characteristics/features include:

- output range, 25 to 300 kW,
- supply voltages, 400 V and 480 V,
- rated speeds, 400 to 2900 RPM,
- maximum speeds in the field-weakening range up to 5000 RPM,
- rated torques, 370 to 1720 Nm,
- frame sizes, 180 to 225,
- IP23 degree of protection,
- even smaller dimensions and lower shaft heights than the compact 1PA6 motors with a comparable output,
- incremental encoder integrated as standard for speed- and position sensing,
- low moment of inertia,
- good smooth running characteristics, even at the lowest speeds.

Thus, you can consider using these motors in the output range up to 300 kW, if mounting space is restricted and if the relatively low IP23 degree of protection does not represent a problem. To engineer suitable drives, information is provided in the Engineering Manual for Motors and in Catalog DA65.3 (1998).

Compact water-cooled three-phase induction motors 1PH4

These are 4-pole squirrel-cage induction motors similar to 1PA6, but with water cooling.
Thus, they are significantly more compact than the 1PA6 motors. Additional essential
features/characteristics include:

- output range, 7.5 to 61 kW,
- supply voltages, 400 V and 480 V,
- rated speed, 1750 RPM,
- maximum speeds in the field-weakening range, 2100 to 2800 RPM,
- rated torques, 48 to 330 Nm,
- frame sizes, 100 to 160,
- IP65 degree of protection,
- even smaller dimensions and lower shaft heights than the compact 1PA6 motors with the
  comparable output,
- incremental encoder integrated as standard for speed- and position sensing,
- low moment of inertia,
- good smooth running characteristics, even at the lowest speeds.

Thus, you can consider using these motors in an output range up to 61 kW, if the mounting space is
extremely restricted or if an extremely high degree of protection is required, under the assumption that
the water cooling does not represent a problem. To engineer suitable drives, information is provided in
the Engineering Manual for Motors and in Catalog DA65.3 (1998).

Siemosyn motors 1FU

Siemosyn motors are permanent-magnet synchronous motors in the torque range up to 58 Nm. In addition to the squirrel cage in the rotor, they also have permanent magnets. The motors are designed according to VDE 0530, so that they can provide a synchronous stall torque of > 1.35 * rated torque.

The motors are switched to the drive converter at a specified frequency, and then accelerate using the squirrel cage in the rotor. Close to the synchronous speed, the rotor is brought into synchronism by the permanent magnets. The squirrel cage acts as a damping cage when the motor is operating synchronously.

The motor, in synchronous operation, runs with a speed which precisely corresponds to the synchronous speed and therefore the frequency. This eliminates the need to provide speed feedback or speed monitoring. The more accurate the drive converter output frequency, the more accurate is the motor speed. For group drives (multi-motor drives) it is therefore possible to achieve precise synchronism between the motors fed from the drive converter.

Maximum speeds up to 24.000 RPM can be achieved. Typical applications include high-speed drives, e. g. in the textile industry, as single drives and as group drives. The motor data is specified in the following Tables 4.1 - 4.3. The external design of the Siemosyn inner-rotor motors corresponds to that of the standard three-phase induction motors, shaft heights 71 to 160.

Detailed information on Siemosyn motors with all of the technical tables are included in Catalog DA 48.

When engineering drives, the drive converters should be selected so that they can provide the motor currents, taking into account the starting currents when switching-in individual motors or motor groups. "V/Hz characteristic for textile applications" should be parameterized as control concept (P100 $\rightarrow$ 2).

Type	Output (50 Hz) [kW]	Torque [Nm]	Rated current [A] (50 Hz)	Starting current [A] (50 Hz)
1FU3084-4T.7	0.3	1.91	3.2	19
1FU3087-4T.7	0.5	3.18	5.0	26
1FU3087-6T.7	0.55	5.25	5.1	20
1FU3097-4T.7	0.6	3.82	5.4	39
1FU3097-6T.7	0.8	7.64	9.5	37
1FU3114-4T.7	1.3	8.28	14.0	77
1FU3114-6T.7	1.4	13.37	14.8	66
1FU3115-4T.7	1.5	9.55	16.5	106
1FU3115-6T.7	1.8	17.19	17.8	62
1FU3134-4T.7	2.6	16.55	35.8	266
1FU3134-6T.7	2.8	26.74	32.5	130
1FU3167-6T.7	5.5	52.52	63.0	279

Table 4.1: Inner-rotor motors, 4- and 6 pole   data for 50 Hz, 100 V / f_{max} = 200 Hz, 400 V

Type	Output (50 Hz) [kW]	Torque [Nm]	Rated current [A] (50 Hz)	Starting curr. [A] (50 Hz)
1FU4081-2T.7	0.4	1.27	5.5	23
1FU4084-2T.7	0.7	2.23	10.2	46
1FU4087-2T.7	0.9	2.86	13.8	72

Table 4.2: Inner-rotor motors 2 pole   frame size 80   data for 50 Hz, 67 V, f_{max} = 300 Hz, 400 V

Type	Output (50 Hz) [kW]	Torque [Nm]	Rated current [A] (50 Hz)	Starting curr. [A] (50 Hz)
1FU4101-2T.7	1.0	3.18	9.5	50
1FU4104-2T.7	1.25	3.98	12.5	73
1FU4107-2T.7	1.7	5.41	15.1	90
1FU4108-2T.7	2.3	7.32	20.0	103
1FU4118-2T.7	3.2	10.19	25.5	150

Table 4.3: Inner-rotor motors 2 pole   frame size 100/112   data for 50 Hz, 95 V, f_{max} = 200 Hz

Separately-excited synchronous motors

Sometimes we receive inquiries as to whether "standard" synchronous motors (with external excitation, e. g. via sliprings) can be fed from the drive converter. For example, for high output, low-speed rolling mill drives or for wind-driven generating systems, which are to be upgraded for variable speed operation and the frequency de-coupling is to be realized via the converter.

Separately-excited synchronous motors such as these can now be used with the closed-loop control software on the CUVC control board. This control concept represents an expansion of the "Current model", described in Section 2.1.2, analog to Fig. 2.1.12. In this case, a pulse encoder with zero pulse is required. The stator current is therefore entered, as a function of the specified torque setpoint and the instantaneous rotor position angle, as current vector and impressed via the current controller and via the de-coupling network (EMF computer for pre-control). The required excitation current is simultaneously output as setpoint (connector K0210). In this case, the „Closed-loop speed control" concept must be selected (P100 $\rightarrow$ 4, P95 $\rightarrow$ 12).

An additional converter to provide the excitation current must also be provided.

Due to the high complexity of this drive system, first contact our specialist sales department.

It should also be mentioned, that Siemens does not manufacture separately-excited synchronous motors in the output range up to 1500 kW.

High output permanent-magnet synchronous motors

For specific applications, e.g. wind-driven generating systems, in some cases, permanent-magnet synchronous motors with outputs of over 100 kW are used, e.g. 750 kW. It generally involves multi-pole generators (e.g. 72 pole) which are then driven directly without any intermediate gear.

Even applications such as these can now be handled using the control software now available on the CUVC control module. The "Closed-loop frequency control" concept, as described in Section 2.1.2.1 was slightly modified. The following have to be parameterized: P100 $\rightarrow$ 3, P95 $\rightarrow$ 13. A speed actual value encoder (tachometer) is not used as, for these applications, from experience it is either difficult to mount or cannot be mounted at all.

The following restrictions must be observed when using this drive system:

*   The „Kinetic buffering " and "Flexible response" functions only operate with some restrictions or cannot be used at all.

*   The „Restart-on-the-fly" function is generally not possible (this is where the drive converter is switched to a motor/generator which is rotating). Thus, the drive can only be powered-up when the motor is stationary. This practically excludes the "Automatic restart" function.

Due to the high complexity of this drive system, this type should only be engineered after prior discussion with our specialist sales department.

Motors/generators which can be used are always special customized products.

Comment: 1FT6 permanent-magnet synchronous motors as servomotors <u>cannot</u> be used with MASTERDRIVES VC; MASTERDRIVES MC should be used instead.

6 Application circuits

6.1 EMERGENCY OFF

Possible EMERGENCY OFF functions and the associated configuring examples have already been discussed in detail in the Application Manual (Order No. E20125-J0003-S202-A1) under Section 4.5. The following information is therefore restricted to additional instructions and selection criteria. Further, the necessity of an additional mechanical brake is discussed.

Background

For specific drive applications, customers may specify an EMERGENCY OFF function. According to VDE 0113, an EMERGENCY OFF must be implemented as a stop, Category 0 or as a stop, Category 1. The significances of categories 0 and 1 are as follows:

Stop, Category 0:
The drive is shutdown in an uncontrolled fashion by immediately disconnecting the power. The motor coasts down. This corresponds to OFF2 (immediate inverter stop) for MASTER DRIVES drive converters in conjunction with an intrinsically safe disconnection of the main contactor or drive converter output contactor.

Stop, Category 1:
This involves a control shutdown, whereby the power is still connected. The power is only disconnected when the drive comes to a complete standstill. For MASTER DRIVES drive converters, this is realized using OFF3 (fast stop), in conjunction with a subsequent intrinsically safe disconnection of the main contactor or drive converter output contactor.

Comment:

For standard drive converters, i.e. drive converters which do not have a braking function, only a stop, Category 0 is practical. An EMERGENCY OFF, Category 1, generally requires a braking function (braking unit or drive converter with regenerative feedback into the line supply, possibly also DC current braking; refer to Section 3.4).

The category must be selected according to the risk evaluation of the driven machine. The drives can be roughly sub-divided into the following groups:

Drive types as far as EMERGENCY OFF is concerned

Case A:

Drives, which when shutdown, are braked down to zero speed in a short time as a result of the connected load.
Typical examples: extruders, pumps.
In this case, an EMERGENCY OFF with stop according to Category 0 is sufficient.

Case B:

Drives with higher moments of inertia, which when shut down are braked down to zero speed as a result of the connected load.

Typical example: Fans.

In this case, an EMERGENCY OFF with stop according to Category 0 is sufficient if the run-down (coast-down) time can be tolerated. However, if an EMERGENCY OFF requires that the drive is shutdown within a specified time, then it may be necessary to use EMERGENCY OFF with stop according to Category 1. This may require a braking function even though this is not required for the actual drive itself.

Case C:

Drives with higher moments of inertia where the drive speed is hardly braked as a result of the connected load at shutdown.

Typical example: Centrifuges, roller table drives, presses, paper machine drives.

In this case an EMERGENCY OFF with stop according to Category 1 is required. Generally, this requires a braking function.

Case D:

Drives which must be shutdown when a fault develops in order to prevent any (significant) subsequent damage.

Typical example: Crane drives, hoisting drives, presses.

In this case, an EMERGENCY OFF with stop according to Category 0 or 1 can be used. For EMERGENCY OFF with stop according to Category 0, a mechanical brake is also required which should also be provided for an EMERGENCY OFF with stop according to Category 1. This means that the drive can still be shutdown even when the drive converter fails.

Is an additional mechanical brake required in conjunction with EMERGENCY OFF for a stop according to Category 1?

The definition of VDE 0113 for a stop according to Category 1 - ...*whereby the power is still connected to shutdown the drive ...* - requires that the drive must be able to be shut down in a controlled fashion after the EMERGENCY OFF pushbutton has been depressed. In this case, the MASTER DRIVES drive converter or inverter must operate perfectly. For most cases, this can be assumed when EMERGENCY OFF is depressed. This is also assumed in the examples provided in the Application Manual in Section 4.4.

However, in seldom cases it cannot be completely excluded that the drive converter itself develops a fault or that the EMERGENCY OFF function was initiated by a fault or by a converter fault. In cases such as these, it can no longer be guaranteed that the drive is braked in a controlled fashion by the drive converter. In this case, it can only be achieved by using a mechanical brake.

If the customer requests an EMERGENCY OFF function for stop according to Category 1, then this must be discussed with the particular customer. If the customer (and this is only in extremely seldom cases) can tolerate a longer braking time (corresponding to the run-down time) when an EMERGENCY OFF is initiated by a drive converter failure, then a mechanical brake is not required. This is generally the case for drive applications B and C discussed above.

However, an additional mechanical brake is absolutely necessary, if the drive must be braked down to zero speed in a controlled fashion when an EMERGENCY OFF is initiated, independent of the drive converter. This is the case for drive application D. However, a mechanical brake may also be required in any of the other applications, B and C.

6.2 Bypass circuit

Background information

If the motor is to be either operated from the line supply or from a drive converter, then a bypass is involved. Bypass circuits are required, for example, to allow the drive converter to be directly connected to the line supply when a fault develops. They are also used for high moments of inertia, to accelerate the motor using the drive converter, and then to connect and operate the motor directly from the line supply. Dedicated switching devices are required to realize this. The basic block diagram of a bypass circuit is illustrated in Fig. 6-1.
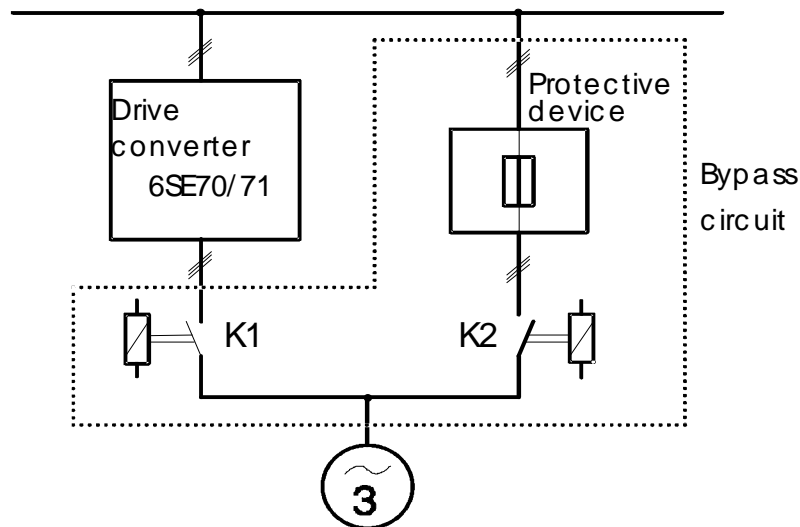
Fig. 6-1: Basic block diagram of a bypass circuit

As for the previous 6SE35/36 and 6SC36/37 drive converters, MASTER DRIVES drive converters also have optional bypass cabinets. However, this option is presently not available. Bypass cabinets must be designed and engineered by sales departments, and then built in a workshop, e.g. FSZ Bielefeld.

Comments regarding contactors at the drive converter output.
It is principally possible to provide a contactor at the output of single-motor drive converters so that the motor can be reliably and safely switched into a no-voltage condition. Even if the contactor opens in operation, no dangerous switching spikes can occur as they are rectified via the free-wheeling diodes of the inverter, and are therefore limited to the drive converter DC link voltage. However, the following two points should be observed.

- The contactor should not be located close to the drive converter, but, if possible, should be accomodated in an adjacent cabinet. If the contactor opens in operation, and an arc is briefly present across the contactor contacts, significant EMC problems could occur with the danger of generating erronous firing pulses.

- If the contactor frequently opens in operation at low frequencies < 10 Hz, then the contactor must interrupt quasi DC currents, and the switching contacts could erode. Thus, a (if possible leading) auxiliary contactor contact should be connected to the binary input „inverter enable" of the drive converter. In this case, when the contactor opens, the motor current is electronically disconnected and an arc cannot occur across the switching contacts, or if it does occur, only briefly for several ms.

6.3 Bumpless transfer of squirrel-cage induction motors to the line supply

Background information

Frequently, motors must be run-up to rated speed using a drive converter and then subsequently changed-over or „transferred" to the line supply. This is necessary, for example, for a system including several pumps, whereby only one is closed-loop speed controlled and the others either run at a fixed speed, or are shutdown. If the flow is to be increased, the speed of the pump motor at the drive converter is increased up to the rated motor speed. This motor is then switched to the line supply and instead, an additional pump is operated closed-loop speed controlled via the drive converter. The motor should be transferred to the line supply as smoothly as possible (bumpless transfer).

Basic changeover with a no-load interval

The simplest method is to power-down the drive converter (inverter stop!), isolate the motor from the drive converter output, and after a specific time, switch it to the line supply as is generally the case for a bypass changeover. This no-load interval must be selected long enough so that the motor field has decayed before the motor is connected to the line supply. (Otherwise, there is a danger that the still available motor EMF is connected, in phase opposition, to the line supply with the appropriately high short-circuit surge current).

Approximately 300% of the main field time constant T_{HF} of the motor should be used as no-load interval:

$$t_{load\ interval} > 3 * T_{HF} \approx 3 * \frac{L_h}{R_2}$$

whereby L_h = main field inductance
   R_2 = rotor resistance

With $L_h \approx \frac{1}{2 * \pi * f_n} * \frac{Vn}{\sqrt{3} * I\mu}$ and $R_2 \approx s * \frac{V_n}{\sqrt{3} * I_n}$ is $t_{load\ interval} > \frac{3}{2 * \pi * fn} * \frac{I_n}{I\mu} * \frac{1}{s}$

Thus, the required no-load intervals of approx.   0.3 s .... 0.7 s .... 1.6 s .... 3.6 s
are obtained for motor outputs of   1 kW .... 10 kW .... 50 kW .... 500 kW

If these no-load intervals are maintained between disconnecting the motor from the drive converter and switching the motor to the line supply, then the motor speed decreases so that the motor, when connected to the line supply, must first accelerate up to the rated speed. In this case, a current surge occurs and the line supply is stressed. Although this is lower than when connecting a stationary motor, the transition isn't smooth which is also reflected in the mechanical stressing.

Realistic possibilities to achieve smooth, synchronized bumpless transfer of the motor from the drive converter to the line supply.

The ideal condition would be if the squirrel-cage motor, which is generally the case in the textile industry when synchronizing Siemosyn motors, is first accelerated up to the rated speed using the drive converter. The drive converter output voltage is then synchronized with the line supply voltage, and the motor is then transferred to the line supply. If this motor transfer is realized without any overlap (i.e. the motor is not connected during the changeover time of approx. 50 to 60 ms), then smooth bumpless transfer is also not achievable here. A real smooth bumpless transfer is only possible by using an overlapping changeover (transfer). The two methods are now described in more detail - overlapping and non-overlapping transfer.

Comment:

It is not possible to synchronize the drive converter output voltage to the line supply voltage using the present software release of the open-loop and closed-loop control (software release 1.2), using the „synchronizing" software function. Also refer to Section 2.4.5. This can only be realized using the T300 technology board (angular synchronous control).

It will be possible to synchronize using a new software release of the CU2 control board, also probably using the TSY tachometer and synchronizing board, but without technology board. You will be separately informed about these options.

Overlapping synchronized transfer

In this case, an additional de-coupling reactor L_{couple} with at least 6 to 8 % u_K (i.e. 6 to 8 % inductive voltage drop when the rated drive converter current flows in the reactor with 50 Hz), is required, as shown in Fig. 6-2.

As this reactor is only briefly loaded and otherwise is bypassed or disconnected, its rated current can be dimensioned lower than the rated drive converter current. Transfer is realized as follows:
The drive converter output voltage is first synchronized to the line supply voltage with contactors K3 and K2 open and contactor K1 closed.
Contactor K2 is then closed and thus the drive converter output is switched to the line supply via the de-coupling reactor.
Contactor K1 then opens, K3 closes and the motor is transferred to the line supply.

The motor can be transferred back to the drive converter in the inverse sequence.
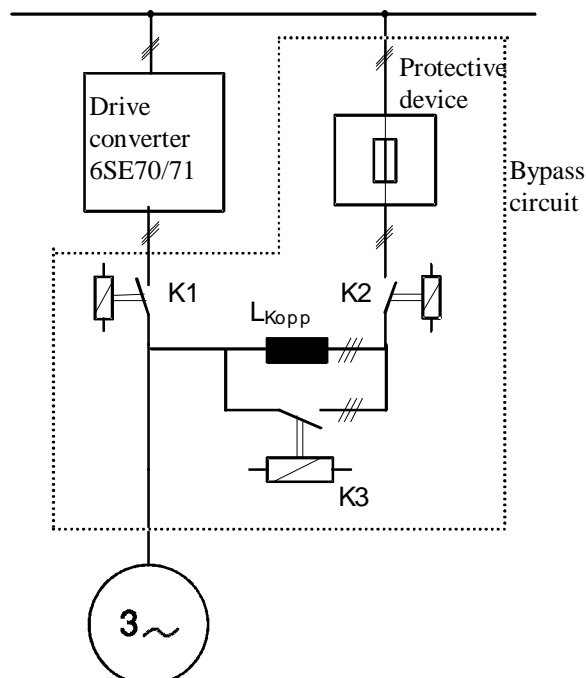
Fig. 6 - 2 Bypass circuit with overlapping transfer
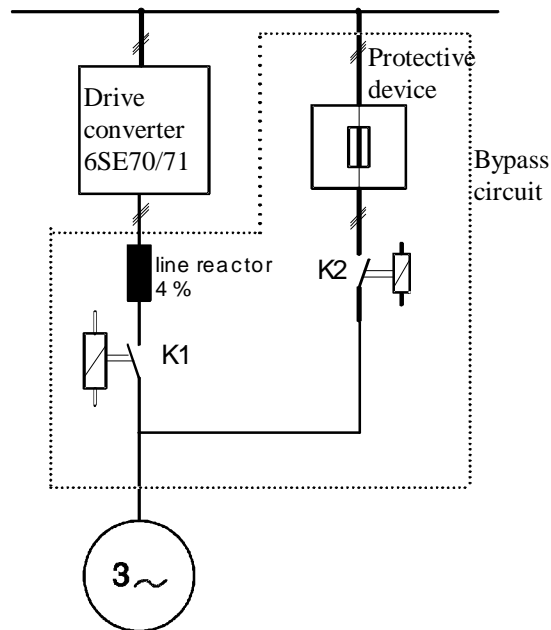
Fig. 6.3 Bypass circuit with overlapping transfer (version)

The adjacent circuit is a possible alternative. It has a line commutating reactor of 4% u_K, which requires one less contactor whereby the reactor must be dimensioned for the full drive converter current in continuous operation.

Non-overlapping, synchronized transfer.

In this case, only the two output contactors as shown in Fig. 6-1 are required. The transfer procedure is as follows:

The drive converter is first ramped-up to the line frequency and line voltage and synchronized to the line frequency. The drive converter is shutdown with „inverter stop" using the synchronism reached signal. The motor is therefore in a no-current condition. The drive converter output contactor is then opened and the line contactor closed. This transfer process should be as short as possible, however, an unavoidable no-load interval of approximately 50 to 60 ms must be assumed. The motor is not controlled in this time. The transfer can only be bumpless if, at the instant that the motor is connected to the line supply, the available motor EMF has approximately the same phase position as the line supply voltage. It will now be investigated in detail just what sort of bumpless transfer can actually be realized.

How does the motor behave in the intermediate (no-load time) of approximately 50 to 60 ms?
If the motor stator current is interrupted, this does not mean that the motor voltage itself decays to zero. In fact, the short-circuit rotor means that the last existing magnetic field is maintained. This magnetic field remains interlinked with the spatial position of the rotor and it decays with the main field time constant $T_{HF} \approx L_h/R_2$. This means that a motor EMF is induced whose frequency corresponds to the rotor speed and which decays with the main field time constant T_{HF}.

Example: Characteristics for a 200 kW drive

Motor investigated: 1LA6 317-4AA.. with 200 kW, 1280 Nm, 1488 RPM, J_{motor} = 4.2 kg m².

When the motor is in a **no-load condition**, i.e. the motor is rotating with 1500 RPM (no slip), the line supply voltage (= drive converter voltage at the instant of changeover) and the induced motor EMF behave as illustrated in Fig. 6-4. The line supply voltage and motor EMF remain in phase and the motor EMF decays insignificantly within the 60 ms transfer time. Under these conditions, the non-overlapping transfer of the motor from the drive converter to the line supply is possible without any additional measures. There is no significant current surge when connecting the motor to the line supply and the transfer is practically bumpless.
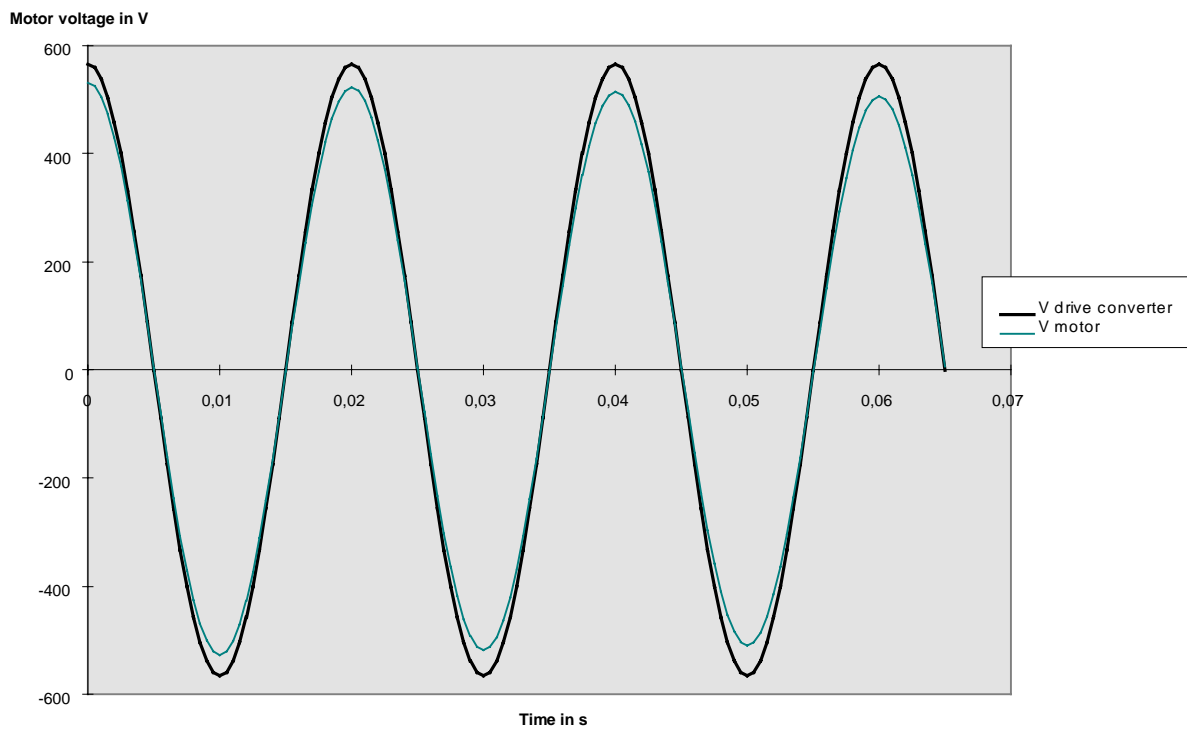
Fig. 6 - 4 Line supply voltage ($V_{drive\ converter}$) and motor-EMF (V_{motor}) under no-load conditions

In practice, the motor is generally not running under no-load conditions when it is transferred to the line supply. In fact, quite the contrary. Generally, the full load torque is present, e.g. for pump- or fan drives. The characteristics for a fan drive (assumption: load moment of inertia ≈ 20 x motor moment of inertia), are illustrated in the following diagram, Fig. 6-5.
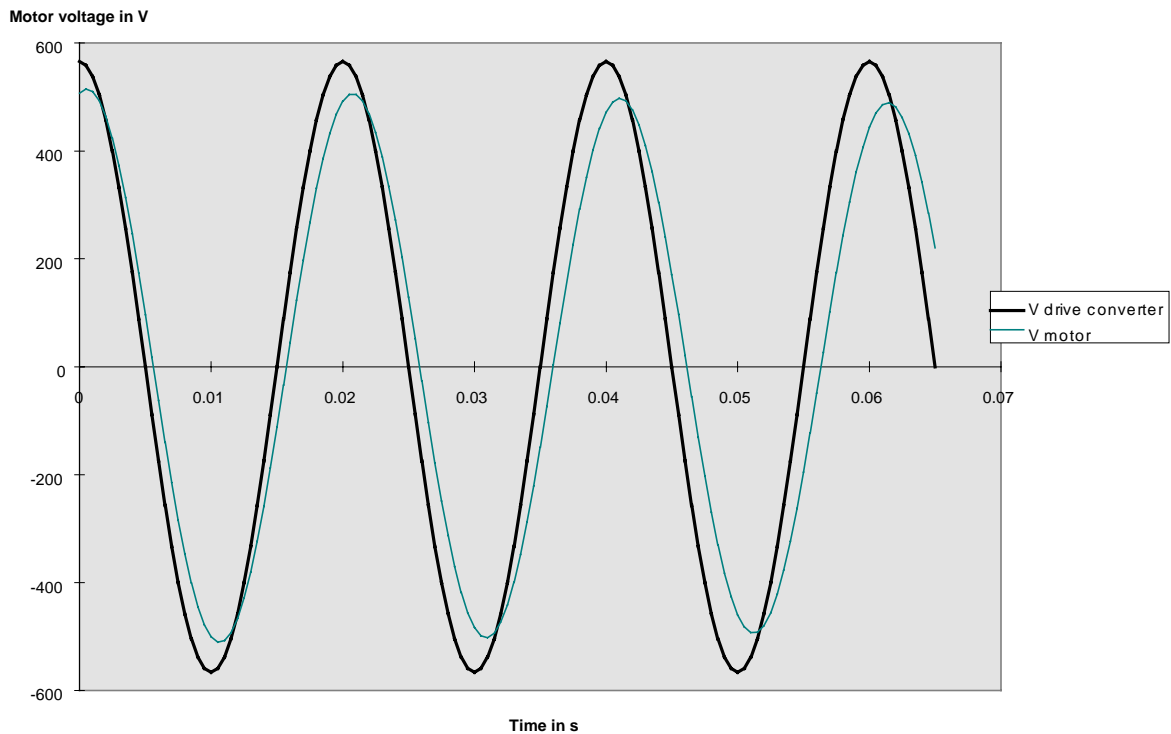
Fig. 6 - 5   Line supply voltage ($V_{drive\ converter}$) and motor EMF (V_{motor}) characteristics
under load and with a high load moment of inertia, e.g. fan with a 200 kW rating

As a result of the load, the motor EMF has, under normal operating conditions, a phase shift to the line supply and drive converter voltage of approximately 10% el. Further, the motor rotates with a slightly lower speed than that specified by the line frequency as a result of the slip of approximately 0.8 %. This means, that after the motor has been disconnected from the drive converter, the motor EMF and the line voltage increasingly drift apart so that after 60 ms, the angular difference has increased from approximately 10° electrical to approximately 20° electrical. The assumed high total moment of inertia means that this angular difference is not higher. Whereby the speed decrease as a result of the load torque can be practically neglected. Under this assumption, the motor can be transferred to the line supply almost bumplessly. If the angular difference between the motor EMF and the line supply voltage is greater than approximately 20 to 25° electrical, then it can be assumed that surge currents flow which can no longer be neglected when the motor is transferred to the line supply.

On the other hand, pump drives are critical, as they have a low moment of inertia and where it would be generally practical to use a bumpless synchronized transfer. The characteristics for a 200 kW pump drive are illustrated in the following diagram, Fig. 6-6.

Assumption: Load moment of inertia ≈ 0. x motor moment of inertia.
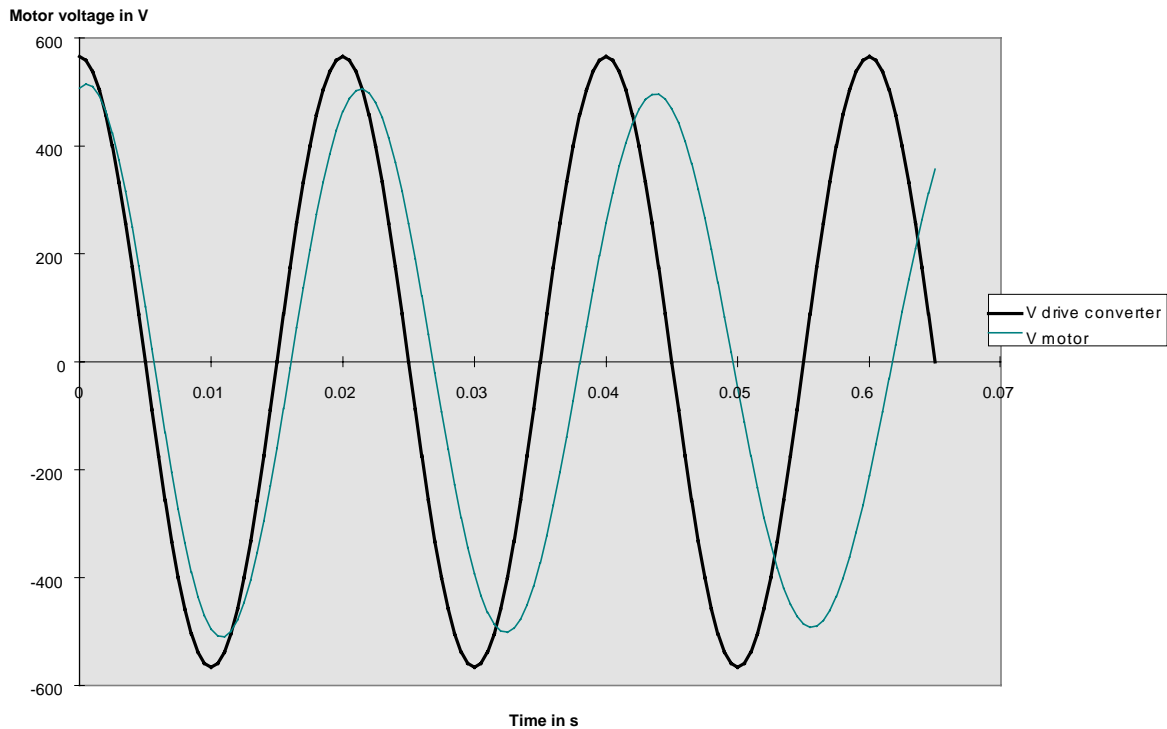
Fig. 6 - 6   Line supply voltage ($V_{drive\ converter}$) and motor EMF (V_{motor}) characteristics under load and with a low load moment of inertia, e.g. 200 kW pump drive

After the motor has been disconnected from the line supply, the motor speed does not significantly decrease as a result of the load and the relatively low total moment of inertia. Thus, the angular difference between the motor EMF and the line supply voltage rapidly increases so that after 60 ms there is almost phase opposition between the motor EMF and line supply voltage. If after 60 ms the motor was to be connected to the line supply, this would result in a high surge current > 10 x $I_{n\ motor}$, i.e. there is no bumpless transfer.

The behavior at lower outputs is even more critical. The motor slip increases with decreasing output and the motor moment of inertia increases over-proportionally with the output. Both of these effects mean that the phase difference between the motor EMF and line supply voltage increase quickly with decreasing drive output. This is illustrated in the following example involving a 22 kW drive.

As a result of the lower main field time constant, the magnetic field of the 22 kW motors and therefore the motor EMF decays faster. Further, just the higher slip of the 22 kW motor of 2.67 % alone, at a practically constant speed, results, even after 60 ms, in a phase difference between the motor EMF and the line supply voltage of over 40 °el. This is illustrated in the following diagram for a fan drive (it was assumed that the load torque $\approx$ 20 x motor moment of inertia).
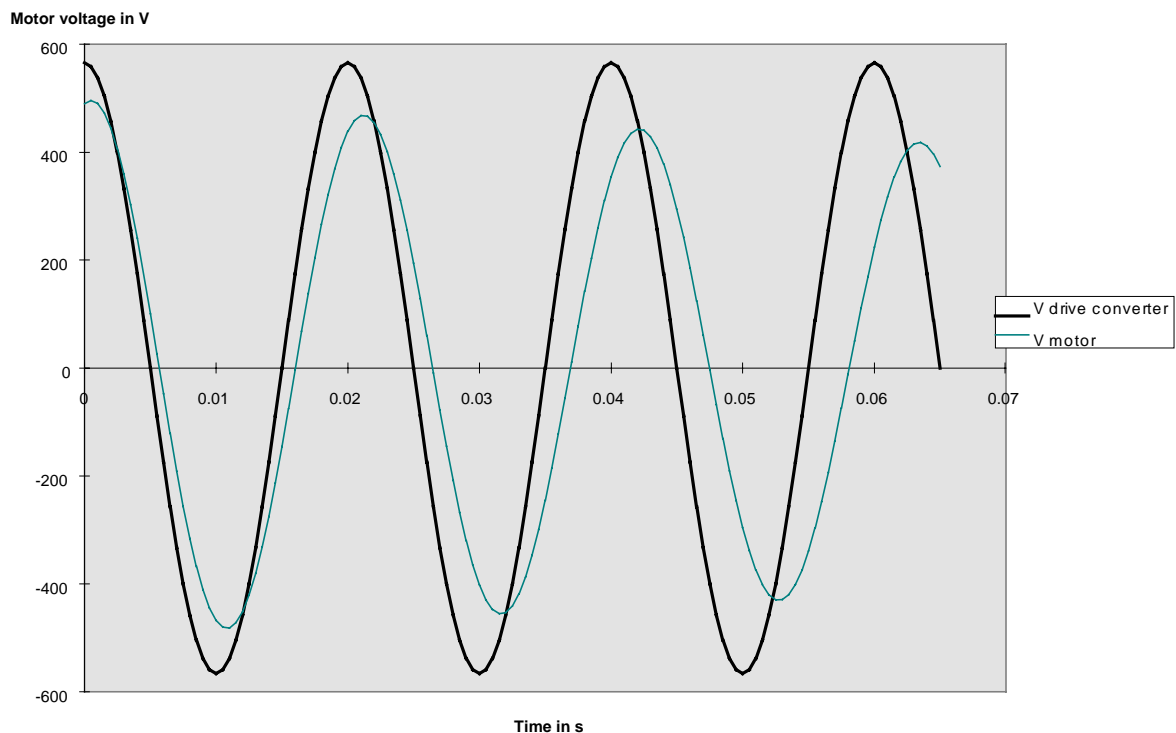
Fig. 6 - 7   Line supply voltage ($V_{drive\ converter}$) and motor EMF (V_{motor}) characteristics under load and with a high load moment of inertia, e.g. 22 kW pump drive.

In this case, bumpless transfer to the line supply is no longer possible.

This is even more critical for a pump drive as is illustrated in the subsequent diagram, Fig. 6-8. In this case, it is assumed that the load moment of inertia is 0.3 x motor moment of inertia.
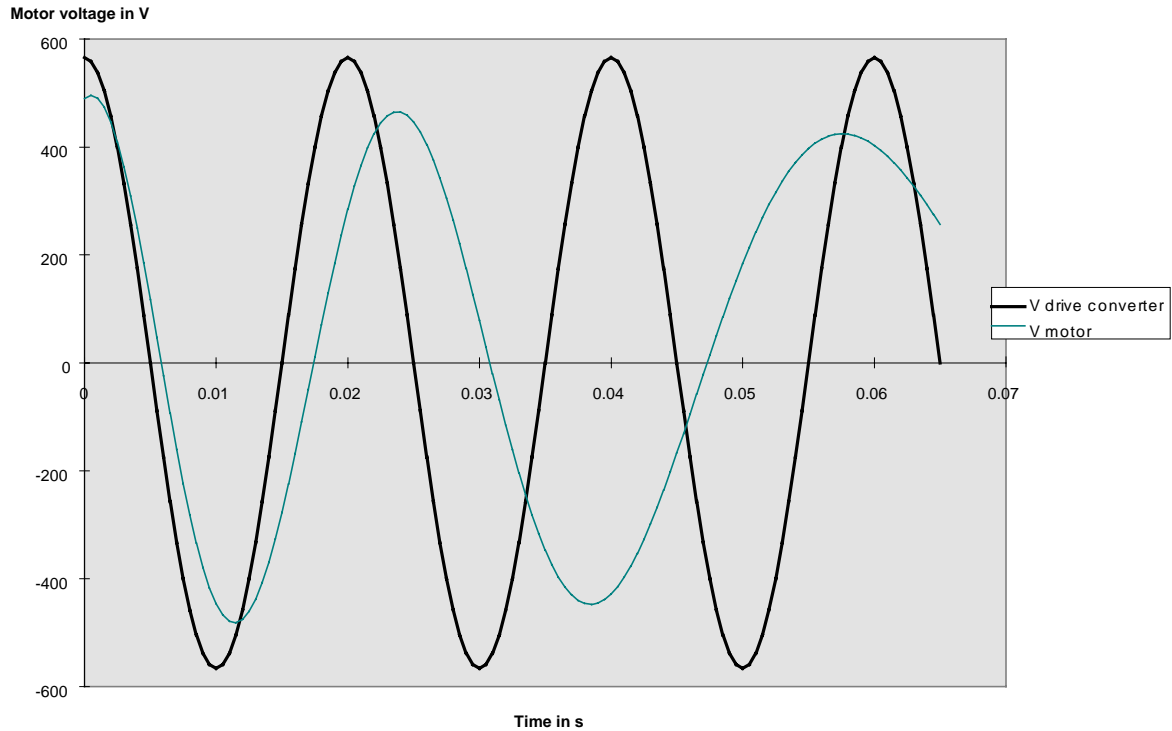
Fig. 6 - 8   Line supply voltage ($V_{drive\ converter}$) and motor EMF (V_{motor}) characteristics under load and with a low load moment of inertia, e.g. 22 kW pump drive

Already after approx. 40 ms, with the higher speed decay, there is phase opposition between the motor EMF and the line supply voltage. There is no longer synchronization nor bumpless transfer.

Summary

Summarizing, the following statements can be made regarding bumpless transfer of the motor from the drive converter to the line supply (and vice-versa):

A **non-overlapping, synchronized transfer** (with a no-load interval < 60 ms) can only be easily implemented, if
- either the transfer is made with the motor running under no-load conditions, or
- if there is a high overall moment of inertia **under loaded conditions and** the rated motor slip is less than 1%.

Thus, this type of transfer cannot be used for pump drives which are working at full capacity at the transfer instant. It can only be conditionally used for fan drives or centrifuge drives with high moments of inertia. However, the issue arises here as to whether the costs for the synchornizing function are justified. The other transfer type, where there is a just a basic transfer with a no-load interval of seconds, should generally be sufficient for these types of drives as the speed only decreases insignificantly and therefore the surge is low when the motor is connected to the line supply.

An **overlapping, synchronized transfer** can be used for all drives but also results in significantly higher costs and should therefore only be used if the customer demands an absolute bumpless transfer to the line supply which can only be guaranteed with this configuration.

A **basic transfer with a no-load interval** of seconds can also be used for all drives and is cheaper. This should always be used wherever possible. In this case, the line supply is subject to some surge, but in any case, this is significantly lower than when connecting a stationary motor to the line supply.

7 Other subjects

This Section include various subjects which cannot be clearly assigned to previous subject groups.

7.1 Motor in a no-voltage condition

Background: Often, work must be carried-out on a motor, which is connected to a drive converter, after the drive converter has been shutdown. For example, the motor may have to be disconnected and replaced by another motor. In order that this work can be safely carried-out, it must be ensured that there are no dangerous voltages at the motor terminals.

The question arises, as to whether the motor is already in a no-voltage condition after the drive converter has been shutdown, or how long it takes until it is in a no-voltage condition.

It must always be assumed, that **as long as a DC link voltage is still available**, even if the inverter is not energized, voltage will be present at the motor terminals via the snubber circuitry. After the drive converter has been shutdown, it still takes a relatively long time until the DC link voltage has decayed; approximately 5 minutes. Thus, dangerous voltages can be present at the motor terminals for this time. It is only permissible to work on the motor and drive converter terminals after this time has expired or after you have convinced yourself, after the drive converter has been shutdown, that the drive converter DC link voltage is less than 60 V.

If the customer requests that the motor- or drive converter terminals must be accessible immediately after the drive converter has been shutdown, then additional measures must be taken.

For example, a resistor can be provided which quickly discharges the DC link. The required resistance corresponds to the pre-charging resistance.

Caution: If the DC link is frequently discharged quickly, then this negativelly effects the lifetime of the DC link capacitors.

Alternatively, a drive converter output contactor or a switch can be provided.

7.2 "Safety off" function

This function is known as „Safety stop" or, for SIMODRIVE units, also as „START INHIBIT".

Background: For many applications, accidental starting of the drive motor or hazardous motion, which could either be caused by switching operations, or due to incorrect operation of the drive converter control, must be reliably prevented.

Example: Paper machine. In this case, after a fault, the torn paper web must be removed from the system and it must be ensured that the rolls don't start to move otherwise this could result in an accident.

The following is decisive in cases such as these:

European Standard EN 1037 (1995): Safety of machines. Preventing unexpected starting. Section 4.1 defines that suitable devices must be provided to isolate the equipment from the power supply and to discharge any energy.
Further, under Section 5.3.1.2 also specifies: "If the discharge of stored energy would significantly restrict the availability of a machine, additional devices must be installed to reliably buffer the remaining energy".
For instance, this involves a multi-motor drive with inverters connected to a common DC link. In this case, suitable resources must ensure that the "stored energy", i. e. the energy stored in the DC link capacitors of the individual inverters, is reliably buffered with the DC link voltage still available.

The safety off function was introduced for this purpose. We have an appropriate letter from the BIA (German regulatory body for safety at work).
The safety off function consists of a recently developed "SSB" board which can interrupt the control signals of the inverter IGBTs.

The basic block diagram of this board is shown in Fig. 7.2.

By withdrawing the power supply for this board, the gating signals are interrupted. If the power supply is disconnected via the safety relay, the inverter power section can no longer power the connected motor, even if the control electronics was to output control commands. In this status, the drive is in the "Safe stop" or „Safety off" status, but the motor is still not electrically isolated from the drive converter output.

The safety relay has 2 contacts; one NO contact and one NC contact, which are positively driven, so that even when it is faulted, e. g. welded contacts, NC- and NO contacts cannot be simultaneously closed. The NO contact connects the optocoupler with the power supply, the NC contact is used as checkback signal, e. g. to control a signal lamp, which displays the "Safety off" status.

It should be observed, that the "SSB" board prevents the motor from accidentally turning, but in the "Safety off" status, dangerous voltages are still present at the motor terminals. Also refer to the information in the previous Section 7.1.

Power supply for the optocoupler
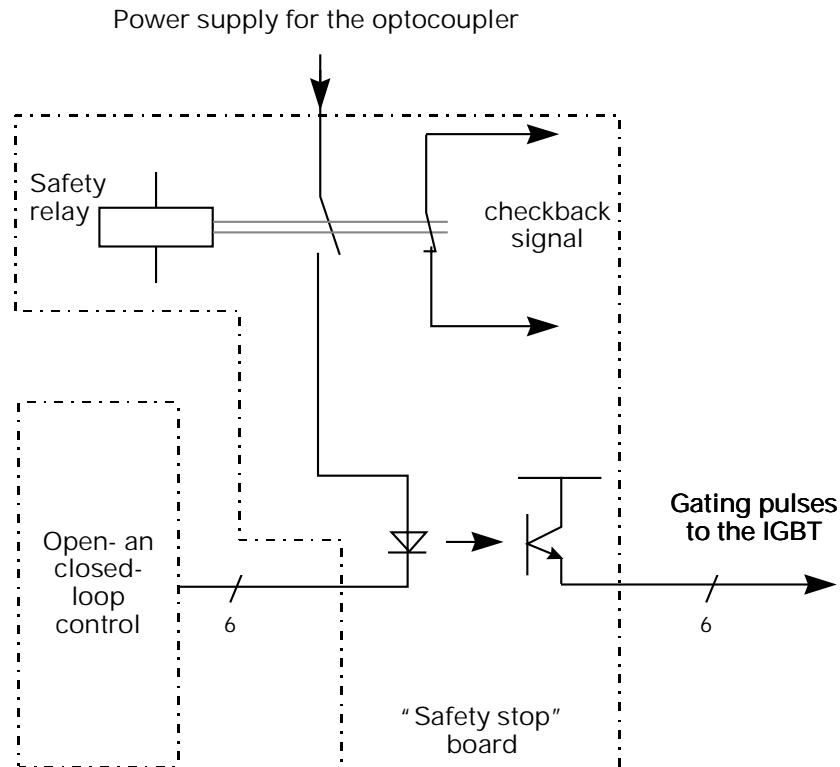
Fig. 7.2 Block diagram of the SSB board for the „Safety off" function

Comment: The safety stop function can also be implemented by locating switches or contactors between the drive converter output and the motor, whose switching status can be proven, e. g. using visible lock-out devices or using the appropriate checkback signals. However, this can be extremely complex. Thus, the above described function has been introduced.

The safety off function using the "SSB" board can be ordered as option K80 for chassis- and cabinet units from 45 kW and above. For the compact units 2.2 to 37 kW, the safety stop function is already included in the standard with the "SSB" board, and more specifically, only for the DC-AC inverters which are connected to a DC link voltage, however not for the drive converter units (AC-AC drive converters).

Note: The „Safety off" function supports Safety Category 3 according to EN 954-1. However, it is not valid as emergency off device according to EN 60204 T.1. For this purpose, as before, electrical isolation is specified.

7.3 MTBF data and availability of the drive converters or inverters.

The MTBF - Mean Time between Failures - is significant regarding the failure rates of the drive converters.

The MTBF values, specified in the following tables, are calculated using the FIT values of the components used in the drive converter. These values specify the time, after which a failure can be expected.

The specified times do not correspond to reality. Long years of experience has shown that equipment only fails after 300 to 400 % of the MTBF value.

Caution: The MTBF values do **not** take into account fuses and fan! Thus, in order to guarantee the maximum disturbance-free operation, the fan should be replaced before its scheduled lifetime expires, in accordance with the Operating Instructions for the drive converters (> 35.000 hours, 10 % of the fans can fail after this time).

Drive converter or inverter	Output for			MTBF years
Size	**400 V**	**500 V**	**690 V**	
A	2.2 to 4 kW	--	--	7.5
B	5.5 to 7.5 kW	2.2 to 7.5 kW	--	6.8
C	11 to 15 kW	11 kW	--	5.5
D	18.5 to 37 kW	18.5 to 30 kW	--	4.8
E and F	45 to 90 kW	37 to 55kW	55 to 75 kW	7.9
G and H	110 to 200 kW	75 to 160 kW	90 to 200 kW	9.5
J	250 kW	200 to 250 kW	250 to 315 kW	8.0
K	315 to 630 kW	400 to 630 kW	400 to 800 kW	7.0
M	710 kW	710 to 1100 kW	900 to 1500 kW	3.5
Rectifier units				
B and C	15 to 37 kW	22 to 55 kW	--	114
E	75 to 250 kW	75 to 315 kW	160 to 400 kW	67
H and K	400 to 800 kW	450 to 1100 kW	630 to 1500 kW	15
Infeed/regenerative feedback units				
C	7.5 to 37 kW	11 to 55 kW	--	38
E	75 to 250 kW	90 to 315 kW	110 to 400 kW	30
H and K	400 to 800 kW	450 to 1100 kW	630 to 1500 kW	15

If the customer requests information regarding the **availability** of a drive converter or a system, then this can be determined from the MTBF data.

Example: The availability of a 400 kW drive converter is to be determined at 400 V. The MTBF of this drive converter is 7 years. It can be expected, that within this period a fault occurs which requires for this specific case, 3 day to resolve it; depending on existing spare parts or the availability of a service engineer. Further, it is assumed

that the fan is replaced during this time, whereby 1 day must be taken into account to do this. The availability of this drive converter is then defined as follows (7 x 365 - 3 - 1) / (7 x 365) > 99.8 %.

Additional example: The availability of a system with a total of 10 drive converters, 400 kW at 400 V is to be determined, whereby if any one drive converter fails, this signifies the failure of the complete system. In this case, it can be assumed, that each drive converter develops a fault condition within 7 years, however at different times. Thus, the availability of the system is obtained as follows (7 x 365 - 10 x 3 -10 x 1) / (7 x 365) > 98.4 %.

7.4 Different inverter loading at the DC bus

Prerequisite: Several inverters are connected to a common DC link through a DC link coupling (e. g. according to Fig. 10.3.2, Catalog DA65.1 for compact- and chassis units or with option L36 for cabinet units). In practice, it is possible that not all of the inverters are powered-up as is normally the case. Quite the contrary, several inverters can be powered-down.

Additional prerequisite: The DC link voltage is supplied from rectifier units, frame size H, i. e. above 400 kW or via infeed/regenerative feedback units. These units include thyristor line current converters with phase control. Their open-loop and closed-loop control concept includes a higher-level closed-loop DC link controller and a secondary current controller.

Problem with this configuration: Each inverter has an associated DC link capacitance. Thus, the total effective capacitance in the DC link is linked with the number of inverters powered-up, and therefore changes if individual inverters are switched-in or out. The setting of the closed-loop control parameters of the rectifier or rectifier/regenerative feedback units assumes however a specific load with DC link capacitances. Thus, the closed-loop control parameters must be set to specific values when all of the converters are switched-in. This is identified using a „Circuit identification" for this particular configuration. If the DC link capacitance changes, for example, by disconnecting inverters, then the DC link is "untuned" and the closed-loop control of the rectifier or the rectifier/regenerative feedback unit becomes instable which can make itself noticeable as a result of oscillation. Fuses can rupture.

Possible counter-measures.

a) Providing an additional DC link capacitance
The above mentioned problem can be resolved using an additional DC link capacitance. However, this is extremely complex, as a capacitance of at least 50 % of the total available inverter DC link capacitance must be additionally made available. Further, it is also not necessary.

b) Adapting the closed-loop control parameters to different inverter loads

In this case, it is possible to adapt the closed-loop control parameters of the infeed and infeed/regenerative feedback units to the various inverter load levels. An example briefly shows the best way to do this.

Example: A system with a total of 12 inverters having the same output is analyzed, whereby the individual inverters can be powered-up or down as required. At least 1 inverter must always be powered-up. In this case, proceed as follows:

The number of inverters to be powered-up should be sub-divided into 4 possibilities, e. g.

Case 1: Up to 10 %   of the DC link capacitance is switched-in   e. g. only 1 inverter is powered-up
Case 2: 10 to 30 %   of the DC link capacitance is switched-in   e. g. 2 to 4 inverters are powered-up
Case 3: 30 to 60 %   of the DC link capacitance is switched-in   e. g. 5 to 7 inverters are powered-up
Case 4: 60 to 100 % of the DC link capacitance is switched-in   e. g. 8 to12 inverters are powered-up.

Which of these cases exists, should be coded and appropriately prepared in the form of 2 binary signals, e. g. in the form of 2 relay contacts. 2 binary inputs of the rectifier and rectifier/regenerative feedback unit can be driven using these signals, which must be parameterized so that various data sets can be selected ("select reserve data set"). Thus, for each of these particular cases, different control parameters are available (but adapted for the particular case). In practice, for each individual case

        e. g. for   1   3   6   10   inverters which are powered-up,

a dedicated „circuit identification" of the rectifier- or rectifier/regenerative feedback unit must be executed, whereby the data found is saved in the particular characteristic data set.

If the switching status of the inverter is sensed in this way, and signaled to the rectifier- or rectifier/regenerative feedback unit, oscillations or instability should not occur and fuses should not rupture.

7.5 Connecting the DC links of drive converters (only for compact units)

Reason: If a multi-motor drive is involved, it is sometimes more favorable to use several drive converters and connect their DC links in order to achieve energy transfer between motoring and generating drives instead of having *several inverters connected to the DC link with a central incoming supply and rectification.* This is illustrated in the following diagram.
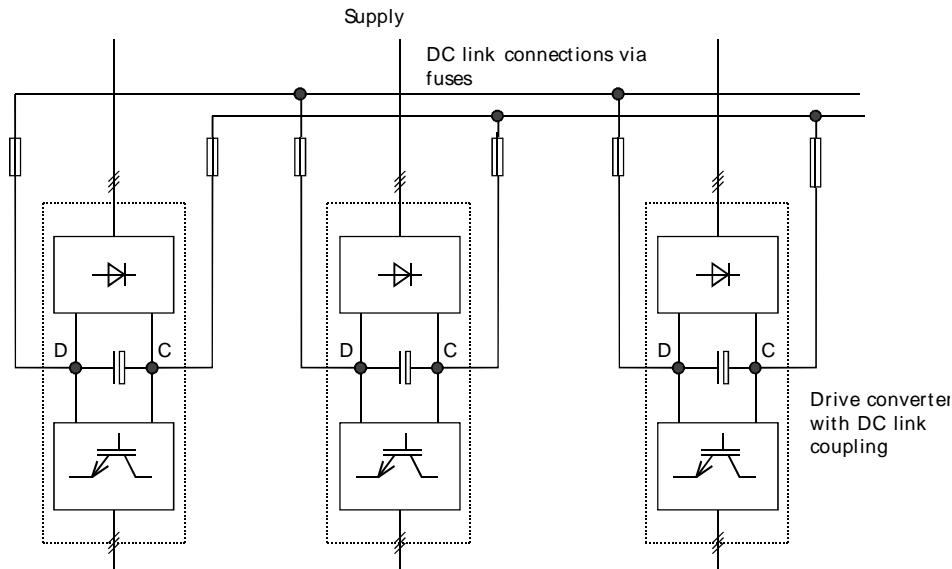
Fig. 7.5-1 Connecting the DC links of drive converters (only compact units up to 37 kW)

Such a solution has the following advantages:

over the solution with inverters connected to the DC bus:
- space saving, the rectifier unit is not required
- higher redundancy, the individual drive converters are not dependent on a central rectifier converter,

over the solution with individual drive converters without DC link connection:
Only 1 braking unit must be provided if individual drives sporadically regenerate, while a braking unit would otherwise have to be provided for each drive which is regenerating.

The ability to connect the DC links of complete drive converters is only possible for compact drive converters up to 37 kW, as is clearly stated in Catalog DA65.1, Section 19.5 on Page 19/4. If the DC links of individual drive converters are connected, then the following requirements must be fulfilled (also refer to the comments in Catalog DA65.1, Section 19.5):

- Line commutating reactors of at least 2 % u_K and a DC link fuse must be provided for each drive converter. Further, the same cable lengths should be used from the drive converter inputs to the supply connection point. Only then is the load- and power uniformly distributed over the parallel incoming rectifiers of the drive converter.

- The drive converters connected in parallel to the DC link, should be considered as a single unit. They should be simultaneously powered-up and down. Further, if one drive converter is faulted, this should cause all of the drive converters connected to the DC link to also be shutdown.

- The DC link connections should, if possible, be short-circuit proof. Fuses must be provided from the drive converter DC link connections to the DC link connections.

Drive converters as chassis units in the output range from 45 kW to 200 kW may not be connected via the DC link. The reason for this is the following:

Only compact drive converters up to 37 kW have input rectifiers consisting of a diode bridge with pre-charging resistors in the DC link which, after the DC link has been charged-up, are bypassed using a relay; refer to the following Fig. 7.5-2.
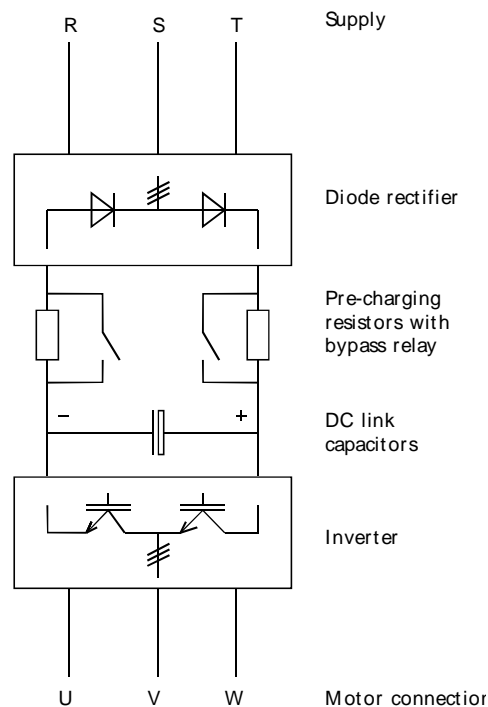
Fig. 7.5-2 Block diagram of the compact drive converter with charging circuit

For the chassis units, with an output range between 45 kW and 200 kW, the DC link is pre-charged differently, as illustrated in the following Fig. 7.5-3.

In this case, pre-charging is realized as follows:

When the line supply voltage is connected, the DC link voltage is pre-charged via the (auxiliary) diode bridge and the pre-charging resistors. The actual rectifier bridge is still not effective, as the thyristor firing pulses are still inhibited. If the DC link voltage is sufficiently high, the firing pulses of the rectifier bridge are enabled which then rectifies the current for normal operation. The special feature of this rectification type is that the firing pulses for the thyristors are derived from their cathode-anode voltages. If several such thyristor rectifiers would be connected in parallel, by connecting the DC links, then the first rectifier, which would be fired as a result of component tolerances, would inhibit the remaining rectifiers. This would mean that, only one rectifier would conduct, and would therefore be overloaded.
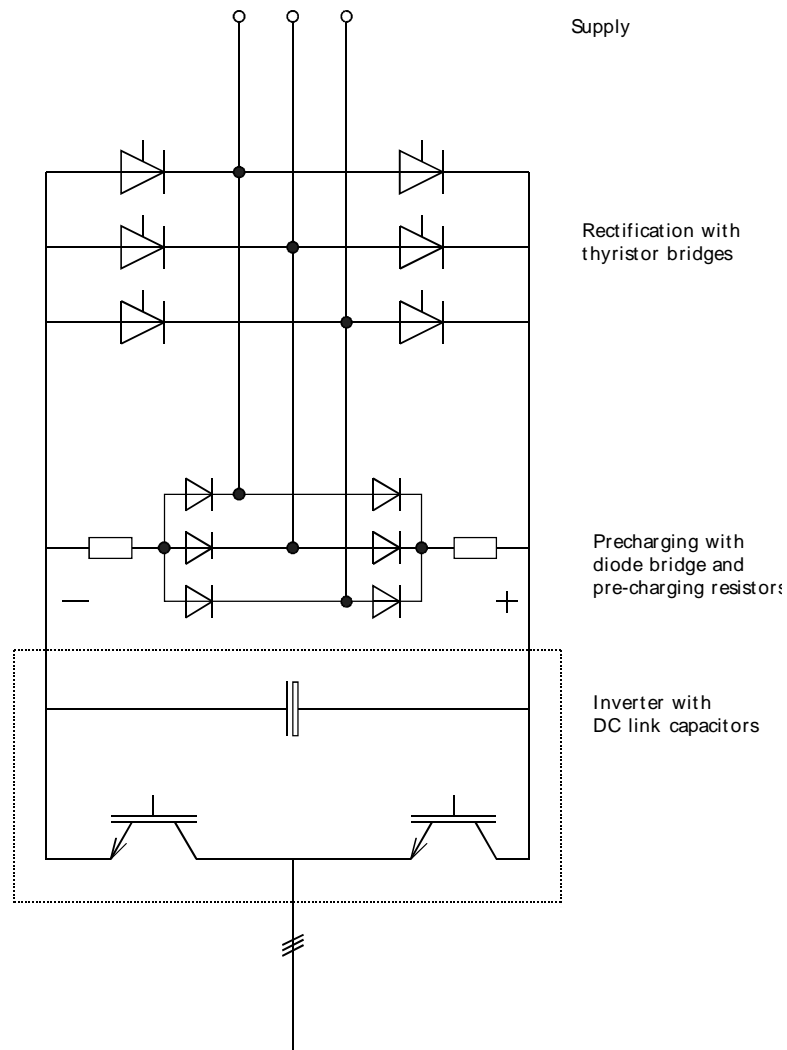
Fig. 7.5-3 Block diagram of the drive converter chassis units with charging circuit

The same would occur if the DC links of compact- and chassis units would be connected in parallel. The diode rectifiers of the compact units would inhibit the thyristor rectifiers of the chassis units, and would therefore be overloaded.

The DC links of drive converter cabinet units with outputs > 250 kW may not be connected. Reason: These drive converters include, as line supply rectifier, fully-controlled, line-commutated thyristor bridges with higher-level closed-loop DC link voltage control and secondary closed-loop DC link current control. If the DC links would be connected for drive converters such as these, the controls of the rectifiers involved, would work against each other, which is not permissible.

7.6 Harmonics fed back into line supplies due to long (screened) motor cables for drive converters operated from IT supply networks.

If Master Drives drive converters are connected to ungrounded line supply networks, and if the motors are connected via long, possibly screened feeder cables, then voltage spikes could occur on the line side, whose frequency could coincide with the inverter pulse frequency, e. g. 2.5 kHz for VC. The amplitude of these voltage spikes on the line supply voltage can exceed 200 V. If other loads are connected to the line supply, then these could be faulted or even damaged by these voltage spikes.

Why do the commutation operations in the inverter manifest themselves so strongly on the line side? This phenomenon can be explained using the following drive converter block diagram Fig. 7.6.
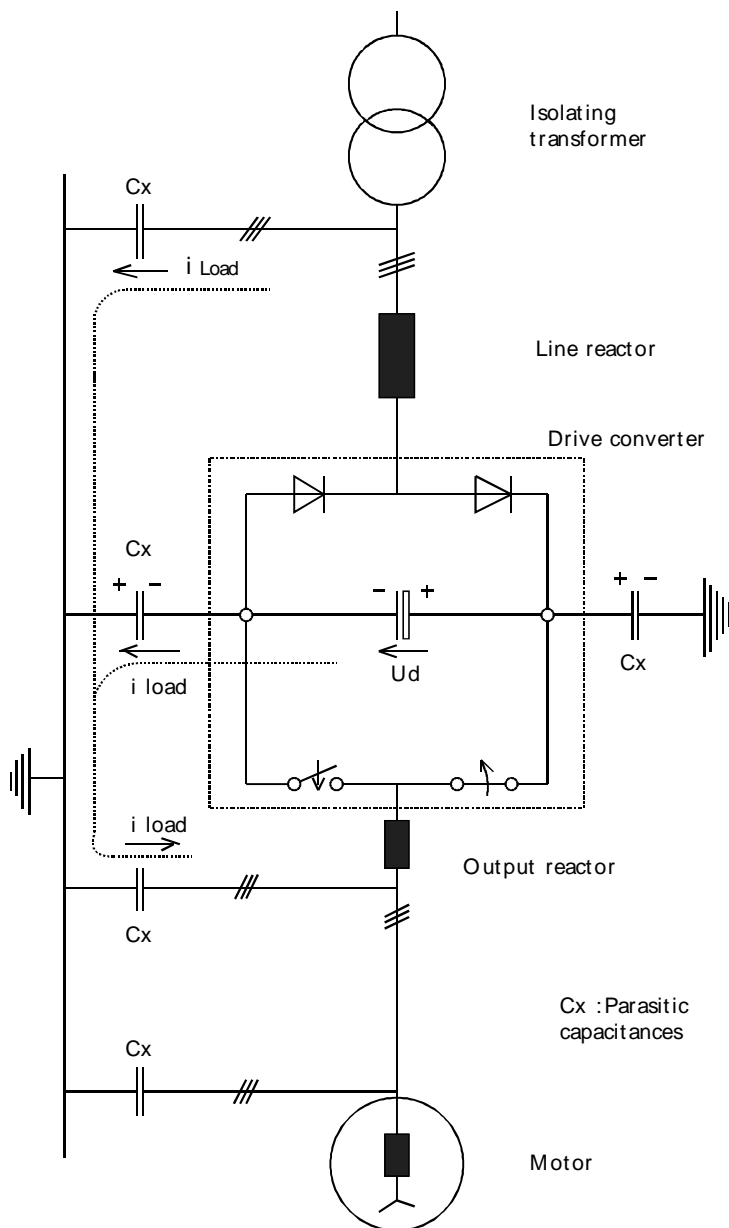
Fig. 7.6 Characteristics of capacitive re-charging currents during inverter commutation

It is assumed, that other loads are also connected to the line supply, and that there is a line commutating reactor. Further, it is assumed, that a drive converter output reactor is required due to the long motor cable length. As result of the long motor feeder cable, especially at the drive converter output, relatively high parasitic capacitances to ground potential are obtained. Additional parasitic capacitances occur between the DC link voltages with respect to ground and between the line supply voltages and ground.

The IGBTs of the inverter are represented by switches in Fig. 7.6. An IGBT switches extremely quickly with voltage gradients (voltage rate-of-rise) of dv/dt = 5 to 10 kV/µs; also refer to the information in Section 3.7. If the current is commutated in one phase of the inverter, e. g. the IGBT opens to the positive DC link side, and the IGBT closes to the negative DC link side, then the parasitic capacitance at the drive converter output is re-charged. Thus, a capacitive re-charging current flows which, depending on the particular situation, searches for a path via the parasitic capacitances, either on the DC link side, or the line-side. Oscillations, at the pulse frequency, can thus occur in the DC link as well as on the line side.

This particular phenomenon is manifested by any voltage-source DC link converter using fast-switching semiconductor devices such as IGBTs. The effects, especially the amplitude of the high-frequency oscillations, depend on the pulse frequency, the voltage gradients (voltage rate-of-rise) the inductances of the input- and output reactors, the motor cable type and its cable length as well as the system damping. It cannot be predicted with any great certainty as to whether voltage spikes such as these will occur in significant amplitudes or will be adequately damped in specific installations.

If high voltage spikes up to 1000 V are obtained on the line side due to this phenomenon then this is inadmissible for the other loads. As counter-measure we recommend that additional MKV capacitors are provided on the line side of the line commutating reactor with respect to ground. This additional capacitance should be several factors higher than the parasitic capacitances of the drive converter, motor feeder cable and motor. The additional capacitance stabilizes the line supply- and DC link voltage with respect to ground. Our experience has shown that a ground fault monitor will neither respond nor trip as a result of the additional capacitance. We recommend the following capacitor type:

B258... with   2.2 µF   2.1kV.

8. What you need to know about feeder- and drive converter transformers

8.1 Block transformers

Block transformers are transformers which only feed one single drive converter and which are adapted to the output of that drive converter.

If a drive converter is fed through a block transformer, then a line commutating reactor is not required for the drive converter under the assumption that the short-circuit voltage u_k of the transformer has a minimum value of 4% (better still: 6%).
Exception: You have a drive converter with rectifier/regenerative feedback unit in which case you must observe the comments made in Section 3.6.

The **rating** of a block transformer S_T can be calculated for a specific application most easily from the power equation of the drive:

$$S_T \quad k \, * \, \frac{P_W}{\lambda \, * \, \eta_{drive\ converter} \, * \, \eta_{motor}} \qquad\qquad \text{whereby}$$

P_W =   Shaft output of the motor (continuous output) or the rated drive converter output

$\eta_{drive\ converter}$ =   Drive converter efficiency

η_{Motor} =   Motor efficiency

λ =   Line power factor ($\approx$ 0.95)

k   =   Factor which takes into account the supplementary transformer losses due to the line-side harmonic currents

Comment regarding the line power factor λ:

The line power factor λ is given by $\lambda = g_1 * \cos\varphi_1 = \dfrac{I_{(1)}}{I_{rms}} * \cos\varphi_1$

In this case: g_1 basic fundamental of the current
                 $\cos\varphi_1$ line-side basic fundamental power factor

For outputs from 50 kW and above, where block transformers are considered, the following can be assumed as a good approximation:

$\eta_{drive\ converter}$ > 0.975 η_{motor} > 0.93

λ = 0.95 ....   for complete drive converters and for rectifier or regenerative feedback units
λ = 1 or λ = cos φ_{AFE} when using an AFE as rectifier (if cos φ_{AFE} is
                      parameterized to be < 1)
k = 1.2 ..... when using a standard distribution transformer and for rectifier- and or
           rectifier/regenerative feedback units
k = 1   ...... when using a drive converter transformer and when using an AFE

Thus, the **rating of the required block transformer is obtained as follows**:

When using a **standard distribution transformer**:

$S_T > 1.4 * P_W$ for complete drive converters and for rectifier- or rectifier/ regenerative feedback units or,

$S_T > 1.1 * P_W / \cos \varphi_{AFE}$ when using an AFE (and if $\cos \varphi_{AFE}$ is parameterized to be < 1)

When using a **drive converter transformer**:

$S_T > 1.15 * P_W$ for complete drive converters and for rectifier- or rectifier/regenerative feedback units or,

$S_T > 1.1 * P_W / \cos \varphi_{AFE}$ when using an AFE (and if $\cos \varphi_{AFE}$ is parameterized to be < 1)

For block transformers, the following **ratings (in kVA) are standardized:**

100   160   250   315   400   500   630   800   1000   1250   1600   2000   2500 kVA

When ordering the transformers, the **no-load ratio** must be specified. Generally, the no-load voltage on the low-voltage side is 5% higher than the voltage under full load conditions. For example, if a transformer is required to step down from 10 kV to 690 V, then it must be ordered with a no-load transformation ratio of 10 kV / 725 V.

Taps are used to adapt the ratio to the local voltage levels. For the standard transformer version, the **primary winding** has taps of ± **2.5 %.** These primary voltage taps can be set, when the transformer is in a no-voltage condition, by using jumpers. Additional taps can be provided when requested, at an additional price.

Circuit configurations and vector groups

The primary- and secondary windings of three-phase transformers can either have a star or delta circuit configuration. The circuit configurations are designated using the following code letters (upper case letters: Primary side, lower-case letters, secondary side):

    Y, y   for star windings,   D, d   for delta windings.

Further, each transformer has a code number n. This specifies by which angle φ the voltages on the primary side lead those of the secondary side. The following is true:

    $\varphi = n * 30°$ with   n = 1, 2, 3, ... , 11.

The usual vector groups of distribution transformers in the **standard version** are **Dy 5** or **Yy 0**. Neutral points are not fed-out (are not accessible).

8.2 Transformer type

Transformers can either be **oil-filled transformers** or **dry transformers (GEAFOL-T.)**.

Generally, **oil-filled transformers** have the lowest capital investment costs. However, they must generally be mounted outside buildings. These types of transformers can only be installed in buildings if there is direct access to the outside. Measures must be provided for ground water- and fire protection. Often, it is not possible to install the transformer close to the main load it is feeding although of course this is very desirable.

The capital investment costs for **GEAFOL transformers** are higher. As a result of their type of construction, without any liquid or combustible insulating medium, they can be mounted in buildings and therefore close to the main load. It is frequently the most cost-effective transformer in plants and systems with a relatively high power density as a result of its low losses and due to the fact that no measures have to be taken to protect ground water against contamination and pollution.

The transformers must be selected so that the cost-effective optimum is obtained for the complete system or plant, i.e. capital investment- and operating costs are a minimum. The following must be taken into account:

• Capital investment costs of the transformers,
• Measures at the point of installation,
• Operating costs as a result of losses, especially in the supply distribution network.

Further information and technical details on the transformers can be taken from these documents:

E50001-K7102-A101-A1   Catalog TV2 · 1996 TUMETIC, TUNORMA Oil-filled distribution transformers 50 to 2500 kVA

E50001-U413-A13   GEAFOL cast resin transformers

E50001-K7101-A101-A2   GEAFOL cast resin transformers 100 to 2500 kVA

E50001-U413-A59   GEAFOL drive converter transformers

8.3 Standard transformer or drive converter transformer?

Drive converter transformers are special transformers which are designed for, as the word suggests, drive converters. They are designed so that they can handle the increased stressing as a result of drive converter operation. Transformer manufacturers recommend that drive converter transformers such as these should be used if the component of the drive converter load represents more than 20% of the total load. What are the differences between drive converter transformers and standard distribution transformers?

The essential differences are as follows:

- The windings of drive converter transformers have an **increased insulation strength**. This means that they can handle extreme voltage increases during drive converter commutation.

- Using a **special winding or lamination design**, e.g. using low radial conductor heights for GEAFOL transformers, the **supplementary** losses due to current harmonics, are kept **low**.

- The transformer is mechanically designed so that low short-circuit forces occur with appropriately high short-circuit strengths. Frequent surge loads up to 250 percent of the rating, for example, typical for main rolling mill drives, can be handled without any problem due to the high thermal capacity of the transformers.

- **Pulse non-symmetry in the drive converter** (e.g. the firing pulses are interrupted for a thyristor but the full power is still drawn, with resulting DC-components of the line supply currents) could cause damaging overheating of the core and pressed components of GEAFOL transformers. This is effectively suppressed by monitoring the temperature of the tie bolt located in the core, and **means that the transformer is not damaged.**

As a result of the characteristics of the drive converter transformers, it is clear, that in some cases they have been designed for extreme operating conditions which generally do not occur in applications using MASTERDRIVES drive converters. For standard applications, if the transformer rating is adapted to the rated converter output, even normal distribution transformers can be used as block transformers instead of drive converter transformers. The following comments can be made for the points just listed:

Higher electrical stressing.
High voltage stressing, in this sense, up to 170 to 230 percent of the line supply voltage, only occurs during converter commutation, if a block transformer feeds a drive converter where the firing angle is 90° electrical, and if there is no line commutating reactor (as voltage spike at the end of the commutation dip, taking into account the effect of the thyristor snubber circuitry). This can occur for both DC drives and for current-source DC link drives (e.g. SIMOVERT A) at full load and at low speeds, whereby the firing angle of the line-side converter is controlled to an angle of approx. 90° electrical (also refer to the information provided in DIN VDE 0160, under Section 5.3.1.2).

On the other hand, for MASTERDRIVES as voltage-source DC link converter, the line-side converter acts just like a diode bridge, with a firing angle of practically $\alpha = 0$ °el. Thus, the commutation voltage dips and the overvoltage spikes are significantly lower and, when it comes to additional voltage stressing, can essentially be neglected. This is further enhanced if line commutating reactors are used which further reduce the commutating voltage dips and the associated overvoltage spikes.

Comment: According to VDE 0160, in a line supply network, overvoltages up to 230% of the peak line supply voltage can occur due to switching operations elsewhere in the supply network, e.g. if fuses interrupt a short-circuit current. This is independent of the drive converter. One must assume, that the insulation of the transformers must be able to handle these sporadic overvoltage conditions, both for standard- as well as for drive converter transformers.

Higher thermal stressing due to current harmonics.

In order that a distribution transformer is not thermally overloaded due to current harmonics, it must be overdimensioned by a minimum of 20 %, as was discussed in the previous Section 8.1. This is not required for drive converters with AFE, which essentially provide sinusoidal current.

High mechanical stressing during load surges
The high mechanical stressing for surge loads up to 250 % of the rated transformer current, which can be easily handled by a drive converter transformer, does not even occur in the first place for a standard application with MASTERDRIVES drive converters.

If the transformer rating is adapted to the drive converter output, then an overload is only possible up to 136 % rated current, due to the internal drive converter closed-loop control. Any load situation which goes beyond this, must be considered as a fault. This will cause the drive converter to be shut down with overload or overcurrent, or, under short-circuit conditions, will cause the specified line supply feeder fuses to blow. Under these conditions, it can be assumed that no inadmissible mechanical stressing occurs, and that a standard transformer can be used for MASTERDRIVES drive converters. Comment: Further, a short-circuit cannot be excluded, neither for standard transformers nor for drive converter transformers.

Subsequent effects when faults develop in the drive converter (pulse dissymmetry)
If pulse dissymmetry occurs for MASTERDRIVES drive converters, e.g. due to a missing firing pulse, in the incoming thyristor converter, used for higher drive converter outputs, then it can be assumed that this will be identified as fault (fault message F028; monitoring the DC link voltage ripple for twice the line supply frequency). The same is true if the same maximum power is drawn, causing the specified line supply fuses to blow as a result of the increased feeder current in the other phases. In both cases, the drive converter would be shutdown with a fault message.

Summarizing, we can say the following:

For standard applications, where the transformer rating is at least as high as the rated drive converter output, according to the formulas in section 8.1 (whereby for P_W, the rated drive converter output must be used), a distribution transformer is adequate. This is generally the case, if AFE is used as incoming drive converter on the line side.

A drive converter transformer is only required in special cases, especially if the average output is lower than the peak- or short-time output of the drive converter, and if the transformer rating is thus deliberately selected to be significantly lower than the rated drive converter output.

Prerequisite: The transformers must be equipped with the usual protective devices, e.g. Buchholz protection relay, oil temperature- and oil level monitoring for oil transformers or temperature monitoring using PTC sensors in the higher voltage winding of the GEOFOL cast resin transformers.

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8.4 Three-winding transformers

When operating variable-speed three-phase high-rating drives, there is often a demand for the lowest possible harmonics fed back into the line supply. With a 12-pulse supply, this can be implemented at a relatively low cost, if a supply transformer (feeder transformer) is required anyway to step down from the high-voltage supply. In this case, the transformer must be a three-winding transformer. Three-winding transformers are always designed as drive converter transformers.

The principle mode of operation of the 12-pulse feed was already explained in Section 3.6.2. The following text only discusses the characteristics, which these transformers must have, when it comes to their use together with MASTERDRIVES drive converters.

Specifications and requirements of three-winding transformers for 12-pulse operation of MASTERDRIVES

In order that an optimum 12-pulse behavior is obtained, i.e. the current harmonics with order numbers (harmonic order numbers) 5, 7, 17, 19, 29, 31 etc. at the transformer high voltage side, must be suppressed as far as possible. On one hand the three-winding transformer should be as symmetrical as possible, and, using suitable measures, it must be ensured that the two incoming rectifiers are uniformly loaded. A uniform current distribution is realized by (mainly ohmic) voltage drops across:
- transformer secondary windings,
- feeder cables
- line commutating reactors, if used.

This also results in the requirement that the feeder cables are identical, i.e. cables with the same cable cross-section and the same cable length.

> **Comment:** Even if the rectifier units use thyristor converters for the rectifier-regenerative feedback units, and the 12-pulse input circuit is a master-slave configuration, then this means that there is still no unified current distribution (this is different than, e.g. for DC link drive converters such as SIMOVERT A). The reason for this is that under standard operating conditions, the firing angle is $\alpha = 0$, and closed-loop current control is not possible if the voltage of the two secondary windings of the transformer are the same. A restricted closed-loop master-slave current control of the two partial currents is then obtained, if the output voltages of the two transformer windings are slightly different and the master-drive converter is connected to the transformer winding with the somewhat lower voltage. A uniform current distribution can only be achieved using closed-loop current control of the master-slave incoming drive converter, if reduced DC link voltage operation is selected. However, we do not recommend this, due to the less favorable supply power factor and the lower available output.

Three-winding transformers should be as symmetrical as possible, as shown in Fig. 8.1, in order to achieve the most uniform current distribution of the two input converters. What is especially important is that the no-load voltages of the two secondary voltages differs by less than 0.5 %: $\Delta U_{US} < 0.5$ %.

The requirement, that the voltages of the two secondary windings, connected in Y and Δ circuit configurations, are as equal as possible can only be partially fulfilled. The winding numbers of the two secondary windings must differ by a factor $\sqrt{3} = 1.732...$so that the same phase voltages are obtained for the same flux linkage. For example, if the Y winding has 20 windings, then the Δ winding may only have 34 or 35 windings; however, the correct value would be 34.64... Alone this difference can result in a deviation of over 1 %.

Further, the short-circuit impedances of the transformer, from the primary winding to the two secondary windings, which can be sub-divided into the primary-side impedance $x_{K\,OS}$ and the secondary-side impedances $x_{K\,US1}$ and $x_{K\,US2}$, refer to Fig. 8.1, should, as far as possible, be the same and independent of the load. Further, the two secondary windings should not influence each other or if they do, the influence should be as low as possible. How successful this is or how successful it can be, depends on the transformer design.
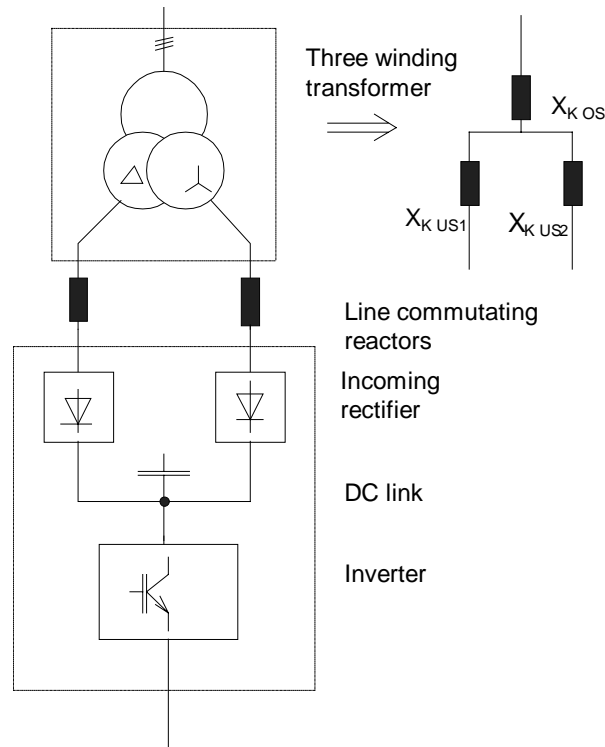
Fig 8.1 Principle of the 12-pulse supply feed

Three-winding transformers can be implemented, either as a favorably-priced version with disk windings, or as double-tier transformer. The different versions of three-winding transformers will now be briefly explained.
The simple version of the three-winding transformer can be implemented, as shown in Fig. 8.2, with concentric windings over the leg.
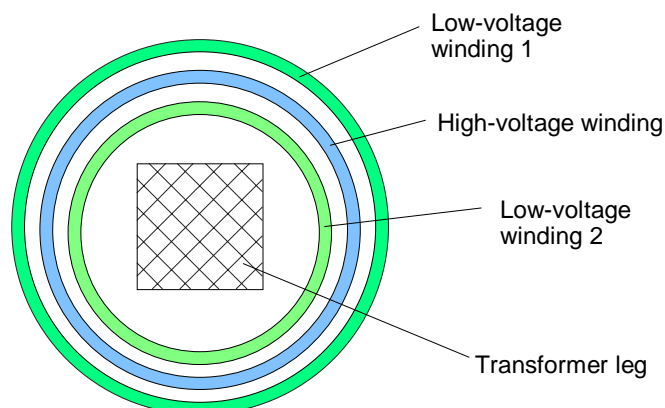
Fig 8.2 Transformer with concentric windings

The two secondary windings are accommodated between the primary winding. Thus, they are not linked with the same, but with slightly different magnetic fluxes. This is manifested in the slightly different u_K of the primary winding in comparison to the associated secondary winding, and therefore in the slightly different induced voltages with increasing load.

For transformers with winding designs such as these, commutating reactors must be used in order to ensure uniform load distribution of the two input systems.

An additional version of the transformer is shown in Fig. 8.3. In this case, the disk-type secondary windings are located one above the other. Thus, the relationships regarding flux linkage and induced secondary voltage are significantly more symmetrical than the arrangement shown in Fig. 8.2. However, additional line commutating reactors should be provided to ensure uniform current distribution of the two partial systems.
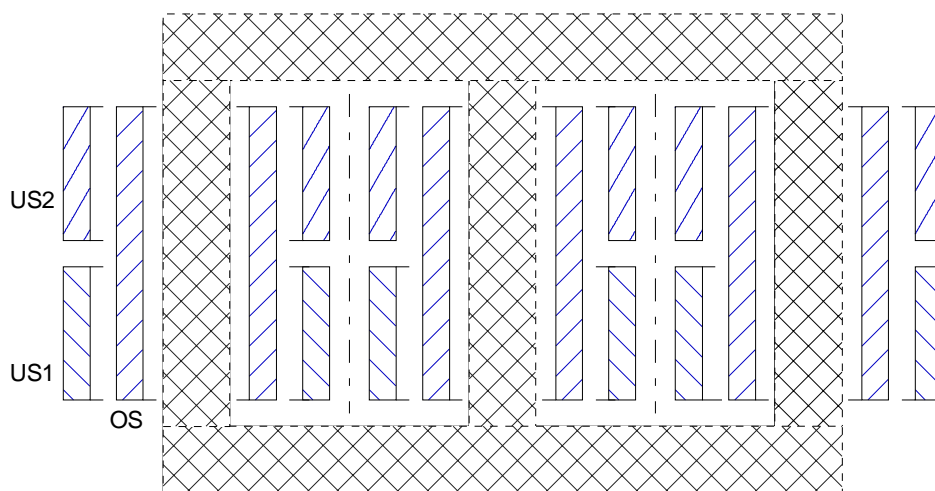
Fig. 8.3 Transformer with disk winding and secondary windings located one above the other

The most costly version is the double-tier transformer, as shown in Fig. 8.4.

8 - 9
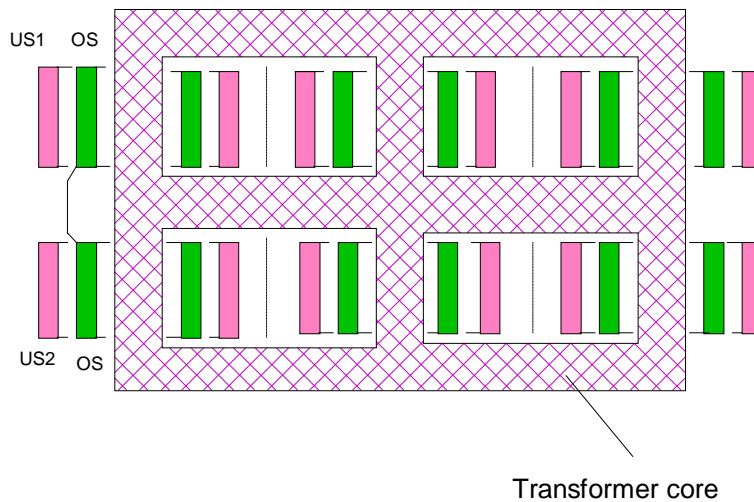
Transformer core

Fig. 8.4 Double-tier transformer version

In this case, the two low-voltage windings are also magnetically de-coupled using an additional center yoke. Thus, the two secondary windings cannot mutually influence each other. This means that the two low-voltage systems are as symmetrical as they can be and additional line commutating reactors for unified current distribution, are not required.

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8.5 Transformers at the drive converter output

Occasionally, existing fixed-speed high-voltage motor drives are to be subsequently operated at variable speed. Although there are presently no drive converters available for certain voltages, e.g. 11 kV, a high-voltage converter is generally far more costly than a low-voltage drive converter. Therefore, it is practical, for applications such as these to use a drive converter for, e.g. a 690 V supply voltage, and to use transformers at the input and output of the drive converter. The transformer at the drive converter output then steps-up the voltage to the rated motor voltage.

What has to be taken into account under these conditions? On one hand, the increased voltage stressing for the transformer and motor, and on the other, the significantly lower starting torque.

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Increased voltage stressing for transformer and motor

The transformer and motor are not fed with sinusoidal voltages, but with pulse-width modulated voltage blocks having the amplitude of the DC link voltage; also refer to the information in Section 3.7. In this case, the transformer has the effect of a reactor at the drive converter output. This significantly flattens the voltage edges at the transformer output. If the distances between the drive converter and the transformer and the transformer and motor are not more than approx. 40 m, then no significant voltage reflections are generated at the transformer secondary windings and at the motor. This means that the increased voltage stressing should be able to be tolerated. If necessary, the motor manufacturer can be contacted to see whether the increased voltage stressing can damage the motor.

A converter transformer should be used.

Reduced starting torque

If the motor is to generate a high starting torque with a transformer connected at the drive converter output, e.g. the rated torque, then the full motor rated current must be available at the slip frequency of e.g. 0.5 Hz. However, the transformer cannot transfer this current at this low frequency as it goes into saturation due to the ohmic voltage drops of the transformer secondary winding, motor feeder cable and motor stator winding. At this low frequency, the transformer can only transfer a small percentage of the primary current to the secondary side of less than 30 to 40 %. This means that only approximately 5 up to max. 15 ..... 20 % of the rated motor torque is available as starting torque. The transformer can only transfer the full current on the secondary side and therefore generate full motor torque from frequencies above approx. 5 Hz. However, it is not practical to try to improve the characteristics by over-dimensioning the transformer, as this only has a low impact on the characteristics.

Thus, the version with a transformer at the drive converter output is only suitable for drives which require a low starting torque, i.e. typical for fan and pump drives. On the other hand, this version is not suitable for drives which require a high starting torque unless it is possible to reduce the load to be accelerated until a minimum speed of 10 % is reached.

Additional comments and information regarding issues relating to transformers at the drive converter output are available in the Application Manual, Order No. E20125-J0003-S202-A1, under Sections 4.3.1 and 4.3.2.

If there is a chance that the high-voltage motor could be damaged due to the increased voltage stressing when fed from a drive converter and transformer, then filters must be used. Special filters have been designed for applications such as these, which feed the motors with almost sinusoidal voltages. This also guarantees that the motors can be operated, as before, at their rated output, i.e. for drives with T (torque) $\sim$ n² the output does not have to be reduced to take into account drive converter operation.

Your contact partner is:

Hr. Apel,   A&D DS A V,   Tel. (09131) 98-4291,   Fax. (09131) 98-1587.

Herr Apel should also be contacted if you have an application with drive converter and transformer to feed a high-voltage motor.

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