4. ELECTRIC DRIVES

4.1 General description

Electric drive is an electromechanical system (mechatronic system) intended to set into motion technological equipment. It consists of an electric motor (motors), a transfer mechanism, an electrical energy converter, and a control system. The control system consists of a microcontroller with data connection interfaces, data channels (data network), sensors and actuators. A generalized structure of the electric drive is shown in Fig. 4.1. In general, the main task of the electric drive is the motion control of mechanisms. An electric drive is an automatic control system with a number of feedbacks where different automatic control principles, such as error driven feedback control, model based control, logical binary control, or fuzzy logic control methods, are used. Depending on a particular technical solution and selected control principle, different sensors for measuring of currents, voltages, velocity, acceleration, torque etc. in an electric drive are used. Other information, like pressure signal for controlling pumps and compressors, air humidity and/or temperature signal for controlling of fans etc. is also necessary. For that reason, the controller of the drive must process different information.
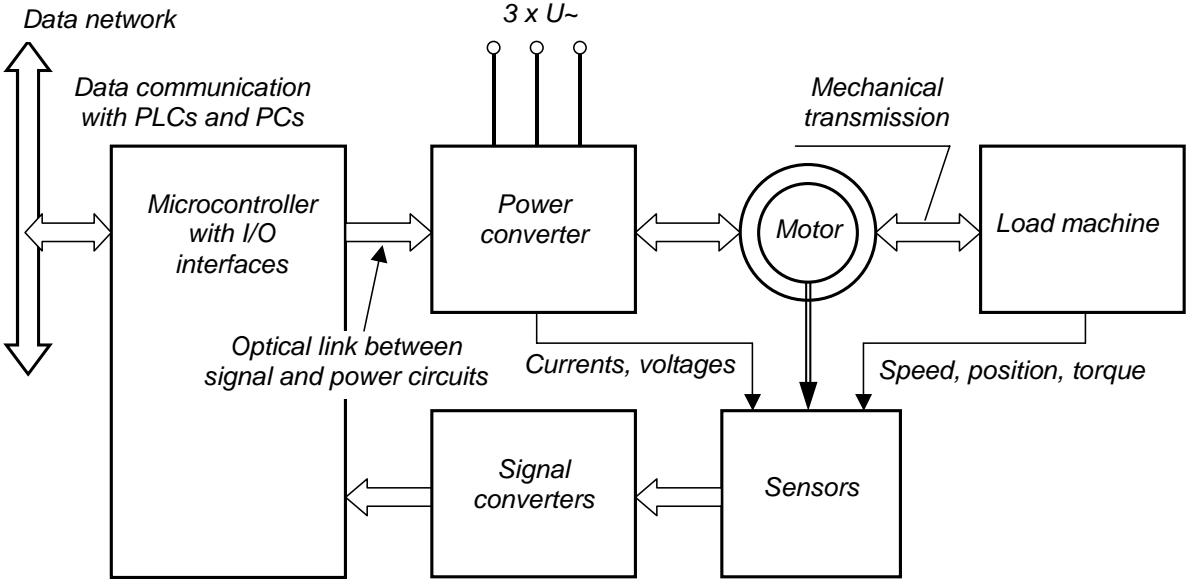

Figure 4.1 Generalized structure of an electric drive

Microprocessor technique enables us to apply different control methods in today's control systems, including control of electric drives. In the drive controller, the signal processors with inbuilt analogue-digital converters, timers, pulse-width modulators and other devices, which simplify drive control, are commonly used.

Integration of devices and functions. Microprocessor techniques make it possible to solve all control tasks, like energy conversion between the drive and the converter, protection and tasks connected with the sequence logic of a technological process. Because of this, a microcontroller is a complex control device, which is realized by the computer control,

programmable controller functions and supervision of the process. A drive controller is programmed and controlled by help of commands and subprograms of special functions. Software of a drive is complemented with supplement functions. Since modern industrial systems are based on data communication networks, recent controllers are intended for action with field buses. A controller guarantees a flexible speed regulation and motor protection.

Software solutions. Today's theories published will be realized as software of devices. You can tell already today that drive controllers are able to solve all problems and tasks described in course-books of electric drives. Controller software includes a number of contemporary control methods, like adaptive control, model based control etc. Vector control of AC-drives was a technical novelty ten years ago, but today this method is largely used in frequency converters.

Economic considerations. A situation may arise when functional qualities of a drive controller and completeness of the interface are not harmonized. To reduce the price market, compelled producers often simplify the interface of converters. Therefore the number of control buttons and decimal places of sign-number display must be reduced to 3. To display the large variety of drive controller states (different faults, signals etc.), every segment of the 7-segment digit indicator could be used to display coded information. It will be very inconvenient for the operator of the drive equipment to acquire this very special coding. Naturally it is a different question if the user needs programming or reprogramming the converter or not or if the programming and service must be done by specialized firms. Power converters with the most intelligent user interface can communicate in common national languages understandable for everyone. Maximum convenience will be achieved by special human-machine interface (HMI) PC software. In this case, all the useful information about the drive and technological machines can be displayed on the PC screen. Different functional diagrams about energy consumption, technological cycles, amount of production etc. can be used. But, unfortunately this software may be more expensive than the converter hardware.

New sensors and optical data connection. Today the numeric control of electric drives is widely used and the traditional analogue sensors will be replaced with the new digital sensors for measuring of speed and position. To measure the position, the sensors may be the pulse sensors as well as the code sensors. Another problem is measuring of voltages and currents with high harmonic components particularly when the control information is required very quickly, but the filtration of the signals is very complicated and slow. Current transformers deface the signals and they are not acting so fast. Bypasses in the current circuits give the accurate current signal but galvanic connected sensor signals with power circuit are not usable in microcontrollers. For this reason, Hall sensors are used. Hall sensors with magnet-electric current converters guarantee galvanic separation between control and power circuits of electric drives. To forward the output signals of the controller to the converter fibre-optic data channels are used.

4.2 Electric Drive with DC Machines

For some reasons, today the term *DC drive* is not clear. First, the operating principle of the electric machine assumes periodic commutation of the current of the winding; because of this, the current of the winding is actually AC current. Second, DC machines with a mechanical commutator today are rarely used. Instead, brush-less DC motors (DC motor with a semiconductor commutator) are used. In terms of construction a brush-less DC motor is similar to an AC synchronous motor fed from the frequency converter. Third, the AC network feeds the electric drives and a supply converter rectifies the voltage of the motor. Supply converters of DC and AC drives consist of rectifiers. Armature windings of a DC motor are commutated depending on the revolutionary angle of the armature. Such a principle can be used to control the synchronous machines too. This is just one difference between the DC and the types of motors.

The principal scheme of a DC drive is given in Fig. 4.2. The power circuit of the drive consists of a non-controlled rectifier, a filter, a braking chopper, and a 4-quadrant pulse width converter. GTO thyristor switches used in drives with large power are shown in the figure. In drives with lower power, IGBT transistor switches are used. Whereas non-controlled rectifier is not able to convert energy between the drive and the network, the energy of the generator must direct to filter capacitor C_F (voltage increased) or dissipate in the brake resistor R_B. For that reason, the brake chopper PL_B is switched on.
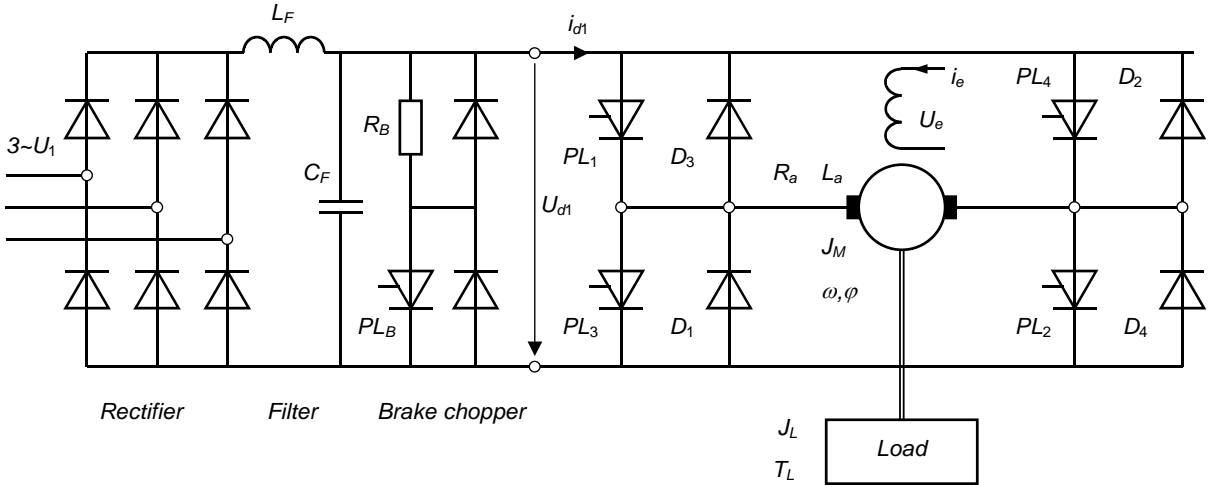

Figure 4.2 Principal scheme of a DC drive

A 4- quadrant pulse width converter enables operating of a DC machine on 4- quadrants of torque-velocity surface. It means that directions of torque and velocity are changeable and the machine may operate as a motor or a generator. There are two ways to control the pulse width converter. First, using couples of semiconductor switches *PL*1 and *PL*2 or *PL*3, and *PL*4 may choose direction of the motor velocity. When one couple is chosen, the other couple is continuously switched off and the direction of motor velocity is not changed. The voltage of the converter and the velocity of the motor are controlled by semiconductor switches (e.g., PL_1 and PL_2), using the principle of the pulse-width modulation.

To control voltage and speed, it is sufficient to have pulse width control of one semiconductor switch (e.g. PL_1). To change the direction of the motor speed, the direction of the armature current will be changed. The direction of the excitation current is not changeable. Therefore the couple of semiconductor switches (e.g. PL_1 and PL_2) are switched off and the other couple (e.g. PL_3 and PL_4) are switched on. To regulate (control) the motor speed, semiconductor switch PL_3 is used. Output voltage diagrams of the 4-quadrant pulse width converter are shown in Fig. 4.3.

A 4-quadrant converter may be used such that semiconductor switches (PL_1 and PL_2) and (PL_3 and PL$_4$) are switched in a couple. Then the output voltage of the converter has a quadrangle form. Changing the relative switching time of semiconductors will control the mean value of the voltage. When durations of positive and negative half wave are equal, output voltage is equal to zero.
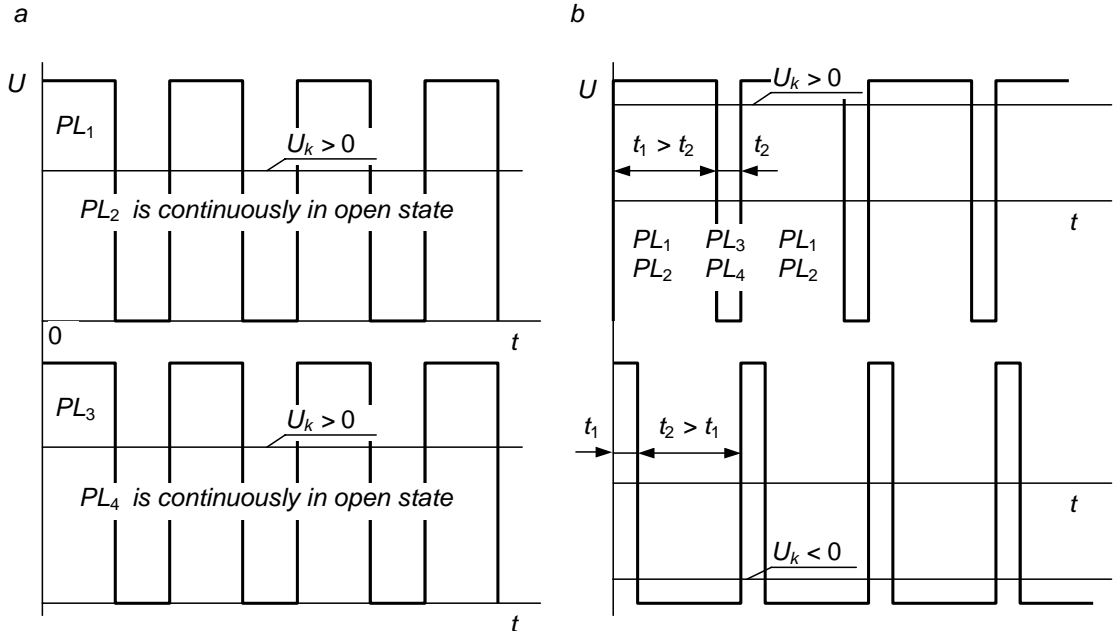

Figure 4.3 Mean value and polarity variation of the motor supply voltage
in the case of 4-quadrant speed-torque control of a drive.
a) by using of pulse-width converter with one or two switches
b) by using of pulse-width converter with four switches

4.3 Soft start of induction motors

Today most commonly used electric motor is an induction motor. As compared to other electrical machines, induction motor is reliable, durable in hard conditions and needs little current maintenance. Because of this, induction motors are economically efficient. For a long time, induction motors were known as electric machines difficult to control and were used only in electric drives with constant speed. Induction motors are mainly used to set into motion general purpose machines, like fans, compressors, pumps and other machines, like disc saws, wood planes. These machines operate in a continuous duty regime, but to optimize processes and save energy, speed or torque control is often necessary. Because ten years ago, flexible speed control of induction motors was very difficult, lower efficiency of a machine or lower quality of production was the case. Problems of starting, braking and protection of induction machines may be solved by help of power electronics and microprocessor techniques using **soft starters.** The progress of power semiconductor techniques, microelectronics calculation techniques and other technologies make it possible to develop an operating regime optimizing soft starters to control the induction motors.

Earlier, induction motors caused a number of problems. For example, high power **induction motor start** was a problem**.** With direct on-line start of the induction motor, the stator current increases up to seven times over the rated value, causing high current peaks in the electrical power lines. Starting current of an induction motor does not depend on the motor load and is a constant value for each motor. Relative starting current I_{start}/I_{rated} is provided on the motor nameplate and commonly it is 4-7 times higher than I_{rated}. In long power lines with high resistance, starting of a high power induction motor causes an essential voltage drop on other consumers. Thereby the starting torque of the induction motor is relatively small as compared to the DC motor. Because of this, the duration of the starting process is so long when the load and moment of inertia are large (heavy start). This causes essential heating of motor windings and is dangerous to the insulation when protection devices are not used. As different firm the DC motor, the torque of which increases proportionally when the load increases, the **mechanical characteristic of the induction motor** (relation between torque and velocity) is non-linear. The mechanical characteristics of the induction motor are characterized by maximum or **breakdown torque.** When the breakdown point is crossed, the velocity decreases and the motor stops when the load remains. This is a short circuit operation of the motor. Because of this, when the load changes in a large area, induction motors are difficult to use or not recommended.

Commonly, **the braking of the induction motor** by plugging with automatic stop on zero speed or by dynamic DC braking can be used. The main drawback of plugging is the high current, slightly greater current than the starting current and a need of zero speed sensors to stop the motor. In the case of dynamic DC braking, the additional DC voltage source or semiconductor diodes must be used. A disadvantage of dynamic braking is also a non-linear dependence between the torque and speed.

It is relatively complicated to protect the induction motor. When the armature current of the DC motor is proportional to the load and the resulting motor load in an induction motor, the dependence between the stator current and the load is much more complicated. Mathematical description of physical processes in the induction motor is difficult. To obtain objective information about the physical processes by measuring electrical signals is complicated

because the rotor current and flux in air gap cannot be measured in simple way. The measuring of stator voltage and current characterize a state of a motor only particularly.

Soft starters are intended for smooth starting and stopping (without current peak and with adjusted acceleration) of an induction motor and reducing of energy consumption on the variable load, specially if the load is smaller than the rated load. By using soft starters it is also possible to control the braking of the induction motor. Some of soft starters allow DC-braking, short time low speed operation or jogging and controllable linear braking ramps by help of a tachogenerator. Also, a kick-start is possible when the starting conditions are hard.

A soft starter is a thyristor-based AC voltage regulator, where thyristors are controlled by help of a microcontroller. Due to a microcontroller, soft starter performs relatively complicated functions. For example, with voltage regulation it is possible to decrease the starting current peak, to choose duration of acceleration and deceleration ramps and to optimize energy consumption (power factor) on a variable load. A microprocessor system makes it possible to realize sufficient second-ampere characteristics of the overload protection. By commutating of thyristors it is possible to switch on and off half waves of 50 Hz alternating voltage. In this way, a short time low speed operation can be used. A microprocessor system of a soft starter is operating as a starting and protecting system. Protection functions are as follows: adjusted over-current limit, protection against input or output phase interruption (circuit break), short circuit of thyristor, heat sink overheating, wrong frequency of feeding voltage and troubleshooting of a microprocessor. Other protection functions, like thermal overload protection, stopped rotor protection, unexpected load disappearance protection, troubleshooting of memory and long lasting start or long lasting low speed operation protection in some soft starters can be realized.

It is possible to connect a soft starter to the industrial data communication network by help of the data communication interface. Soft starters with analogue and digital control panels are manufactured. A soft starter can protect also other technological devices. For example, a smooth starting of pumps externalizes hydraulic shock in the piping.

Construction and operating principle of a soft starter. The scheme of power circuits and external control circuits of a soft starter is shown in Fig. 4.4. Push buttons *Start* and *Stop* are connected to the input terminal of the control circuit. The two push buttons with impulse contacts or one tumbler with two fixed position may be used. Thermal relay FT is intended for motor protection and will be selected depending on the motor rated current. The fuses F1 protect feeding circuits of a soft starter. The thermistor is intended for the motor protection against the overheating. To regulate speed automatically and obtain the linear starting ramp, the signal of a tachogenerator is connected to the input terminal. When starting conditions are hard (heavy start), rated voltage can be provided to the stator winding. A separated switch makes it possible to select a low speed operation or jogging. A soft starter has a number of output terminals. They are intended to control the relays connected series with the voltage source or the contactor. A possible use of output terminals is shown in Fig. 4.4.

The voltage and current time diagrams of starting, stopping and the energy saving operation (Fig. 4.5) can characterize the operation of the soft starter. The dynamic braking after the end of the deceleration ramp (at low speed) is possible.
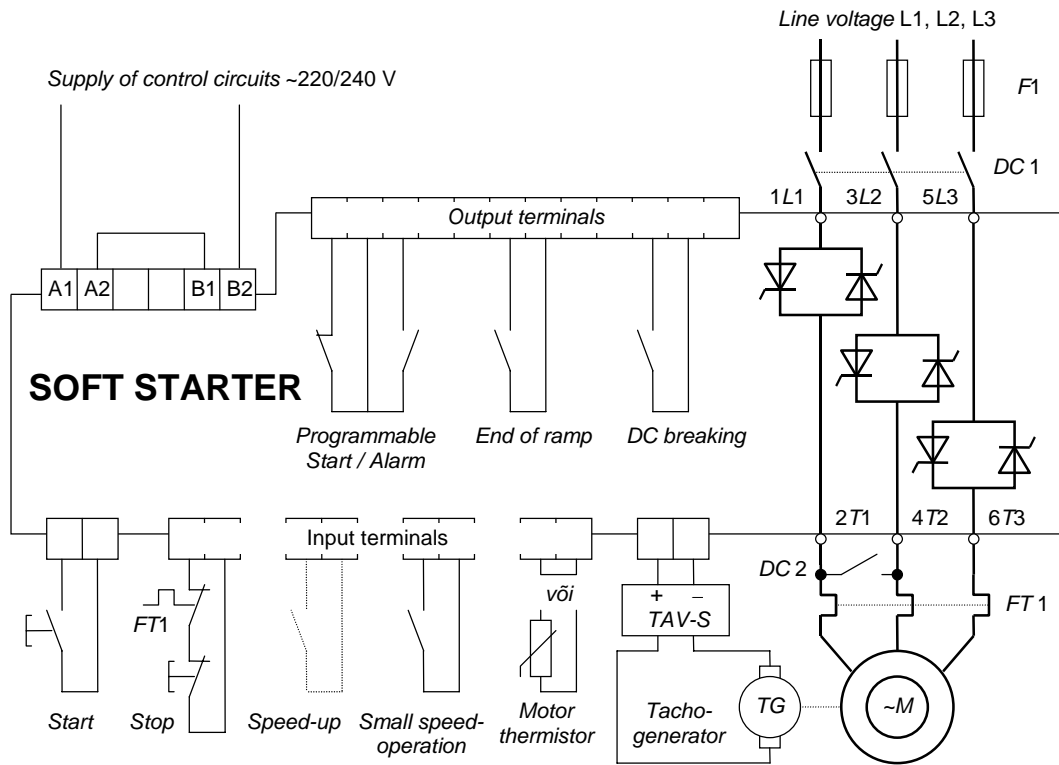
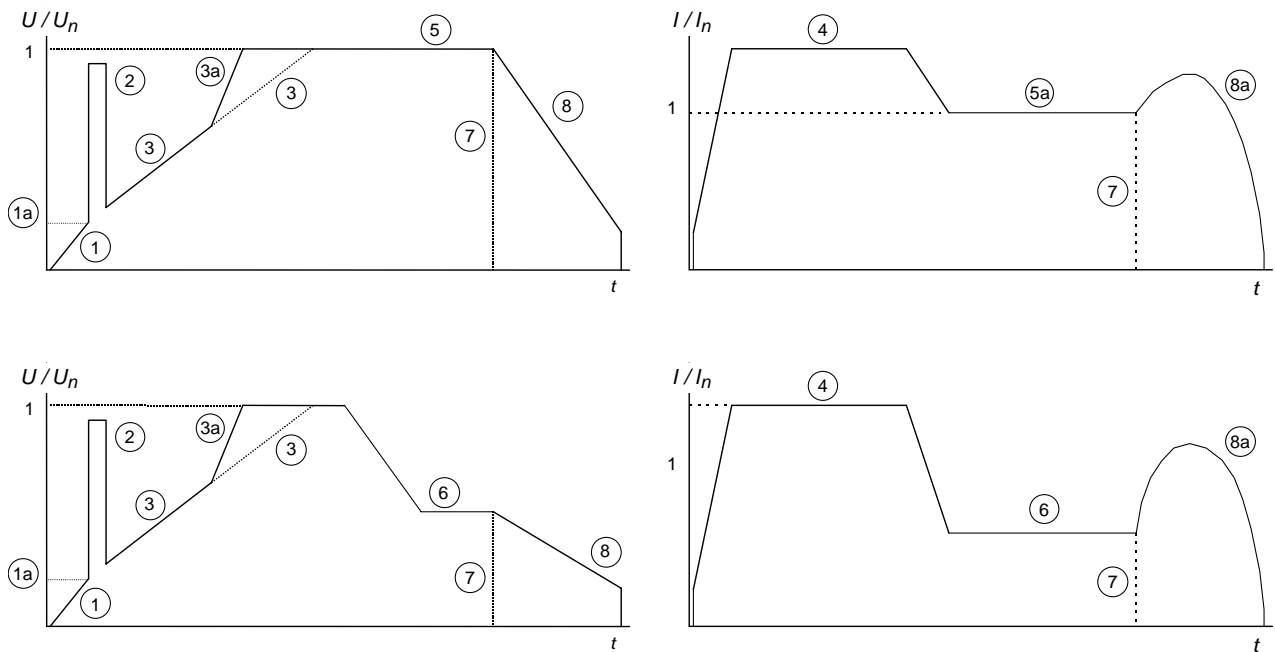Figure 4.4 Scheme of power circuit and external control circuits of a soft starter

Figure 4.5 Voltage and current time diagrams of starting, stopping
and energy saving operation (down)

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The voltage and current time diagrams consist of the following stages:

1   Acceleration ramp (duration of ramp some periods, e.g., 0.1 s)
1a Voltage of acceleration ramp (regulation area 30-95% U_r)
2   Shock start voltage selected until 95% U_r
3   Duration of acceleration ramp ($t_r = 0.5...60$ s)
3a Rapid increase of motor voltage after reaching the rated velocity
4   Current limit of motor 2-5 I_r (where I_r is the rated current)
5   Rated voltage U_r
5a Rated current I_r
6   Energy saving operation (motor operating at reduced voltage)
7   Stopping with the motor switch off (coasting)
8   Deceleration ramp. Duration of deceleration ramp depends on the moment of inertia and duration of acceleration ramp (e.g. $t_{d.ramp} = 2\ t_{a.ramp}$). Deceleration ramp may be linear or non-linear.
8a Variation of voltage on deceleration
9   Dynamic braking, e.g., duration of braking is 5 s. Braking begins after the end of deceleration ramp. Current of dynamical braking can be selected (e.g., 2 I_r)

Energy saving operation is possible only when the motor operates at constant speed. Motor voltage is regulated depending on the power factor. Motor's efficiency, power factor and energy consumption depend on supply voltage, and the optimal value of feeding voltage can be determined (Fig. 4.6). As the result of the regulation of motor voltage, the active energy depending on motor load will be saved and the power factor will be improved (reactive energy decreases).
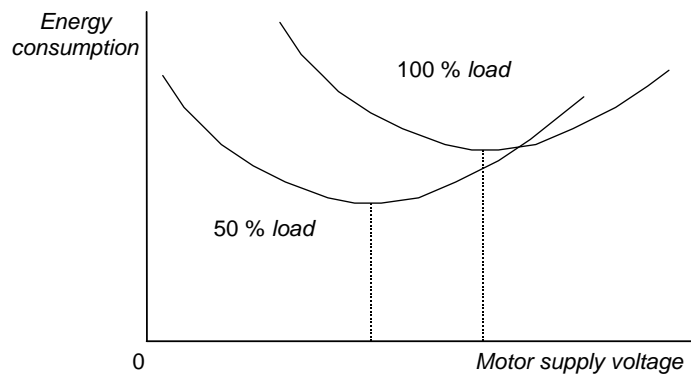

Figure 4.6. Energy consumption depending on the load and supply voltage

Low speed or jogging makes it possible to position the shaft of motor or the driven machine. This is a short time operation (e.g., up to 120 s) and the speed may be selected as 7% or 14% of the rated speed. Jogging speed is achieved by the selected switching of thyristors. Thyristors are switched to the stator winding every 7 or 14 half wave of the alternating current. Thus, variable polarity current pulses at the frequency of the first harmonic $1/7 = 14\%$ or $1/14 = 7\%$ are generated.

Linear acceleration and deceleration ramp is achieved by using the feedback signal of the tachogenerator (see Fig. 4.4). By help of switches connected with the soft starter we can select the operating mode of the motor, e.g., acceleration, deceleration, dynamic breaking, jogging speed etc.

There is a possibility of motor **overload protection** in a soft starter. To determine the operating state of the induction motor, the rotor current and resistance or the magnetic flux of the air gap must be measured. However it is very difficult. Because of this, the induction motor, which has a reliable and simple construction, fails because of overload when its protection device is faulty. Because of this microprocessor technique (software) based protection systems are used. The operating time of the protection device depends on the value of over-current. The higher the over-current, the shorter the operating time of the protection device is. The time-current characteristics of protection are shown in Fig. 4.7. The protection may be set on the standard duty or heavy-duty operation mode of the motor. On the heavy-duty operation mode of the motor, the permitted overload and temperature of windings are higher. Characteristics show that the operation time of protection is 30 seconds and over-current is $3I_r$ on standard duty operation mode and $4.5I_r$ on heavy operation mode.
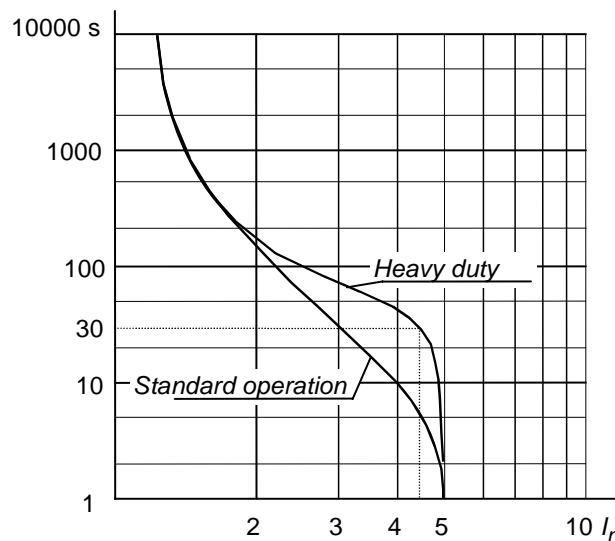

Figure 4.7. Time-current characteristics of overload protection

After the operation of overload protection, the cooling period will follow. During the cooling period of the motor, the restart is impossible.

4.4. Frequency-controlled electric drives

Many problems arise with **velocity control of an induction and a synchronous motor.** It is well known that the best way of speed control of a squirrel cage induction motor and a synchronous motor is variation of frequency of the supply voltage. For a long time, there was no simple and cheap way for frequency control. For that reason, the variation of the pole number of a motor is used. The speed control of an induction motor makes it possible to use the induction motor with the phase winding (with slip-rings and brushes) because the slip of the rotor and the speed of this motor are inversely proportional to the resistance of the rotor circuit. However, in this case, there are high losses in the rotor rheostat.

Today, the **frequency control** of induction machines is the main method of speed regulation and frequency converters are the main components of electric drives. Traditionally, the frequency converter was intended for smooth control of voltage and frequency of a motor. But modern frequency converters have a number of functions. In principle, a frequency converter with an induction motor is a complex electric drive. A frequency converter consists of a feeding converter, sensors and a control system. The control system is able to control the actuator or complicated automatic circuits of the technological process. By help of network interface, a frequency converter is usable on automatic systems with a number of levels. A frequency converter has a user interface for the drive operation mode control.

The use of frequency converters in electric drives was intended already after the invention of the induction motor. First, machine converters were used for this purpose. Machine converters consist of a variable speed DC motor connected mechanically to a synchronous generator. This converter, a feeding source of variable speed drive, was very expensive and economically inefficient. After invention of the thyristor (1956), the idea of developing static (without rotating machines) frequency converters became realistic. At the beginning of the 1960s, the first thyristor frequency converters were built. At the same time, the first pilot thyristor frequency converter was built at the Department of Electrical Drives and Power Electronics of Tallinn Technical University. However, the use of frequency converters use in industrial drives was very slow for a long period. The main reason was the high price and low reliability of thyristor frequency converters. Appearance of high power transistors as **insulated gate bipolar transistors (IGBT)** changed the situation profoundly. Today, frequency-controlled AC drives are applied almost everywhere where only DC drives were used before.

Frequency control is traditionally intended to adjust motor torque, speed or motor shaft position (rotating angle) by help of closed or open loop control circuits, provided output voltage and frequency change relatively slowly and motor operates in a continuous duty. Closed loop control systems make it possible to increase the measuring accuracy of output signals and make dynamical qualities better. In converters with traditional control, duration of acceleration and deceleration ramps is strongly limited.

At conventional frequency control the overloading level of an induction motor is relatively small (2-2.5 times). A sharp and large change in the motor load may cause a breakdown of an induction motor. Then the motor is stopped or rotates at a very low speed (jogging). Motor losses are increased and the temperature of windings grows sharply. For these reasons, conventional frequency converters for the control of continuous duty operating devices, such as pumps, cooling fans and compressors, are used.

Today's fast operating electric drives are controlled by help of the **vector control method**. Vector control is based on the control of the rotating field vector in electric machine. Therefore, vector control is called **field orientation control**. Conventional frequency control may be called scalar control because it is based on measuring of the effective values of frequency and voltage. These values are average. On the other hand, the vector control is based on the dynamical model of the induction motor (i.e., that is a **model-based control**).

Vector control is similar to the DC drive control and may be used to control mechanisms with the dynamical load (elevators, robots etc.).

Power circuits of a frequency converter are shown in Fig. 4.8 and the connection scheme of control circuits in Fig. 4.9. To control a frequency converter by local and remote control methods, program control is used. Standard software of a frequency converter consists of a number of typical macro program and the selection and settings of parameters determine the operation mode of the drive. Setting parameters of the frequency converter may be classified to some groups. Traditionally, three groups of parameters are distinguished:

- frequently varied parameters
- rarely varied parameters
- parameters varied by the producer

The first two groups of parameters may be changed by a user. As a rule, a user has no information about the parameters of the third group and only the producer may change these.

Parameters of a frequency converter are changed digitally. Frequently, varied parameters are frequency setting, frequency setting for jogging, acceleration/deceleration time, torque boost, DC brake setting and sometimes settings of input signals.

Frequency setting. Frequency setting entered from the control panel in the case of local control mode influence directly the operating speed of the drive. Frequency is selected by help of keys ↑ (increment) and ↓ (decrement). Frequency setting on the local control mode may also be given by using a potentiometer connected to the converter, DC voltage or current source and on the remote control by help of a control computer.
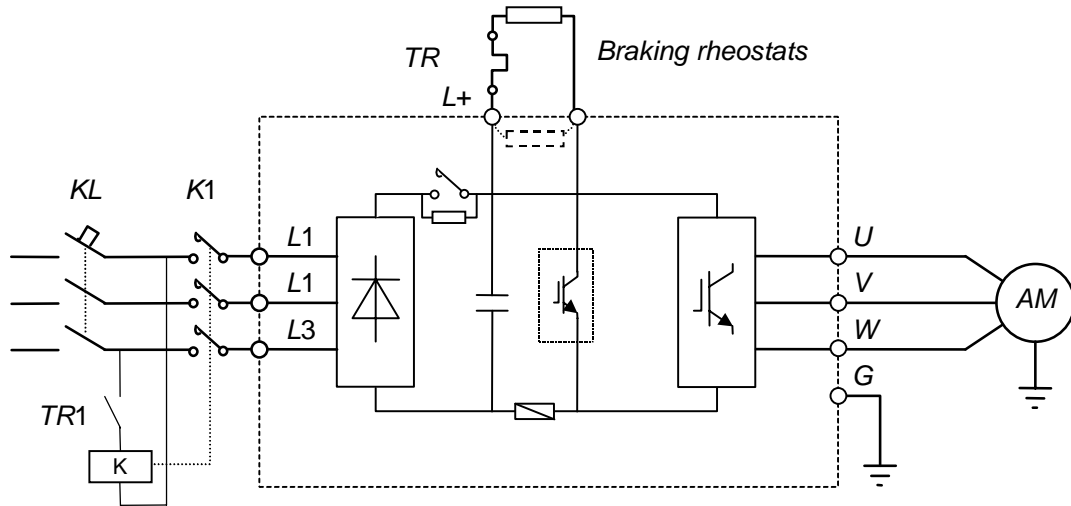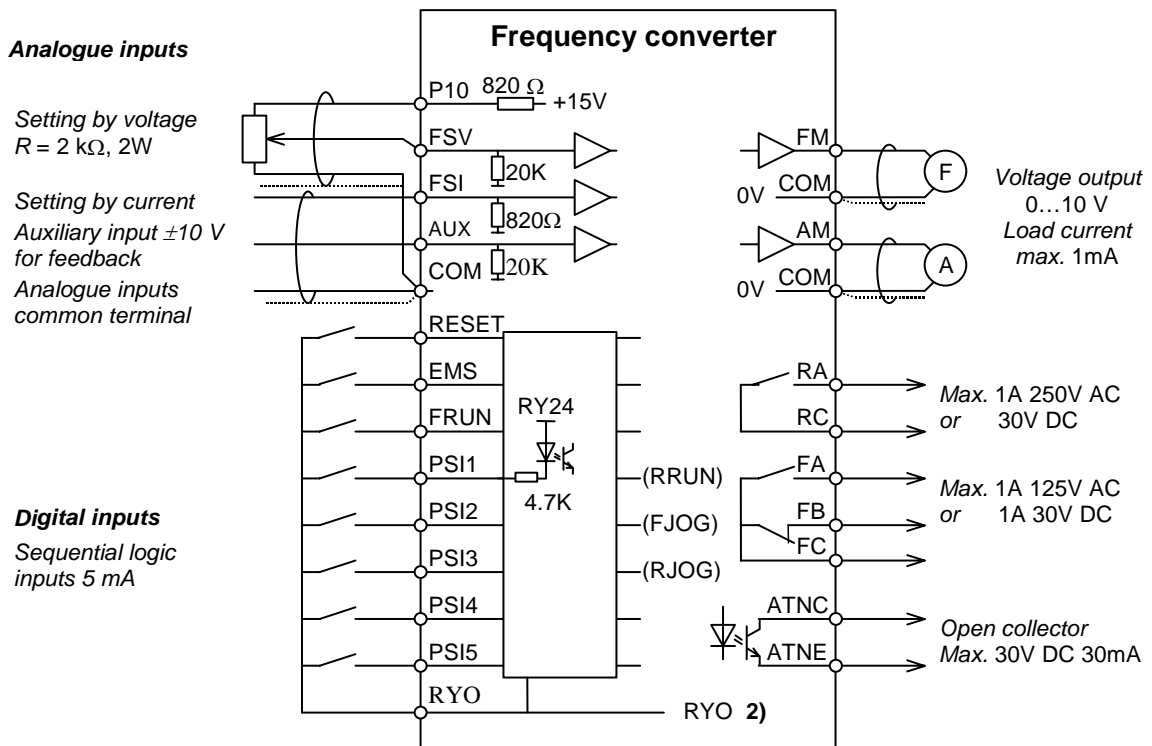
Figure 4.8. Power circuits of a frequency converter

Figure 4.9. Connection scheme of control circuits

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Conventional digital frequency settings consist of **robust and exact settings**. By using robust setting, frequency is changed with step 1 Hz and by help of exact setting frequency is changed with step 0.01 Hz.

Acceleration and deceleration time settings are changeable in a large area (0.1-6000 s). Acceleration and deceleration time settings are given in Fig. 4.10. Frequency at the beginning of the start is called the start frequency. Braking frequency is the frequency when the dynamical braking is turned on. The value of DC voltage used for dynamical braking depends on the power of the converter and changes within the range 0.1-20% (default 5 %), whereas at higher power, lower voltage is selected. The duration of dynamical breaking is determined by the corresponding parameter in the range of 0-20 s.

Jogging frequency setting is selected before the start. Jogging frequency setting is intended for motor short time operation at low speed and for the positioning of the mechanism. A motor start to the forward or reverse direction of jogging takes place by help of commands F JOG or R JOG (forward jogging or reverse jogging). Acceleration and deceleration times will be set by help of parameters B21-9 and B21-3 (Fig. 5.7).
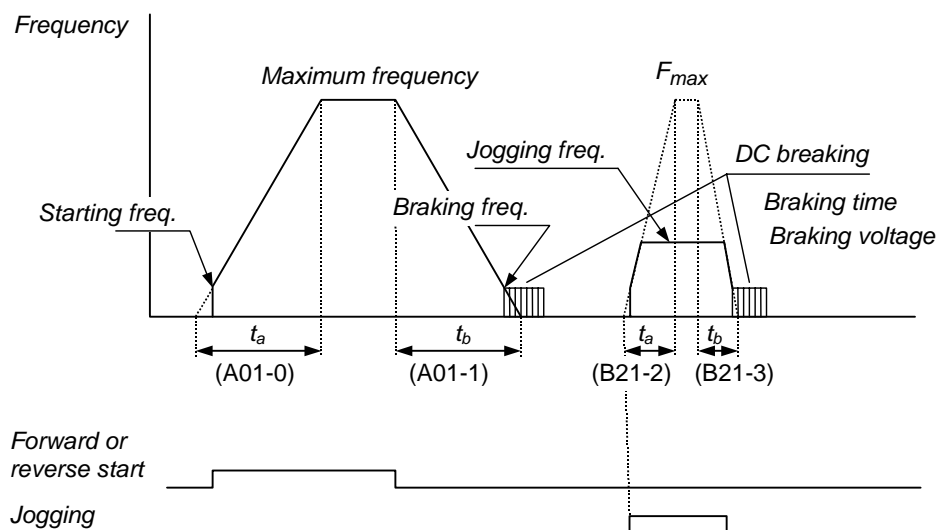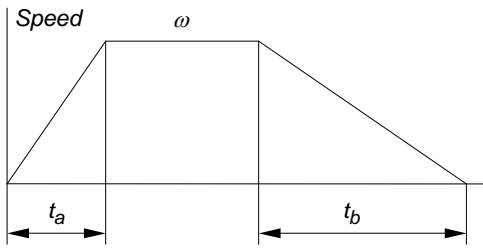
Figure 4.10. Programmable acceleration and deceleration times

Acceleration and deceleration times must be fitted with the real parameters of the electric drive. For drives with high inertia, very short acceleration and deceleration times cannot be selected because of high torque and power of the drive required. In real drives, selection of so short acceleration and deceleration times causes protection setting and motor stopping. For this reason, acceleration and deceleration times are selected by using the formulas in Table 4.1.

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Table 4.1

For motor **torque compensation**, voltage-frequency function $U = f(f)$ settings are used (Figure 4.11). Before setting of parameters, the character of the motor load must be determined, e.g., torque is independent of the speed (T = const.) or torque is proportional to the speed (fans, pumps). Nonlinear voltage-frequency function (A02-1) is selected on the fan load. Linear voltage-frequency function is sufficient at a constant load. In either case, the decrease in torque at low frequency must be compensated with a voltage increase (A02-0). The value of **basic frequency** f_{base} is 50 Hz. If the basic frequency, which determines the control area of the frequency, differs from the default value, then its value must be set before the motor start with parameter (B00-3).
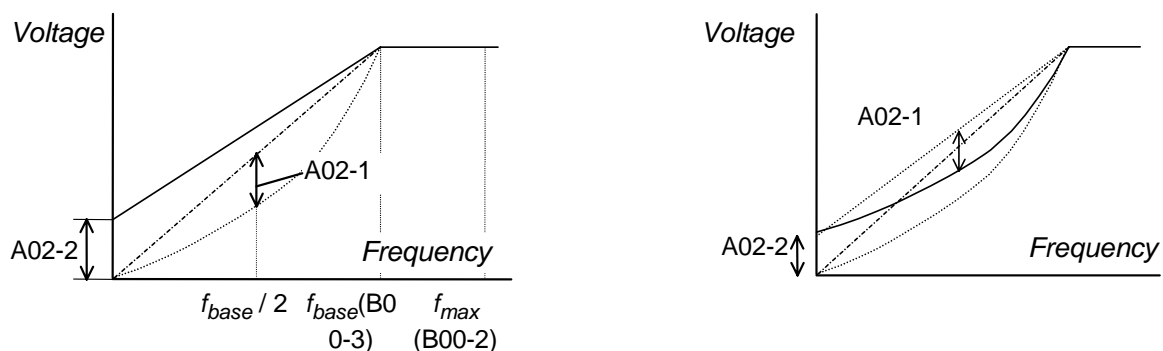
Figure 4.11. Settings of torque compensation of the voltage-frequency function

Automatic torque compensation decreases the voltage automatically when the motor load decreases (Figure 4.12). Compensation parameter (A02-2) on the rated current is selected in the range of 0-20 % of the rated voltage (conventionally 3-5 %). Too high value of parameter A02-2 makes the drive unstable and overcurrent protection turns on.
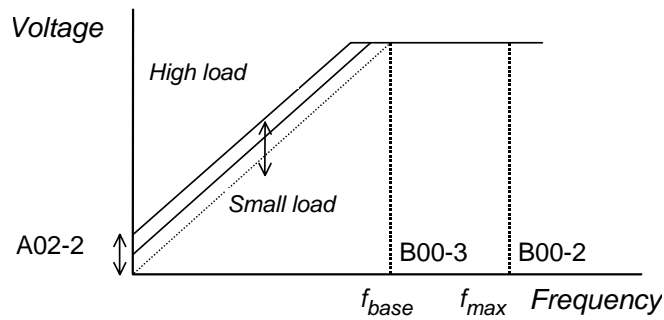
Figure 4.12. Automatic torque compensation

Slip compensation is intended to stabilize motor speed when the load increases (Figure 4.13). The value of setting is equal to the motor slip on the rated load and is selectable in the range of 0-5 %.
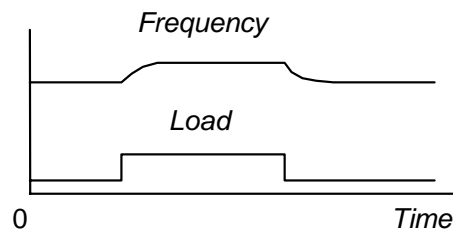

Figure 4.13. Motor slip compensation

The character of the output voltage depends on: if the DC voltage automatic control is operating or not (B00-4 = 0) and if the output voltage on the basic frequency is equal to the input voltage. DC voltage automatic control decreases the output voltage fluctuations caused by the variation of input voltage. If the setting of the maximum frequency f_{max} (parameter B00-2) is used, it must be observed that its value does not exceed the value on the motor nameplate.

Basic frequency, output voltage and current of the converter must be stated in relation to the motor nameplate values. Output voltage must be not higher than the rated voltage of the motor. The motor rated current I_r (parameter B00-5) must not be greater than the rated current of the converter or smaller than 30 % of the rated current of the converter. It means that $I_{rm} > I_r > 0.3\ I_{rm}$ (where I_{rm} is the rated current of the converter).

Increasing the carrier frequency, the pulse width modulation can reduce the electromagnetic noise. Sometimes the carrier frequency is decreased automatically when the load increases (Fig. 4.14. Because of this, when the carrier frequency is lower, the loading capability of the motor increases. Relation between the maximum relative current of the motor and the carrier frequency is shown in Fig. 4.15. For example, on the variable torque load, when the temperature of the heat sink of the converter rises up to 70 °C, the carrier frequency decreases automatically to 4 kHz.
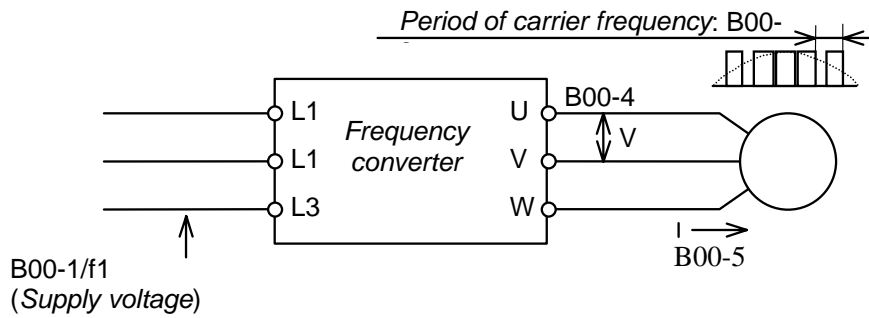
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Figure 4.14. Settings of the carrier frequency and the output voltage and current
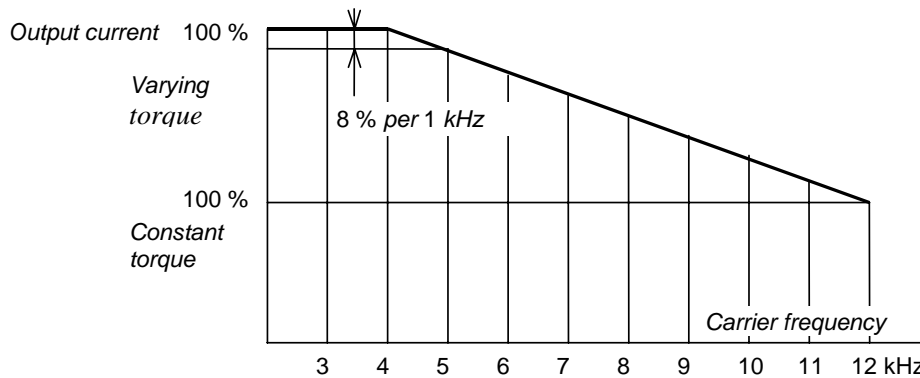

Figure 4.15. Relation between the maximum relative current of the
motor and the carrier frequency

The selection of **starting and stopping methods** helps to determine the type and purpose of the switches that will be used for drive control. The drive may be stopped by coasting or by the deceleration ramp. With the deceleration ramp, motor speed is reduced when the frequency decreases until the braking frequency and then dynamical braking is used.

To start the motor after coasting, it should be observed that the motor stops. Switched off but until rotating, the motor is started by using start with pick-up (flying start), then the converter synchronizes the frequency with the motor speed automatically. When the rotating motor starts without pick-up, the protection may operate.

Setting parameters of the converter determine the auto start conditions. When the corresponding parameter is on state 1 = OFF, the auto start is switched off. The drive will be started by command RUN = ON after the recharging of DC circuit capacitor. When the corresponding parameter is on state 2, after switching on the power supply voltage, the motor starts automatically without the pick-up start, provided that command RUN and converter recharging are finished. When the corresponding parameter is on state 2, then 3, the motor starts with the auto pick-up start. The latter method is used to continue operation after the motor stops due to interruption of the power supply voltage. The drive starts automatically after the power supply voltage is recognized.
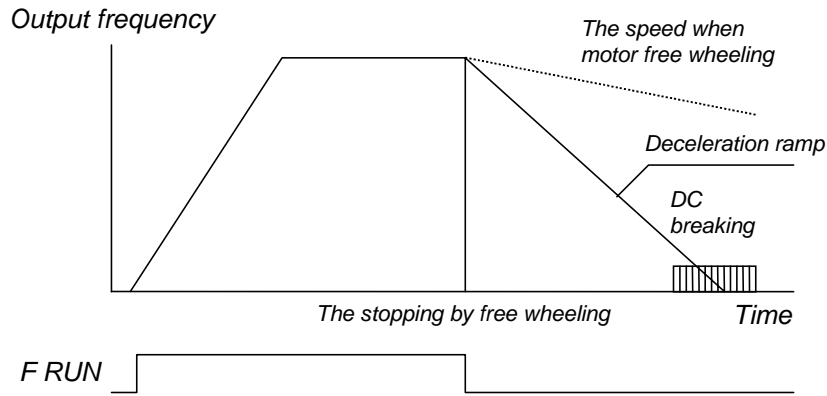
Figure 4.16. Methods of stopping the drive

Recurrence switching and pick-up is used to restart of the drive after unexpected switching off. This function is very important if the drive is intended for continuous duty operation (Fig. 4.17). This function is useful if the supply voltage is occasionally switched off due to the operation of any protection device, but the fault occurring is probably temporary. By the corresponding parameters, the number of recurrence switching and retry wait time will be set. When the flying start is impossible, the converter will send the output signal that the retry time is out.
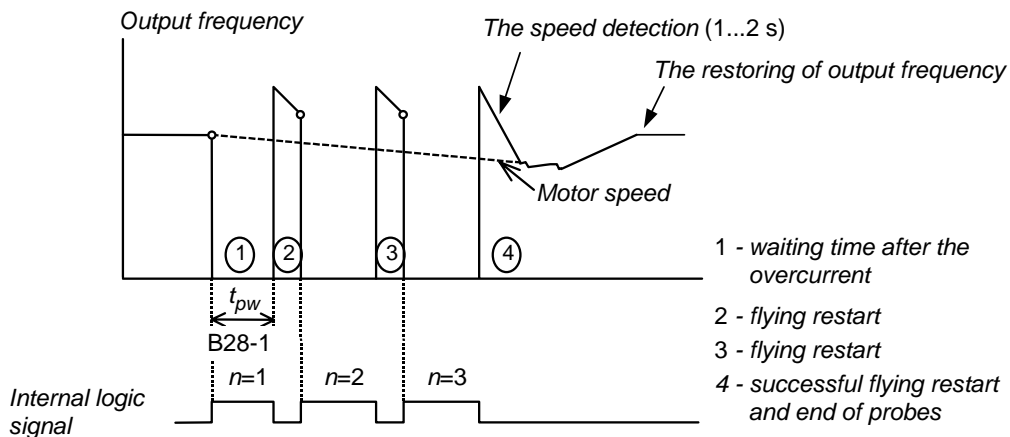

Figure 4.17. Recurrence switching and flying start

A frequency converter has the emergency stop function, which makes it possible to select the emergency stop method, e.g., stopping by coasting or by deceleration ramp. For smooth starting and braking, **S-shape acceleration** and **deceleration ramps** are used (Fig. 4.18). By help of parameter B21-4, the time interval t_s of smooth change of acceleration is determined, whereas acceleration and deceleration times t_a and t_b set the shape of the ramp and are not changing. Different converters enable ramp setting by the selection of typical ramps. Smooth control of acceleration is very important in control systems of electric drives of trams, trains, trolleys etc. because passengers are very sensitive to the variation of acceleration (push).
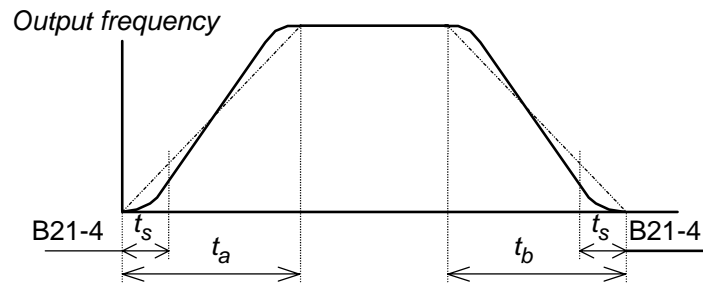
71

Figure 4.18. S-shape acceleration and deceleration ramps

Frequency skip settings are intended to externalize the operation of a drive at the mechanical resonance frequency. For this, some prohibition places are determined in the frequency control area of the motor, with width of 0-10 Hz, where the continuous control of frequency is impossible. To set the frequency skip, mechanical qualities of the drive and the actuator must be studied.

Ratio interlock settings and upper/lower limits make it possible to fit analogue frequency setting signals with the regulation qualities of the system. To select the module and the polarity of the amplifier coefficient A, the amplitude and polarity of the displacement signal B and limits of control signal (upper and lower limits) must be established. A scheme of signal fittings and ratio interlock settings is given in Fig. 4.19. The output signal is calculated by help of the formula $Y = AX + B + C$. Auxiliary input is used as displacement signal C. Ratio interlock settings are principally used in drives with closed loop control systems, e.g., to control a pump by help of pressure feedback.

Signal level detections are intended to check output signals of the drive (frequency, current and speed) and to obtain logic signals in the output, which shows the logic state of the analogue signal (below or over the threshold level). The logic output signal can be used to control the output relay.

Detection of output frequency, current and speed is shown in Fig. 4.20. Detection level is selected by the parameter B26-0 lower F_{max} 1-20%. Control signal ATN attains the output switched ON when the output frequency approaches the frequency setting. For output current detection, a detection level by setting B26-1 5-300 % rated current is selected. Control signal IDET current detection level is switched ON or OFF with hysteresis 5 %. For speed detection, the detection level SD1 or SD2 is selected by setting B26-2 or B26-3, depending on the maximum frequency f_{max} in the range of 1-105 %. Control signal SPD depends on the speed detection level and is switched ON or OFF with hysteresis 1%.
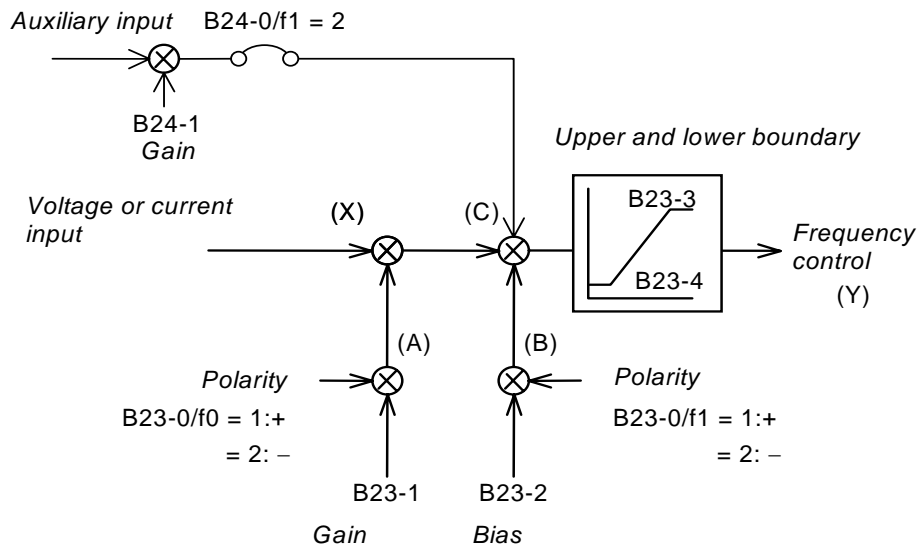
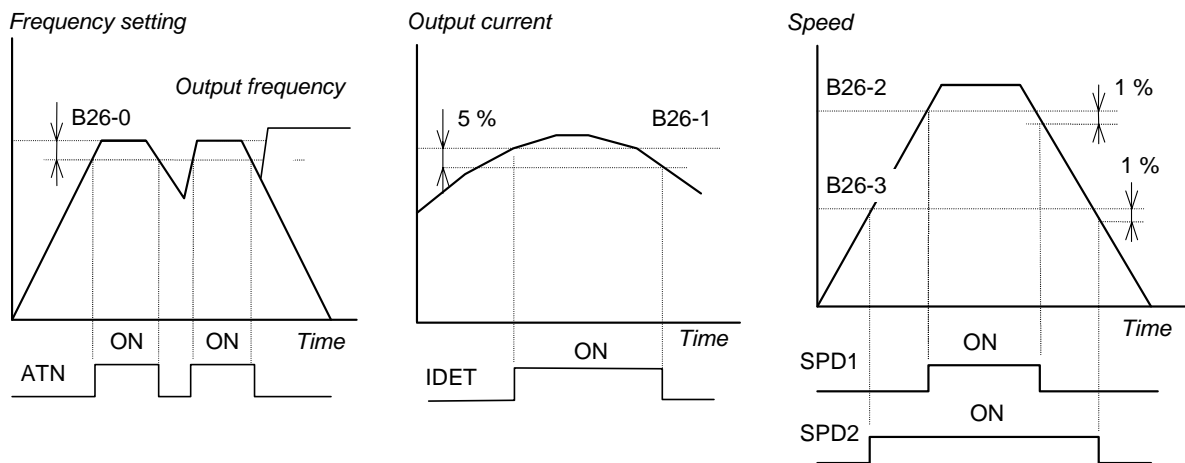Figure 4.19. Signal fittings and ratio interlock settings

Figure 4.20. Detection of output frequency, current and speed

Motor current can be limited by the frequency (speed) decreasing such that it does not exceed the value set by the parameter B29-0. The motor rated current is considered as 100 % current. The setting of **over-current limit** must be higher than the current of the unloaded motor.

At drive braking or at constant speed operation, the regenerative torque is limited. The limit of the regenerative torque is, e.g., 10 % (parameter B29-1), when dynamical braking is not used. When the dynamical braking is used, the **regenerative torque limit** is determined by the formula

$$T_{LIM.RM} = \left[\left(\frac{V2}{Braking\ resist,\ \Omega} \right) \Big/ Motor\ power,\ kW \right] \cdot 100\% \,,$$

where coefficient V2 is 148.2 when the power supply voltage is 230V and 539 when the power supply voltage is 400 V.

The heating time of the motor depends on energy losses (current of windings), the thermal time constant and cooling conditions. Cooling conditions depend on the speed of motor rotation. Because of this, motor protection is set on in relation to the time-current characteristic. The form of characteristics must be selected as a function of the real operation mode. Over-current limit settings are selected by the time-current characteristics parameter B30-0. Depending on the setting of the parameter B30-0, the form of the time-current characteristic varies (Fig. 4.21). The form of the characteristics depends also on the motor load, e.g., CT, constant torque or VT variable torque. Relative current is determined on the base of the rated current (100%).
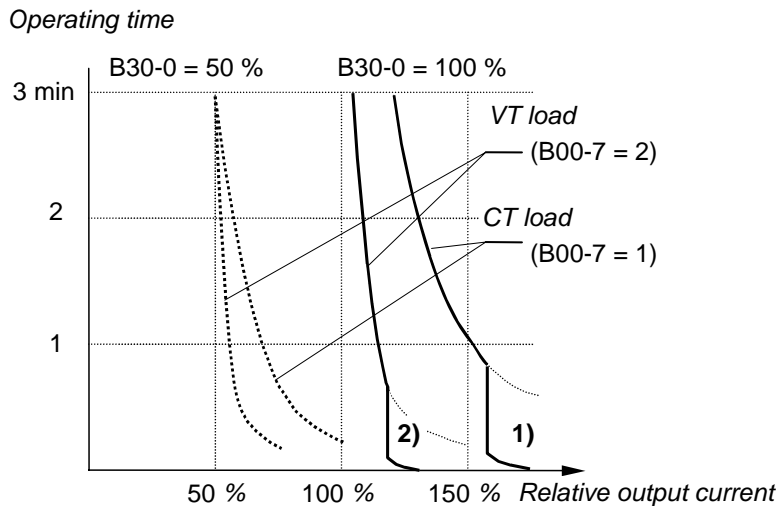

Figure 4.21. Second-ampere characteristics of the over-current limit

There are additional settings for forward F RUN and reverse R RUN commands. The lower limit of the starting and braking frequency determines the frequency level when the motor will stop. At frequency setting 0, the real minimum frequency is 0.1 Hz and motor does not stop. Motor stopping is possible by using the special setting (B32-0). The upper limit of the starting frequency is used when the motor must work on the low speed. The motor does not start when the frequency setting is higher than the upper limit f = 0-20 Hz, despite the command RUN is at state ON. The difference (0-20 Hz) between the starting and braking frequencies will guarantee the stability of the drive operation.

Starting time delay is used to synchronize the operation with other devices, such as mechanical brake. A time diagram of the starting timer is shown in Figure 4.22 (parameter B32-3). The starting timer forms a programmable time delay t_{delay} after the given start command F RUN.
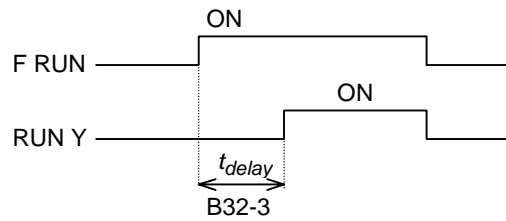
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Figure 4.22. Starting time delay

The **programmable operation mode** enables a cyclic operation of the electric drive on the principles of sequential logic. The direction rotation, frequency (speed) and operating time different operation intervals can be determined by the programmable settings of macro program. The alternation of different operation intervals will be controlled automatically.

On **PID-control**, a feedback signal to the additional input AUX is used. The block scheme of the PID-control is shown in Fig. 4.23.

Setting parameters of the described frequency converter provide only an overview of the possibilities of using contemporary converters. Full information about programmable parameters is given in the user's manual of every type of a converter.
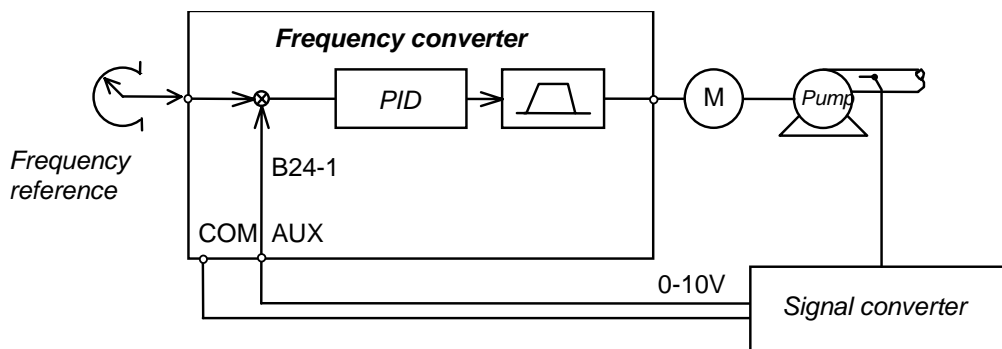

Figure 4.23. PID-control of a pump drive