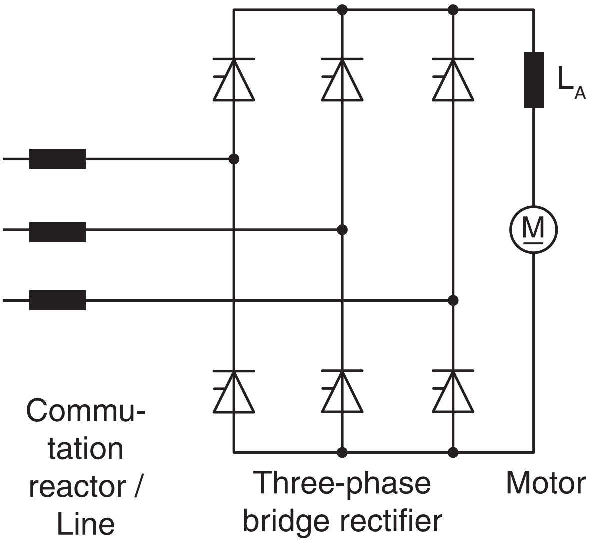
Application note
Mains harmonics and commutation notches in DC drives

DC drives were first drives, which allow continuous adjustment of the rotational speed from zero to maximum speed. Today, in many areas AC drives are used for this task. However, DC drives still have their use in certain areas. They are still used in new machinery and plants. Especially for drives with energy-efficient regeneration capability and for high power drives, DC drives are significantly smaller, lighter and the more compact solution compared to AC drives.



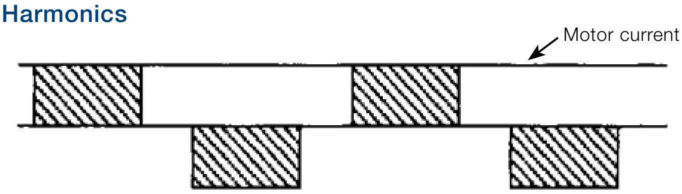
DC drive

Modern DC drives consist of a DC motor, a so-called three-phase bridge rectifier (B6 bridge) and a line reactor, the so-called commutation reactor.

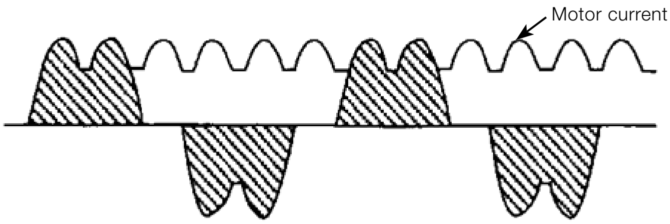
In configurations with a few large DC drives along with other small consumers connected to the same supply, there are occasional problems and disturbances of the small devices, which are then summarized under the general term EMC interference. AC drives produce high frequency disturbances. The problems are solved using line filters and shielded motor cables. In DC drives low-frequency interferences predominate, so-called mains distortions.

In case of EMC interference in plants with DC drives then expensive network analyzes are carried out to find out what is already known anyway. It would be better to carry out an analysis of the low-voltage cabling and low-voltage distribution. By paying attention to a few basic rules during the planning phase of the low-voltage distribution, these problems would probably not have arisen.

Harmonics



Mains current at perfectly smooth direct current



Mains current at typical 6-pulse motor current

The three-phase bridge rectifiers (B6 bridges) produce in the mains characteristic block-shaped currents. Such currents also occur in AC drives with diode rectifiers.
The frequency analysis of this block-shaped current results in the following spectrum:

	h	5	7	11	13	17	19	23	25
Idealized	I_h / I_1	20 %	14 %	9 %	7 %	6 %	5 %	4 %	4 %
Typical	I_h / I_1	26 %	10 %	9 %	5 %	2 %	1 %	1 %	1 %

=> $THD_{current}$ = 36.1 % (Total Harmonic Distortion of line current)
Mains harmonics for 6-pulse motor currents

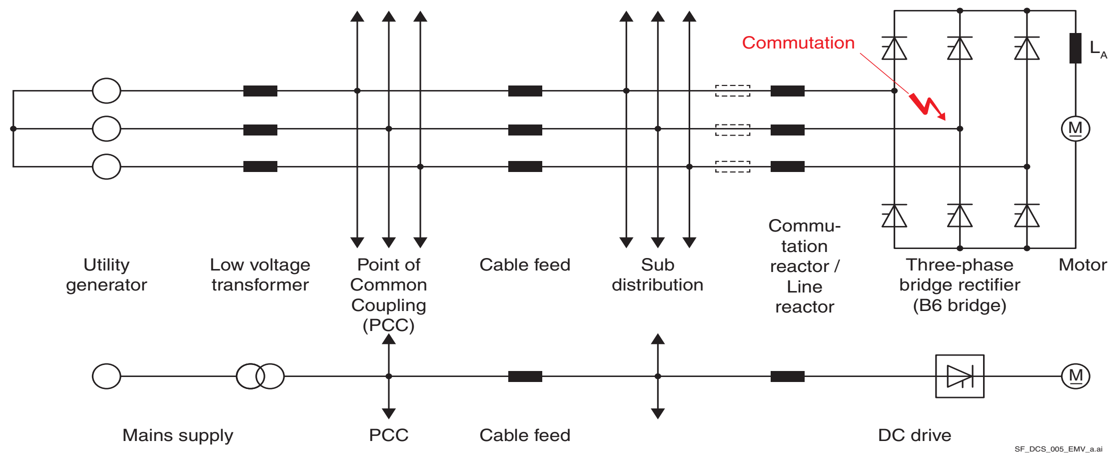
For motor circuits with a low armature inductance or under partial load of the DC drive, the 5th harmonic current can increase up to 45 %.

The values given in the table can be found in the standard EN60146-1-2.

The relatively high spectral values in the mains current are not desired by the utility companies. These current distortions are usually not the cause of disturbances of small consumers.

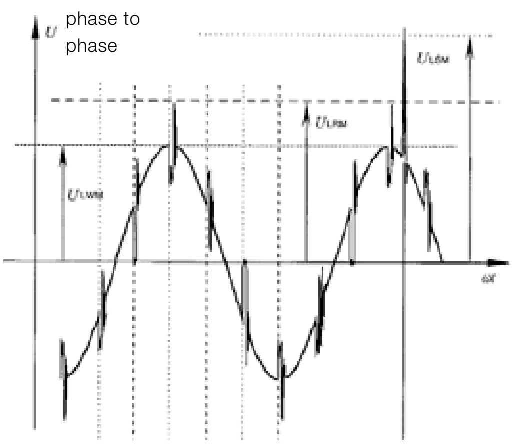
The root cause of disturbances of other consumers at the same point of common coupling (PCC) are usually the commutation notches. Unfortunately, mains with low current harmonics tell us nothing about the voltage quality, since the mains may still be affected by large commutation notches.

Commutation notches



Modern DC drives consist of a three-phase bridge rectifier (B6 bridge) with six thyristors. By switching the thyristors the mains current is passed from the conducting phase straight to the next phase. This process takes only a few microseconds, but the currently switched phase-to-phase voltage is short-circuited during this time. That creates at the input of the three-phase bridge rectifier (B6 bridge) a so-called commutation notch in the line voltage.

The distant power supply station of the network equals an ideal voltage source. Therefore, voltage dips are not measurable at that location. During commutation, an inductive voltage divider is formed between the power supply point and the three-phase bridge rectifier (B6 bridge). The inductances are made up of the commutation reactor, the cable feed, the supply transformer and the mains inductances.

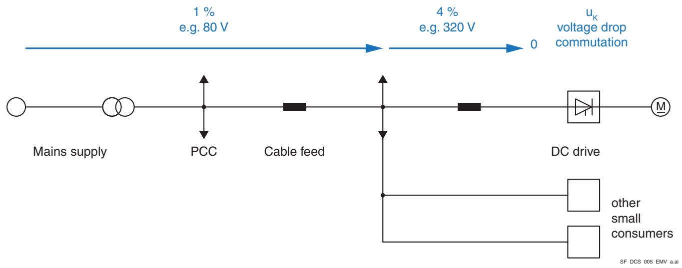


In IEC61800-3, the permissible values of the commutation notches on the supply side of the line reactor are defined (see table).

	First environment	Second environment
Largest notch depth	20 % IEC 60146-1-1, Class C	40 % IEC 60146-1-1, Class B,

Maximum commutation notch

In the field of light industry DC drives are typically equipped with 4 % line reactors. If the commutation notch on the supply side of the line reactor is too high (the voltage drops too deep), then the inductance on the mains side must be lowered. This corresponds to: The short-circuit power on the mains side must be increased.
The document *Econtrol* shows the necessary formulas for the calculation.
Typically, the formulas do not work with the inductance but with the relative voltage drop (uk).



During commutation 80 % (= 320 V) of the mains voltage should drop at the line reactor. On the mains side a maximum of 20 % (= 80 V) mains voltage should drop at the sum of all inductances. Thus, the mains supply must only have a relative uk of 1 % (related to the DC drive).

Power DC drive @ 400 V	P [kW]	50	100	200	300	500	700	1000
AC current DC drive	I [A]	102,5	205	410	615	1025	1435	2050
Minimum short-circuit power mains	Sk [MVA]	7	14	28	42,5	71	99	142

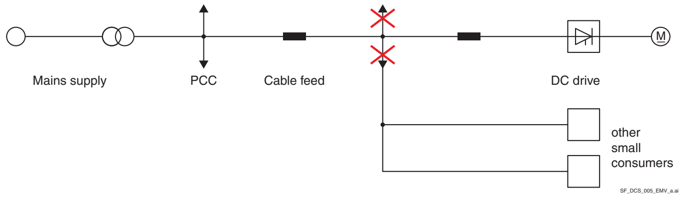
Minimum short circuit power with a 4 % line reactor and at a maximum commutation notch of 20 %

$Sk = Sn / u_K$ $\quad$ $I_{AC} = P_{DC} / U_{DC} * 0.82$

This table shows the correlation between the converter power (4 % line reactor) and the required short circuit power at the point of common coupling (PCC) to limit the commutation notch to 20 %.
Another important aspect is the configuration of the low voltage network, because 200 meter low voltage cables have approximately the same u_K as a 1 MVA supply transformer.
An increase of the short circuit power of the transformer would be only be effectively at its output. At the end of the cable, only a slight improvement is achieved. The disturbance of consumers which are connected jointly at the end of the 200 meter cable would not be resolved.

Therefore, the following design rule applies:

If small or sensitive consumers are supplied along with large DC drives, then the consumers should be grouped and connected as close as possible with separate cables to the transformers supply point.

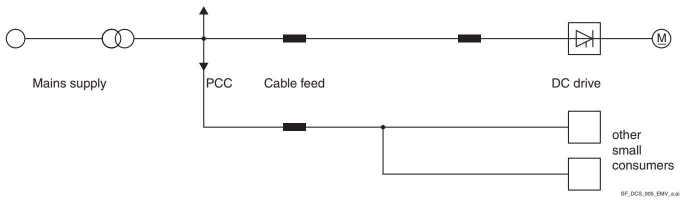


Thus, the behavior of DC drives with respect to the mains does not change. However, the commutation notches for the group with the small sensitive devices are significantly reduced.

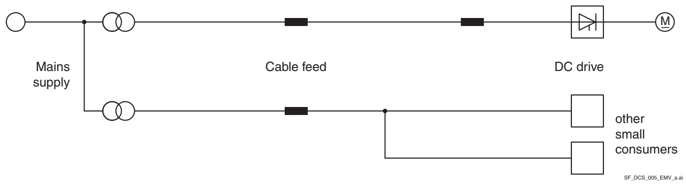
Summary commutation notches:

In case such faults occur on small consumers, the following measures should be carried out in the given order:

- Check: Works the current controller of the DC drive stable (no oscillation)?
- Check the low voltage distribution and if possible move the common point at the sub distribution towards the supply transformer.

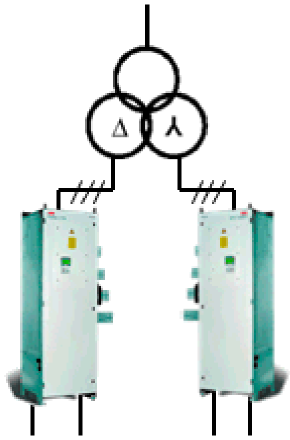


- Increase the short-circuit power at the transformer's supply point or supply the DC drives via a separate transformers.



12-pulse configurations

Large new installations using DC drives are nowadays implemented as 12-pulse or as quasi 12-pulse configurations.



12-pulse und quasi 12-pulse

The ratio of the mains harmonics on the primary side of the 12-pulse transformers are significantly improved.

	h	5	7	11	13	17	19	23	25
Idealized	I_h / I_1	0 %	0 %	9 %	7 %	0 %	0 %	4 %	4 %
Typical	I_h / I_1	3 %	2 %	6 %	5 %	1 %	1 %	2 %	1 %

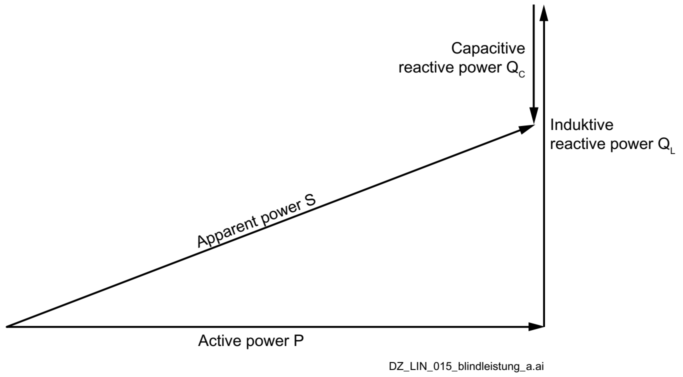
=> $THD_{current}$ = 11.8 % (Total Harmonic Distortion of line current)

Mains harmonics for 12-pulse motor currents

Additionally the commutation notches are significantly reduced. A transformer usually has a u_K of 7 % to 8 %, thus reducing the commutation notches by 50 % compared with a 4 % line reactor. A 12-pulse transformer carries only half the power via each leg. Thus, the 8 % refer to half the power, so that the commutation notches can be further reduced to a total of 25 % compared to a 4 % line reactor.

Commutation notches and power factor compensation

Industrial buildings are often equipped with a power factor compensation in order to reduce the reactive current consumption from the utility company.



Vector diagram reactive power

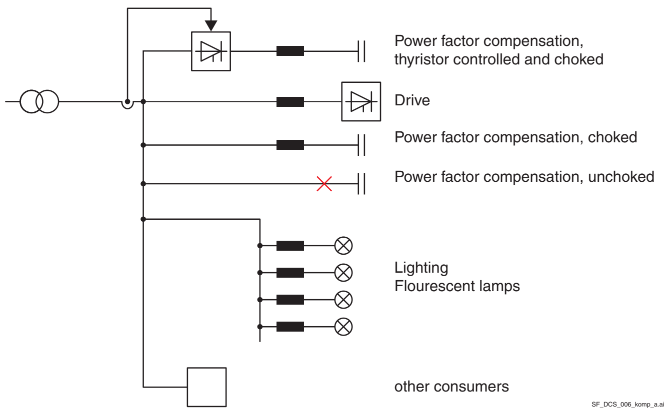
In the vector diagram, the reactive power is perpendicular to the active power. The apparent power results from the geometrical addition of the active power and the reactive power.

Such a power factor compensation meets the inductive reactive power requirements of fluorescent lamps.
In case no other inductive loads are connected to the network often unchoked power factor compensation are used.

However, if a consumer with semiconductors is connected to the input (e.g. drives, heating controllers) then an unchoked power factor compensation is stressed with high-frequency currents. This additional current leads to increased losses, possibly even to faster aging of the capacitors in the power factor compensation.

Commutation notches induce oscillations in unchoked power factor compensations. These resonances can heighten voltage peaks, interfere with other consumers and even destroy them.

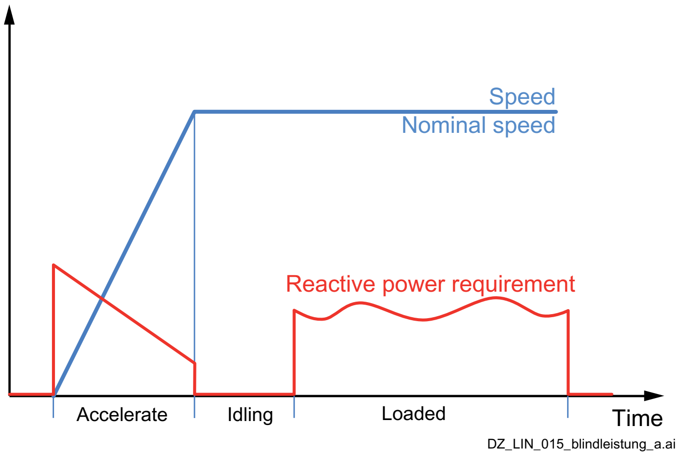
Aging and excess voltage can be limited by a using a choked system. Therefore, an unchoked power factor compensation should be replaced by a choked power factor compensation.



Single-phase equivalent circuit diagram, drive and lighting

Reactive power requirements of DC drives

DC drives have an inductive reactive power consumption. Compared to lighting devices this reactive power consumption is dependent on speed and torque and thus dynamically very quickly changing. The power factor compensation for drives and DC drives is usually carried out by thyristor controlled power factor compensations.



Reactive power requirements of a DC drive as a function of time

Estimation of the reactive power requirements of a DC drive:

Reactive power (Q) 4-q drive = $U_{motor} * I_{motor} * 0.7$

Reactive power (Q) 2-q drive = $U_{motor} * I_{motor} * 0.35$

In thyristor controlled power factor compensations, the reference of cos Phi can be set. A typical value is a cos Phi of 0.9. If the reference values are increased in direction of cos Phi = 1, then the compensation control cannot follow fast changes in the drive current. This can lead to strong oscillations.

For more information:

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