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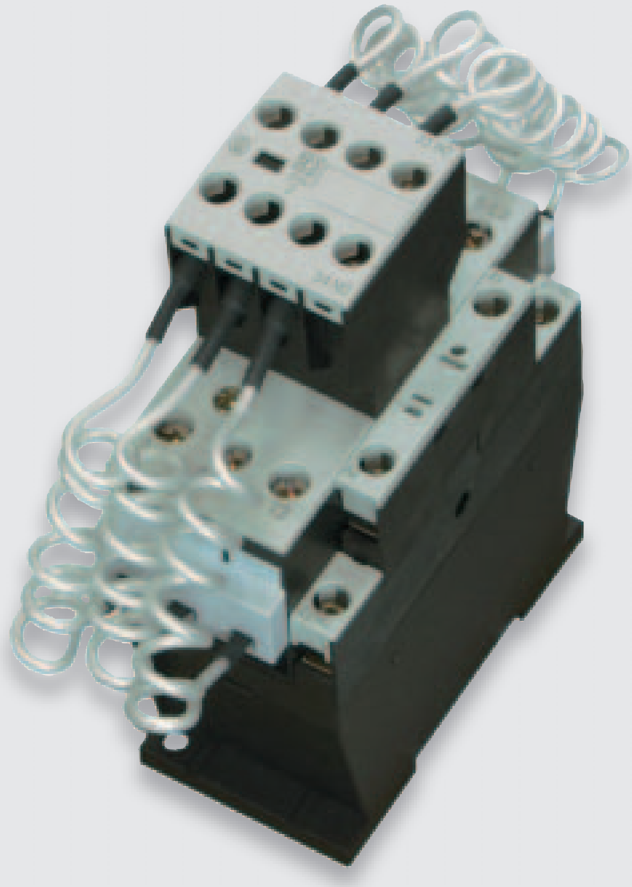
Switchgear for Power Factor Correction Systems



Technical Paper

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Powering Business Worldwide

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Switchgear for power factor correction (PFC) systems

When implementing PFC, it is important to differentiate between various circuit types or capacitor assignments to inductive loads.

A differentiation is made between individual PFC and group PFC.

With individual PFC, the capacitor is individually assigned or switched to a load.

With group PFC, the power factor of a load group is determined with varying power configuration. Multiple capacitors are automatically switched in or out by a VAr controller. The task of both application types is to improve the power factor and thus achieve a reduction of the reactive power.

The level to which the power factor can be improved and the individual economic effects resulting from a cheaper electricity tariff, should be clarified with the tariff consultants of the local electricity supply company (utility company).

This article examines the switchgear involved. The stresses and demands placed on the contactors and the capacitors differentiates for individual PFC and for group PFC. Both situations are dealt with in the following.

The differences in circuits and demands have been subject to particular attention as a result of new technologies employed in the manufacture of capacitors.

In the last few years, the use of new materials and manufacturing processes has resulted in a reduction of the inductive internal resistance‘s in the capacitors. The peak inrush currents have increased dramatically as a result of the lower impedance‘s, which have less of a limiting effect on the current of the high frequency transients during switch on.

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Individual PFC

With individual PFC, the capacitor draws its current from the mains supply. In order to also reduce the reactive power to the cables, the capacitor is installed as close as possible to the equipment with this circuit arrangement. With this application, the contactor is generally not in the proximity of the transformer – e.g. in the main distribution board – but rather in a sub-distribution board.

As evident in Figure 1, numerous individual impedance‘s which add up together exist on the current path from the medium-voltage transformer to the capacitor, and generally have the effect of limiting the peak inrush currents to < 30 x I_N of the capacitor. The peak inrush currents thus flow for a few millisecond‘s during switch-on, which is generally within the range of the making capacity of the normal DIL M.... contactor. Normally, the capacitors are switched directly in parallel to the load with individual power factor correction. This means that the capacitor is switched with the same contactor as the motor. In accordance with Figure 2, the motor protection must be set differently depending on whether the capacitor is connected upstream or downstream of the overload relay, and whether the reactive current flows or does not flow through the thermal release.

From the point of view of demands placed on the contactor, normal DIL M... contactors can be used for individual PFC.

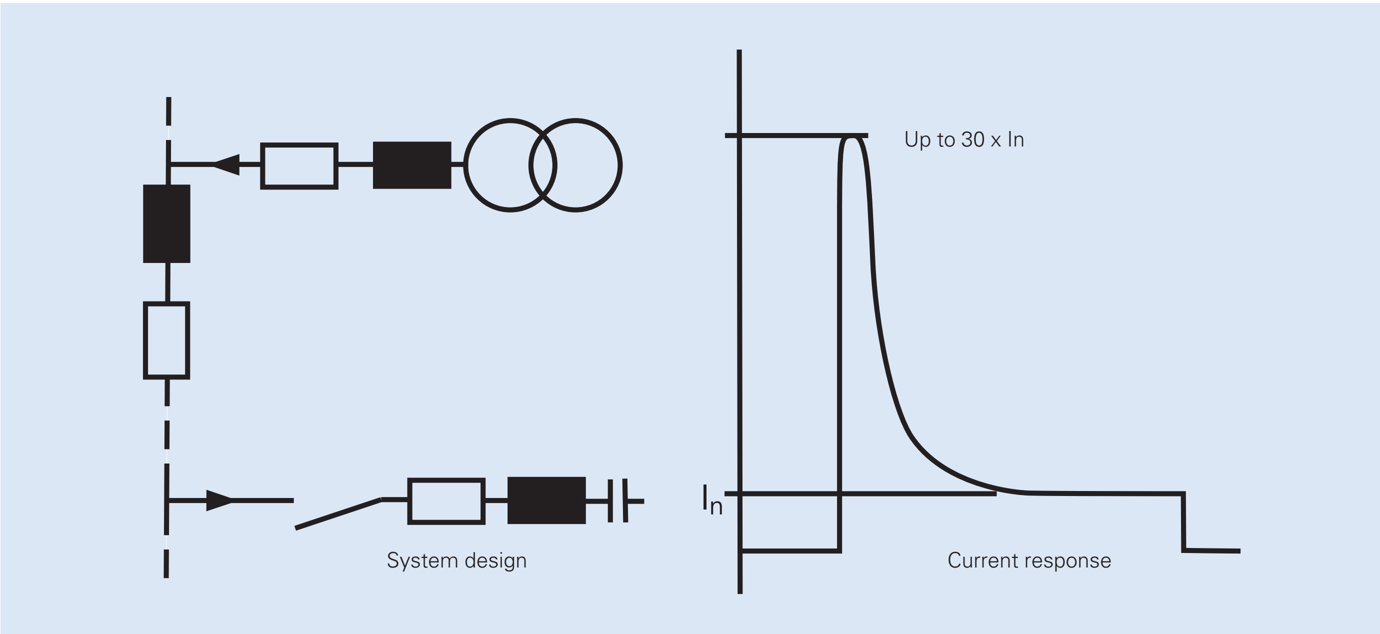
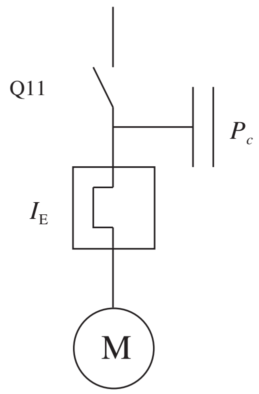
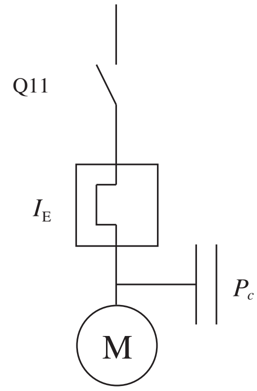


Figure 1

Capacitor connected

to the contactor terminals	to the motor terminals
	

Setting of the overload relay

$I_E = I_N$	$I_E = \sqrt{I_W^2 + (I_B - I_c)^2}$

Note

Capacitor does not reduce the load on the cable from the contactor	Capacitor reducing the load on the cable from the contactor to the motor, general arrangement

I_N = rated motor current [A]

I_W = active current of the motor [A]

I_B = reactive current of the motor [A]

I_C = capacitor current [A]

I_E = current setting of the protective relay [A]

$\cos\varphi$ = power factor of the motor

U_N = rated voltage [V]

P_C = capacitor nominal output [kvar]

C = capacity of the capacitor [μF]

$$I_W = I_N \times \cos\varphi$$

$$I_B = \sqrt{I_N^2 - I_W^2}$$

$$I_C = \sqrt{3} \times U_N \times 2\pi f \times C \times 10^{-6}$$

$$I_C = \frac{P_C \times 10^3}{\sqrt{3} \times U_N}$$

Figure 2

Group PFC

With group power factor correction, the physical arrangement of the contractors and capacitors is mostly in the proximity of the low-voltage transformer, e.g. in the low-voltage sub-distributor. At this point, it is important to observe that the operating voltage and the short-circuit rating are higher during a fault.

The higher voltage has been taken into consideration by the manufacturers of the capacitors by the higher rated operational voltage of the capacitor. The power ratings of the contactors for switching capacitors relate to these voltages.

With group PFC, the charging current of the capacitors is not just supplied via the impedance-associated path by the mains supply, but also from the neighbouring low-impedance connected capacitors which are already charged. For this reason, the peak inrush currents are in the order of > 150 x I_N.

The making capacity of a normal contactor is thus exceeded. Viewed from a physical viewpoint, the high needle-shaped current peaks strip constituents from the contact material alloy which prevents welding of the contacts. After just a few hundred switching operations only pure silver will remain and the contacts will weld. Special devices or respective measures are required here.

a) Special – DILK... contactor for capacitors

These contactors for capacitors have been developed from the DILM... series contactors and fit perfectly and fully into the product range in terms of handling and accessories. In addition to a special anti-weld contact material, this contactor also contains series resistors. The capacitors are pre-charged via a special early-make auxiliary switch. The main contacts then close and conduct continuous current.

b) Choking of the PFC stages

The proportion of harmonics are increasing on the mains supply due to the ever-increasing proportion of "non-linear loads" (e.g. power electronics, switched-mode power supply units...). This can lead under certain conditions to thermal overload of the capacitors, as the resonance frequency and the oscillating circuit which is formed by the line inductance and PFC capacity, can be in the frequency range of a harmonic. Depending on the size and number of stages, many resonance frequencies can be passed through with regulated reactive-power factor correction equipment.

In order to avoid possible damage, PFC equipment is equipped with an upstream choke. Furthermore, the chokes ensure that the ripple control systems of the electricity supply company are not subject to interference, and are therefore stipulated quiet frequently in the technical connection guidelines.

Power factor correction equipment with chokes

- correct reactive power
- remove undesirable harmonics from the mains supply
- avoid resonance phenomenon with harmonics
- are suited for electrical power networks with ripple control systems

Systems equipped with chokes also have a further advantage:

The inrush current peak which occurs when a capacitor stage is switched on is dampened considerably. Thus, when switching choked PFC stages, it is possible to use normal DILM... series contactors. The same applies for non-choked systems when an additional nductivity of > 5 μH is added between the contactor and capacitor (corresponds to an air-core inductor with 4 windings and a diameter of 14 cm)

The contactors which are used however must be dimensioned correctly. The contactor must be capable of continuously conducting 1.5 times the capacitor on-load current conform to EN 60931-1. It is thus possible to determine the maximum capacitor nominal output of a choked capacitor bank, which is to switch a contactor with the formula [kvar]:

$$P_C = \sqrt{3}\, U_N \times 0{,}66 \times I_{AC-1} \times 10^{-3}$$

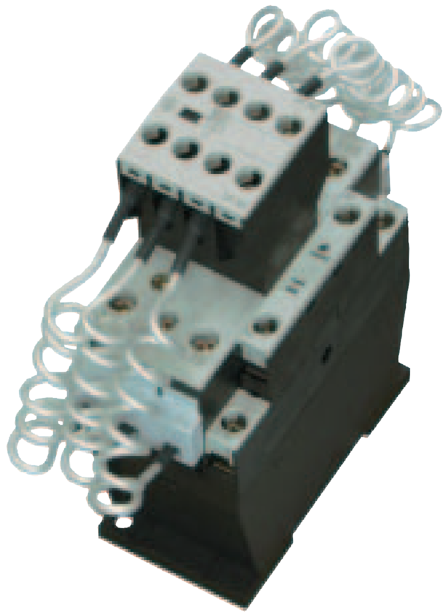


Figure 4

c) Circuit requirements with the contactor control

If the switching operations of a capacitor bank are observed, it is often noted that multiple contactors are continuously remain on and only a few of them perform the control tasks. It is also advantageous for enhancement of the lifespan of a contactor to ensure that the number of switching operations are distributed evenly across all the contactors of PFC equipment. Various manufacturers of PFC regulators offer so-called ring regulators which cyclically exchange the switching sequence of the contactors.

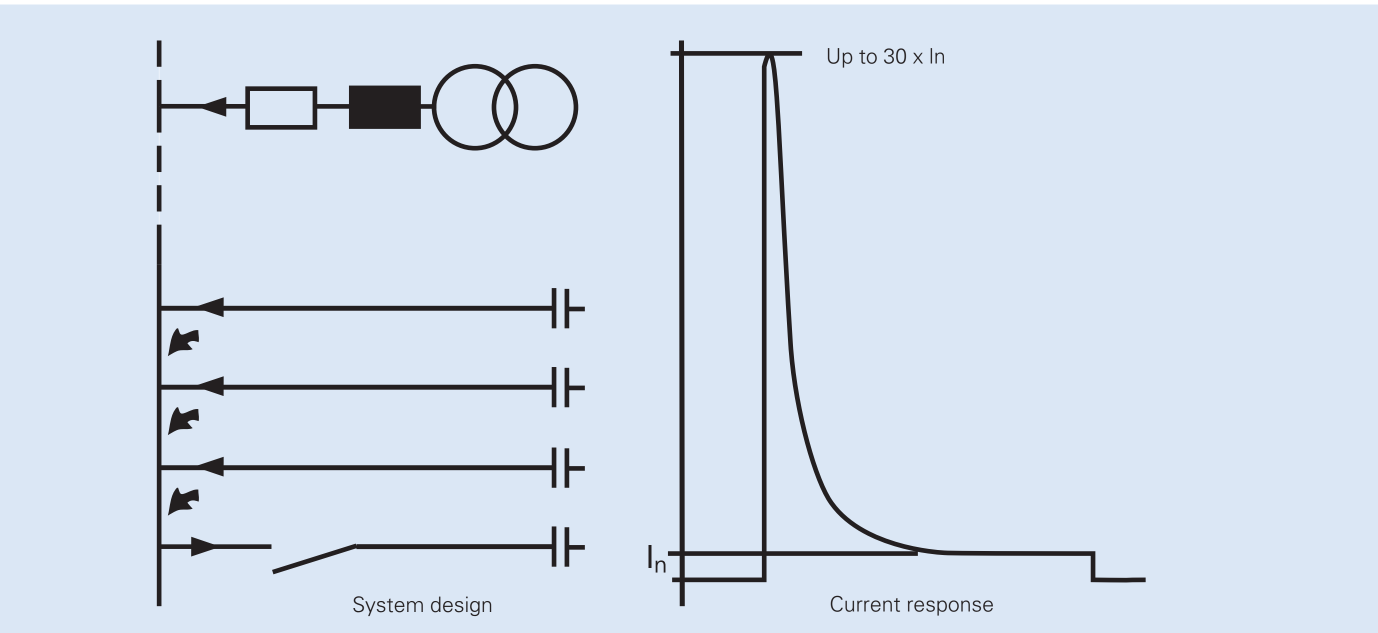


Figure 3

Engineering Note

Contactors for PFC

Type	230V kvar	400V 420V 440V kvar	525V kvar	690V kvar
Individual PFC				
DILM7	1.5	3	3.5	5
DILM9	2	4	4.5	6
DILM12	2.5	4.5	5.5	7
DILM15	2.5	4.5	5.5	7
DILM17	6.5	12	14.5	19
DILM25	7	13.5	16	21
DILM32	7.5	14.5	17	22.5
DILM40	11	20.5	24.5	32
DILM50	11.5	22	26	34.5
DILM65	12.5	23.5	28	37
DILM80	16	30.5	36.5	48
DILM95	18	34	41	54
DILM115	24	46	54.5	72
DILM150	28	53	63.5	83.5
DILM185	87	150	190	150
DILM300	115	200	265	200
DILM580	175	300	400	300
Group PFC with choke coil				
DILM7	4	7	7.5	12
DILM9	5	8	10	14
DILM12	5.5	10	12	16
DILM15	5.5	10	12	16
DILM17	7.5	16	20	28
DILM25	9	18	23	30
DILM32	10	20	24	32
DILM40	13	25	30	40
DILM50	16	30	36	48
DILM65	19	36	43	57
DILM80	30	58	68	90
DILM95	34	66	79	104
DILM115	44	80	100	125
DILM150	50	97	115	152
DILM185	80	150	200	260
DILM225	100	175	230	300
DILM250	110	190	260	340
DILM300	130	225	290	390
DILM400	160	280	370	480
DILM500	220	390	500	680
Group PFC without choke coil				
DILK12	7.5	12.5	16.7	20
DILK20	11	20	25	33.3
DILK25	15	25	33.3	40
DILK33	20	33.3	40	55
DILK50	25	50	65	85
DILM185	66	115	145	115
DILM300	85	150	195	150
DILM580	145	250	333	250

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