Application Paper **AP03407004E**

Effective April 2016
Supersedes July 2008

Application of electromechanical contactors for power factor correction

Application

When applying electromechanical contactors for power factor correction (PFC), it is important to understand the type of capacitor installation involved. There are two basic types of capacitor installations:

- Individual capacitors on linear or sinusoidal loads
- Banks or groups of fixed or automatically switched capacitors at the feeder or substation

This application note discusses the stresses and demands on contactors and how to apply Eaton's ***XT*** contactors in each application.

Power factor correction (PFC)

Most loads in modern electrical distribution systems are inductive. Examples include motors, transformers, gaseous tube lighting ballasts, and induction furnaces. Inductive loads need a magnetic field to operate and require two kinds of power:

- **Working power (kW)** to perform the actual work of creating heat, light, motion, machine output, and so on
- **Reactive power** (kVAR) to sustain the magnetic field

Working power and reactive power together make up **apparent power (kVA)**, supplied by the electrical utility.

Power factor (PF) is a measure of electrical distribution efficiency. In simple terms, it is the ratio between the amount of energy used (working power—kW) and the amount of energy supplied (apparent power—kVA). When apparent power (kVA) is greater than working power (kW), the power factor is not optimized and the utility must supply the excess reactive current plus the working current. This low power factor can result in higher energy costs or premature equipment failure. Utilities commonly charge penalties when power factor is below that specified on energy contracts.

$$PF = \frac{\text{Working Power}}{\text{Apparent Power}} = \frac{kW}{kVA}$$

Power factor correction capacitors act as reactive power generators. By providing the reactive power, they reduce the total amount of current your system must draw from the utility—see **Figure 1**.

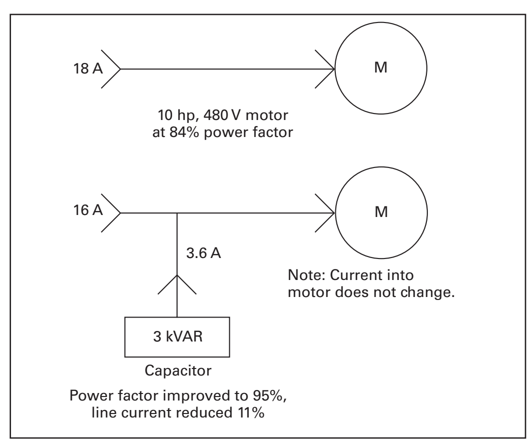

Figure 1. Power factor improvement

Types of power capacitor installations

There are two basic types of capacitor installations: **individual** capacitors on linear or sinusoidal loads, and **banks/groups** of fixed or automatically switched capacitors at the feeder or substation.

With **individual PFC**, the capacitor is individually assigned or switched to a load. With **banked/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 minimize the reactive power required from the utility.

The differences in circuits and demands for each type of installation are 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 in the capacitors. This makes them better at the job for which they are designed, but it also makes them a more difficult load to switch, because there's less impedance to limit the inrush current as the capacitor charges. The peak inrush currents have increased dramatically as a result of the lower impedances, which have less of a limiting effect on the current seen when switching capacitors.

Individual PFC

With individual PFC, the capacitor draws its current from the line power supply. In order to reduce the reactive power to the cables, the capacitor is installed as close as possible to the equipment. 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 subdistribution board. Because the capacitor is near the load and remote from the distribution board, the impedance of the supply cables will tend to limit the charging current.

As evident in **Figure 2**, numerous individual impedances 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 (I_n = capacitor's steady-state operating current) of the capacitor. The peak inrush currents flow for a few milliseconds during switch-on, which is generally within the range of the making capacity of the normal XTCE contactor.

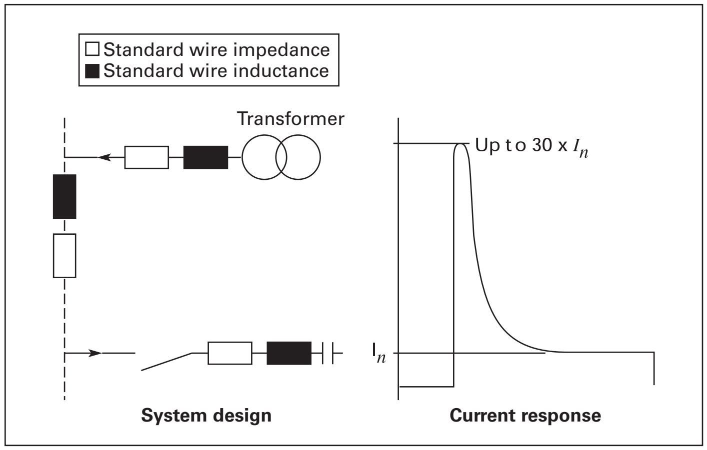

Figure 2. Peak inrush for individual PFC

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. From the point of view of demands placed on the contactor, normal XTCE contactors can be used for individual PFC—see **Table 1** for the capacitive ratings of XTCE contactors for individual compensation.

Table 1. Individual compensation

Frame size	Contactor	200 V kVAR	230 V kVAR	400 V kVAR	440 V kVAR	480 V kVAR	525 V kVAR	600 V kVAR	690 V kVAR
B-Frame	**XTCE007B**	1.5	1.5	3	3	3.5	3.5	4	5
	XTCE009B	1.5	2	4	4	4	4.5	5	6
	XTCE012B	2	2.5	4.5	4.5	5	5.5	6	7
	XTCE015B	2	2.5	4.5	4.5	5	5.5	6	7
C-Frame	**XTCE018C**	5.5	6.5	12	12	13.5	14.5	17	19
	XTCE025C	6	7	13.5	13.5	14.5	16	18	21
	XTCE032C	6.5	7.5	14.5	14.5	16	17	20	22.5
D-Frame	**XTCE040D**	9.5	11	20.5	20.5	22.5	24.5	28	32
	XTCE050D	10	11.5	22	22	24	26	30	34.5
	XTCE065D	10.5	12.5	23.5	23.5	26	28	32.5	37
F-Frame	**XTCE080F**	14	16	30.5	30.5	33.5	36.5	41.5	48
	XTCE095F	15.5	18	34	34	37.5	41	47	54
G-Frame	**XTCE115G**	21	24	46	46	50	54.5	62.5	72
	XTCE150G	24.5	28	53	53	58	63.5	73	83.5
L-Frame	**XTCE185L**	75.7	87	150	150	165.2	190	190	150
	XTCE225L	191	220	220	220	191	220	220	133
	XTCE250L	191	220	220	220	191	220	220	133
M-Frame	**XTCE300M**	100	115	200	200	265	265	265	177
	XTCE400M	100	115	200	200	265	265	265	177
	XTCE500M	100	115	200	200	265	265	265	177
N-Frame	**XTCE580N**	175	175	300	300	400	400	400	265
	XTCE650N	175	175	300	300	400	400	400	265
	XTCE750N	175	175	300	300	400	400	400	265
	XTCE820N	175	175	300	300	400	400	400	265
	XTCEC10N	175	175	300	300	400	400	400	265

Banked/group PFC

With banked/group power factor correction, the physical location of the contactors and capacitors is typically in the area of the low voltage transformer. At this point, it is important to observe that the operating voltage and the available short-circuit current are generally high. Capacitor manufacturers have taken the higher voltage into consideration with 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 not only comes from the main supply power (with impedance), but also from the other low impedance capacitors within the group, which are already charged. For this reason, the peak inrush currents when a capacitor is switched in a bank are in the order of >150 x I_n (see **Figure 3**). The making capacity of a standard XTCE contactor is thus exceeded. From a physical viewpoint, the high needle-shaped current peaks would strip constituents from the contact material alloy, designed to prevent welding of the contacts. After just a few hundred switching operations, only pure silver would remain and the contacts would weld. To handle this application, special devices or design considerations are required and discussed.

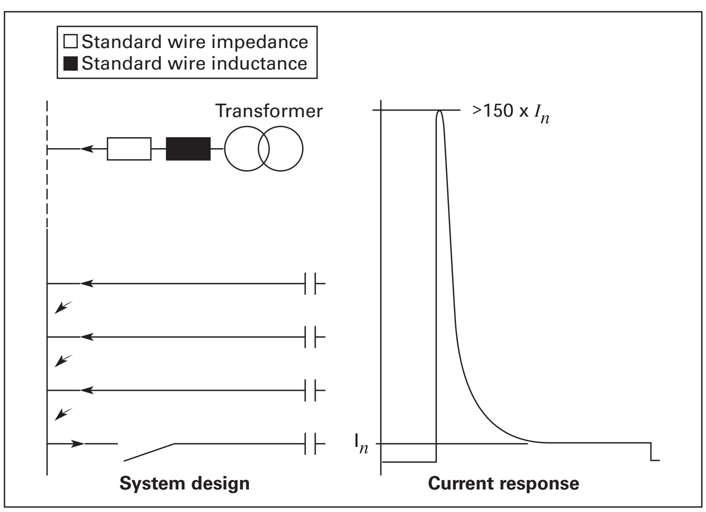

Figure 3. Peak inrush with group PFC

Consideration 1. XTCC capacitor contactors

The XTCC capacitor contactors are specifically designed to handle the unique application requirements for banked or group PFC. Developed from the ***XT*** family of contactors, the XTCC have special anti-weld contact material and resistors that are in parallel with the capacitors. The resistors work in conjunction with a special early make auxiliary contact to pre-charge the capacitors so the main contacts do not see the peak inrush. After the pre-charge, the main contacts then close after a time lag and conduct continuous current.

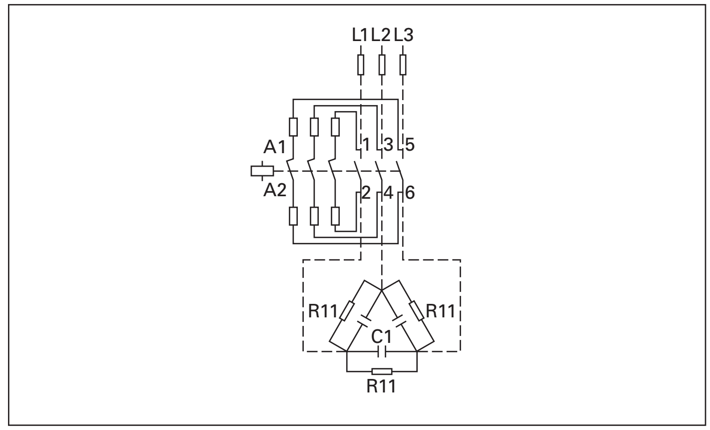

Figure 4. Wiring diagram

The XTCC capacitor contactors fit into the ***XT*** family of IEC power control and are similar in terms of handling and accessories. Available in the same frame sizes as the ***XT*** standard contactors (XTCE), these units are an ideal solution for power factor correction applications. For a full listing of complementary products, consult Volume 5: Motor Control and Protection, Tab 1, ***XT*** IEC Power Control, (CA08100006E), available at www.eaton.com.

See **Table 2** on **Page 4** for a listing of ***XT*** ratings for banked/group compensation without a choke.

Consideration 2. Choking the PFC stages

Another option for PFC systems is to have them equipped with an upstream choke.

With the increase of "nonlinear" loads in electrical installations, there is an increase of harmonics on the main supply lines. In some cases, this increase in harmonics can lead to thermal overload of the capacitors, and possible damage. Upstream chokes will help avoid this damage and offer other potential benefits. Systems with upstream chokes:

- Correct reactive power
- Remove undesirable harmonics from the main power line
- Avoid resonance phenomena with harmonics
- Are suited for electrical power networks with ripple control systems

Beyond the advantages, upstream chokes can also dampen the inrush current peak that occurs when a capacitor stage is switched on. Thus, when switching choked PFC stages, it is possible to use normal XTCE Series contactors. The same would also apply for nonchoked systems when an additional inductivity of >5 mH is added between the contactor and the capacitor (corresponds to an air-core inductor with four windings and a diameter of 14 cm).

The contactors that are used must be sized correctly, however, and must be capable of continuously conducting 1.5 times the capacitor on-load current to 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:

$$P_C = \sqrt{3}\, U_n \times 0.66 \times I_{AC\text{-}1} \times 10^{-3} \text{ [kVAR]}$$

P_C = Capacitor nominal output

U_n = Rated voltage

See **Table 3** on **Page 4** for a listing of ***XT*** ratings for banked/group compensation with a choke.

Consideration 3. Circuit requirements with the contactor control

Another consideration for contactors used in banked/group PFC is the distribution of switching operations among all of the contactors. Very often, multiple contactors used in group PFC continuously remain on and only a few are performing the control tasks. It is helpful for the lifespan of the contactors that the number of switching operations be evenly distributed across all of the contactors within the PFC equipment. Various manufacturers of PFC capacitors offer VAR controllers that cyclically exchange the switching sequence of the contactors and capacitors.

For further technical information on applying power capacitors, consult Eaton's *Power Factor Correction: A Guide for the Plant Engineer* (publication SA02607001E), available at www.eaton.com.

Table 2. Banked/group compensation without a choke

Frame size	Contactor	200 V kVAR	230 V kVAR	400 V kVAR	440 V kVAR	480 V kVAR	525 V kVAR	600 V kVAR	690 V kVAR
C-Frame	**XTCC020C11__**	11	11	20	20	20	25	30	33.3
	XTCC025C11__	15	15	25	25	31	33	38	40
D-Frame	**XTCC033D10__**	20	20	33	33	40	40	50	55
	XTCC050D10__	25	25	50	50	60	65	74	85
L-Frame	**XTCE185L__**	66	66	115	115	132	145	165	115
M-Frame	**XTCE300M__**	85	85	150	150	178	195	222	150
N-Frame	**XTCE580N__**	145	145	250	250	304	333	380	250

Table 3. Banked/group compensation with a choke

Frame size	Contactor	200 V kVAR	230 V kVAR	400 V kVAR	440 V kVAR	480 V kVAR	525 V kVAR	600 V kVAR	690 V kVAR
B-Frame	**XTCE007B**	3	4	7	7	7	7.5	10	12
	XTCE009B	4	5	8	8	8	10	12	14
	XTCE012B	4.5	5.5	10	10	11	12	14	16
	XTCE015B	4.5	5.5	10	10	11	12	14	16
C-Frame	**XTCE018C**	6	7.5	16	16	18	20	23	28
	XTCE025C	7.5	9	18	18	20	23	25	30
	XTCE032C	9	10	20	20	22	24	27	32
D-Frame	**XTCE040D**	11	13	25	25	27	30	34	40
	XTCE050D	13	16	30	30	34	36	41	48
	XTCE065D	16.5	19	36	36	40	43	50	57
F-Frame	**XTCE080F**	25	30	58	58	66	68	80	90
	XTCE095F	30	34	66	66	72	79	90	104
G-Frame	**XTCE115G**	40	44	80	80	95	100	110	125
	XTCE150G	44	50	97	97	105	115	132	152
L-Frame	**XTCE185L**	69.5	80	150	150	183	200	228	260
	XTCE225L	87	100	175	175	210	230	263	300
	XTCE250L	95.5	110	190	190	238	260	297	340
M-Frame	**XTCE300M**	113	130	225	225	265	290	331	390
	XTCE400M	139	160	280	280	370	370	422	480
	XTCE500M	191	220	390	390	457	500	571	680

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

Publication No. AP03407004E / Z18084
April 2016