FRAKO

APPROPRIATE DIMENSIONING OF PFC SYSTEMS

Information on correct dimensioning of Power Factor Correction Systems

INFORMATION ON CORRECT DIMENSIONING OF POWER FACTOR CORRECTION SYSTEMS

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WHY CORRECT POWER FACTOR?

Avoid charges for reactive power, prevent transformer overload, minimize power losses, optimize on-site electricity generation (photovoltaic, CHP) and improve power quality

REACTIVE POWER CHARGES

With most power supply contracts, customers are charged for the following:

- Power [kW], measured with a maximum demand meter, e. g. monthly or even yearly maximum demand, as a rule determined over a 15-minute period.
- Active energy [kWh], measured with an active energy meter, usually split into regular and off-peak tariffs.
- Reactive energy [kvarh], measured with a reactive energy meter, sometimes split into regular and off-peak tariffs.

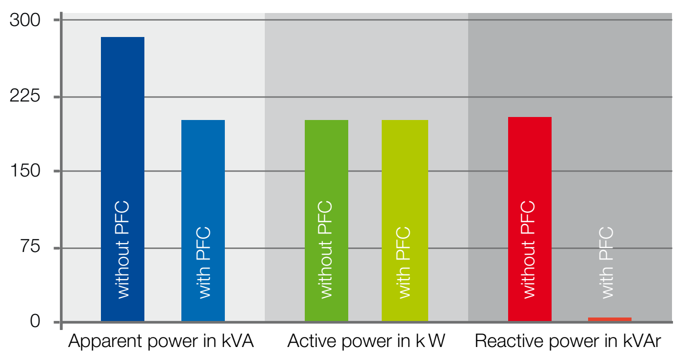
It is normal practice to invoice for the costs of reactive energy only when this exceeds 50 % of the active enϕergy drawn. This corresponds to a power factor cos φ 0.9. It is not stipulated that the power factor must never dip below this value of 0.9. Invoicing is based on the power factor monthly average. Utility companies in some areas call for other power factors, e. g. 0.95 or 0.98.

TRANSFORMER OVERLOADING

Transformer capacity is normally stated in units of apparent power [kVA]. As is the case with electrical consumers, the apparent power is given by the vector addition of active power [kW] and reactive power [kvar]. If the reactive power at the connected loads is completely compensated for, the apparent power drawn is exactly equal to the active power required. This reduces the load current through the transformer.

Example:

A 200 kW electrical installation with no power factor correction has a cos φ value of 0.7. The load on the transformer is 286 kVA, corresponding to a current of 412 A. The same 200 kW installation with its power factor cos φ corrected to 1.0 only causes a 289 A current to flow through the transformer. A corrective power of about 200 kvar is needed to achieve this.



POWER LOSSES

Just as power factor correction directly at the connected load reduces the transformer loading and its associated power losses, it also does the same for the power cables, where losses due to factors such as voltage drop and heat dissipation can also be reduced to a minimum.

Using the same example as above:

Without PFC, apparent power = 286 kVA, cos φ 0.7, phase current ≈ 412 A. With 200 kvar corrective power, the phase current is reduced to about 289 A.

If there are 50 m of power cable with a cross section per phase of 2 × 185 mm², the power losses would be reduced from about 408 W to approx. 201 W per phase. This translates into an annual saving of some 4666 KWh if the installation runs for 7500 hours per year.

ON-SITE ELECTRICITY GENERATION

Sites that generate their own electricity, by combined heat and power plants, photovoltaic systems, biogas turbines, etc., reduce the amount of active energy they need to import from the power supplier. The level of reactive power tolerated by the supplier is therefore also less, as outlined in the first paragraph of this document. To avoid reactive power costs, it is therefore essential to leave as little reactive power as possible uncompensated. To do this, a finely adjustable (automatic) PFC system with a target cos φ as near as possible to 1.0 inductive is necessary.

POWER QUALITY

A correctly dimensioned PFC system really does contribute to improving power quality in the supply network. Depending on the degree of detuning, some of the harmonics close to the frequency range of the detuning system are absorbed by the PFC system.

50 Hz mains frequency:
A detuning factor p of 7 %, for example, corresponding to a resonant frequency of 189 Hz, can also reduce on the 5^{th} harmonic (250 Hz), the efficacy of which depends on the system impedance.

60 Hz mains frequency:
A detuning factor p of 7 %, corresponding to a resonant frequency of 227 Hz, can also reduce on the 5^{th} harmonic (300 Hz).

TO SUM UP, POWER FACTOR CORRECTION OFFERS:

- Lower power costs
- Better energy efficiency
- Reduced CO_2 emissions
- Increased service life of transformers and cabling
- Improved power quality and system reliability

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HOW IS THE RIGHT CORRECTIVE POWER DETERMINED?

The key words here are measurements, system analysis, electricity bill, empirical estimation, and the FRAKO dimensioning sheet (Excel).

MEASUREMENTS AND SYSTEM ANALYSIS

In the ideal case, the characteristic profile of active, apparent and reactive power can be recorded with suitable instrumentation and then analyzed. When this is done, all operating conditions of the electrical installation must be covered as far as possible. In addition to this power data, the voltage quality is a key parameter and is usually measured as well. The best way to assess power quality is by following the standards EN 50160 and IEC/EN 61000-2-2. The measurement period (one week) is defined and the acceptable limits for power quality are specified. This allows the various measurements to be compared meaningfully.

ELECTRICITY BILL

The utility company's invoice stating the active and reactive energy figures as well as the consumer power demand can also be used to determine the reactive power requirements. A detailed specimen calculation is described on page 13 of the FRAKO Manual of Power Quality.

ESTIMATION FROM EMPIRICAL DATA

Often, however, an electrical installation may still be in its planning phase. Despite this, the following empirical figures may be used for a rough estimate of the required corrective power:

- Motors with individual PFC
  - 35 – 40 % of motor rated power
- Transformers with individual PFC
  - 2.5 % of transformer power rating
  - 5 % for older transformers
- Central PFC
  - 30 – 40 % of transformer power rating at target cos φ = 0.95
  - 40 – 50 % of transformer power rating at target cos φ = 1

A list of the loads to be installed, complete with their electrical data, gives an overview of the reactive power to be expected. The simultaneity factor should also be taken into account.

TO SUM UP, CORRECTIVE POWER IS DETERMINED FROM:

- The **FRAKO** dimensioning sheet (Excel)
- Data from the system analysis, electricity bill or individual load data sheets

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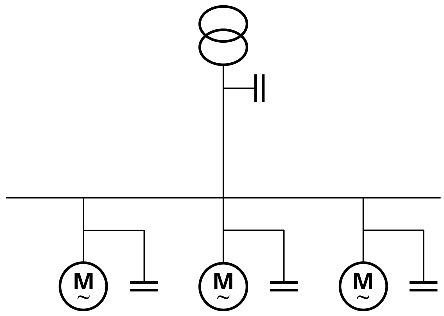
WHICH TYPE OF PFC IS THE RIGHT ONE FOR US?

The key words here are individual, central and group PFC

INDIVIDUAL POWER FACTOR CORRECTION

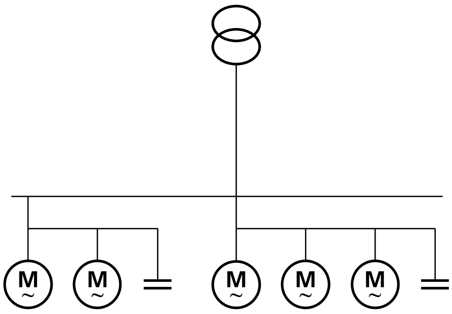
In the simplest case, an appropriately sized capacitor is installed in parallel with each individual load. This can totally eliminate the reactive current in the cables feeding the compensated load. The disadvantage of this method, however, is that the capacitor is only utilized during the time that its associated load is in operation. Additionally, it is not always easy to install the capacitors directly adjacent to the equipment that they compensate (space constraints, installation costs).



e. g. Individual power factor correction

GROUP POWER FACTOR CORRECTION

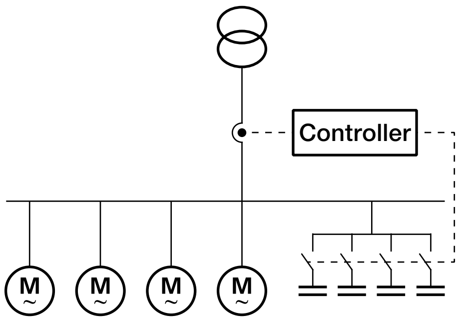
Electrical machines that are always switched on at the same time can be combined as a group and have a joint correction capacitor. An appropriately sized unit is therefore installed instead of several smaller individual capacitors.



e. g. Group power factor correction

CENTRAL POWER FACTOR CORRECTION

The PFC capacitance is installed at a central point, for example at the main low voltage distribution panel. This system covers the total reactive power demand. The capacitance is divided into several stages, which are automatically switched in and out of service by automatic reactive power control relays and contactors to suit load conditions.



e. g. Central power factor correction

TO SUM UP, THE RIGHT TYPE OF PFC DEPENDS ON:

The electrical installation in question, i. e. any or all of the 3 types may be used in combination to achieve the optimum cost-benefit ratio.

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WHAT SIZE OF CAPACITOR STAGE IS RIGHT?

The key words here are the profiles of reactive power, on-site generation and switching frequency

REACTIVE POWER PROFILE (MEASURED)

The smallest necessary capacitor stage for each application can be determined from the profile of the reactive power demand. A key requirement is that no reactive power charges will be incurred, so the 15-minute average value of reactive power is an important parameter. It is recommended that 6 – 8 stages be installed, for example 300 kvar in steps of 50 kvar. If it is necessary to correct cos φ to near 1.0, more stages will be needed (possibly 10 to 12). The total corrective power needs must always be made available, i. e. 200 kvar in steps of 25 kvar will require 8 stages, whereas steps of 12.5 kvar will necessitate 16 stages.

PFC FOR ON-SITE GENERATION

When electricity is generated on-site, the corrective power should in principle always be divided into finer steps than when power is only imported from the external utility supply. 15 stages are recommended (e. g. 93.75 kvar in steps of 6.25 kvar).

FREQUENCY OF SWITCHING

Frequency of switching must also be taken into account when selecting the capacitance of the stages. The smaller the steps, the more frequently will the smallest stage be switched in and out to meet the need for corrective power. For this reason, there should always be two of the smallest stages so that the high number of switching operations can be shared between them (e. g. 12.5 kvar + 12.5 kvar + 25 kvar + 50 kvar for a total of 100 kvar).

TO SUM UP, THE RIGHT SIZE OF CAPACITOR STAGE DEPENDS ON:

The reactive power profile, the desired target cos φ and the maximum expected frequency of switching.

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DETUNING, BUT HOW?

The key words here are power quality, harmonics and remote control frequency.

POWER QUALITY AND HARMONICS

Reactors (inductors) are installed in series with the capacitors to protect them from the excessive currents that can be caused by harmonic voltages. Together they form an oscillator circuit with a frequency that prevents harmonic currents, say from the 5^{th} and 7^{th} harmonics, overloading the capacitor. At the same time, there is an additional benefit due to the absorption effect on the harmonic currents, reducing some of them. This gives the power factor correction system the side effect of 'cleaning up' the power circuits. Various detuning factors with different frequencies and absorption effects can be selected to address the harmonics disturbing a particular installation.

RIPPLE CONTROL FREQUENCY

Where installations use a ripple control frequency for remote control purposes (e. g. switching between regular and off-peak tariffs), the detuning factor (and its associated frequency) must be selected so that the PFC system does not cause malfunctioning of the ripple control signal.

The table below shows the relationship between detuning factors, their corresponding frequencies and their impact on the harmonics.

Utility ripple control frequency 50 Hz (60 Hz)	**PFC version** (detuning factor) 50 Hz (60 Hz)	**Main advantages and disadvantages**
≥ 166 (≥ 192)	p = 14 % f_r = 134 Hz (f_r = 160 Hz)	Only offers blocking effect on harmonics, suitable for systems with harmonics of orders divisible by 3, but highly cost-intensive installation
≥ 216.67 (≥ 251)	p = 8 % f_r = 177 Hz (f_r = 212 Hz)	Moderate absorption effect on harmonics, not suitable for systems with harmonics of orders divisible by 3, relatively cost-intensive installation
≥ 228 (≥ 266)	p = 7 % f_r = 189 Hz (f_r = 227 Hz)	Inexpensive installation, adequate absorption effect on harmonics, not suitable for systems with harmonics of orders divisible by 3
≥ 270 (≥ 312)	p = 5.67 % f_r = 210 Hz (f_r = 252 Hz)	Absorption effect on harmonics often too great, not suitable for systems with harmonics of orders divisible by 3, not recommended without prior system analysis

TO SUM UP, THE RIGHT DETUNING ACTS TO:

Optimize the service life of the power factor control system with the side effect of 'cleaning up' the installation to improve its power quality.

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WHAT MATTERS MOST IN A CAPACITOR?

High overload tolerance, maximum safety and reliability, long service life

5 out of 6 breakdowns in switchgear can be traced back to the wrong choice of capacitor (poor quality or simply not robust enough for the intended duty).

What matters are:

HIGH OVERLOAD TOLERANCE

In particular:

- Overvoltage rating
- Current-carrying capacity (double the nominal current)
- Thermal endurance

MAXIMUM SAFETY AND RELIABILITY

- **Safety factor 1** Self-healing polypropylene film:
  its self-healing property ensures that the dielectric film automatically repairs any puncturing that may occur.
- **Safety factor 2** Solder-free connections:
  FRAKO's innovative and patented contact ring totally eliminates the potential risk of damaging the winding by soldering the connections on as in conventional capacitor designs.
- **Safety factor 3** Mechanical fuse against excessive pressure:
  The mechanical fuse disconnects the capacitor safely and without disruption to the power supply if excessive internal pressure develops due to overloading.
- **Safety factor 4** Segmented metallizing:
  The segmented film is a valuable supplement to the self-healing property and the mechanical fuse. If several punctures occur in a greater area of metallized film, the amount of energy involved could be too much for the self-healing action alone to cope with. In this case, the segmented film provides an EXTRA fail-safe function, since the severely overloaded segment is completely isolated from the power supply.

LONG SERVICE LIFE

In addition, the patented contact ring design has enabled **FRAKO** to manufacture a lead-free capacitor, yet another contribution to improved reliability. **FRAKO** power capacitors give you the ideal performance to meet your specifications for current-carrying capacity, ambient temperature and service life.

> "Don't undersize your PFC system; the power supply is more volatile than you think – harmonics and ambient conditions will be there to challenge you."

TO SUM UP, THE RIGHT CAPACITORS OFFER:

Safe and reliable operation throughout their service life, even when faced with higher temperatures and heavy current loads.
Recommended Voltage for detuned PFC-Systems:

V_{nom}	V_c for $p = 7\,\%$
240 V	264 V
480 V	528 V
600 V	660 V

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HOW DO WE CHOOSE THE RIGHT REACTIVE POWER CONTROL RELAY?

Automatic commissioning, power quality control, compatibility with all control characteristics, switching cycle counter/preventive maintenance

AUTOMATIC COMMISSIONING

- The automatic, intelligent calibration procedure prevents mistakes being made in the programming, the reactive power control relay itself determining the correct phase angle and the configuration of the connections without operator intervention.
- Costly, time-consuming troubleshooting is avoided. Incorrect connections or wrong positioning of the instrument transformers are detected, indicated and internally corrected.

POWER QUALITY CONTROL

To prevent damage to the PFC system through poor power quality or supply network disturbances, the reactive power control relay monitors all key parameters. If any of them go outside their set limits, an alarm is displayed and an alarm signal is transmitted. This therefore protects the PFC system against overloading, and if necessary individual stages or the complete system are switched out, thus significantly reducing the risk of damage within the PFC system itself. Defective or partially defective capacitor stages are identified and excluded from the control process.

COMPATIBILITY WITH EVERY CONTROL CHARACTERISTIC CURVE

Universal control characteristic curves offer power factor correction strategies for every conceivable requirement in all 4 control quadrants. In addition to avoiding reactive power charges, this also provides other benefits:

- Reduced losses in consumer and supply-side power networks
- Increased yield from power generation systems
- Minimization of system wear and tear by reducing the number of switching cycles

PARAMETERS ARE MONITORED FOR PREVENTIVE MAINTENANCE

- Voltage is monitored.
- Individual stage currents are monitored.
- Harmonic levels are monitored.
- Individual stage switching cycles are monitored.
- The built-in switching cycle counter indicates when the contactors are due for replacement, thus preventing worn switchgear from causing damage to other parts of the installation.

If the value of a parameter goes outside the set limits, an alarm signal is initiated via the alarm contact.

CAUTION: PF controller switches based upon PF requirement, not harmonic filtering needs. Capacitor may become overloaded when small stage(s) are energized while large harmonic producing loads are operating.

TO SUM UP, THE REACTIVE POWER CONTROL RELAY SHOULD OFFER:

Straightforward start-up, compatibility with all control characteristics, and additional monitoring functions for power quality and the installation.

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WHAT KIND OF SWITCH?

Electromechanical or electronic—contactor or thyristor switch?

CONVENTIONAL ELECTROMECHANICAL SWITCHING

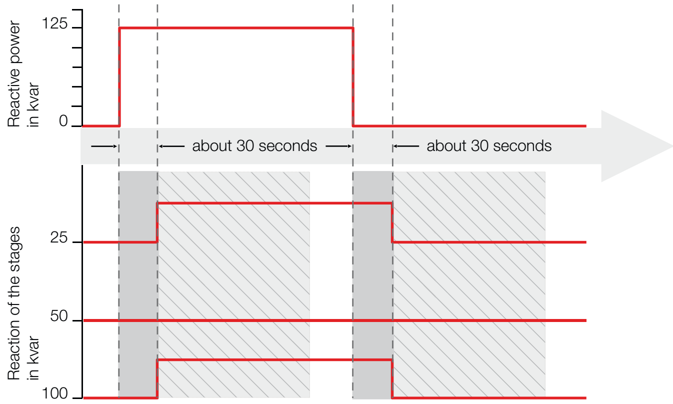
In most power factor correction systems, the individual capacitor stages are switched in and out electromechanically, i. e. by means of contactors. Depending on the nature of the compensation duty (frequency of load changes), this can result in rapid wear, as the number of switching cycles is limited for electromechanical contacts. It is therefore important to manage the PFC system with a reactive power control relay that minimizes the number of switching cycles while at the same time optimizing power factor correction.

DYNAMIC CONTROL WITH ELECTRONIC SWITCHES

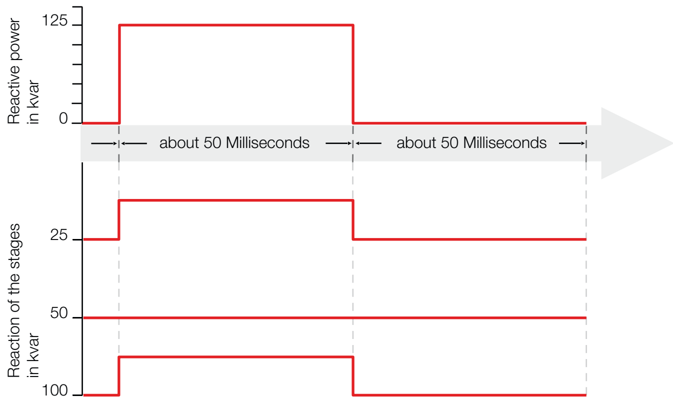
If the reactive power demand fluctuates widely and/or dynamically or PFC is needed very quickly (e.g. with presses or welding machines), electronic switching is used. These devices are virtually wear-free and can switch the required corrective power in or out within a fraction of a second.

INFINITELY VARIABLE ELECTRONIC PFC (ACTIVE FILTER)

If the technical specifications call for infinitely variable power factor correction, electronic PFC is used, especially where the corrective power demand fluctuates rapidly and can in addition vary between capacitive and inductive.



Switching times with contactors



Switching times with thyristor switches

TO SUM UP, THE RIGHT SWITCH DEPENDS ON:

The reactive power demand profile, the desired target-cos φ and the maximum expected frequency of switching.

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CONSTRUCTION—SPACE REQUIREMENTS

Freestanding cabinet, wall cabinet, modules, fixed PFC in small enclosure, components, ventilation

Depending on the type of PFC (individual-, group or central compensation), various hardware options should be taken into consideration:

- **Freestanding cabinet (large)**
  Up to a maximum of 500 kvar, extendable, modular construction
- **Wall cabinet (compact)**
  Up to a maximum of 100 kvar, small stages for fine control
- **Module/mounting plate**
  (for installation in existing switchgear enclosures)
- **Small enclosure for fixed PFC capacitance**
  Low space requirement and reduced current loads in the cabling

TO SUM UP:

The enclosure size and components can be selected appropriately to suit site space constraints and to offer the optimum solution for all conditions.

HOW DO WE AVOID QUALITY PROBLEMS WHEN SETTING UP A PFC SYSTEM?

Components, heat dissipation, maintenance

COMPONENTS

For a PFC system to function correctly and have a long service life, it is essential to use components of highest quality and with adequate ratings that are designed to work together, such as the capacitors, reactive power control relay, switchgear and reactors described in the foregoing.

HEAT DISSIPATION

Suitable measures must be taken, such as the layout of the components in the enclosure and its adequate ventilation, to guarantee that the system can always function correctly under all ambient conditions.

MAINTENANCE

Regular maintenance increases the service life of the installation. The reactive power control relay can monitor the system temperature and the number of switching cycles of the individual stages. It is strongly recommended to inspect the enclosure visually inside and outside to ensure that there is no build-up of dirt.

TO SUM UP, A WELL DESIGNED PFC SYSTEM:

Uses suitable components as described adjacent, has adequate ventilation and heat dissipation, and is maintained regularly to ensure good working order throughout its entire service life.

If in doubt, contact the specialists at **FRAKO.**

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WHAT DANGERS MUST BE AVOIDED AND WHY IS MAINTENANCE SO IMPORTANT?

Fire hazard, overvoltage and component failure
Ventilation, temperature, ambient conditions, harmonics, resonance, life expectancy

HAZARD AVOIDANCE

- Risk of fire through charred contactors that have exceeded the maximum number of switching cycles
- Disabled stages due to defective capacitors
- Overvoltages from resonance due to defective capacitors
- Dangerously high temperatures due to inadequate ventilation
- Bursting, burning or even exploding capacitors if protective systems are missing or wrongly dimensioned
- Negative impact on operating procedures from defective capacitors

MAINTENANCE

- Regular maintenance to ensure adequate ventilation increases system safety and reliability.
- Operation of the capacitors within their specified temperature range is ensured.
- Maintenance guarantees compliance with the temperatures, voltages, currents and power levels specified on the data sheet.
- The maximum allowable levels of harmonics are regularly monitored.
- Defective capacitors are identified so that the risk of resonance is eliminated.
- Short intervals in the maintenance schedule ensure risk-free operation in dusty and polluted environments.

TO SUM UP, DANGER IS AVOIDED THROUGH MAINTENANCE:

All the above points illustrate potential dangers. Regular maintenance minimizes these and significantly increases the service life and reliability of the system.

ENERGY EFFICIENCY

Payback time, energy savings, safety and reliability, positive impact on complete installation

PAYBACK TIME

If reactive power charges are being incurred before the PFC system is installed, the payback time is relatively easy to calculate. It usually takes 2–3 years for the savings in electricity costs to compensate for the investment in a new power factor correction system.

Payback time depends on what kind of PFC has been chosen (individual, group or central – or a mix of those 3 solutions). Best payback is achieved through central compensation.

ENERGY SAVINGS

In addition to eliminating the reactive power charges, a correctly dimensioned PFC system also reduces the costs for the energy losses occurring in the cabling and transformers.

In this way, not only energy costs but also CO_2 emissions are cut.

SAFETY AND RELIABILITY

The operational safety of the installation and the transformer is increased, since compensating for the reactive power reduces the power lost as heat. Lower temperatures mean safer system operation and longer life.

TO SUM UP ENERGY EFFICIENCY:

A correctly dimensioned power factor correction system cuts energy costs and reduces CO_2 emissions.

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