

Correcting mill power factor with a synchronous condenser

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The impact of all the methods of power factor correction must be considered because the least expensive initial option may not be the most cost-effective method in the long run.

Why worry about plant power factor? Can it affect operating costs? The first cost associated with poor power factor is possible increased energy costs. Why? The utility company is responsible for the generation, transmission, and distribution of electric power. Most utilities charge small users a fee based solely on the amount of kilowatt-hours used. This works well for one's home and most small businesses. Larger electricity consumers, however, negotiate contracts with their utility to achieve a lower monthly bill. When this happens, there are several components that the utility uses to calculate the bill at the end of the month:

1. Peak plant demand (kilovolt-amperes)
2. Peak plant demand (kilowatts)
3. Monthly power usage (kilowatt-hours)
4. Average monthly power factor.

The peak plant demand in kilovolt-amperes is the apparent power that the utility sees as it meters the power flowing into the plant. What this means is the utility has installed electrical metering equipment in the service to the plant which monitors the kilovolt-amperes used. This metering equipment records the maximum kilovolt-amperes used in a 15-minute period (a typical interval). This peak usage value is saved until a new peak occurs. When the plant meters are read the kilovolt-ampere meter is reset to zero.

Peak plant demand in kilowatts is recorded in the same way as the kilovolt-amperes. When a new peak number of kilowatts occurs, it is saved until the meter is read. This value is also reset with the kilovolt-amperes reading.

The third major component that the utility company looks at in calculating the monthly bill is the total energy usage (kilowatt-hours) for the period.

The fourth component is the power factor of the energy used.

Why do some utilities penalize users whose power factor is low? The major reason is that the energy consumer pays

only for the energy used.

The utilities are responsible for getting the energy to a plant. One of the major losses they experience is the transmission I^2R losses. The utility is selling kilowatts but is delivering kilovolt-amperes. To minimize the I^2R losses, the kilowatts and the kilovolt-amperes should be nearly equal. When kilowatts and kilovolt-amperes are not equal, the utility must absorb the extra costs of the transmission I^2R losses due to reactive current.

The other cost aspect is that all transmission lines and distribution transformers are sized by kilovolt-ampere capacity. If the user's power factor is low, the utility may need to install larger equipment to get enough energy to the user. If the utility maintains a unit (1.0) power factor on its system, it can use its facilities to the maximum.

Another issue to be considered is voltage drop. If the utility has a large user with a low power factor ($\cos\theta$, with θ representing the phase angle between the voltage and the current), the lines to that user may experience large voltage drops ($IR \cos\theta + IX \sin\theta$), resulting in low voltage or voltage sags at the plant. Low voltage or voltage sags may cause any of the following:

1. Lost computer data
2. Motor failures from low-voltage operation (unable to accelerate load, overheating, short life)
3. Dim lights
4. Excessive number of blown fuses
5. Drives may not reach maximum load or speed if they work at all.

Capacitor vs. synchronous condenser

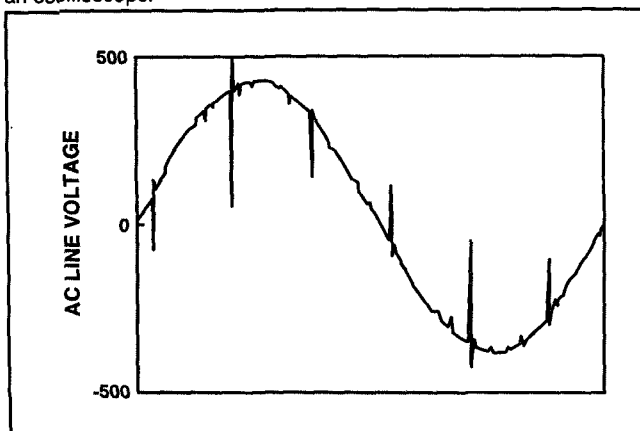
Several power factor correction methods can be used in the plant:

1. Install capacitors
2. Run synchronous motors over-excited to produce kVARs (kilovolt-amperes reactive).
3. Install a synchronous condenser.

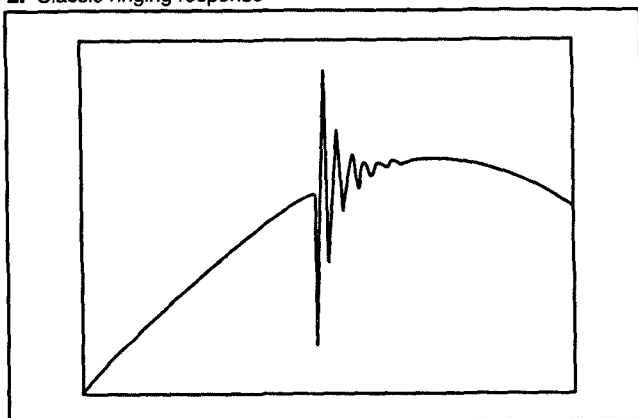
Installing capacitors has been a long used and widely accepted method of power factor correction. The capac-

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1. A line-to-line short on the system shows up as line notching on an oscilloscope.



2. Classic ringing response



itors can be distributed throughout the plant or installed as a large bank near the plant service entrance.

Installing capacitors throughout the plant has several advantages. First, the capacitors are sized for the connected loads and give optimum performance. Second, when the load is disconnected, the capacitor is also disconnected, thereby eliminating the problem of over-correction. The main disadvantage is the cost of purchasing and maintaining a large number of small capacitors.

Other disadvantages of installing capacitors at or near the point of use stem from the fact that a large amount of modern equipment uses solid-state devices to control the load or speed of the equipment. When a solid-state power device [such as a silicone control rectifier (SCR)] turns on, large amounts of current are suddenly allowed to pass through a particular circuit. When this happens, the device that was previously turned on must cease conduction, but at the instant the second device turns on there is a line-to-line short on the system. This phenomenon is seen in oscilloscope traces as line notching (Fig. 1).

When serious line notching occurs, the effects are normally seen as erratic behavior of other solid-state equipment. (SCRs may commutate off too early in the cycle, or false timing may occur.)

To minimize the effects of this problem, many people have installed capacitors near the solid-state control device. This will help minimize the line notching problem

because the capacitor can supply instantaneous power to the SCR as it turns on. This in turn has two negative side effects: One, if too much current is allowed to flow through the SCR instantaneously the SCR can experience di/dt failure. Second, with distributed capacitance installed in the system and inherently distributed inductance, one cannot avoid resonant circuits. Each time the SCR fires, it has the ability to excite these distributed resonant circuits and cause a phenomenon called ringing (critical damping) to appear on the voltage waveform (Fig. 2). This ringing and the associated harmonics can cause a significant amount of heating losses throughout the plant. The ringing may also cause capacitor failure. The best way to eliminate this problem is to install an inductor in series with each capacitor to filter the high-frequency harmonics. Each inductor must be designed for the value of the capacitor and associated circuitry.

Methods of power factor correction

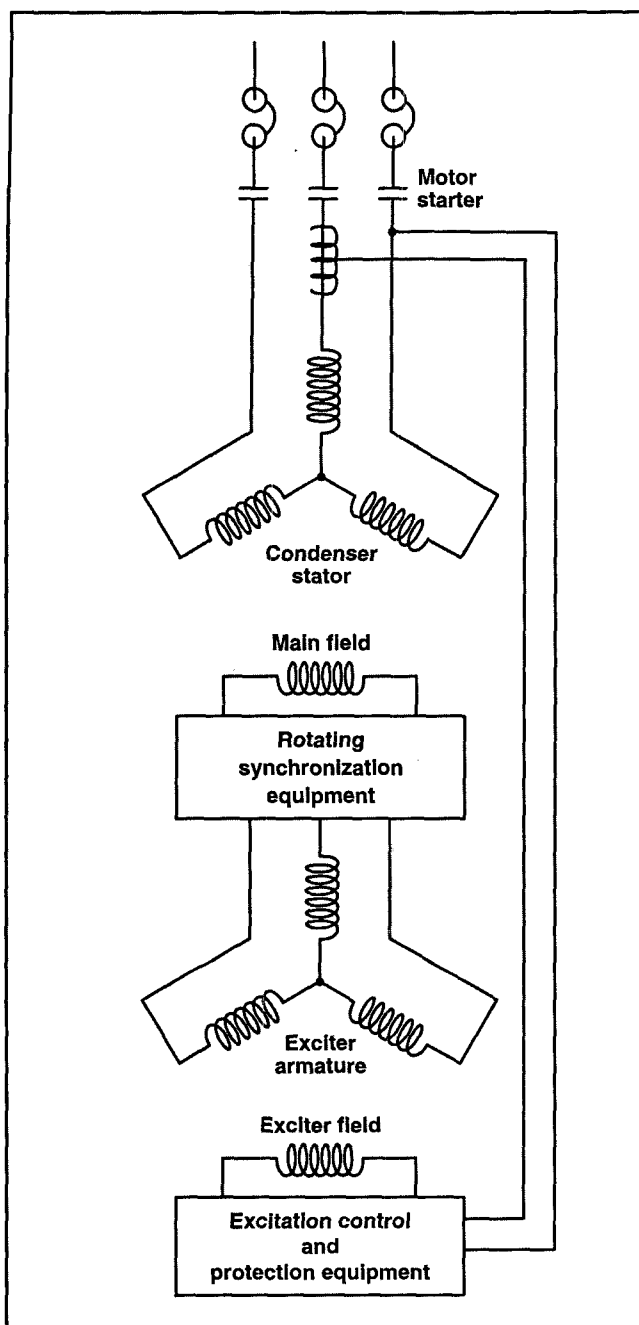
Installing capacitors in the switchyard near the service entrance has advantages, the first of which is cost. One large capacitor is easier to purchase, install, and maintain than many smaller ones. It also tends to have less problems with circuit resonance because of line inductance between the capacitor and the solid-state load.

The disadvantages are that if expensive sensing and switching equipment are not installed, the power factor at the plant may change to a leading power factor at periods of light load. When leading power factor occurs, serious over-voltages may result. Capacitors are not tolerant of over-voltage conditions because they tend to increase the heating of capacitors and shorten their life. Also, the distribution equipment will see the same I^2R losses that occur with an equivalent lagging power factor. With a leading power factor, system stability is sacrificed; voltage swings may be experienced. This condition may be worse than having no power factor correction at all. Also, when switching is used to control capacitors, the switching transients may cause sufficient over-voltages on the line to damage solid-state equipment or the capacitors themselves.

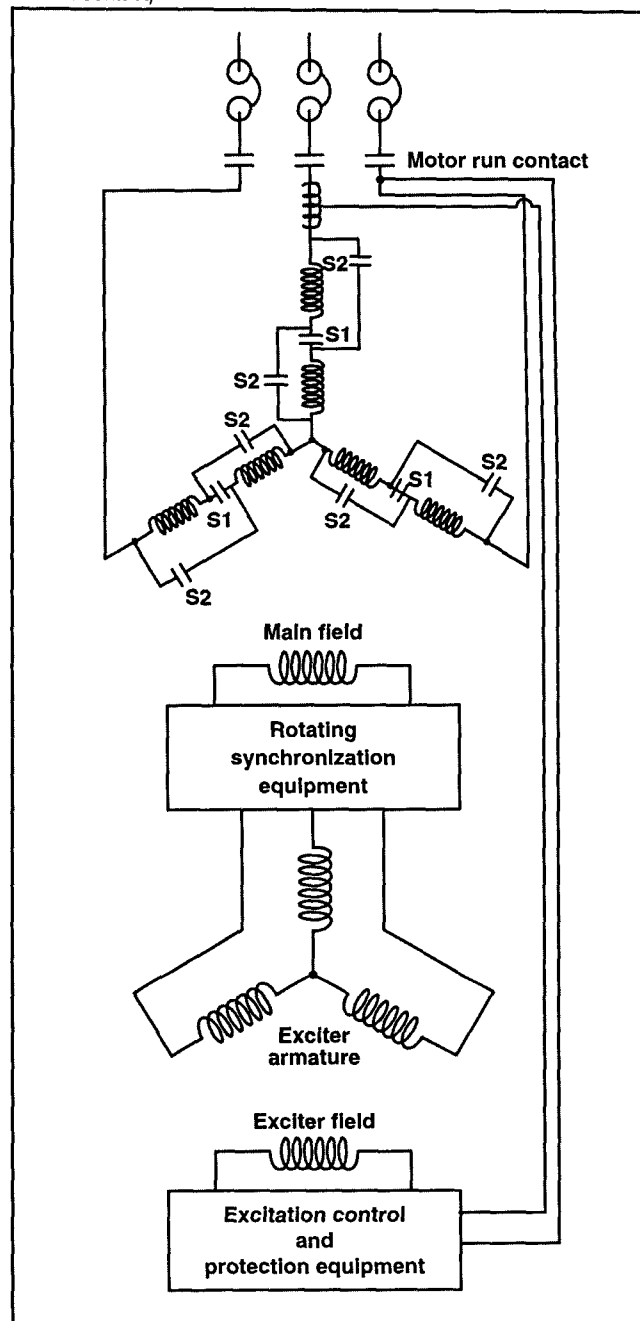
The second method of power factor correction is the use of large synchronous motors to offset the inductive loads in the plant. By running the synchronous motor over-excited, one may be able to offset an equal amount of inductive loads. When using a synchronous motor at unit (1.0) power factor, all the lagging load associated with that motor is eliminated. Synchronous motors work well for power factor correction when used to drive loads such as refiners, chippers, grinders, compressors, and pumps. When considering the prime mover for new equipment of this type, synchronous motors are often the most cost-effective choice.

The third method of power factor correction is the use of synchronous condensers. Synchronous condensers are not new to the electrical generation industry. Before modern technology made efficient medium- and high-voltage capacitors possible, many electric generation plants had synchronous condensers to correct power factor. Some utilities still use what they call spinning reserve: smaller steam turbines or small hydro plants that are not

3. Across-the-line starting



4. Reduced-voltage starting (S1 = first start contact, S2 = second start and run contact)

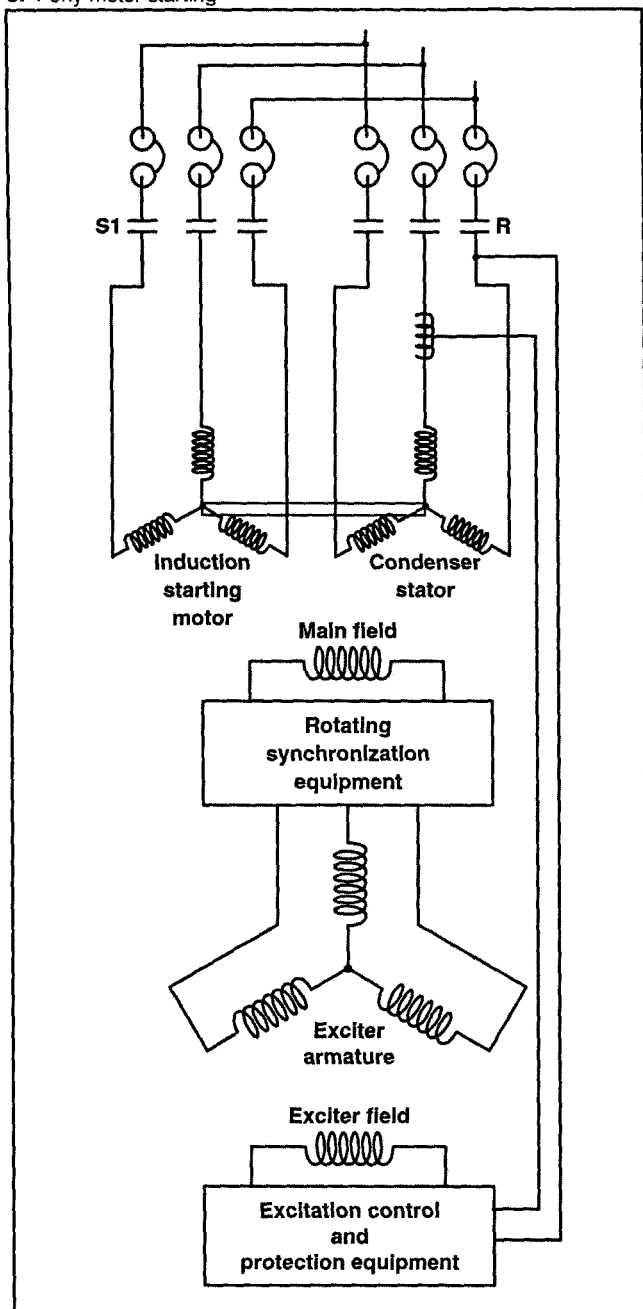


producing their full output in kilowatts but are still over-excited to add reactive capacity to the system.

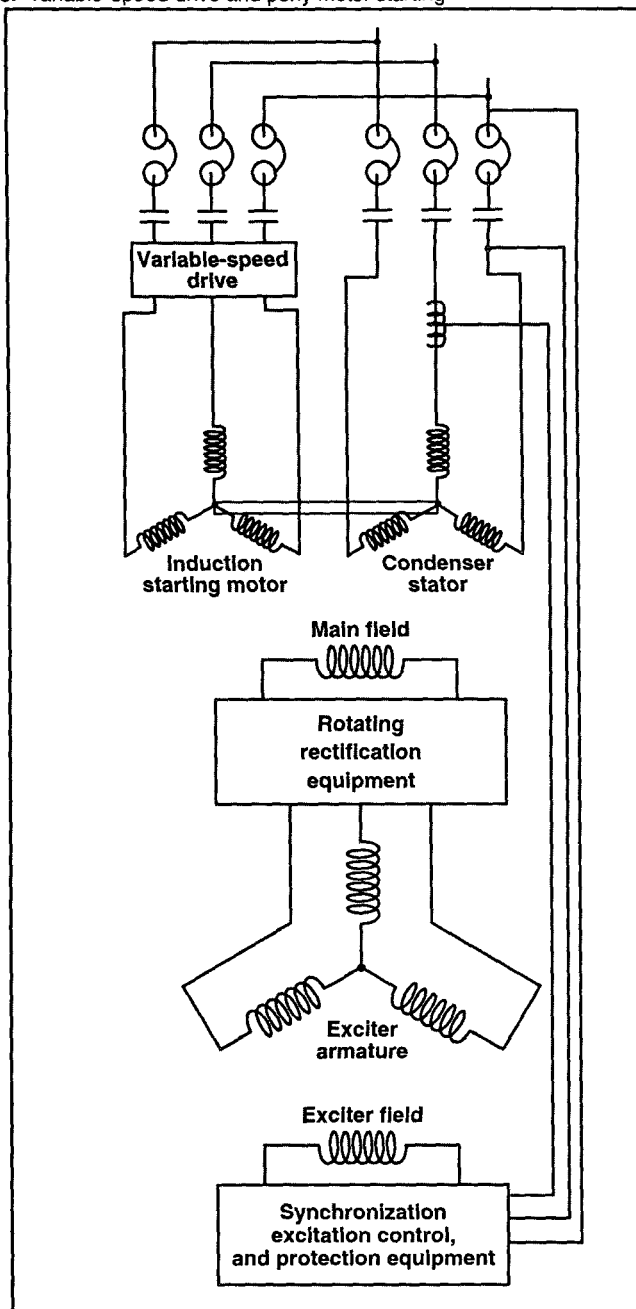
A synchronous condenser is simply a synchronous machine that is connected to the grid with no load or very low load on the shaft. This synchronous machine is then over-excited so that reactive power flows into the grid. Care must be exercised to avoid under-excited operation, because, if the synchronous machine is operated under-excited, the grid will supply kVARs to the machine to compensate for excitation not supplied by the rotor. When this condition occurs, the utility experiences a lagging power factor, as if an induction motor or some other inductive load were connected to the system.

The use of synchronous condensers for power factor correction has many distinct advantages. First, because of the intrinsic nature of the machine, the output appears to be inductive to the load. This eliminates the problems associated with high di/dt turn-on characteristics of SCRs. Second, because of its inductive source impedance, there is no problem associated with resonant circuits or a need to selectively filter damaging harmonics. Third, it is easy to maintain. Maintenance would be the same for the synchronous condenser as it would be for any other motor in the plant. Fourth, with the use of automatic control equipment, the system can automatically adjust the machine excitation, thereby controlling the power factor or kilovolt-amperes produced to a preset value. The ability

5. Pony motor starting



6. Variable-speed drive and pony motor starting



to adjust the kilovolt-ampere output easily and without discrete steps is an advantage to many users. Fifth, synchronous equipment has a proven history, and, with continuous improvements in insulation materials, a useful lifetime of 20–40 years is realistic.

Methods of synchronous condenser starting and control

What methods are available for starting synchronous condensers? The easiest and most cost-effective method is to start the condenser across-the-line as a synchronous motor (Fig. 3). The advantages are that low-cost motor starter and uncomplicated synchronization equipment are used. The main disadvantage is that, when the line has

a very limited capacity, the voltage drop experienced at machine startup may be objectionable.

The second method of starting synchronous condensers is reduced-voltage starting techniques (Fig. 4). There is no load torque on the shaft and no starting torque required, except for the breakaway torque of the bearings. The machine may be started with any number of reduced-voltage methods, but series parallel or autotransformer starters are preferred. Reduced-voltage starting techniques have the advantage of reducing the in-rush required of the plant service, minimizing the voltage drop experienced on the line. Across-the-line starting and reduced-voltage starting use the same power factor control equipment. The disadvantage of reduced-voltage starting

I. Electrical energy savings for ABC Paper

Precondenser costs	
Inputs	
Plant peak demand	15,000 kVA at \$9/kVA
Power	11,250 kWh at \$0.04/kWh
Monthly power usage	6,480,000 kWh
Old power factor	0.75
kVAR demand from utility	9922 kVAR
Monthly power cost	
Demand	US\$135,000
Power	US\$259,200
Power bill	US\$394,200
Post-condenser costs (monthly)	
Demand	11,804 kVA at \$9/kVA
Power	11,450 kW
Power usage	6,595,200 kWh at \$0.04/kWh
New power factor	0.97
kVAR demand from utility	2870 kVAR
New monthly power costs	
Demand	US\$106,236
Power	US\$263,808
	US\$370,044
Monthly savings	US\$ 24,156
Annual savings	US\$289,872
Reactive power needed	7052 kVAR
Estimated equipment cost	US\$450,000.00
Payback	1.55 years

is that the motor starter is slightly more expensive and complicated.

The third starting method is the use of a small induction motor to accelerate the condenser to near synchronous speed (Fig. 5). The condenser is then connected to the line. The advantage of this method is that the induction motor draws a smaller current from the line, eliminating most of the voltage drop. This motor starting technique is less complicated than that used with a reduced-voltage starter. The same type of power factor control is used with either method. One disadvantage of this method is that the starting motor (pony motor) is connected to the shaft and must rotate with the condenser at all times. Therefore, it cannot be used for other purposes.

The fourth starting method is the use of a variable-speed drive and a pony motor (Fig. 6). Instead of connecting the unexcited condenser to the line, one must synchronize to the line as though paralleling a generator. The advantages of this system are a low in-rush during acceleration and a smooth transition as the condenser is placed on-line. The disadvantage of this method is that the voltage regulator must change operating parameters when the condenser is connected to the line. Before the condenser is connected, the controller regulates the voltage output of the condenser. After this transition, the controller regulates the power factor by using different circuitry. Additional circuitry is needed to achieve a smooth transition from one mode of operation to the other.

Large improvements have been made in the last 10-15 years in the devices that are used to control synchronous equipment. These devices include accessory controls used

to monitor the system and determine if it is functioning within normal operating limits. The automatic voltage regulator has become reliable and trouble-free. Many accessories are now available to allow operation without constant operator intervention. Recommended accessories for synchronous condenser control equipment includes the following:

1. Automatic voltage regulator
2. VAR/Power factor controller
3. Time over current protection
4. Differential protection (if larger than 1000 kVA)
5. Minimum/Maximum excitation limiter
6. Loss of phase protection
7. Temperature alarms/shutdown.

The following additional equipment would be necessary if a smooth synchronization to the line is required: synch check relay and automatic paralleling equipment.

Sizing the condenser for the plant

To size the condenser and develop cost justification for this equipment, one must fully understand the rate structure of the electric utility servicing the area and put together an electric bill history. This history should be at least one year in length (two or three years is better). Look at the billing periods where the highest charges were incurred, then project the energy usage and power factor for the next 2-3 years. Will this increased demand have a profound effect on the charges? Recalculate your bill using the demand kilovolt-amperes, demand kilowatt-hours used, and power factor. Now calculate the amount of kVARs needed to reduce or eliminate the power factor portion of the utility bill, and recalculate the new utility bill. If electric rate increases are imminent, use the new rates to calculate the estimated electric bill with and without power factor correction. The numbers are surprising.

Table I is a simplified example of an electric bill and payback justification. It shows that reducing the plant power factor can have a significant impact on the operating cost of a plant. The impact of the various methods of power factor correction must be considered. Because of interaction between equipment, possible over-voltages, and transient conditions, the least expensive initial option may not be the most cost-effective method in the long run.

Utilities seldom have problems when users install synchronous condensers in their plants. The condenser is inherently slow in response (10-300 cycles) and therefore does not complicate system stability. Also, switching transients are not a concern. There are numerous installations where the synchronous condenser can, and will, reduce operating costs and may reduce or eliminate power factor or harmonic problems in the plant. □

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