5

Power Factor

What is Power Factor?

Power factor is the difference between the power needed to perform work and the electrical energy needed so the work can be performed. Think of it as water running down a stream and across that stream is a water wheel. The water that pushes the wheel does the work. Now, just because the water that was not pushing the wheel wasn't doing any work, it does not mean it is not needed. If only the amount of water that did work was sent downstream to the water wheel, the stream would not be deep enough for the wheel to turn. In electricity, we call power that does the work *real power*, and the rest *reactive power.* The difference between real and reactive power is known as power factor.

To understand why poor power factor is a problem, we have to look at our stream and water wheel in a different way. First, assume that the water that pushes the wheel is used up. The water company charges you only for what you used. However, that is not the only cost to the water company. Because you not only needed the water company to keep the stream full, but to supply the water to turn the wheel, the water company had to furnish a lot of water.

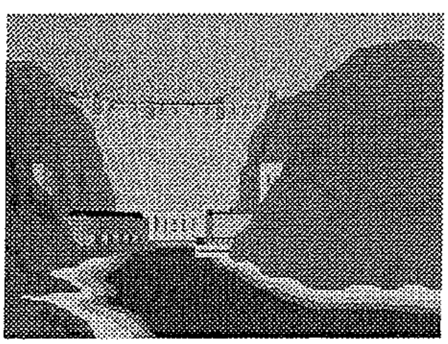

Figure 16 Hydroelectric Power

The water company got the water back you did not use so they really can't charge you for it. Right? Well, not really because as the water ran down your stream, some of it was absorbed by the stream bed, some of it evaporated, etc. In any event, the water company had losses. Not only that, the water you needed to fill your stream filled up the water companies pipes, which meant they did not have the capacity to sell water to another customer.

Now, let's look at power factor in electrical terms. Real power is measured in watts and reactive power is measured in VAR's. When you look at your power bill, you are charged based on kilowatt hours, (kilo means thousands). In some parts of the country, the power companies charge extra if you have a poor power factor. As with our stream, the reactive power you require causes power company losses and the extra VAR's filled up the transmission lines. Keeping with our water wheel and stream analogy, how could we reduce the amount of water we need to turn the water wheel? Well, the water to do the work doesn't change if we want to do the same amount of work, so we have to reduce the amount of water needed to fill the stream. The way we do this is to make the stream narrower but we keep it just as deep, and we fill in the stream banks so we need less water. Call this "water factor correction."

With electricity, we can reduce the reactive power by adding devices to compensate for poor power factor. If we know how much reactive power is needed, we can furnish systems to supply the reactive power and only take real power from the power company. This reduces the power companies' losses and reduces the power bill.

There are different ways to furnish reactive power and different places you can install correction devices. Until recently, the most common way to apply power factor correction was to install a capacitor at the electrical load that was causing the problem. Understand that the power factor is only improved from the correction point through to the power source. The motor, or whatever had the poor power factor, still has a poor power factor but now it does not bother anyone. The power factor correction reduced not only the power companies' losses and losses inside the factory where the motor was installed, but also the demand. You pay only for power you use.

Remember, not all power companies charge for poor power factor. In most cases, it is only where the cost of a new transmission line is very high (extra wire to carry the reactive current) or the customer's reactive demand is really bad. However, we expect more and more power companies to charge their customers for problems their customers cause.

Power Factor Correction

When a power factor problem has been identified, the traditional solution has been to install capacitor banks. This approach worked in the past, but it has become more difficult to apply capacitors in a system containing both high harmonic content and sensitive loads that cannot tolerate voltage transients.

Harmonic Current

The presence of harmonic current in a system typically causes power capacitor ratings to be exceeded. Capacitors will absorb harmonics as frequency increases and their impedance decreases. The effect is overheating and increased stress, which results in premature failure. Capacitors will resonate with the system inductance. This can cause high voltage spikes and current up to 10 times the normal levels. Fuses will blow and the capacitors will be stressed to total failure or may even burst.
A power factor controller can be used to regulate the addition or removal of numerous small banks of capacitors to meet the objective of closely approaching unity. The switching performed by the controller to accomplish the mission also creates voltage transients which cause overvoltage to the load. This can damage solid state equipment such as variable frequency drives.

If the capacitor system does not use a power factor controller, synchronous motor loads could present an overabundance of reactive power. This can lead to an overvoltage condition in the plant that results in a leading power factor during light load periods. This creates serious problems for equipment used in the plant and also for the local electric utility. The resulting overvoltage causes dangerous instability. The presence of harmonic current in a system typically causes power capacitor ratings to be exceeded.

- Capacitors will absorb harmonics as their impedance decreases and frequency increases. The effect is overheating and increased stress, which results in premature failure.

- Capacitors will resonate with the system impedance. This can cause high voltage spikes and current up to 10 times the normal levels. Fuses will blow and the capacitors will be stressed to total failure or may even burst.

- The switching of the capacitor banks in and out creates voltage transients. These transients cause overvoltage to the load and can damage solid state equipment, such as variable frequency drives.

- Current harmonic filters must be designed to protect the capacitor bank. This protection will be effective only as long as the original loads (those in place when the study was conducted) remain in place. If you change out or add new equipment, the harmonic spectrum will shift outside the window it was designed to protect. At that point, shutting the capacitor bank down may be necessary to prevent resonance.

- Introducing capacitor banks into a harmonic rich environment also introduces an ongoing battle to reduce harmonics. Condenser operation is unaffected by current harmonics and does not create any system problems.

Synchronous Condenser

A cleaner approach is to apply a rotary, brushless, synchronous motor referred to as a condenser. Together with its controls, the condenser applies reactive power (kVAR's) to the system by sensing power factor level. When necessary, this system will over excite the field of the synchronous condenser to provide reactive power to the bus, always attempting to maintain a power factor of unity (1.0) or the preset desired power factor.

Applying a synchronous condenser for power factor correction provides many advantages and no risks. This is not the case with capacitor banks. Correcting power factor with a condenser is much smoother (no voltage spikes) and will not adversely affect a system loaded with current harmonics (no resonance). The condenser is a low impedance source and appears inductive to loads.

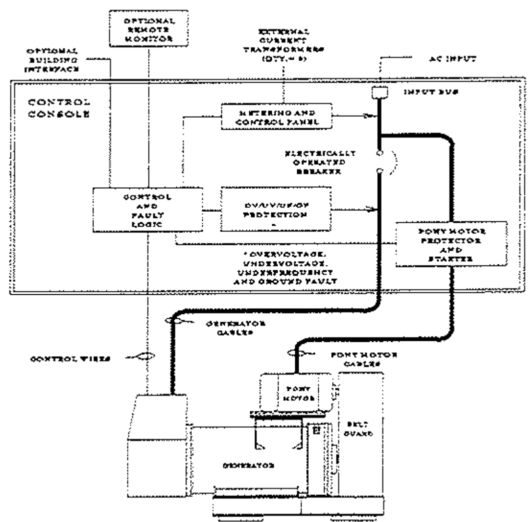

Figure 17 Series SC - Functional one-line

A major advantage of using a synchronous condenser is its long, useful life and its record for reliability. Synchronous condensers have a proven track record utilizing brushless synchronous technology. Synchronous condensers will deliver over 25 years of money saving service. PS&C's synchronous condenser is that same piece of equipment used in critical applications in the engine generator, petroleum, and mining industries where they accept only the most reliable motors available.

Many plant operators will be surprised to learn that a rotary condenser does not require more maintenance than a capacitor bank. The condenser simply requires an annual greasing, performed with the condenser running. Capacitors, on the other hand, require annual, scheduled shutdowns to have connections cleaned, tightened and to allow for visual inspection for expansions that might lead to bursting (explosion) of the capacitors.

Introducing capacitor banks into a harmonic rich environment also introduces an ongoing support nightmare. Synchronous condenser operation is unaffected by current harmonics and does not create any system problems.

Capacitors have been used for the past 25 years. Prior to that, synchronous condensers with brushes had been employed. Today, however, nonlinear loads have changed the picture. Nonlinear loads were the exception 25 years ago. Current harmonics were not understood and even considered black magic. When industry demanded smaller and less expensive methods of correcting power factor, capacitors emerged as the new technology. Now, however, with the introduction of nonlinear devices used throughout business and industry, the once useful capacitors are themselves becoming a serious problem. Consequently, there is a re-emergence of the rotary condenser, which today are smaller, less expensive and require less maintenance.

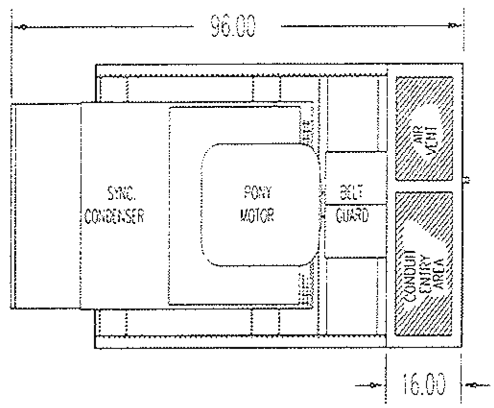

Figure 18 Series SC Top View

A synchronous condenser constantly monitors the actual power factor and continually provides the leading kVAR's needed to offset the lagging kVAR's generated by the load. It adjusts its correction without any of the damaging switching problems experienced with capacitors. As an added benefit, the condenser will act as a transient voltage stabilizer, and depending upon the machine and the service, will also reduce total harmonic distortion reflected to the utility.

When the machine is applied as a synchronous generator, the voltage regulator monitors the machine output voltage. As the output load increases, the generator voltage decreases. This is sensed by the voltage regulator and to compensate, the regulator increases the generator field current, which causes the voltage to return to the regulation set point. The same is true for reductions in load. As load is removed, the generator voltage will tend to rise; the voltage regulator sees this and reduces the field current. The state-of-the-art voltage regulator allows the voltage to be regulated to within 0.5% of the set point.

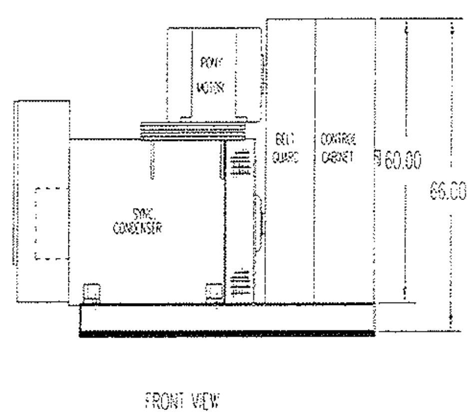

Figure 19 Series SC - End Mounted Controls

When a synchronous motor or generator is applied as a synchronous condenser, one additional component is added to the regulation system - the power factor controller. This device monitors the phase difference between the voltage and current at the point where power factor correction is needed. The controller then sends a signal to the voltage regulator that increases or decreases field current. The result is to force the current to move into phase with the voltage. The effect of the field current is to produce leading kVAR's that exactly match the lagging kVAR of the service being corrected. When the voltage and current are exactly in-phase, the power factor is unity (1.0) and only real power is drawn from the source.

As with any power generator, the field current adjustment is automatic and continuous across the operating range. There's no need to adjust the machine if the load changes the power factor controller automatically compensates. If the amount of kVAR's needed to correct power factor exceeds the capability of the machine, the synchronous condenser will produce all it can and will operate at full load as long as the phase difference is out of range. The only effect of an overload (requiring more kVAR than the machine can produce) is that the power factor will not reach the desired value but will only decrease by the difference between the machine's output and the lagging kVAR's from the load.

The application of a synchronous condenser requires that the machine being electrically connected to the service be power factor corrected. For automatic operation, a means of sensing the bus power factor is needed. This is normally done with current transformers (CT's) installed at the point where power factor is measured. The reactive power (kVAR) connection is via a three phase circuit breaker rated for the full load amps produced by the synchronous machine. For the best response, the CT's should be reasonably close to the synchronous condenser.

However, if the total service load is not on the same bus as the condenser, the condenser could be adjusted to produce a leading power factor in the same manner as synchronous motors, which have replaced condensers in many industrial

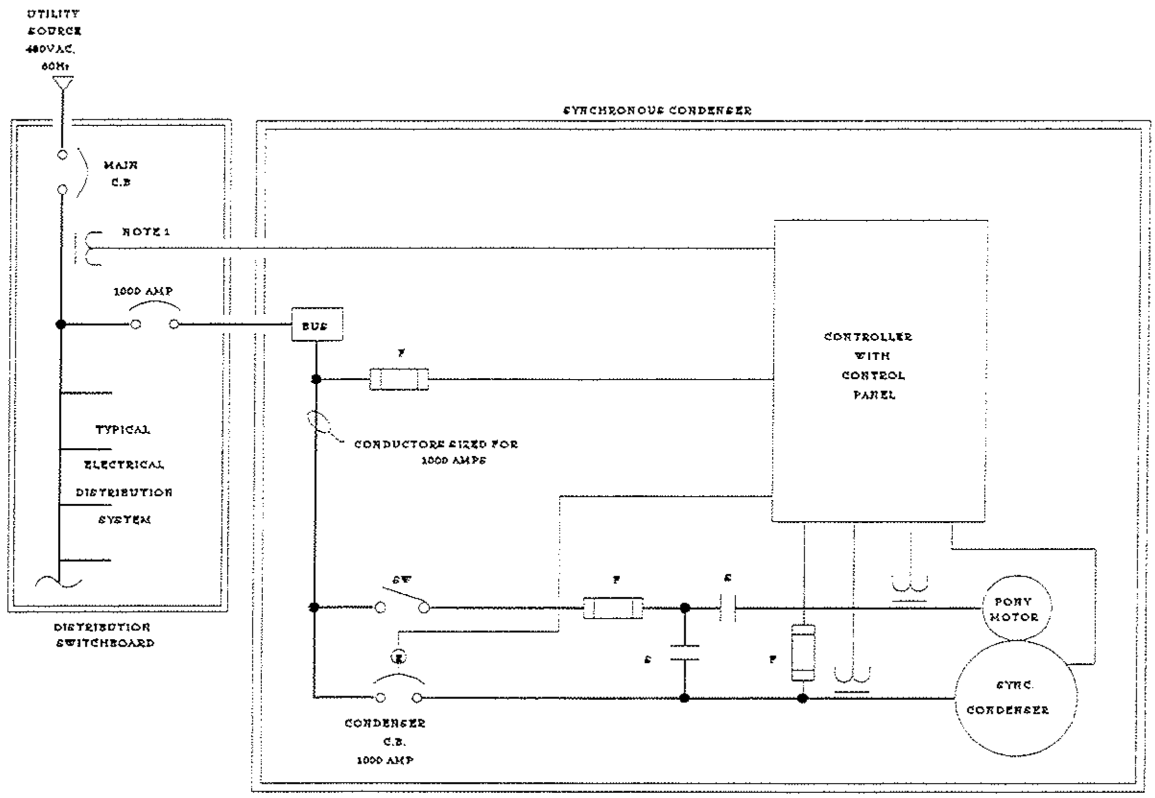

Figure 20 Series SC Power One-Line

facilities.

The original equipment cost of a synchronous condenser can be higher than that of capacitors. However, systems of 500 kVAR and above will have a 20 year life cycle cost - much lower than capacitors and their filters.

Why, you might ask, have synchronous condensers not been used more? The answer is very simple; cost. Remember, the most common way to correct power factor is to install a capacitor on the problem load. Well, synchronous condensers do not become cost effective until they get large. In most cases where power factor is bad, it is not 1 motor but 10 or 20 machines. In most cases, they were not all installed at the same time. Factories change their production line or processes as their products change. Until now, it has been easier to deal with the individual motors rather than the whole factory.

The big change is that the cost of replacing capacitors now is greater than the cost of the condenser due to increased maintenance costs. This, coupled with the potential damage that can happen when a capacitor explodes, makes the long life and low maintenance of a synchronous condenser very attractive.

- Correcting power factor with a condenser is much smoother (no voltage spikes) and will not adversely affect the system loaded with current harmonics (no resonance).

- The condenser is a low impedance source and appears inductive to variable speed drives.

- The synchronous condenser is much kinder to the site diesel generator set and presents it with a predictable load.

- Two major advantages of using a synchronous condenser are its long useful life and its record for reliability. PS&C has a proven track record using brushless-synchronous technology. Synchronous condensers will deliver over 25 years of money-saving service. (Compare that with the average 5 year life span of a capacitor bank.)

- A rotary synchronous condenser requires less maintenance than a capacitor bank. The condenser simply requires an annual greasing, performed with the condenser running. Capacitors on the other hand, require annual, scheduled shut downs to have connections cleaned, tightened and to allow visual inspections for expansion that might lead to bursting (explosion) of the capacitors.