I/O modules capable of monitoring power factor, voltage, and current draw are now widely available. DIN rail-mounted PLCs often have enough computational horsepower assess demand and keep records that can be used to optimize energy use and keep down utility bills.

Measure what you use

Closely monitoring energy use can spark useful insights about power factors and other influences on demand charges levied by utilities.

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The industrial sector consumes about 32% of the total electrical energy in the U.S. And approximately 64% of U.S. electrical power goes into ac motors. Small wonder, then, that manufacturers of all stripes are becoming more and more aware of how they use energy and what accounts for their biggest energy drains.

The trend is accelerating with the coming introduction of smart-grid features and more widespread use of demand-response power pricing. Increasingly, it looks as though major energy users can expect additional fees if their highest power demands coincide with times of high stress on the utility grid.

Of course, it is difficult to predict the impact of stringent pricing measures without understanding electrical loads, their timing, and their peak-demand qualities. New energy-efficient equipment such as NEMA Premium-class motors and variable- frequency motor drives can cut energy use. But such measures may not seem worth their extra cost if the underlying process still consumes electrical energy at the utility's highest rate.

Conversely, there can be a powerful incentive to implement energy efficient equipment when such an installation brings a lower rate structure. Firms that use a significant amount of electricity may not know whether these two scenarios are in play without making measurements that characterize how they use energy.

Consequently, it increasingly makes sense for industrial firms to monitor the energy efficiency of processes and find inefficient areas. Typical factors to monitor include voltage, current, and the effective power factor. Monitoring equipment typically gauges power factor by watching the varying angle between each of the three phases of ac lines. Phase angle can be affected by different inductive and capacitive loads. Typically, the power factor serves as a measure of power efficiency. Electricity supply companies normally levy extra charges on consumers that have a power factor of 0.95 or less.

Power factor basics

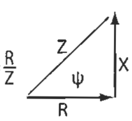
Discussions of ac power factor sometimes treat the phase relationship between ac current and voltage as a vector in a plane. The usual reference for zero phase is taken to be the positive x-axis and is associated with pure resistance because the voltage and current in a resistor are in phase. The length of the phasor is proportional to the magnitude of the quantity it represents, and its angle represents its phase relative to that of the current through the resistor.

The phase angle is the difference in phase between voltage and current in an ac circuit and is the phase angle associated with the impedance Z of the circuit. For a dc circuit power is P = VI, and this relationship also holds for the instantaneous power in an ac circuit. However, the average power in an ac circuit expressed in terms of the rms voltage and current is

$$P_{avg} = VI \cos \psi$$

where Ψ is the phase angle between the voltage and current. The additional term is called the power factor.

$$\text{POWER FACTOR} = \cos\psi = \frac{R}{Z}$$



From the phasor diagram for ac impedance, it can be seen that the power factor is R/Z. For a purely resistive ac circuit, R = Z and the power factor = 1.

Understanding demand charges

It is helpful in understanding electricity costs to be familiar with demand charges and some of the factors that influence them. Demand is how much electricity, in kilowatts, an entity uses at a given time. Utilities measure demand over a fixed period, commonly 15 min, though this is likely to change with the introduction of smart-grid features. The utility then applies a charge for the highest (peak) 15-minute demand period over the billing period (typically one month).

Some industrial customer demand charges may be affected by historical demand data or contract demand rates. These factors may set a minimum demand charge based on demand in previous months. Thus it is critical to understand how demand charges are calculated to get the most out of any efforts to minimize the charges.

Power factor also plays a role in utility charges. In general, power factor can be viewed as a measure of how efficiently an entity uses power. A unity power factor means all power consumed goes into productive work. A power factor below unity indicates some power is going into charging and discharging reactive components with each ac cycle. This reactive power does no productive work. Reactive power is necessary for running reactive loads such as ac induction motors, however. A power factor well below unity may force the utility to boost the capacity of its transmission and distribution lines to handle the additional reactive component. So some utilities charge customers whose power factor drops below 0.95.

Electric motors can have a major impact on power factor and, thus, on energy efficiency. Motor sizing can also affect efficiency because induction motors run most efficiently when operated at around 75% of their full rated load. And power factor drops when a motor runs below its nameplate power rating.

Motors on new equipment are typically sized correctly. Replacing motors on existing machinery may be more problematic from the standpoint of both power and physical sizing – equivalent motors may no longer come in the same form factor as the original, for example. Variable-frequency drives (VFDs) may be an alternative in cases where demand only matches the full-load capability at demand peaks. VFDs, of course, increasingly get deployed on pumps, fans, chillers, compressors, and cooling towers to reduce power to motors when they handle less than a full load.

However, VFDs can cut power consumption in another way: By reducing the inrush currents that sizeable motors can draw when turned on. These currents can be six to ten times the full-load current. For large integral horsepower motors, they can be high enough to induce momentary voltage sag on the facility distribution system. A VFD can avoid such difficulties by ramping the motor to desired speed, thus reducing peak demand which can be quite high otherwise.

Moreover, VFDs can also improve displacement power factor (strictly speaking, the power factor due only to the difference in phase between motor voltage and current) over the speed range of the motors. Moreover, VFDs can typically work in regenerative mode, sending energy generated from the deceleration of loads back to power lines. But regenerative op-

Example: The impact of demand charges

Suppose the utility charges 7.63 cents/kWh and demand charge is $5.08/kWh. If the plant runs a 50-kW load for five hours, the energy use is

Energy use = 50 kW × 5 hr = 250 kWh
Demand = 50 kW
Energy charge = 250 kWh × 0.763 = $19.08
Demand charge = 50 kW × 5.08 = $254
Total of demand and energy charge = $273.08

Now suppose the plant runs a 5-kW load for ten hours.
Energy use = 5 kW × 10 hr = 50 kWh
Demand = 5 kW
Energy charge = 50 kWh × 0.0763 = $3.82
Demand charge = 5 kW × 5.08 = $25.40
Total of demand and energy charge = $29.22

eration may not make sense for smaller loads. Below a certain horsepower rating, it may be more economical to dissipate energy into a resistor, often referred to as a braking resistor. This may work well for applications that just don't generate much regenerative energy.

Machines containing several axes, however, typically use any energy the drive regenerates. One common technique for using this energy is to share the dc bus connection among axes, so power flowing back from one axis gets used by other axes that are motoring. Such systems may also incorporate a braking resistor to soak up power not used by the other axes.

More info

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An even more efficient configuration interconnects the dc buses and lets drives draw power from a single active front end (AFE) rather than from ac mains. The AFE converts ac to dc, then the dc powers the drives. As before, any axis can use regenerative power generated by another. However, excess energy goes into the ac supply rather than into a braking resistor. This makes any regenerated power available to other equipment fed from the ac supply.

AFEs can also implement power factor correction. In addition, AFEs can reduce the harmonic content on ac mains because VFDs, which can be a source of power line harmonics, draw power from the AFEs rather than the ac line.

Measuring energy efficiency

The typical way of deducing what kind of measures would be effective for cutting power consumption is through a sizing analysis. For existing installations, it may make sense to install controls to monitor and record demand current, voltage, and power factor. One device in this category is the CM0985 I/O module which monitors between two and five different power supplies. Designed originally for facilities run by on-site generators, it has been pressed into service in recent years as a way to gauge power factor and power demand of individual loads. It is a DIN rail-mounted module that can interface to multiple fieldbuses like Modbus TCP, Devicenet, Profibus DP, Ethernet IP and Ethernet Powerlink. It is equipped with facilities for making the high-precision voltage and current measurements necessary for smart-grid functions on the drawing board.

This device and others like it help engineers determine when an existing axis is motoring or regenerating. In installed equipment, it may be more convenient to measure these factors directly rather than deducing them from a sizing analysis.

Although surveys can be made to give snapshot measurements of use, it is better to devise a way of continuous monitoring which could also adjust power use. A simple example of this would be an HVAC pumping system. Designed to keep constant pressure or flow in large multistory buildings and hotels, a pump typically uses two to four motors. In less expensive installations, these assemblies do not use VFDs and have simple contactor control.

But even under these circumstances there are opportunities to maximize efficiency. One approach is to add measurement I/O to the control system that will gauge demand and power factor. A controller/HMI then runs algorithms that ensure each pump operates in the optimum area of it's pressure/flow curve.

For example, suppose a waste water system draws 22 kW and runs two pumps at a particular flow/pressure level. Insight about the motors and pumping demand might reveal that a single pump could handle the job and use less power. At this stage the controller would select the pump with the least hours run and actuate it. This process can happen continually, each time another toilet is flushed or drink poured in the bar, so the system runs more economically and has more flexibility.

It is common for such systems to log each hour the motor runs between service intervals, refitting or refurbishment. This keeps pumps operating at the optimum point on their pressure/flow chart. But this kind of optimization is easier said than done. A group of sensors sends back to the controller information on the pressure and flow in each out-going pipe from the pumping. Similarly, controls monitor the system's effective power to ensure motors/pumps run at their most effective speed.

A similar scheme could also be used to monitor electrical grid parameters or power used in energy-intensive operations such as plasma cutting, as with measuring power going through a plasma torch. ■