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POWER FACTOR & UTILITY RATES

By John Wolfram

In basic terms, *Power Factor* is a measure of how effectively electric power is being used at the customer location. The assumption by the utility that customer power factor is close to 1.0 ("unity power factor") introduces little operations and ratemaking risk for most rate classes. However, because of the nature of the loads at industrial facilities, the utility cannot make that same assumption for the large power rate classes. Because the large power loads with a poor power factor draw a larger current and place a heavier drain on the power source as well as on the transmission and distribution system, many utilities impose a charge or "power factor penalty" on the bills of industrial customers when their power factor falls below a predetermined threshold.

There is no universally-accepted methodology for determining the appropriate power factor for industrial facilities; no single national standard that is based on engineering principles or electric power system operating standards exists in the U.S. Many utilities have established a minimum power factor for their industrial customers; these are set at the utilities' discretion and are typically documented in their tariffs, rules or regulations.

Utilities across the United States employ several different forms of power factor penalties. The purpose of these ratemaking structures is to compensate the utility for the incremental costs associated with providing the increased current, supplying the additional losses, and otherwise covering the costs associated with the effects of poor power factor on the electric system. The most appropriate rate design for a power factor charge should be determined based on the individual considerations of the case in question – including the makeup of industrial loads in the service territory, historical power factor performance of those loads, overall utility costs, regulatory precedent, and other factors.

Background

Power Factor in Electric System Operations

Electric power in an AC circuit has three components. *Real power* is considered to be the power that produces work, measured in watts (W) or kilowatts (kW). For example, real power produces the mechanical output of a motor. *Reactive power* does not produce work but is needed to operate equipment and is measured in volt-amperes-reactive (VAR) or kilovar (kVAR). *Apparent Power* is the vector sum of the real power and reactive power, measured in units of volt-amperes (VA) or kilovolt-amperes (kVA).

Power Factor is the ratio of the real power to apparent power and represents how much real power electrical equipment utilizes. It is a measure of how effectively electrical power is being used. Power factor is also equal to the cosine of the phase angle between the voltage and current waveforms. Power factor by definition falls into a numeric range between 0 and 1 and is often described as a percentage.

AC Circuits containing purely *resistive* heating elements (filament lamps, cooking stoves, etc.) have a power factor of 1.0 (or 100%). The voltage and current waveforms are sinusoidal and remain in step (or in phase), changing polarity at the same instant in each cycle. All of the power entering the load is consumed; no energy is stored in the load.

AC Circuits containing *inductive* elements (electric motors, solenoid valves, lamp ballasts, and others) often have a power factor below 1.0. For these circuits, where inductive loads are present, energy storage in the loads results in a time difference between the current and voltage waveforms. During each cycle of the AC voltage, extra energy, in addition to any energy consumed in the load, is temporarily stored in the load in electric or magnetic fields, and then returned to the power grid a fraction of a second later in the cycle. The ebb and flow of this reactive power increases the current in the line. Thus, a circuit with a low power factor will use higher currents to transfer a given quantity of real power than a circuit with a high power factor.

Take for example an industrial customer that utilizes an induction motor in a particular facility. Induction motors convert at most 80 – 90% of the delivered power into useful work or electrical losses. The remaining power is used to establish an electromagnetic field in the motor. The field is alternately expanding and collapsing (once each cycle) so the power drawn into the field in one instant is returned to the electric supply system in the next instant. Therefore, the average power drawn by the field is zero. The reactive power does not register on a kilowatt-hour or kilowatt meter. The magnetizing current creates reactive power. Although it does no useful work, it circulates between the generator and the load and places a heavier drain on the power source as well as on the transmission and distribution system.

Stated another way, when a utility serves a facility that has poor power factor, the utility must be capable of supplying higher current levels to serve a given load. Many industrial loads are inductive such as motors, transformers, fluorescent lighting ballasts, power electronics, and induction furnaces. These kinds of loads draw higher currents and can impact the operations of the utility in the following ways:

- Increased line losses
- Wasted generation capacity
- Wasted distribution / transformer capacity
- Reduced overall system efficiency
- Increased maximum demand
- Increased maintenance of equipment and machinery

Improving power factor can result in the following:

- Reduced energy costs
- Lower transmission and distribution losses
- Higher and improved quality voltage regulation
- Increased capacity available to serve actual working power requirements
- Reduced non-productive loading on the system

Power Factor in Ratemaking

Most utilities base their charges on real power – i.e. demand charges on kW (or real power at peak) and energy charges on kWh consumed (or real power for each hour). Also note that the reactive component of current does not register on a kilowatt-hour or kilowatt meter. For these reasons, many utilities impose a power factor billing element to recover the costs associated with the total power they are required to deliver to a given customer.

As the power factor drops the system becomes less efficient. As an example, if real power demand at two plants is the same, but one has a power factor of 0.85 and the other has a power factor of 0.70, the utility must provide 21% more current to the second plant to meet the demand. Without a power factor billing element, the utility would receive no more revenue from the second plant than from the first, even though serving the second plant places a greater cost burden on the utility than does serving the first plant. From the customer's point of view, the transformers and cable in the second plant would need 21% more current-carrying capacity, and the utility would need to supply more current to the second plant in real time to provide service.

Thus, as a means of compensation for the burden of supplying extra current, many utilities establish a power factor penalty in their rate schedules, especially for large industrial customers.

Standards

There is no single standard established in the U.S. for power factor of commercial or industrial facilities interconnected to the power grid. No universally-accepted methodology for determining a minimum or target facility power factor is established based on engineering principles or electric power system operating standards.

Certain utilities establish a minimum power factor as an operational requirement pursuant to their rules and regulations, as approved by regulatory entities (for investor owned utilities and other regulated utilities), city councils (for municipal utilities) or boards of directors (for electric cooperatives). The theory behind this approach is that a minimum power factor is needed to protect the overall transmission and/or distribution system from disturbances, harmonics or other events originating at the customer facility that might cause the utility's protective relaying schemes to activate and initiate outages on the grid. However, these minimums are not based on a published standard or other nationally-accepted engineering code. For the most part, these minimums are established at the discretion of the utility (subject to approval by the appropriate entity).

Alternatives

While there is no standard power factor requirement established for large power facilities, there is a small number of different billing structures typically imposed by electrical utilities for power factor compensation.

One method is for the utility to set a minimum power factor and charge the customer an incremental amount if the customer's power factor dips below the minimum. A minimum power factor anywhere from 0.80 to 0.95 is typically established. When a customer's power factor (as determined at the monthly peak by the appropriate metering) drops below the minimum value, the utility adjusts the total billed demand by the ratio of the minimum power factor to the actual power factor. An alternative is for the utility to adopt a sliding (non-linear) scale, so that the billings are adjusted by a specific scalar depending on the actual power factor; typically the lower the power factor, the higher the escalator and thus the penalty.

Another way some utilities collect a low power factor premium is to charge for kVA (apparent power) rather than kW (real power). This requires different metering technology and may require a modification to off-the-shelf billing systems to accommodate billing units other than kW. This avoids any estimation of a penalty amount by billing the customer on the apparent power, which includes the effects of the power factor in any event. However, the metering for this approach may be more costly.

Other utilities employ a balanced methodology using kW billing that provides customers with a credit for high power factor or a penalty for low power factor. The utility establishes a target power factor; if the actual power factor exceeds that target, a bill credit is provided, and if the actual power factor falls below the target, a penalty is assessed. This approach is sometimes employed with a bandwidth around the target power factor. While this approach is reasonable and balanced, it is less common; more often than not, utilities assess a penalty for low power factor and forego credit for power factors above the target or minimum established by the utility.

Generally, utilities impose power factor penalties or apply credits only on their larger commercial and industrial customers. In theory, all customer classes experience power factors less than unity; however, utilities do not typically address power factor penalty for non-industrial customer classes (particularly residential and small commercial service) for several reasons:

- The costs for metering are prohibitively high
- The relative size of customer load is small (i.e. power factor variations are immaterial)
- The power factor diversity within the class is high (i.e. power factor variations of numerous individual consumers offset one another)

Evaluation

To properly determine which method of power factor compensation is most appropriate for a particular utility, the utility should evaluate several factors. These include but are not limited to the following:

1) Does the utility currently have a power factor charge/credit in effect?

2) Do large power customers comprise a significant portion of the utility's customer base?

3) Do large power customers historically perform well or poorly with respect to power factor?

4) Does the historical power factor data indicate that a change is warranted?

5) Can the utility assess the impact that poor power factor customers have on its planning and operations? More specifically, do equipment failures or does maintenance on facilities in close proximity to large power customers occur at a higher frequency relative to the total system? Do the utility engineers have any analysis or other information indicating that poor power factor is adversely impacting utility infrastructure?

6) Is reliance on either kVA or kVAR metering a plausible alternative? What are the incremental costs for the necessary metering? Can the utility billing system accommodate this method?

7) If the utility is regulated, what is the regulatory precedent with respect to power factor penalties? Has the regulator mandated a particular method? Have other utilities proposed methods that have been accepted or denied? What support for the accepted methods was required by the regulator?

8) How will the implementation of a particular methodology affect customer satisfaction? Will it have a significant cost impact on large customers? Will it generate formal complaints? What are the public relations consequences?

Many of these considerations are qualitative rather than quantitative. All should be considered on a comprehensive basis when formulating a recommended approach for power factor charge or credit in the ratemaking arena.

Recommendation

Generally, a utility should put in place a ratemaking structure that allows it to recover the costs associated with variations in power factor. The most advantageous method is to rely upon kVA billing, so that the variations in power factor are "built-in" to the apparent power value used for billing purposes. However, this method may be cost prohibitive depending upon the required metering, any necessary changes to the billing systems, and the number of affected customers. If relying on kW billing is required, methods that establish a baseline or target power factor, and which then scale the billed demand up for poor power factor or down for favorable power factor, are generally encouraged.

Specifically, any utility reviewing its options for power factor charges or credits should assess all of the issues noted in the previous section and consider them all on a comprehensive basis when determining the best approach for that particular utility for a power factor charge or credit for ratemaking purposes.

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