PQSoft Case Study

Power Factor Correction
Estimating Financial Savings

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Abstract:

Low power factor means that you are using a facility's electrical system inefficiently. It can also cause equipment overloads, low voltage conditions, and greater line losses. Most importantly, low power factor can increase total demand charges and cost per kWh, resulting in higher monthly electric bills. This case study provides a summary of interrupting electric utility rates and billing, and estimating financial savings when applying low voltage power factor correction capacitors.

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GLOSSARY AND ACRONYMS

ASD	Adjustable-Speed Drive
DPF	Displacement Power Factor
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
TPF	True Power Factor

REVIEW OF UTILITY RATES AND PENALTIES

Each electric utility has their own unique method and related rates for determining power factor penalties (if they have a penalty), and it is not within the scope of this case study to summarize all of the possible rates and penalties. In addition, there is no one single industry standard that provides a summary of this information.

Therefore, this case provides some general background information and examples for related power factor penalties and economic evaluations for determining the financial benefits when applying power factor correction capacitors.

There are a number of methods for charging for poor power factor:

- Charges for kVArh
- Charges for kVAr demand
- Charges for kVA demand
- Charges for adjusted kW demand
- Charges based on a percentage of the demand or base charge

Utilities charge for energy and demand. Energy is produced by burning fuel to drive turbines to produce electricity. The energy charges are in cents/kWh and are used to pay for energy production (e.g., fuel). The demand charges are a charge for the rate at which you demand the energy (also known as a demand penalty). The demand charges are in $/kW and are used to pay for energy transmission (e.g., transmission lines).

Interpreting Utility Bills

Utility monthly billing must be analyzed before it can be determined if capacitors are economically justified. Preferably, all bills for the previous year should be collected in order to establish seasonal variations and long term trends in electric consumption. If these are not available, the key data to request from the utility are maximum demand, power factor, typical energy usage, and power factor penalty or demand charge. Industrial consumer bills generally have two main parts, including the energy charges and the demand charges. There are also taxes and other miscellaneous charges, but these typically do not have a significant impact on the economic justification for power factor correction capacitors.

The energy charge is determined by multiplying the number of kWh of energy consumed in the month times the energy rate ($/kWh). The demand charge is more complicated. It is typically based on the peak kW demand over a given 15-, 30-, or 60-minute interval during the month. This is nominally multiplied by the demand charge rate ($/kW). However, many utilities assess a penalty to the demand if the power factor is lower than a predetermined value. There are two common formulae in use for determining the billed demand when the actual power factor is lower than power factor penalty value (lagging):

$$kW_{billed} = kW_{actual} * \left(\frac{PF_{penalty}}{PF_{actual}} \right)$$

or

$$kW_{billed} = kW_{actual} * \left(1 + PF_{penalty} - PF_{actual} \right)$$

Both of these are applied only when the actual power factor is less than power factor penalty value (lagging). Otherwise, the billed demand is the same as the actual demand.

The difference between the amount paid for the billed demand and the amount for the actual demand is often termed the power factor penalty. This quantity is generally responsible for the bulk of the justification for capacitors:

$$\text{Penalty} = \left(\text{kW}_{\text{billed}} - \text{kW}_{\text{actual}}\right) * \left(\$/_{\text{kW}}\right)$$

The power factor (PF) used in billing is generally an average power factor determined over the entire month, although a few utilities may bill interval-by-interval. The usual procedure for determining the power factor is to meter the kVArh as well as the kWh. This may be done by two separate meters or may be contained within one electronic meter. The kVArh are then combined with the kWh to obtain an equivalent kVAh:

$$\text{kVAh} = \sqrt{\left(\text{kWh}^2 + \text{kVArh}^2\right)}$$

The average power factor is then:

$$\text{PF}_{\text{avg}} = \frac{\text{kWh}}{\text{kVAh}}$$

The kVArh meter is usually “detented” so that it only records lagging VArs; that is, the VArs drawn by motors. No credit is given for leading VArs (a meter which is detented will record power flow in only one direction).

It should be noted that some utilities have considered billing for kVArh similarly to kWh. Existing meter technology can separately track leading and lagging kVArh. This provides the opportunity to have flexible rate structures to create incentives for customers to control var consumption and production.

Determining Financial Savings when Applying Power Factor Capacitors

This section provides several examples illustrating power factor penalties and economic evaluations for determining the financial benefits when applying power factor correction capacitors. It should be noted that the examples are only intended for general illustration purposes and in no way imply that the quoted rate structures and tariffs are indicative of the actual rate design methodologies and typical rates used by utilities.

Three-Phase Induction Motor Example

A small machine tool plant has an induction motor load that uses an average of 100 kW with an existing power factor of 80%. The desired power factor is 95%. Existing power factor, desired power factor, and kW are the three quantities that are required to properly select the amount of kVAr required to correct the lagging power factor of a three-phase induction motor. The required kVAr may be determined by either using the data provided in Table 1 (kVAr = kW * multiplier) or the following expression:

$$\text{kVAr} = \text{kW} * \left(\tan\phi_{\text{original}} - \tan\phi_{\text{desired}}\right)$$

where:

kVAr = required compensation in kVAr
kW = real power in kW
$\tan\phi_{\text{original}}$ = original power factor phase angle
$\tan\phi_{\text{desired}}$ = desired power factor phase angle

$$\mathrm{kVAr} = \mathrm{kW} * \left(\tan\phi_{\mathrm{original}} - \tan\phi_{\mathrm{desired}}\right)$$
$$= 100\mathrm{kW} * \left(\tan\left(\cos^{-1} 0.80\right) - \tan\left(\cos^{-1} 0.95\right)\right) = 42.2\mathrm{kVAr}$$

						Corrected Power Factor					
Orig PF	**0.80**	**0.82**	**0.84**	**0.86**	**0.88**	**0.90**	**0.92**	**0.94**	**0.96**	**0.98**	**1.00**
0.50	0.982	1.034	1.086	1.139	1.192	1.248	1.306	1.369	1.440	1.529	1.732
0.52	0.893	0.945	0.997	1.049	1.103	1.158	1.217	1.280	1.351	1.440	1.643
0.54	0.809	0.861	0.913	0.965	1.019	1.074	1.133	1.196	1.267	1.356	1.559
0.56	0.729	0.781	0.834	0.886	0.940	0.995	1.053	1.116	1.188	1.276	1.479
0.58	0.655	0.707	0.759	0.811	0.865	0.920	0.979	1.042	1.113	1.201	1.405
0.60	0.583	0.635	0.687	0.740	0.794	0.849	0.907	0.970	1.042	1.130	1.333
0.62	0.515	0.567	0.620	0.672	0.726	0.781	0.839	0.903	0.974	1.062	1.265
0.64	0.451	0.503	0.555	0.607	0.661	0.716	0.775	0.838	0.909	0.998	1.201
0.66	0.388	0.440	0.492	0.545	0.599	0.654	0.712	0.775	0.847	0.935	1.138
0.68	0.328	0.380	0.432	0.485	0.539	0.594	0.652	0.715	0.787	0.875	1.078
0.70	0.270	0.322	0.374	0.427	0.480	0.536	0.594	0.657	0.729	0.817	1.020
0.72	0.214	0.266	0.318	0.370	0.424	0.480	0.538	0.601	0.672	0.761	0.964
0.74	0.159	0.211	0.263	0.316	0.369	0.425	0.483	0.546	0.617	0.706	0.909
0.76	0.105	0.157	0.209	0.262	0.315	0.371	0.429	0.492	0.563	0.652	0.855
0.78	0.052	0.104	0.156	0.209	0.263	0.318	0.376	0.439	0.511	0.599	0.802
0.80	0.000	0.052	0.104	0.157	0.210	0.266	0.324	0.387	0.458	0.547	0.750
0.82		0.000	0.052	0.105	0.158	0.214	0.272	0.335	0.406	0.495	0.698
0.84			0.000	0.053	0.106	0.162	0.220	0.283	0.354	0.443	0.646
0.86				0.000	0.054	0.109	0.167	0.230	0.302	0.390	0.593
0.88					0.000	0.055	0.114	0.177	0.248	0.337	0.540
0.90						0.000	0.058	0.121	0.193	0.281	0.484
0.92							0.000	0.063	0.134	0.223	0.426
0.94								0.000	0.071	0.160	0.363
0.96									0.000	0.089	0.292
0.98										0.000	0.203
1.00											0.000

$$\mathrm{kVAr}_{\mathrm{required}} = \mathrm{kW} * \left(\tan\left(\cos^{-1}\phi_{\mathrm{original}}\right) - \tan\left(\cos^{-1}\phi_{\mathrm{desired}}\right)\right)$$

$$\mathrm{kVAr}_{\mathrm{required}} = \mathrm{multiplier} * \mathrm{kW}$$

Table 1 - kW Multiplier for Determining kVAr Requirement

kVAr Demand Charge Example

A facility with a demand of 1800 kVA, 1350 kW, and 1200 kVAr has a contract for power factor that includes an energy charge for kWh, a demand charge based on kW, and other demand charge based on kVAr. The kVAr charge is $1.50 per month for each kVAr of demand in excess of 1/3 of the kW demand.

The first step is to determine the kVAr demand in excess of 1/3 of the kW demand

1200 kVAr – (1350 kW/3) = 750 kVAr

The second step is to estimate the annual savings if the 750 kVAr demand charge is eliminated by the addition of 750 kVAr of power factor correction capacitors.

$1.50 demand charge * 750 kVAr * 12 months = $13,500

The third step is to determine the cost to purchase and install 750 kVAr of capacitors. It is assumed that on a 480 volt system, the installed capacitor cost is $30/kVAr.

750 kVAr * $30/kVAr = $22,500

The final step is to determine the payback period for the capacitor installation.

$22,500/$13,500 = 1.67 years (20 months)

Therefore the low voltage capacitor installation will pay for itself in about 20 months.

kW Demand Charge Example

A facility with a demand of 1,000 kW has a power factor of 80%. The utility has a demand charge of $9.00/kW for customers with power factors below 85%.

The first step is to determine the monthly kW billing.

1000 kW * (0.85 target power factor / 0.80 existing power factor) = 1063 kW

1063 kW * $9.00 = $9,567

The second step is to determine the amount of power factor correction capacitors that are required to improve the power factor to 85%.

$$\mathrm{kVAr} = \mathrm{kW} * \left(\tan\phi_{\mathrm{original}} - \tan\phi_{\mathrm{desired}}\right)$$
$$= 1000\mathrm{kW} * \left(\tan\left(\cos^{-1}0.80\right) - \tan\left(\cos^{-1}0.85\right)\right) = 130\mathrm{kVAr}$$

The third step is to determine the cost to purchase and install 130 kVAr of capacitors. It is assumed that on a 480 volt system, the installed capacitor cost is $45/kVAr.

130 kVAr * $45/kVAr = $5,580

The fourth step is to determine the monthly kW billing with the new power factor.

1000 kW * (0.85 target power factor / 0.85 existing power factor) = 1000 kW

1000 kW * $9.00 = $9,000

The final step is to compare both monthly billing values and determine the payback period for the capacitor installation.

$9,567	80% power factor billing
$9,000	85% power factor billing
$567	monthly savings

$5,580/$567 = 10.32

Therefore the low voltage capacitor installation will pay for itself in approximately 10½ months.

kVA Demand Charge Example

A facility with a 400 kW load has a demand of 520 kVA. The utility has a demand charge of $3.00/kVA for customers with power factors below 95%.

The first step is to determine the present power factor.

power factor = kW/kVA = 400kW/520kVA = 0.769 or 77%

The second step is to determine the amount of power factor correction capacitors that are required to improve the power factor to 95%.

$$\begin{aligned} kVAr &= kW * \left(\tan\phi_{original} - \tan\phi_{desired}\right) \\ &= 400kW * \left(\tan\left(\cos^{-1}0.77\right) - \tan\left(\cos^{-1}0.95\right)\right) = 200kVAr \end{aligned}$$

The third step is to determine the new kVA demand after the capacitors have been installed.

kVA = kW/ power factor = 400/0.95 = 421 kVA

The fourth step is to determine the cost to purchase and install 200 kVAr of capacitors. It is assumed that on a 480 volt system, the installed capacitor cost is $35/kVAr.

200 kVAr * $35/kVAr = $7,000

The final step is to compare both monthly billing values and determine the payback period for the capacitor installation.

(520 kVA – 421 kVA) * $3.00/kVA = $297/month

$7,000/$297 = 23.57

Therefore the low voltage capacitor installation will pay for itself in approximately 2 years.

Increase in System Capacity Example

A facility with a demand of 400 kW and 520 kVA has a power factor of 77%. The facility manager would like to add power factor correction capacitors to increase the facility's capacity by 20%.

The first step is to determine the power factor required to release the desired amount of system kVA:

$$PF_{new} \approx \frac{PF_{old}}{1 - kVA_{release}}$$

where:

PF_{new} = corrected power factor
PF_{old} = existing power factor
$kVA_{release}$ = amount of kVA to be released (in per-unit of existing kVA)

$$PF_{new} \approx \frac{PF_{old}}{1 - kVA_{release}} = \frac{0.77}{1 - 0.20} = 0.9625 \quad \text{or } 96\%$$

The second step is to determine the amount of power factor correction capacitors that are required to improve the power factor to 96%.

$$\begin{aligned} kVAr &= kW * \left(\tan\phi_{original} - \tan\phi_{desired}\right) \\ &= 400kW * \left(\tan\left(\cos^{-1}0.77\right) - \tan\left(\cos^{-1}0.96\right)\right) = 215kVAr \end{aligned}$$

The third step is to determine the cost to purchase and install 215 kVAr of capacitors. It is assumed that on a 480 volt system, the installed capacitor cost is $45/kVAr.

215 kVAr * $45/kVAr = $9,675

Therefore the facility manager will be able to increate the plant's capacity by 20% by spending $9,675 to add 215 kVAr of power factor correction capacitors. The additional capacitor will be available for new motor and lighting loads without having to add new transformers or other distribution equipment.

Power Factor Penalty Example

A facility has the following electrical usage data:

163 kW load, 480 volt, three-phase service
730 hours per month operation
65% power factor
Power Factor Penalty - $0.0015 per kVArh (below unity)

The first step is to determine the facility kVA and kVAr.

kVA = kW/ power factor = 163/0.65 = 251 kVA

$$\mathrm{kVAr} = \sqrt{\left(\mathrm{kVA}^2 - \mathrm{kW}^2\right)} = \sqrt{\left(251^2 - 163^2\right)} \approx 190\mathrm{kVAr}$$

Adding 190 kVAr of power factor correction will correct the power factor to unity (100%) and eliminate the power factor penalty.

The second step is to determine the monthly power factor penalty.

190 kVAr * $0.0015/kVArh * 730 hrs = $208.05

The third step is to determine the cost of 190 kVAr of compensation. It is assumed that on a 480 volt system, the installed capacitor cost is $30/kVAr.

190 kVAr * $30/kVAr = $5,700

The final step is to determine the payback period for the capacitor installation.

$5,700/$208.05 = 27.397

Therefore, the low voltage capacitor installation will pay for itself in approximately 27 months.

SUMMARY

Power factor is a measurement of how efficiently a facility uses electrical energy. A high power factor means that electrical power is being utilized effectively, while a low power factor indicates poor utilization of electric power. Low power factor can cause equipment overloads, low voltage conditions, and greater line losses. Most importantly, low power factor can increase total demand charges and cost per kWh, resulting in higher monthly electric bills.

Low power factor is generally solved by adding power factor correction capacitors to a facility's electrical distribution system. Power factor correction capacitors supply the necessary reactive portion of power (kVAr) for inductive devices. The principle benefit is lower monthly electric bills.

REFERENCES

IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book, Std 141-1986), October 1986, IEEE, ISBN: 0471856878

IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book, Std 399-1990), December 1990, IEEE, ISBN: 1559370440

IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, March 1988, IEEE, ISBN: 0471853925