Understanding Power Factor and How it Affects Your Electric Bill

Presented by
Scott Peele PE
Understanding Power Factor

- Definitions
  - kVA, kVAR, kW, **Apparent Power vs. True Power**
- Calculations Measurements
- Power Factor Correction
  - Capacitors
- System Impacts
  - $I^2 R$ losses, Chapter 9 NEC
  - Equipment sizing
- Power Factor Charges
- Problems with adding Caps
  - Harmonic resonance
  - Volt rise
- Power Factor vs Load Factor
What is Power Factor

Power Factor is the cosine of the phase angle between current and voltage.

Power Factor is the ratio of true power to apparent power.
Understanding Alternating Current (AC)

- **Magnitude**: 169 volts
- **Voltage Level**: 120 Volts RMS
- **One Cycle**: 0.01666 seconds
- **Duration**: 60 Hertz/second

Diagram showing the waveform of AC with key points marked.
Phase Angle

Magnitude
Voltage Level

Duration
Degrees

120 Volts RMS
90°
180°
360°
270°

One Cycle
Three Basic Circuits or Loads

- Resistive
- Inductive
- Capacitive
- Or any combination
  - Resistive Inductive
  - Inductive Capacitive
  - Resistive Capacitive
  - Resistive Inductive Capacitive
Types of Loads

- Resistive – Incandescent Lamp
  Resistance heat
- Inductive – Motors – Contactor Coils – Relays (coils)
- Capacitive – Capacitors – Start Capacitors
  – Run Capacitors – Power Factor Correction Capacitors
Resistive Loads In Phase

Magnitude

Level

Current voltage

Duration

Time
Capacitive Loads Leading

Magnitude

Level

Duration

Time

Progress Energy
What is Power

- Power is measured in Watts.
- Volts X Amps X Power Factor = Watts
- Watts only equals Volts X Amps when the Power Factor is 1 or unity.
- Most of the time the Power Factor is less than 1.
- Power = Watts : True Power
- Volts X Amps = VA : Apparent Power
Understanding Right Triangles

- $\theta$: Angle
- $A$: Side Opposite
- $B$: Side Adjacent
- $C$: Hypotenuse

Right Angle $90^\circ$
Power Triangle

Power Factor = \frac{\text{True power}}{\text{Apparent power}}

\cos \theta = \frac{\text{Adjacent side}}{\text{Hypotenuse}}

\text{Power Factor} = \cos \theta
Power Factor = \frac{\text{True power}}{\text{Apparent power}}

\[ \begin{align*}
\theta & \quad \text{Right Angle 90°} \\
B & = \text{True Power} \\
A & = \text{Reactive Power} \\
C & = \text{Apparent Power}
\end{align*} \]
Understanding Power Triangle

C = Apparent Power
VA (Volts – Amps), kVA,

A = Reactive Power
VAR, kVAR, Reactance

B = True Power
Watts, KW, Power

θ
Graphical representation of resistance, reactance, and impedance

Inductive Motors

- Resistance: $R$
- Inductive Reactance: $X$
- Impedance: $Z$

Angle: $\theta$
Graphical representation of resistance, reactance, and impedance
Capacitive Capacitors

Inductive Motors

Real - WATTS – kW (KWH over Time)

Cosine of $\theta$

POWER FACTOR

True Power

Apparent Power VA or kVA

kVAR Reactance Imaginary

Imaginary

Progress Energy
### 10 HP 460 Volt 4 Pole Motor

#### Transformer

#### Conductor

#### Motor

<table>
<thead>
<tr>
<th>Load</th>
<th>Power Factor</th>
<th>VA</th>
<th>Amps</th>
<th>Watts</th>
<th>VAR</th>
<th>Amps Reactive</th>
<th>Amps Resistive</th>
</tr>
</thead>
<tbody>
<tr>
<td>125%</td>
<td>0.82</td>
<td>13203</td>
<td>16.6</td>
<td>10883</td>
<td>7476</td>
<td>9.4</td>
<td>13.7</td>
</tr>
<tr>
<td>115%</td>
<td>0.81</td>
<td>12240</td>
<td>15.4</td>
<td>9972</td>
<td>7099</td>
<td>8.9</td>
<td>12.5</td>
</tr>
<tr>
<td>100%</td>
<td>0.79</td>
<td>10830</td>
<td>13.6</td>
<td>8592</td>
<td>6593</td>
<td>8.3</td>
<td>10.8</td>
</tr>
<tr>
<td>75%</td>
<td>0.73</td>
<td>8771</td>
<td>11.1</td>
<td>6397</td>
<td>6002</td>
<td>7.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50%</td>
<td>0.61</td>
<td>7105</td>
<td>8.9</td>
<td>4323</td>
<td>5639</td>
<td>7.1</td>
<td>5.4</td>
</tr>
<tr>
<td>25%</td>
<td>0.40</td>
<td>5886</td>
<td>7.4</td>
<td>2331</td>
<td>5405</td>
<td>6.8</td>
<td>2.9</td>
</tr>
<tr>
<td>min load</td>
<td>0.17</td>
<td>5399</td>
<td>6.8</td>
<td>911</td>
<td>5322</td>
<td>6.7</td>
<td>1.1</td>
</tr>
</tbody>
</table>

- **Blue** = KW Load (resistive)
- **Red** = KVAR Load (reactive)
10 HP Energy Flow

Transformer

Power Factor = .79
Measured Amps = 13.6
Reactive Amps = 8.3
Resistive Amps = 10.8

Conductor

A = Reactive Power
VAR = 6593
B = True Power
Watts = 8592

C = Apparent Power
VA = 10830

Motor

= KW Load (resistive)
= KVAR Load (reactive)

Progress Energy
10 HP Adding Capacitance

Motor

Transformer

Conductor

B = True Power
Watts = 8592

A = Reactive Power
VAR = 6593

C = Apparent Power
VA = 10830

θ

Measured Amps = 10.8
VA = 8595
Watts = 8592

VAR = 1

Measured Amps = 8.3

Measured Amps = 13.6

= KW Load (resistive)

= KVAR Load (reactive)
10 HP Energy Savings

Saving are calculated on $I^2 R$ losses.

Using a #12 gauge wire from Table 9 in the NEC the resistance is 2 ohms per 1000 feet. 200’ @ 2 Ohms/1000’ is .5 ohms. Using this the total saving will be approx. 11.8 watts. **NOTE: This is only if the capacitor is at the motor.**

$I^2 R = $Watts

\[
2.8^2 \times .5 = 3.92 \\
3 \times 3.92 = 11.76
\]

- blue = KW Load (resistive)
- red = KVAR Load (reactive)
10 HP Capacitor Sizing

Transformer

Conductor

Utility Meter

Capacitor to large then var flow in both directions and one may increase cost.

Motor

= KW Load (resistive)

= KVAR Load (reactive)
Based on one month operation at 8 hours a day

### Example of Power Factor Charge

<table>
<thead>
<tr>
<th>PF Charge Factor</th>
<th>NC Charge</th>
<th>kW Charge</th>
<th>Max Billing kW</th>
<th>Max Billing kWh Charge</th>
<th>Power Factor</th>
<th>kWh Charge</th>
<th>kWh VAR</th>
<th>Total Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.40</td>
<td>$10.25</td>
<td>$0.03854</td>
<td>8.592</td>
<td>2064</td>
<td>0.79</td>
<td>8.6</td>
<td>6.6681</td>
<td>$168.23</td>
</tr>
</tbody>
</table>

Less than .85 then a $0.40 charge

For kVAR – (kW X .62)

In this Case $0.54

<table>
<thead>
<tr>
<th>PF Charge</th>
<th>$0.54</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW Charge</td>
<td>$88.15</td>
</tr>
<tr>
<td>kWh Charge</td>
<td>$79.55</td>
</tr>
<tr>
<td>Total Charge</td>
<td>$168.23</td>
</tr>
</tbody>
</table>
10 Horse Power Motor

VA Watts VAR

<table>
<thead>
<tr>
<th>Power Factor</th>
<th>VA</th>
<th>Watts</th>
<th>VAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.82</td>
<td>125%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.81</td>
<td>115%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.79</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.73</td>
<td>75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.61</td>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>Min</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Progress Energy
# Power Factor vs Amps

<table>
<thead>
<tr>
<th>Volts</th>
<th>Amps</th>
<th>VA</th>
<th>kW</th>
<th>Power Factor</th>
<th>VAR</th>
<th>Amps Reactive</th>
<th>Amps Resistive</th>
</tr>
</thead>
<tbody>
<tr>
<td>208</td>
<td>83</td>
<td>10000</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>88</td>
<td>10526</td>
<td>10</td>
<td>0.95</td>
<td>3287</td>
<td>28</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>92</td>
<td>11111</td>
<td>10</td>
<td>0.9</td>
<td>4843</td>
<td>41</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>98</td>
<td>11765</td>
<td>10</td>
<td>0.85</td>
<td>6197</td>
<td>52</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>104</td>
<td>12500</td>
<td>10</td>
<td>0.8</td>
<td>7500</td>
<td>63</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>111</td>
<td>13333</td>
<td>10</td>
<td>0.75</td>
<td>8819</td>
<td>74</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>119</td>
<td>14286</td>
<td>10</td>
<td>0.7</td>
<td>10202</td>
<td>85</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>139</td>
<td>16667</td>
<td>10</td>
<td>0.6</td>
<td>13333</td>
<td>111</td>
<td>83</td>
</tr>
<tr>
<td>208</td>
<td>166</td>
<td>20000</td>
<td>10</td>
<td>0.5</td>
<td>17321</td>
<td>144</td>
<td>83</td>
</tr>
</tbody>
</table>
Power Factor vs Amps

The graph shows the relationship between power factor and amps across different kW values. The x-axis represents kW, and the y-axis represents amps and the power factor. Each section of the graph indicates a different kW value, with corresponding amp and power factor values.
10 HP Voltage Rise

Transformer

Conductor

200 Feet of #12 Gauge wire

kVAR * X_{source}/kVA/100 = Voltage Rise %

Note: This does not include the wire inductance that will cause some additional rise in voltage.
Note: With this voltage rise an increase in kW and kwh can occur.

= KW Load (resistive)  = KVAR Load (reactive)
System VAR Requirements
(Met by Power Plant Generator)

Power Plant
Generator

MVAR

MW

Transmission Circuit

T/D Substation

KVAR

KW

Substation Capacitor Bank

Distribution Circuit

Industrial Load

Commercial Load

Residential Load

L

L

L

= KW Load (resistive)

= KVAR Load (reactive)
System VAR Requirements
(Met by Power T/D Substation)

KW Load (resistive)
KVAR Load (reactive)
System VAR Requirements
(Met by T/D Sub and Feeder Capacitors)

Power Plant
Generator

MW

Transmission Circuit

T/D Substation

KVAR

KW

Distribution Circuit

Feeder Capacitor Bank

Industrial Load

L

Commercial Load

L

Residential Load

L

System VAR Requirements
(Met by T/D Sub and Feeder Capacitors)

- KW Load (resistive)
- KVAR Load (reactive)
Things We have Talked About And Other Things to Talk About

- Phase Angle
- Power Factor
- $I^2R$ Loss
- Power Factor Penalty
- Voltage Rise
- Harmonic resonance
- Load Factor --- Power Factor
Harmonic Resonance

3 PHASE AC INPUT

X_{Source}  

X_T

X_C

Harmonic Source

Equivalent Circuit

X_{Source}  

X_T
Harmonic Filters

\[ L_1, L_2, L_3 \]

\[ X_F, X_C \]

\[ L_1, L_2, L_3 \]
Power Factor Vs Load Factor

- They have no relation
- Load Factor is kW at 100% operation

Yielding so many kWh vs. Actual kWh

Example

Hours in a Month = 30 X 24 = 720 Hours

Load is at 8 kW

8 X 720 = 5760 kWh

Actual kWh by load is 3240

Load Factor then is 3240/5760

Load Factor = .56
BOTTOM LINE ON Understanding Power Factor and How it Affects Your Electric Bill

- Very small charge with penalty, most customers have no Power Factor Penalty

- None or very small savings or possible increase cost when using Power Factor Correction Devices
Questions