Power Factor and Harmonics Primer
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Definition of Power Factor

Power Factor (PF) is a term used in regard to the efficiency of an electrical power distribution system. Also known as displacement power factor, power factor is a measurement between the current and voltage phase shift waveforms.

Power factor consists of three components: KW, which is the working, or real, power; KVA, which is called the apparent power; and KVAR, or reactive power. KW does the actual work, whereas KVAR does not do any beneficial work. The measurement of the relationship between KW and KVAR is the KVA. Reactive power is measured in volt-amperes reactive (VAR), also known as KVAR when the number exceeds 1,000.

The power triangle in Figure 1 shows the relationship between these three elements. As the KVA used decreases, the power factor of the load increases, based on a constant KW.

To determine your power factor, divide the working power (KW) by the apparent power (KVA). Normally, a power factor measurement is expressed as a decimal of 1 (e.g., 0.85), with 1, or unity, being the highest (or best) power factor possible.

When correcting power factor, in general, a measurement of .9 or higher is considered good.
If you have a low power factor, you are not using all the power you are paying for. Industries where poor power factor is common are:

- Steel/Foundries
- Chemicals
- Textiles
- Pulp and paper processing
- Automotive and other automated assembly
- Rubber and plastics processing
- Breweries
- Electroplating

Load types that can cause poor power factor include:

- Induction motors
- Electric arc furnaces
- Machining
- Stamping
- Welding
- Variable Frequency Drives (VFDs)
- Fluorescent lights with magnetic ballasts
- Computers
- Computer controlled equipment

If you are in one of these businesses, or use the type of equipment listed above, you would probably benefit from improving your power factor.

These are just some examples of industries and equipment that require reactive power to generate an electromagnetic field for operation, and can produce a low power factor.

This increases operational costs, as the utility company transfers its excess operational costs to the user. Depending on how the utility computes its bills, poor power factor can significantly increase electric costs.
Improving Power Factor

Improving your power factor can:

- Lower your electricity costs
- Increase KVA capacity (increase the KW used for the same KVA)
- Improve voltage regulation
- Allow for size reductions in cables, transformers and switchgear
- Allow for expansion without additional electrical improvements

Improving power factor can reduce operating costs by eliminating or deferring the need for new equipment, help existing equipment last longer, and make future expansions less costly. Also, lower rating sized equipment can be used, saving unnecessary capital expense. All this is in addition to a quick return on investment and long term savings that are realized from installing capacitor systems to improve power factor.

From the utility company’s point of view, raising the average operating power factor of the entire grid network from .70 to .90 means:

- Reduced costs from inefficiencies in the network
- Increased generation and distribution potential
- Lower demand on the grid

This means the utility can save hundreds of thousands of tons of fuel (and produce fewer emissions), have more transformers available, and reduce the likelihood of building new power plants and their support systems.

For this reason, many utility companies charge a power factor penalty so they can recover the additional costs they incur from supporting an inefficient system.

Power Factor Improvement Examples:

Improving your power factor increases the capacity of your electrical system:

Assume you have a load of 100 KVA. If your existing power factor is .80, then you have enough power to light eight hundred 100-watt light bulbs. If you improve your power factor to .95, then you will have enough power to light nine hundred and fifty 100-watt light bulbs. Figure 2 shows the effect that power factor improvement has on a power triangle.

Improving your power factor can save you money:

No matter how your utility bills for electric consumption, you can save money by installing power factor correction capacitors, because you will use less energy, lengthen the life of your existing equipment and reduce electrical requirements for any new or future equipment that you install.

KVA Billing

If your utility uses KVA billing, you are charged for the current you draw from the grid. By improving your power factor rating, you will pull less current. Your charges will be lower, to more closely align with the actual amount of power you are using.
"Depending upon how your utility bills for electric consumption, you will save money by installing power factor correction capacitors."

Example: If you are using 100 KW and have a power factor of .70, then improve it to .95:

100 KW at .70 PF = 142 KVA
100 KW at .95 PF = 105 KVA

In this example, you would use 37 less KVA, and lower your bill by the per KVA charge for 37 KVA.

**KW Billing**

When your utility uses KW billing, you are charged for the KW you use, which is closest to the actual working power you use.

However, many utilities add a surcharge or adjustment for power factor. Depending on the classification of user you are, a contract with specific tariffs, interruptible rates, off-peak rates, exportation of power and other types of rates may be in place.

Some utilities will also give you a credit or bonus for having a higher than average power factor, or one that is above a predetermined level.

**Figure 2: Power triangle before and after capacitor installation**
Return on Investment Example:

Using the previous example, where KVA is the primary billing component, if you are billed $11.22 per KVA:

- 100 KW at .70 PF = 142 KVA, or $1,593
- 100 KW at .95 PF = 105 KVA, or $1,178

This represents a monthly savings of $415, or $4,980 annually. If you assume an equipment cost of $5,600 (not including installation), this example shows an ROI of about 14 months. After the payback period, there can be an ongoing 26% savings for this customer.

This is just one example of how to calculate your savings, and each situation will have unique variables to consider. However, a 12 – 18 month ROI is considered average.

Power Factor Correction Capacitors

A capacitor’s function is to provide kilovars to a system at the point where it is connected. Capacitors improve power factor, reduce lagging components on the circuit, reduce power losses, and reduce KVA load. By using capacitors, the power system becomes more efficient. Capacitors provide reactive power to replace the VARs wasted by an inefficient load.

**Capacitor systems generally are the most economical means of improving power factor because of their:**
- Relative Low Cost
- Easy Installation
- Minimal Maintenance
- High Efficiency and Low Losses

The capacitor requirements of each user will vary widely. Low voltage class systems, such as those offered by Staco Energy Products Co., are available as everything from off-the-shelf components to highly unique, specially designed power systems.
Determining Your Power Factor

A review of the previous twelve months utility bills will help to evaluate power factor and demand usage. Monitoring at the incoming service entrance or at specific loads can help identify problems within a facility. Monitoring equipment may include powermeters, which offer a wide range of measurements and can supply a great deal of information about a suspect load.

More detailed power factor determinations can be found through a facility review by a power analyst. Some utility companies offer analysis, or have a referral program for businesses wanting to improve their efficiency. Also, Staco Energy Products Co. has partnerships with many independent consultants throughout the country who can provide this service for you.

Types of Capacitor Systems

Simple, small fixed capacitors can be installed at single motor locations. Larger fixed assemblies can be installed to work with more than one motor. Still larger automatic switched capacitor systems can be installed for a large sector of a facility, or at the service entrance, to help correct the power factor of an entire facility.

Capacitor systems may be integrated with switchgear, retrofitted, or installed in a match-and-line arrangement. Detuned capacitors with iron-core reactors are used when harmonics may become a problem. Although capacitors do not create harmonics, they can amplify existing harmonics if they are not de-tuned. Harmonics are discussed in-depth later in this booklet.

<table>
<thead>
<tr>
<th>Installation Location</th>
<th>Cost</th>
<th>Benefit</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Motor</td>
<td>Low</td>
<td>Acceptable</td>
<td>Minimal</td>
</tr>
<tr>
<td>At Feeders</td>
<td>Medium</td>
<td>Good</td>
<td>Better</td>
</tr>
<tr>
<td>At Service Entrance</td>
<td>Highest</td>
<td>Best</td>
<td>Maximum</td>
</tr>
</tbody>
</table>

Table 1. Installation location options.
Choosing Power Factor Correction Equipment

When you choose a power factor correction system, there are several factors to consider. Your particular problem will help you determine the location of your capacitors. Table 1 on the previous page shows the costs and benefits of different installation locations.

From a technical standpoint, installing small fixed capacitors to each load, to be switched on and off with the load, is ideal. However, this can become expensive, and can create technical problems, since it may require a larger number of low-power capacitors installed at different points throughout a facility, making it difficult to monitor and maintain over time. In reality, this solution is only feasible in smaller facilities or where there are very high individual power loads.

The most appropriate correction method for most facilities is an automatic capacitor bank installed on the bus bars of the distribution panel, as shown in Figure 3. This provides centralized power factor correction for an entire facility. If necessary, fixed capacitors can be added to correct the power of any piece of equipment that creates a significant problem.

For most facilities, fixed or automatically switched low voltage systems are all that is needed to bring the power factor up to a good level. There are types of higher rated capacitors that are used by very large facilities and utility companies.

Medium voltage classifications of 2.4 KV and higher use power factor correction equipment installed indoors, such as in a large manufacturing facility, or most often, outdoors. Outdoor installations can be either pole mounted, fixed or switched, or located at a distribution substation.

When found in a substation rated at 2.4 - 34.5 KV, capacitors can be either open rack style (capacitors mounted on a fabricated structure and field installed), metal enclosed equipment (completely manufactured and tested from the factory), an integrated hybrid version, or a mobile (self contained trailer) arrangement.

After you have determined what type of capacitor system you need, the next step is to determine the size, or the amount of KVAR, you need to correct your power factor. Table 2 on the following page gives you an easy way to determine the number of KVAR you need to add to your system to improve your power factor, and can be used for any type of system.
**How to use this table:** Find your existing power factor in the left column, then across the same line, locate your desired power factor. This gives you a KVAR multiplier, which you then use to figure the number of KVAR you need.

For example, if your existing power factor is .71 and you want to bring it up to .95, the multiplier in the table is .663. Multiply .663 by the number of KW your system uses (say, 590). The total KVAR this would require is 390, which can be rounded up to 400 KVAR.

### KW Multipliers for Determining Kilovars

<table>
<thead>
<tr>
<th>Original Power Factor</th>
<th>Corrected Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>0.682</td>
</tr>
<tr>
<td>0.60</td>
<td>0.858</td>
</tr>
<tr>
<td>0.70</td>
<td>1.023</td>
</tr>
<tr>
<td>0.80</td>
<td>1.181</td>
</tr>
<tr>
<td>0.90</td>
<td>1.338</td>
</tr>
<tr>
<td>1.00</td>
<td>1.498</td>
</tr>
</tbody>
</table>

The most appropriate correction method for most facilities is an automatic capacitor bank installed on the bus bars of the distribution panel.
Automatically Switched Capacitors provide power factor correction for an entire facility or sector of a facility. They are normally installed at the distribution panel, at the Point of Common Coupling (PCC).

The advantage of a switched bank is that it controls the power factor based on every piece of equipment downstream from it, and provides centralized monitoring. Automatic systems provide more efficient operation and minimize load transients.

An automatic capacitor bank system switches in the necessary capacitance according to the load requirements at each given moment.
# A Checklist for Switched Capacitor Banks

The following checklist can be used to help you determine your exact requirements, and assist in choosing the best system for your needs.

## Nominal System Voltage:

<table>
<thead>
<tr>
<th>Voltage Level</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>208 V AC</td>
<td>____________</td>
</tr>
<tr>
<td>240 V AC</td>
<td>____________</td>
</tr>
<tr>
<td>415 V AC</td>
<td>____________</td>
</tr>
<tr>
<td>480 V AC</td>
<td>____________</td>
</tr>
<tr>
<td>600 V AC</td>
<td>____________</td>
</tr>
<tr>
<td>Other</td>
<td>_______________</td>
</tr>
</tbody>
</table>

## Wiring Connection:

<table>
<thead>
<tr>
<th>Connection Type</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELTA</td>
<td>____________________</td>
</tr>
<tr>
<td>Ungrounded WYE</td>
<td>____________________</td>
</tr>
<tr>
<td>Grounded WYE</td>
<td>_____________</td>
</tr>
</tbody>
</table>

## Frequency:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Hz</td>
<td>______________</td>
</tr>
<tr>
<td>60 Hz</td>
<td>______________</td>
</tr>
<tr>
<td>Other</td>
<td>____________</td>
</tr>
</tbody>
</table>

## KVAR Requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rating</td>
<td>___________________</td>
</tr>
<tr>
<td>Fixed KVAR</td>
<td>______________________</td>
</tr>
<tr>
<td>Number of Switched Steps</td>
<td>_________________________________________</td>
</tr>
</tbody>
</table>

## Size of Step:

<table>
<thead>
<tr>
<th>Step</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>______</td>
</tr>
<tr>
<td>2</td>
<td>______</td>
</tr>
<tr>
<td>3</td>
<td>______</td>
</tr>
<tr>
<td>4</td>
<td>______</td>
</tr>
<tr>
<td>5</td>
<td>______</td>
</tr>
<tr>
<td>6</td>
<td>______</td>
</tr>
</tbody>
</table>

## Capacitor Type:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Duty STD</td>
<td>_________________________________________________</td>
</tr>
<tr>
<td>Harmonic Filter Application</td>
<td>______________________</td>
</tr>
<tr>
<td>Special Type</td>
<td>_________________________________________________</td>
</tr>
</tbody>
</table>

## Capacitor Switching:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Phase Electro-Mechanical Contactor</td>
<td>______________________</td>
</tr>
</tbody>
</table>

## Type of Disconnect and Incoming Lugs Only:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Circuit Breaker or Switch</td>
<td>______________________</td>
</tr>
<tr>
<td>Existing Customer Disconnect</td>
<td>______________________</td>
</tr>
</tbody>
</table>

## Cable Entry:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom: STD</td>
<td>Top: ______</td>
</tr>
<tr>
<td>Other: ______</td>
<td>(Dead Front, Roof Bushings)</td>
</tr>
</tbody>
</table>

## Non-Standard Type of Fusing:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAC: ______</td>
<td>Fusing: Main (Group)  Amps: ______</td>
</tr>
<tr>
<td>Fusing: Capacitor  Step: STD</td>
<td>Type: ______</td>
</tr>
</tbody>
</table>

## Type of Enclosure:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor STD</td>
<td>Outdoor: ______________________</td>
</tr>
<tr>
<td>Special Environment</td>
<td>______________________</td>
</tr>
<tr>
<td>Paint Color: Grey STD</td>
<td>Other: ______________________</td>
</tr>
<tr>
<td>Heater/Thermostat</td>
<td>Fans: ______________________</td>
</tr>
<tr>
<td>Conditioned Air</td>
<td>______________________</td>
</tr>
<tr>
<td>Lighting (Internal/External):</td>
<td>______________________</td>
</tr>
<tr>
<td>Receptacles:</td>
<td>______________________</td>
</tr>
</tbody>
</table>

## Power Factor Controller:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>StacoVAR® STD</td>
<td>Real Time: ______________</td>
</tr>
</tbody>
</table>

## Type of Controls:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Unbalanced Protection</td>
<td>______________________</td>
</tr>
<tr>
<td>Blown Fuse Indication</td>
<td>______________________</td>
</tr>
<tr>
<td>Customer Specific Devices</td>
<td>______________________</td>
</tr>
<tr>
<td>PLC/Networking/SCADA:</td>
<td>______________________</td>
</tr>
</tbody>
</table>

## Other Devices or Integration:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surge/Lightning Arrestor or TVSS (Type):</td>
<td>______________________</td>
</tr>
<tr>
<td>Lights:</td>
<td>______________________</td>
</tr>
<tr>
<td>CT:</td>
<td>______________________ (split core or other type)</td>
</tr>
<tr>
<td>Ratio:</td>
<td>______________________</td>
</tr>
<tr>
<td>Other:</td>
<td>______________________</td>
</tr>
<tr>
<td>Harmonic Filtering Description:</td>
<td>______________________</td>
</tr>
</tbody>
</table>

For additional information on harmonic filtering, including applications, reactor type, and active filters, please refer to the Harmonic Mitigation section of this document.

## Other Considerations

Some general power factor determinations can be found simply based on a facility review and electric billing by an analyst. Some electric utilities may offer analysis support. Contact Staco for a complete review of your power bill and application recommendations.

---

"Some utility companies offer analysis or referrals for businesses wanting to improve their electrical efficiency."
Fixed Capacitors

Fixed capacitor assemblies, sometimes called motor load capacitors, are ideal for improving power factor where induction motors are located. They are also used anywhere there are small KVAR requirements.

Motor Capacitor Selection

You can achieve maximum benefits from capacitors when they are located at the load. Because the capacitor is usually switched on and off with the load, over-correction is also avoided.

However, capacitors must be carefully sized when switched with the motor as a unit, because dangerous over voltages and transient torques can occur if the capacitor's KVAR exceeds the motor's magnetizing current. The motor reference tables on the following pages are provided to help you select the correct capacitor size for your load.

CAUTION: All conditions of the motor reference tables must be met to ensure that over-correction does not occur. If any condition is in doubt, then the motor manufacturer should be consulted.

Installation Locations

Location 1: Motor Side of Overload Relay

Use this location for:
- New motor installations where overloads can be sized in reference to reduced current draw.
- Existing motors where no overload change is needed.

Location 2: Motor Side of Starter

Use this location for:
- Existing motors when the overload rating exceeds code.

Location 3: Line Side of Starter

Use this location for:
- Multi-speed motors.
- Motors that are jogged or reversed.
- Motors that start frequently.
- Starters that disconnect/reconnect capacitors during cycle, and starters with open transition.
- High inertia loads, when disconnecting the motor with the capacitor turns the motor into a self-excited generator.

Locating Capacitors on Motor Circuits

Figure 4. Locating capacitors on motor circuits.
Locating Capacitors on Reduced Voltage and Multi-Speed Motors

Start: Close 6-7-2-3-4
Transfer: Open 6-7
Run: Close 1-5

Figure 5. Autotransformer — Closed Transition
Note: Connect capacitor on motor side of starting contacts (2, 3, 4) at points A – B – C.

Start: Close 1-2-3
Second Step: Open 4-5-6
Third Step: Close 7-8-9

Figure 6. Series Resistance Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

Start: Close 1-2-3
Run: Close 4-5-6

Figure 7. Part Winding Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

Wye Start: Close 1-2-7-8
Delta Run: Close 1-2-3-4-5-6

Figure 8. Wye-Delta Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

Start: Close 1-2-3
Run: Close 4-5-6

Figure 9. Reactor Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

“Fixed capacitors are ideal for improving power factor where induction motors are located.”
## Power Factor Correction

### Motor Reference Tables

#### U-Frame NEMA Class B Motors and High Efficiency

**A or B Normal Starting Torque - Normal Running Current**

<table>
<thead>
<tr>
<th>HP Rating</th>
<th>3600 RPM KVAR</th>
<th>1800 RPM KVAR</th>
<th>1200 RPM KVAR</th>
<th>900 RPM KVAR</th>
<th>720 RPM KVAR</th>
<th>600 RPM KVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.5</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>7.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
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<tr>
<td>10</td>
<td>4.5</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>15</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
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</tr>
<tr>
<td>20</td>
<td>7.5</td>
<td>8.0</td>
<td>8.0</td>
<td>8.0</td>
<td>8.0</td>
<td>8.0</td>
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<tr>
<td>25</td>
<td>9.0</td>
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<td>30</td>
<td>10.5</td>
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<tr>
<td>35</td>
<td>12.0</td>
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<td>16.5</td>
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</tr>
</tbody>
</table>

The capacitor sizes specified in these tables will increase the full load power factor to approximately .95.

Larger sizes should not be used without consulting Staco Energy Products Co. beforehand.

#### NEMA Class B T-Frame Motors

**Normal Starting Torque - Normal Running Current**

<table>
<thead>
<tr>
<th>HP Rating</th>
<th>3600 RPM KVAR</th>
<th>1800 RPM KVAR</th>
<th>1200 RPM KVAR</th>
<th>900 RPM KVAR</th>
<th>720 RPM KVAR</th>
<th>600 RPM KVAR</th>
</tr>
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<tbody>
<tr>
<td>3</td>
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<tr>
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</tr>
<tr>
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</tr>
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</tr>
</tbody>
</table>

Note: Review published KVAR recommendations from motor manufacturers for other motor types, such as severe duty, TEFC, etc.

Note: These tables all refer to three-phase, 60 Hz motors when switched with capacitors as a single unit. For single phase or motors running on a different frequency, please consult Staco Energy Products Co. for assistance.

Table 3. U-Frame NEMA Class B Motors and High Efficiency Motors. %R is the percent of full load line current reduction.

Table 4: T-Frame NEMA Class B Motors. %R is the percent of full load line current reduction.
Staco Energy Products Co.

NEMA Class 2B Open Squirrel Cage Motors

<table>
<thead>
<tr>
<th>HP</th>
<th>Normal Starting Torque</th>
<th>Normal Running Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.5 14</td>
<td>1.5 14</td>
</tr>
<tr>
<td>5</td>
<td>2 12</td>
<td>2 13</td>
</tr>
<tr>
<td>7.5</td>
<td>2.5 11</td>
<td>2.5 12</td>
</tr>
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<td>10</td>
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<td>3 11</td>
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<tr>
<td>15</td>
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<td>4 10</td>
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<td>5 10</td>
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<td>25</td>
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<td>6 10</td>
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<tr>
<td>30</td>
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<td>60</td>
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<td>75</td>
<td>17 8</td>
<td>16 8</td>
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<tr>
<td>100</td>
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<tr>
<td>125</td>
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<td>26 8</td>
</tr>
<tr>
<td>150</td>
<td>32.5 8</td>
<td>30 8</td>
</tr>
<tr>
<td>200</td>
<td>40 8</td>
<td>37.5 8</td>
</tr>
<tr>
<td>250</td>
<td>50 8</td>
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<td>65 6</td>
</tr>
<tr>
<td>450</td>
<td>75 8</td>
<td>67.5 6</td>
</tr>
<tr>
<td>500</td>
<td>77.5 8</td>
<td>72.5 6</td>
</tr>
</tbody>
</table>

Table 5: NEMA Class 2B Open Squirrel Cage Motors. %R is the percent of full load line current reduction.

NEMA Class C, D, and Wound-Rotor Motors

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
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<td>70</td>
<td>75</td>
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<tr>
<td>300</td>
<td>65</td>
<td>90</td>
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</table>

Table 6: NEMA Class C, D, and Wound-Rotor Motors.

“Power Factor Correction saves money on new equipment because you can buy it at lower ratings.”
### Power Factor Correction

**Recommended Wire Sizes, Switches and Fuses**

<table>
<thead>
<tr>
<th>KVAR</th>
<th>240 VAC</th>
<th></th>
<th>480 VAC</th>
<th></th>
<th>600 VAC</th>
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<tr>
<td></td>
<td>Current</td>
<td>Wire</td>
<td>Fuse</td>
<td>Switch</td>
<td>Current</td>
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<tr>
<td></td>
<td>(Amps)</td>
<td>Size</td>
<td>(Amps)</td>
<td>(Amps)</td>
<td>(Amps)</td>
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<td>3.6</td>
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</tr>
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<td>200</td>
<td>54</td>
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<td>3/0</td>
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<td>400</td>
<td>72</td>
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<td>400</td>
<td>90</td>
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<td>400</td>
<td>96</td>
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<td>400</td>
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<td>108</td>
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<td>150</td>
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<td>600</td>
<td>600</td>
<td>180</td>
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<td>432</td>
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<td>750</td>
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<td>216</td>
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<td>481</td>
<td>(2)400M</td>
<td>800</td>
<td>800</td>
<td>241</td>
</tr>
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<td>—</td>
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</tr>
</tbody>
</table>

**Table 7:** Recommended Wire Sizes, Switches and Fuses for 3-Phase, 60 Hz Capacitors. Wire sizes based on NEC at 135% rated current, using 90°C rated wire. **Note:** Review published KVAR recommendations from motor manufacturers for other motor types, such as severe duty, TEFC, etc.
**Capacitor Maintenance**

Capacitors require very little maintenance. Fuses should be checked monthly. If you have high voltages, harmonics, switching surges, or vibration, check the fuses more frequently. StacoVAR capacitors operate slightly warm to the touch. If the cases feel cold, check for blown fuses, open switches or other power losses.

Automatic switched capacitor bank fuses should also be checked regularly, and a periodic preventative maintenance and check-up by an authorized factory service person is recommended to ensure that all safety components, indicators, and capacitor assemblies are working at maximum efficiency.

**Technical Data**

<table>
<thead>
<tr>
<th>Technical Data</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance Tolerance</td>
<td>-0%, +10%</td>
</tr>
<tr>
<td>Discharge Resistors</td>
<td>Capacitors rated at 600 volts or less must reduce the charge to less than 50 volts within 1 minute of de-energization. Capacitors rated above 600 volts must reduce the charge within 5 minutes.</td>
</tr>
<tr>
<td>Continuous Operation</td>
<td>Up to 135% rated (nameplate) KVAR, including the effects of 110% rated voltage, 15% capacitance tolerance and harmonic voltages over the fundamental frequency 60 Hz.</td>
</tr>
<tr>
<td>Dielectric Strength Test</td>
<td>Twice the rated AC voltage, or a DC voltage 4.3 times the AC rating for non-metalized systems.</td>
</tr>
<tr>
<td>Overcurrent Protection</td>
<td>Fusing between 1.65 and 2.5 times the rated current to protect case from rupture. <strong>Exception:</strong> when the capacitor is connected to the load side of a motor’s overcurrent protection, fused disconnects or breakers are not required. However, it is highly recommended that they are used wherever employees may be working nearby.</td>
</tr>
</tbody>
</table>

Table 8. Technical requirements for capacitors.
Harmonic Mitigation

Basics of Harmonic Mitigation

All businesses should be concerned with harmonic power quality. From a manufacturing facility to an accounting firm, the need for harmonic-free electric power exists. Environments rich in harmonic content can put serious burdens on power distribution systems and the equipment that is connected to it.

Understanding Harmonics

Harmonics is a term used to explain currents and voltages that have multiplied within an electrical system. A harmonic spectrum can exist from the 2nd through the nth order. A harmonic order is a specific, measurable amplitude existing within this spectrum. They are expressed as orders, and each order has its own unique amplitude, values for current, and voltage. Most industrial and commercial applications usually involve odd ordered harmonics, typically the 3rd, 5th, 7th, 9th, 11th and 13th.

Figures 10 and 11 show an example of the 5th harmonic compared to a fundamental sinewave, and how the sinewave looks when the 5th harmonic is present. As you can see, harmonics can cause serious distortions in the sinewave, which can cause a multitude of problems within a system.
The IEEE 519 Guide for Harmonics references different kinds of harmonics and the recommended methods for mitigating them. It has established limits for both voltage and current distortion.

### Maximum Harmonic Current Distortion in % of Load Current

*Individual Harmonic Order (Odd Harmonics)*

<table>
<thead>
<tr>
<th>Ratio</th>
<th>h&lt;11</th>
<th>11&lt;h&lt;17</th>
<th>17&lt;h&lt;23</th>
<th>23&lt;h&lt;35</th>
<th>35&lt;h</th>
<th>TDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>20-50</td>
<td>7.0</td>
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<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50-100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
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<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Even harmonics are limited to 25% of odd harmonic limits

Table 9. IEEE 519 current distortion limits

<table>
<thead>
<tr>
<th>Bus Voltage at PCC</th>
<th>Individual Harmonic</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69 KV &amp; Below</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>69.001-161-161 KV</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>161 KV and Up</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 10. IEEE 519 voltage distortion limits

---

### Common Causes of Harmonics:

- Adjustable Speed Drives (ASDs)
- Variable Frequency Drives (VFDs)
- Electric Arc Furnaces
- Electronic Welding Equipment
- Transformers and Generators
- UPS and Storage Systems
- Medical Imaging Equipment
- Dental Equipment
- Lighting Controls/Dimmers
- Computers, Copiers and Scanners
Industries Where Harmonics May Be Present

- Water/Wastewater Treatment
- Chemical Processing
- Printing/Publishing
- Plastics/Coatings
- Steel Processing
- Automotive Assembly
- Petrochemical
- Glass Making
- Paper Processing
- Packaging Data Centers
- UPS Installations

Effects of Harmonics

Certain orders of harmonics may cause serious equipment and system problems. Harmonic distortion disrupts operations, especially productivity and throughput. Some of the effects of harmonics include:

- Interference with telephones and communications systems
- Overheated conductors, bus bars, and switchgear
- Tripped or arcing circuit breakers
- Inaccurate readings from meters and instruments
- Overheated motors
- Breakdown of insulation
- Reversed torque on AC motors
- Reduced equipment life
Many utility companies are considering imposing penalties on their customers who inject excessive harmonics into the power distribution system, even when their power factor is good.

As an accepted guideline, voltage at a 5% TDD (Total Demand Distortion) or less at the Point of Common Coupling (PCC) is a practical recommendation. This value generally refers to system wide harmonics, helping assure efficiency and reliability for your operations. Some electrical power distribution centers may function well at higher limits, and may need only minimal mitigation.

Overall, it is important to understand how the various components within your system interact with each other and with the distribution system as a whole.

### Harmonic Problems and Solutions

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Cause</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>High voltage distortion, no harmonic source near equipment</td>
<td>Capacitor bank in a resonance condition, harmonic currents drawn to bank</td>
<td>Locate source of harmonics, relocate capacitor bank, change capacitor bank size, convert / add filter</td>
</tr>
<tr>
<td>High voltage distortion, exceeds limits</td>
<td>Network is in a resonance condition with one or more dominant harmonic frequencies</td>
<td>Locate source of harmonics, move capacitor bank, change controller settings (KVAR steps), add filters</td>
</tr>
<tr>
<td>Distortion is intermittent, comes and goes at similar intervals</td>
<td>Harmonics generated from a planned load (operation or process), industrial environments</td>
<td>Locate the source, install filters</td>
</tr>
<tr>
<td>Capacitor blown fuses, capacitor failure, high harmonics present</td>
<td>High frequency resonance, with high currents (fuses), peak voltage due to a 3rd or 5th order resonance condition (capacitors)</td>
<td>De-tune the network, change capacitor size</td>
</tr>
<tr>
<td>Power transformer overheating below rated load, and machinery overheating at no load or below rated load</td>
<td>Excessive harmonic currents (transformer), high voltage distortion (machinery)</td>
<td>De-tune or change the capacitor equipment size (transformer), determine the source, install filters if necessary</td>
</tr>
</tbody>
</table>

Table 11. Harmonic symptoms, causes and solutions.
Diagnosing Harmonic Related Problems

If you suspect that you have a harmonics problem, first look at the effects of harmonics listed earlier in this section. If one or more of these symptoms occurs regularly, then the following steps will help you narrow down the problem.

1. If you have power factor correction capacitors, measure the current going into the capacitors. It should be measured using a “true rms” current meter. If the current value is higher than the capacitor’s rated current by 5% or more, the presence of harmonics is likely.

2. Audit any harmonic producing loads and your system configuration. Start by listing the kVA or horsepower data on all major non-linear devices and capacitors. Also list the rating information on the service entrance transformers. A short requirements review form is given later in this document to help with this process.

3. If your electrical distribution system is complex, or the labor to perform an internal audit is too intensive, consider having an on-site audit conducted by an independent consultant. Your local utility may be able to provide or recommend an experienced consultant. If not, contact Staco Energy Products Co. for a referral to an independent consultant in your area who can perform a complete power quality audit for you.

Normally, a power quality audit involves inspection of the electrical system layout, connected loads, and harmonic measurements at strategic locations. Measurements are taken over time to get a realistic assessment of the system’s load. All the data is then analyzed to get an accurate picture of your situation and suggest options for correction when needed.
There are Three Major Classes of Harmonic Producing Devices:

1. **Ferromagnetic (magnetizing) device:** Basically a coil wound around an iron core. Examples here include transformers and motors. These devices normally do not present a problem unless resonant conditions exist. Then they can amplify the harmonics present in the system.

2. **Electronic rectifiers and inverters:** Examples are computers, adjustable speed drives, and UPS systems.

3. **Arcing devices:** Examples include fluorescent vapor lighting, arc welders and arc furnaces.

*Harmonics from a 6-Pulse Rectifier (UPS System)*

![Harmonic orders generated by a UPS system with a 6-pulse rectifier.](image)

“Normally, a power quality audit involves inspection of the electrical system layout, connected loads, and harmonic measurements at strategic locations.”
Requirements Review Checklist

Initial review data should include:
- Previous six to twelve months of electric utility billing data, contract, and tariffs agreements. This should also include rate structure, load usage, KW/KVA, peak demand and power factor penalty.
- Single line diagram of the building or facility, with all updates or revisions
- Plans for new capital equipment installations, general equipment upgrades, facility expansion, or improvements
- Most recent data from instrument measurements, site survey, general equipment and system notes, past electrical system studies

Complete the following information to better understand the application requirements and assist with initial system parameters.

Primary voltage____________________________________________ (line-to-line)
Secondary voltage _________________________________________ (line-to-line)
System short circuit capability____________________________________
Transformer rating (KVA) _______________________________________
Transformer impedance (%) ______________________________________
Wire/Cable/Bus Systems ________________________________________
Copper or aluminum __________________________________________
Ratings and size ______________________________________________
Length of runs, ways, systems and locations (provide single line with specific comments) ______________________________

Installed Equipment

List each device or piece of equipment. Nameplate data and/or instruction manuals should contain pertinent information. Office equipment, computer and communication systems should also be considered.

For example:
Drive Type(s): Manufacturer, H.P./KW, Amperes, KVA, PF Pulse (AC/DC)

Capacitor Type: Manufacturer, KVAR, voltage, fixed/switched, phases, fusing, present minimum power factor, maximum power factor, utility limit, and desired power factor, if applicable

Communications: Interface, tele/data, satellite
Other Considerations

What equipment, processes and operations are the most vulnerable?
________________________________________________________________________________________________

Are there critical loads and a need for "high nines" type power?  _____________________________________________
_______________________________________________________________________________________________

Have there been both long and short term outages?   _____________________________________________________
_______________________________________________________________________________________________

Does a routine maintenance plan exist?   _______________________________________________________________
_______________________________________________________________________________________________

Have UPS, voltage regulation, generation, power distribution, motors/drives, and other power quality equipment been evaluated to meet existing and future expansion needs?   __________________________________________________
________________________________________________________________________________________________

What are the costs for downtime, maintenance, scrap, lost production, return to uptime (waiting for parts, new equipment)?
________________________________________________________________________________________________

Other Equipment to Consider:

☐ UPS          ☐ Battery Chargers       ☐ Rectifiers       ☐ Motors        ☐ Other Storage Systems
☐ Load Banks    ☐ Resistor Banks       ☐ Furnaces         ☐ HVAC          ☐ Generators
☐ Lighting Systems ☐ Compressors     ☐ Prime Power/DG   ☐ Emergency/Standby Power

After collecting this information, an engineering service firm or power quality consultant may be required to perform an analysis and computer modeling and equipment sizing study. There may be several solutions, which should be reviewed based upon the need to correct an isolated problem, resolve system wide concerns, or develop and implement a long-term power quality strategy.
Harmonic Mitigation

Solutions

Many standard harmonic reduction solutions are available, including reactors, isolation transformers, filters and active devices.

Harmonics solutions can range from simple corrections like tightening connections in a switchboard to help the overheating of conductors, using a 200% rated neutral in a panel board, all the way to incorporating sophisticated active harmonic filters. All have strengths and weaknesses, and should be considered carefully in the context of your particular harmonics problems.

Harmonic mitigation is especially important when power factor correction capacitors are already installed in your facility, or if you plan on adding them in the future. Even though capacitors do not create harmonics, they resonate and amplify existing harmonics. Adding passive harmonic filters to your capacitors will protect your capacitors from being damaged by existing harmonics.

There are two approaches to harmonic mitigation: treat the symptoms, or treat the source.

Treat the Symptoms

In some facilities, it’s best (and easiest) to treat the symptoms of harmonics. If your only problem is neutral conductor overheating, you can increase the conductor’s size. If your transformers are overheating, you can install special K-rated transformers designed to better tolerate harmonics. You can relocate harmonic producing loads around your facility to balance the harmonics and produce a better sine wave. You can also use a “zigzag” transformer for a similar re-distribution.

Treating the symptoms of harmonics may be a simple exercise in some facilities. Others have more problems from harmonics than can be addressed symptom by symptom.

Treat the Source

When treating the source of harmonics, a power quality study or measurements from monitoring equipment, normally will show a need for a more complex solution. To reduce the level of harmonics produced by a facility’s equipment, impedance may be added by installing line reactors at the source, or passive filters can be installed to eliminate specific harmonic frequencies, or an active filter can be installed to address a broad range of harmonic orders when they are present.

An ideal time to consider harmonic mitigation strategies is during the design of new facilities or at the time of equipment purchases. Harmonics producing equipment can be identified and mitigation devices installed with the equipment. Transformers and neutral conductors can be specified properly. However, once operational, additional equipment may be needed.

Six-pulse rectified power supplies like those found in many variable frequency drives, may be replaced with twelve or higher pulse rectifiers. However, this solution is not likely to be cost effective unless done when the equipment is purchased.

Some variable speed drive manufacturers now offer harmonics correcting components as standard features of their drives, and others offer them as factory installed options. Be sure to ask your drive representative about harmonics correction when specifying a new variable speed drive.
Selecting Harmonic Mitigation Equipment

Some widely used mitigation options include:

- **Over-sizing or Derating**
- **Series Reactors**
- **Passive Filters**
- **Tuned Filters**
- **Active Filters**

With most filtering options, the installation location is critical to the filter’s effectiveness. Eliminating harmonics at their source is the most effective option from a systems point of view. Many manufacturers today are adding some filtering within the equipment itself. But many can’t, due to the nature of the machinery, or a prohibitive cost.

**Over-sizing the Installation**

This method doesn’t really mitigate harmonics, but simply over-sizes the elements in the system that are likely to resonate harmonics, such as transformers, cables, circuit breakers and the distribution panel. The most common way of dealing with harmonics in this way is to over-size the neutral conductor or to derate the distribution equipment that is subjected to harmonics.

Over-sizing or derating results in significantly higher costs in the distribution system. It also means that the system cannot be used to its full potential, and puts an increased demand on the system.

**Series Reactors**

Series reactors are often used for mitigating the harmonics caused by variable frequency and adjustable speed drives. Reactors are connected in series, upstream of the load. One must be installed for each drive or load. If you have multiple drives, or other non-linear loads that need mitigation, this can be an expensive solution. Although series reactors can cut harmonic distortion in half, it can still be higher than the IEEE 519 standard.

---

*Passive De-Tuned Filters*

When harmonic conditions are present with low power factor, a passive, or de-tuned capacitor bank will add capacitance while controlling any adverse system interactions. The reactors have a smoothing effect on the sinewave. Passive filters are designed to mitigate a single harmonic order, such as the 5th order. Some mitigation of close order harmonics occur, but are minimal.
Passive Tuned Filters

Also called shunt, parallel or harmonic trap filters, these filters use inductance and capacitance to provide mitigation for a specific harmonic order. Although a shunt filter is also a passive harmonic filter, it does not provide any power factor correction.

The filter is connected in parallel with the power system to divert the tuned frequency currents away from the power source. Shunt filters perform best at full loads. At lighter loads, distortion can increase and performance will be less efficient.

With any passive filter installation, an application engineering or power quality study should be done to determine the sizing and installation locations of the filters for an individual facility.

In some cases, installing or retrofitting passive filters can be cost prohibitive. In these cases, an active harmonic filter can supply the necessary mitigation more efficiently, and at a lower cost.

Figure 14. Compensating sinewave from an active harmonic filter.
Active Harmonic Filters

Active harmonic filters monitor and dynamically correct a wide range of harmonic orders, such as the 3rd to the 51st. They work by injecting a “mirror image” compensating current to restore the waveform. They can dramatically reduce distortion to less than 5% TDD, meeting IEEE 519 and international standards.

Active filters continuously adapt to rapid load conditions, and can be used in a variety of environments. Most active filters can also provide a degree of power factor correction, depending on the size of the filter and the load. They benefit on-site power, emergency power, and distributed generation. An active filter increases electrical capacity and stabilizes the electrical system.

A notable feature of active filters is that you do not need an expensive site survey or application engineering before installing them. Once you’ve determined that harmonics are causing problems in your system, you can be assured that an active filter will mitigate the range of harmonics present and resolve the issues.
Your Situation

High electric utility bills or motor loads?

Determine PF impact. Evaluate present tariff rate for cost reductions.

Historical Utility Bill Audit

The Problem

Power factor improvement needed.

Diagnostic Factors

Various small motor loads? or Incoming to facility or large feeders?

Your Solution

StacoVAR® ML Fixed Capacitor

StacoVAR® Automatic Capacitor

Staco Energy custom capacitor design, StacoSine®

StacoVAR® Fixed and Automatic Capacitors

StacoVAR® Capacitors (detuned with filters), StacoSine®
Need to cancel high order harmonics?

Harmonic mitigation needed.

Harmonics above the 13th order?

StacoSine® Active Harmonic Filter

Harmonics from the 3rd to the 51st order?

StacoSine® AHF or custom engineered tuned filter system

Capacitors already installed, need harmonic correction?

StacoSine® Active Harmonic Filter

Need to integrate, match & line with switchgear?

StacoVAR® or StacoSine®

“...The Guide to Product Selection flowchart is designed to be an interactive decision making tool for power factor improvement and harmonic mitigation.”
Capacitor Selection Guide

Product Selection Information

1. Determine voltage.
2. Determine frequency.
3. Determine total KVAR required.
4. Determine switched or fixed equipment; if switched, determine number of steps and KVAR per step.
5. Determine if equipment is to be used indoors or outdoors.
6. Determine product type and options.
7. General wiring connection is three phase and ground; power factor controller uses an internal 120 VAC input signal and the current transformer uses an input signal 3000:5 multi-tap from an optional or customer supplied CT (current transformer).

When Harmonic Conditions Are Present:

1. Advise Staco Energy of harmonic applications, because it can affect the type of product or the components used.
2. Provide any known information about the harmonic conditions, such as a harmonic spectrum, known harmonic orders, or power quality data collected from a site survey or analysis.

Product Descriptions:

Staco Energy Products Co. provides a variety of solutions to correct poor power factor.

The equipment available:

- StacoVAR® ML fixed capacitors from 2.5 to 400 KVAR. Consult the factory for reactor applications.
- StacoVAR® automatically switched capacitors from 25 to 600 KVAR (240 VAC) and 50 to 2400 KVAR (480 and 600 VAC).

Terminology for Power Factor Correction Equipment

- Capacitor Bank or Cap Bank:
- Auto Bank:
- Switched Bank:
- Rack of Capacitors:
- Reactive Power Compensation:
- Dynamic Compensation
- Reactive Compensation
- Capacitor Rack
- VAR Regulation
- VAR Compensation

Terminology for Power Factor Correction Equipment with Reactors

- Filter Bank:
- Detuned Capacitors:
- Anti-Resonant Bank:
- Tuned System:
- Harmonic Mitigation Capacitors
- Harmonic Suppression with Power Factor Correction
- Automatic Capacitors w/Filtering
- Capacitor / Filter System
Fixed Power Factor Correction

**StacoVAR® PF**

Motor load fixed capacitor products contain self-healing, metallized polypropylene capacitor cells with discharge resistors and over pressure protection. Consult the factory when reactors are required for harmonic filtering.

### Fixed and Automatic StacoVAR® Products

<table>
<thead>
<tr>
<th>StacoVAR® Designation</th>
<th>Product Background — Application</th>
<th>CAP TYPE</th>
<th>TYPE OF SWITCH Contactor</th>
<th>TYPE OF CONTROLLER 5 - 300 ms</th>
<th>TYPE OF CONTROLLER 16-20 ms</th>
<th>REACTOR Detuned</th>
</tr>
</thead>
<tbody>
<tr>
<td>StacoVAR® PF</td>
<td>Power factor correction, fixed only, no switching, no control, located at individual motor loads. PFH provides reactors for harmonic filtering.</td>
<td>Heavy Duty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>StacoVAR® PA or PM</td>
<td>Power factor correction, automatically switched (contactors), basic, economical. Product accommodates most requirements.</td>
<td>Heavy Duty</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>StacoVAR® PH</td>
<td>Power factor correction, automatically switched (contactors), for a harmonic environment where capacitors may be damaged. Use of iron-core reactors necessary for a detuning - majority of requirements for the 5th order. Product accommodates many applications and is cost effective.</td>
<td>Heavy Duty Derated</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

Table 12. StacoVAR® product features.
## StacoVAR® Automatic Power Factor Correction

### StacoVAR® PA, StacoVAR® mini PM

**Automatic Power Factor Correction**

**Standard Features:**
- NEMA 1 enclosure, with bottom entry access and modular design allowing for easy future expansion
- UL 508A, c-UL listed, complete assembly
- Heavy duty, dry type three phase power capacitors, with discharge resistors and over pressure protection.
- Individual step fuse protection (200 kaic) with blown fuse indication.
- PA units accommodate up to 10% THD environment
- PH units use higher voltage derated capacitors
- 5-year warranty on capacitors.
- Control power transformer with fused primary and secondary, and silver-plated, electrical grade copper bus bar system.

**Product Options**

**Note:** Options are not intended for StacoVAR® ML fixed capacitor units.

**Circuit Breakers**

Circuit breakers are three-pole molded case type with a thermal-magnetic trip. Amperes are based upon breaker frame size. Circuit breaker option may increase standard cabinet dimensions. Consult the factory for sizing.

**TVSS Surge Protection**

**Description:** Rugged suppressor capable of handling high energy transients, rated at minimum 40kA per phase plug-in type; power circuitry provides the lowest possible clamping voltages, high energy withstand and discharge capabilities; dual MOV arrangement for primary and secondary protection; UL1449, c-UL, CSA, IEC compliant; common mode protection rated at 150VAC; includes visual status indication; surge suppressor for added safeguarding of controller, fuses, thermocouples and other electronic/electric/electro-mechanical devices located within the StacoVAR apparatus.

**Current Transformer – CT**

Current transformer is multi-tap: 3000:5, 2500:5, 2200:5, 1500:5, 1200:5, 1000:5, 800:5, 500:5, 300:5. 1-5% accuracy, depending on ratio. Split core type for easy installation. CTs are shipped loose.

**Top Entry**

Bottom incoming entry is standard, consult factory for top entry connection.

---

**StacoVAR PH**

**Automatic Power Factor Correction, Detuned for Harmonics**

**Additional Standard Features:**
- **Type of Switching:** Electro-mechanical, heavy duty contactors
- **Controller:** Adjustable (0.5 to 300 sec.) response microprocessor based controller (twelve-step regulation) with front panel LED display
- **Reactor:** Three phase 5th order, iron-core reactors with a 227 Hz tuning frequency

---

**Selection Guide**

www.stacoenergy.com
Part Number Designation Guide

1. **Product Type:**
   - PF = StacoVAR® PFC, Fixed (ML and Larger KVAR)
   - PA = StacoVAR® PFC, Switched
   - PH = StacoVAR® PFC, Detuned

2. **KVAR Rating:**
   Total KVAR required, four (4) digit field

3. **KVAR Steps and Size:**
   Total of three (3) or six (6) digits comprised of:
   Number of steps required, two digit field 01-12 (00 for fixed);
   followed by the size of steps, one (1) letter field:
   A= 25 KVAR  C= 100 KVAR
   B= 50 KVAR  D= 200 KVAR

4. **Reactor:**
   N = Reactor not included
   5 = 5th order, detuned Fixed Capacitors

5. **Voltage Rating:**
   - 20 = 208 VAC
   - 24 = 240 VAC
   - 38 = 380 VAC
   - 41 = 415 VAC
   - 48 = 480 VAC
   - 60 = 600 VAC

6. **Frequency:**
   - 5 = 50 Hz
   - 6 = 60 Hz

7. **Enclosure Type:**
   - W1 = Wall Mounted/Freestanding NEMA 1 (standard)
   - F1 = Freestanding NEMA 1 (standard)
   - F2 = Freestanding NEMA 12
   - F3 = Freestanding NEMA 3R

8. **Circuit Breaker Option:**
   - B = Molded Case Circuit Breaker
     (consult factory for application)

9. **Transient Suppression Option:**
   - S = TVSS (surge protection)

10. **Transient Suppression Option:**
    - T = Top Entry Input/Output connection location
     (consult factory)
    - L = Blown Fuse Indicating Lights

11. **Current Transformer (CT) Option:**
    Split-core, multi-tap, Part #712-1470

---

Part Number Example:

```
P A - 0 0 7 5 - 0 1 A 0 1 B – N 4 8 6 F 1 – B S T
```

1. **PA = StacoVAR® Power Factor Correction**
2. **0075 = 75 KVAR**
3. **01A = (1), 25 KVAR step**
   **01B = (1), 50 KVAR step**
4. **N = No reactors**
5. **48 = 480 VAC**
6. **6 = 60 Hz**
7. **F1 = Free Standing NEMA 1**
8. **B = Molded Case Circuit Breaker (option)**
9. **S = TVSS – surge protection (option)**
10. **T = Top entry, incoming connection (option)**

---

Enclosure and KVAR Ratings (without Circuit Breaker)

All StacoVAR enclosures are single door. Each enclosure accommodates the following KVAR ratings:

- **PA:** Maximum 400 KVAR @ 240 VAC OR 800 KVAR @ 480 VAC
- **PM:** Maximum 150 KVAR @ 240 VAC OR 300 KVAR @ 480 VAC
- **PH:** Maximum 200 KVAR @ 240 VAC OR 400 KVAR @ 480 VAC

Larger KVAR ratings use multiple enclosure assemblies, provided with internal bus. Consult factory for use of circuit breaker option and enclosure requirements.
**StacoSine® Product Selection Guide**

**Product Highlights:**
- Improves electrical system efficiency and helps reduce operational costs
- Dynamically corrects a wide spectrum of harmonic orders (3rd to 51st)
- Quick and easy installation, with virtually no downtime
- No need for a complex site analysis
- Stand-alone and multi-integrated systems
- Graphics display and analyzer
- Voltage ratings from 208 to 480 VAC, step up transformer used for 600 VAC and higher voltages
- 25 to 200 amp ratings, parallel up to six (6) units
- UL508 and c-UL Listed
- Enclosures available in NEMA 1 (Standard), NEMA 12, 3R and others available

**Product Description:**
The StacoSine® active harmonic filter uses power electronics to monitor the nonlinear load and dynamically correct every odd order from the 3rd to the 51st. By injecting compensating, or mirror image current into the load, the sine wave is restored and distortion is dramatically reduced to less than 5% TDD, to meet the stringent IEEE 519 standards.

StacoSine's high speed process cancels high frequency output current, while it determines the precise value of injected load current.

StacoSine's power electronics platform has been designed to operate at levels that continuously adapt to rapid load fluctuations. With its efficient operation and small physical size, it is ideal for a wide variety of industrial and commercial environments.

**This allows the StacoSine® to:**
- Eliminate all harmonic currents from nonlinear loads
- Compensate reactive power of lagging loads
- Act as a damping resistor to prevent harmonic resonance

**StacoSine® Part Numbering System**

**Part Number Example:**

```
A F - 0 1 0 0 - 0 0 E - 3 4 8 6 W 1 - R
```

1. **AF** = Active Harmonic Filter
2. **0100** = 100 Amp
3. **00E** = Not Used
4. **3** = 3 Wire
5. **48** = 480 VAC
6. **6** = 60 Hz
7. **W1** = Wall Mounted NEMA 1 Enclosure
8. **R** = Communication RS232/485, TCP/IP (optional)
   Option Part # AF-ESD  Monitoring software
### Part Number Designation Guide

<table>
<thead>
<tr>
<th></th>
<th>Product Type</th>
<th>AF StacoSine® Active Harmonic Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Amp Rating</td>
<td>Total amps required, four digit field</td>
</tr>
<tr>
<td>3</td>
<td>Not Used</td>
<td>00E = Not used</td>
</tr>
<tr>
<td>4</td>
<td>3 Wire</td>
<td>3 = 3 wire configuration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 = 4 wire, consult factory</td>
</tr>
<tr>
<td>5</td>
<td>Voltage Rating</td>
<td>20 = 208 VAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 = 240 VAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>38 = 380 VAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 = 400 VAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41 = 415 VAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48 = 480 VAC</td>
</tr>
<tr>
<td>6</td>
<td>Frequency</td>
<td>6 = 50 or 60 Hz.</td>
</tr>
<tr>
<td>7</td>
<td>Enclosure Type</td>
<td>W1 = Wall Mounted/Free Standing NEMA 1 (standard)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F1 = Freestanding NEMA 1 (standard)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* NEMA 12, 3R and other rated enclosures are available to complete the required NEMA rating as a finished assembly. Consult factory for enclosure part numbers.</td>
</tr>
<tr>
<td>8</td>
<td>Communication</td>
<td>R = Communication Option</td>
</tr>
</tbody>
</table>

Table 13. StacoSine part number designation guide.

**Consult the factory for:**
1. Specific user and application requirements.

### StacoSine® Product Options

**Communications Option:**

J-Bus / MODbus protocol, RS232/485, TCP/IP for on-site monitoring, equipment servicing, local and remote monitoring.
Option Part # AF-ESD Monitoring software for local and remote operation. Provides full monitoring, control, event logs, utility parameters, waveform and spectrum data.

“With its efficient operation and small size, the StacoSine® is ideal for a wide variety of industrial and commercial environments.”
# Useful Capacitor Formulas

<table>
<thead>
<tr>
<th>Nomenclature:</th>
<th>K = 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = Current</td>
<td>PF = Power Factor</td>
</tr>
<tr>
<td>C = Capacitance in μF</td>
<td>V = Voltage</td>
</tr>
<tr>
<td>F = Frequency</td>
<td></td>
</tr>
</tbody>
</table>

1. **Power Factor** = \( \cos \theta = \frac{KW}{KVA} \)

2. **KW** = \( \frac{V \times A \times PF}{10^3} \)

3. **KVA** = \( \frac{V \times A}{10^3} \)

4. **Line Current** = \( \frac{\text{KVA} \times 10^3}{V} \)

5. **Capacitor Current** = \( (2\pi f) CV \times 10^4 \)
   
   Also: \( \frac{\text{KVAR} \times 10^3}{V} \)

6. **Capacitors connected in parallel**
   \( C_{\text{total}} = C_1 + C_2 + C_3 + \cdots \)

7. **Capacitors connected in series**
   \( C_{\text{total}} = \frac{C_1 \times C_2}{C_1 + C_2} \)
   
   For two capacitors in series
   \( C_{\text{total}} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots} \)

8. **Reactance - Xc (Capacitive)**
   A. \( X_c = \frac{10^4}{(2\pi f)C} \)
   
   B. \( X_c = \frac{2653 \times 60 \, \text{Hz} \times (1 \mu F = 2653 \, \Omega)}{C} \)
   
   C. \( X_c = \frac{\text{KVAR} \times 10^3}{\text{KVAR}} \)

9. **Capacitance — C**
   A. \( C = \frac{10^4}{(2\pi f)Xc} \)
   
   B. \( X_c = \frac{\text{KVAR} \times 10^3}{(2\pi f)(\text{KV})^2} \)

10. **Capacitive Kilovars**
    A. \( \text{KVAR} = \frac{(2\pi f)C (\text{KV})^2}{10^3} \)
    
    B. \( \text{KVAR} = \frac{10^4 (\text{KV})^2}{X_c} \)

11. **Reduced Voltage**:
    Actual KVAR (Output) = Rated KVAR \( \left( \frac{\text{Actual Voltage}}{\text{Rated Voltage}} \right)^2 \)

12. **Reduced Frequency**:
    Actual KVAR = Rated KVAR \( \left( \frac{\text{Actual Freq.}}{\text{Rated Freq.}} \right) \)

13. **Simplified Voltage Rise**:
    \% V.R. = \( \frac{\text{KVAR (Cap.)} \times \% \text{ transformer reactance}}{\text{KVA (transformer)}} \)

14. **Losses Reduction**:
    \% L.R. = \( 100-100 \left( \frac{\text{Original PF}}{\text{Improved PF}} \right)^2 \)

15. **KVA = KW (KW Motor Input)**
    PF

16. **KW (Motor Input) = hp \times 0.746**
    efficiency

17. **Approx. Motor KVA = Motor HP (at full load)**

**Examples:**

a. **Voltage Reduction**
   
   KVAR (208) = KVAR (240) \( \left( \frac{208}{240} \right)^2 = 0.75 \)
   
   (10 KVAR @ 240V = 7.5 KVAR @ 208V)
   
   KVAR (120) = KVAR (240) \( \left( \frac{120}{240} \right)^2 = 0.25 \)
   
   (10 KVAR @ 240V = 2.5 KVAR @ 120V)

b. **Frequency Reduction**:
   
   KVAR (50 Hz) = KVAR (60 Hz) \( \frac{50}{60} = 0.83 \)
   
   (60 KVAR @ 480V 60 Hz = 50 KVAR, 480V, 50 Hz)
Service Options
With our ServiStar® program, a wide range of planned maintenance and extended
service options are offered to maximize equipment life and reliability of your FirstLine®
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- Annual Service Plan
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- Preventive Maintenance
- Programs tailored to meet your needs

About Staco Energy Products Company
Since 1937, customers worldwide have been relying on Staco Energy Products Company
to deliver voltage control and power quality solutions tailored to their needs.

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Staco develops total power solutions for OEM and end user applications.

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