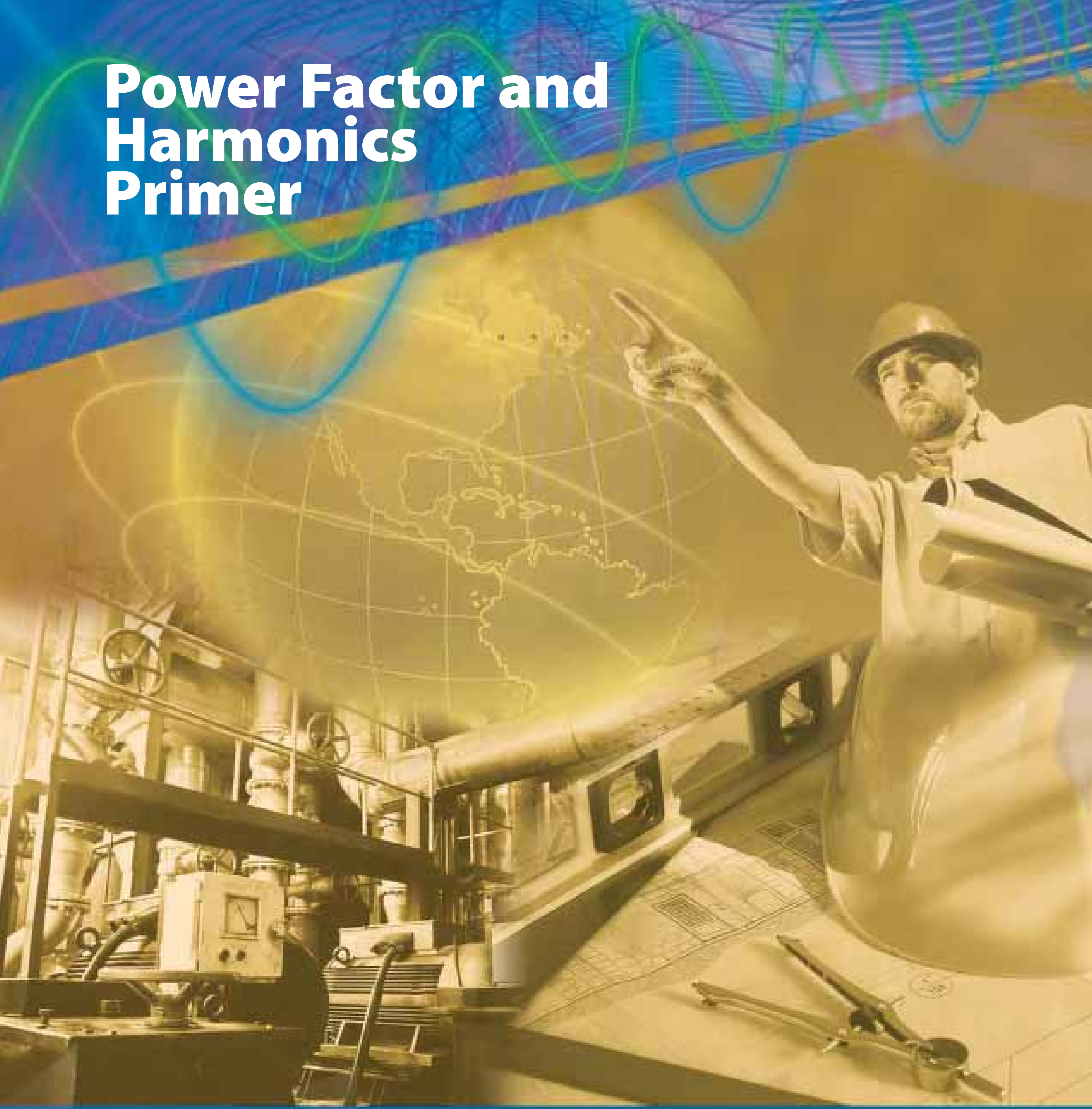
Power Factor and Harmonics Primer



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Definition of Power Factor

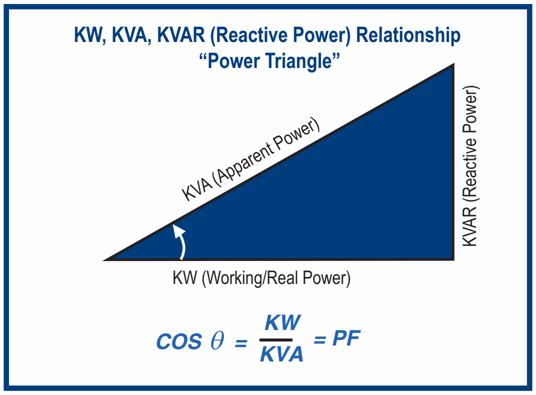
Power Factor (PF) is a term used in regard to the efficiency of an electrical power distribution system. Also known as displacement power factor, power factor is a measurement between the current and voltage phase shift waveforms.

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.



$$\cos\theta = \frac{KW}{KVA} = PF$$

Figure 1: *A power triangle shows the relationship between KW, KVAR, and KVA.*

> *"Power factor (PF) is a term used in regard to the efficiency of an electrical power distribution system."*

Applications and Industries With Low Power Factor

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 requires 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 onto 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.

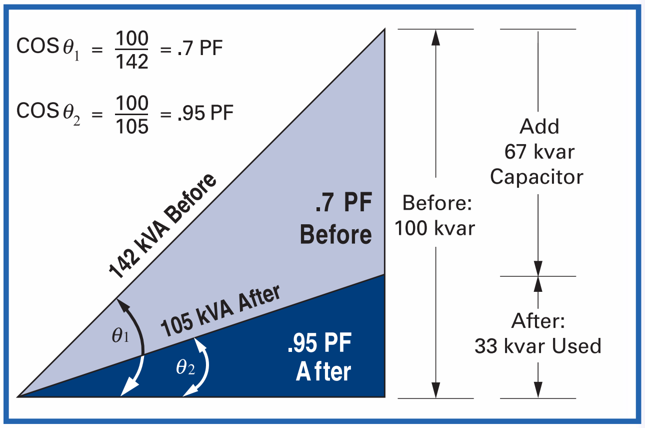


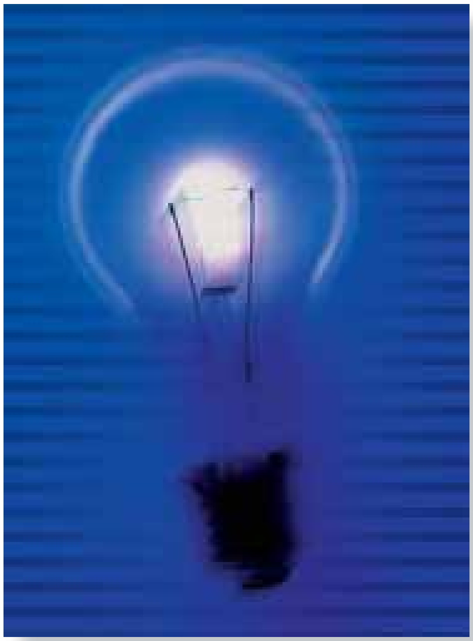
Figure 2: *Power triangle before and after capacitor installation*

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.



[Power Factor Correction]

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***

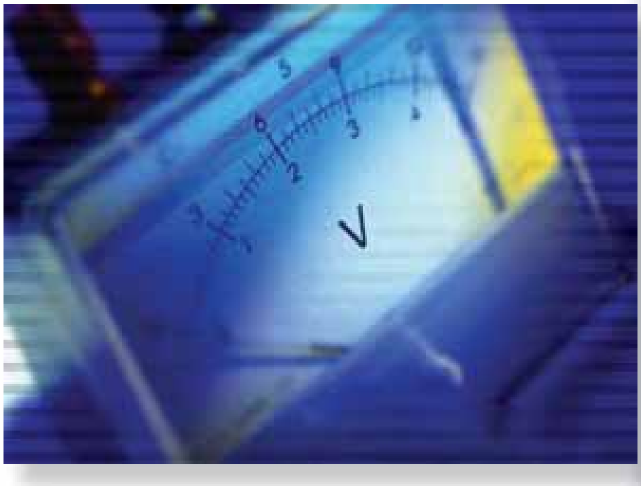
The capacitor requirements of each user will vary widely. Low voltage class systems, such as those offered by Staco Energy Products Co., are available as everything from off-the-shelf components to highly unique, specially designed power systems.

> “Capacitor systems may be integrated with switchgear, retrofitted, or installed in a match-and-line arrangement.”

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.

Installation Location	Cost	Benefit	Flexibility
At Motor	Low	Acceptable	Minimal
At Feeders	Medium	Good	Better
At Service Entrance	Highest	Best	Maximum

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.

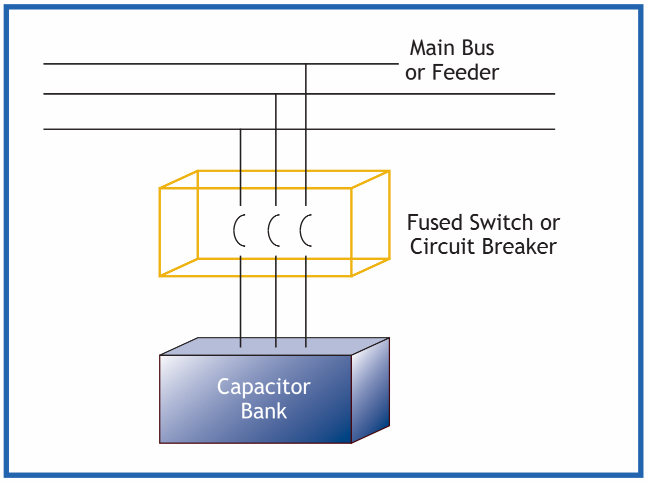


Figure 3. *Installing capacitors online.*

> ***“The most appropriate correction method for most facilities is an automatic capacitor bank installed on the bus bars of the distribution panel.”***

KW Multipliers for Determining Kilovars

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 KW 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.

Original Power Factor	Corrected Power Factor																				
Existing Power Factor	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143
																					0.000

Table 2. *KW Multipliers for Determining Kilovars*

Automatically Switched Capacitors

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.

StacoVAR® Automatically Switched Capacitor System

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

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:

240 VAC: ____________ 380 VAC: ____________ 415 VAC: ____________

480 VAC: ____________ 600 VAC: ____________ Other: ____________

Wiring Connection:

DELTA: ________________ Ungrounded WYE: ________________

Grounded WYE: ____________

Frequency:

50 Hz: ______________ 60 Hz: ______________ Other: ______________

KVAR Requirements:

Total Rating: ________________ Fixed KVAR: ________________

Number of Switched Steps: ________________________________

Size of Step:

1:_______ 2:________ 3:________ 4:________ 5:________ 6:________

Capacitor Type:

Heavy Duty STD: ________________________________

Harmonic Filter Application: ________________________________

Special Type: ________________________________

Capacitor Switching:

Three Phase Electro-Mechanical Contactor: ____________________

Three Phase Electronic Switch: ____________________

Type of Disconnect and Incoming

Lugs Only: ________________________________

Type of Circuit Breaker or Switch: ____________________

Existing Customer Disconnect: ____________________

Cable Entry:

Bottom: **STD** Top: ______ Other: _______ (Dead Front, Roof Bushings)

Non-Standard Type of Fusing:

VAC: ________

Fusing: Main (Group) Amps: ________ Type: _______

Fusing: Capacitor: Step: **STD**

Type of Enclosure:

Indoor **STD** Outdoor: ________________________________

Special Environment: ________________________________

Paint Color: Grey **STD** Other: ________________________________

Heater/Thermostat: ____________ Fans: ____________________

Conditioned Air: ________________________________

Lighting (Internal/External): ________________________________

Receptacles: ________________________________

Power Factor Controller:

StacoVAR® **STD** Real Time: ______________

Type of Controls:

Neutral Unbalanced Protection: ________________________

Blown Fuse Indication: ________________________

Customer Specific Devices: ________________________

PLC/Networking/SCADA: ________________________

Other Devices or Integration:

Surge/Lightning Arrestor or TVSS (Type): ____________________

Lights: ________________________________

CT: ________________________________ (split core or other type)

Ratio: ________________________________

Other: ________________________________

Harmonic Filtering Description: ________________________

____

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.

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.

StacoVAR® Motor Load Capacitor

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.*

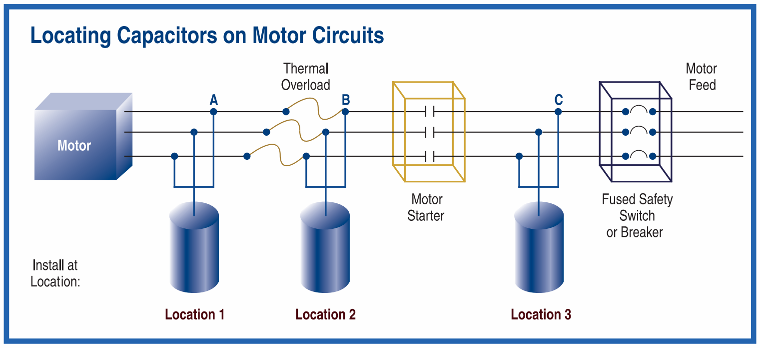


Figure 4. *Locating capacitors on motor circuits.*

> *"Fixed capacitors are ideal for improving power factor where induction motors are located."*

Locating Capacitors on Reduced Voltage and Multi-Speed Motors

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

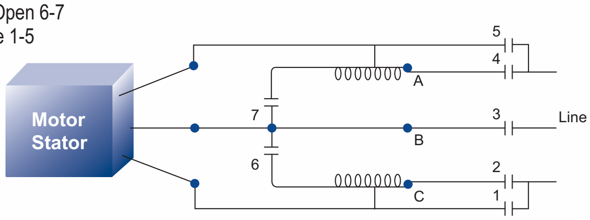


Figure 5. Autotransformer — Closed Transition
Note: Connect capacitor on motor side of starting contacts (2, 3, 4) at points A – B – C.

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

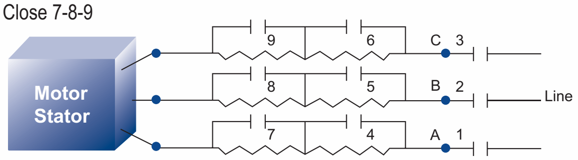


Figure 6. Series Resistance Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3,) at points A – B – C.

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

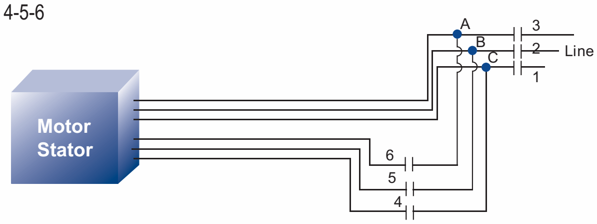


Figure 7. Part Winding Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

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

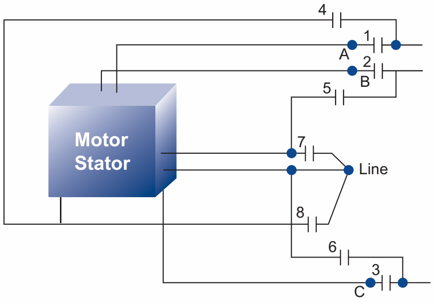


Figure 8. Wye-Delta Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

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

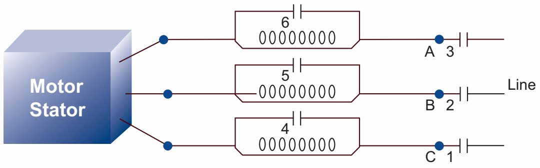


Figure 9. Reactor Starting
Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A – B – C.

Motor Reference Tables

The following are reference tables for types of motors and their appropriate KVAR sizing.

U-Frame NEMA Class B Motors and High Efficiency

A or B Normal Starting Torque - Normal Running Current

HP Rating	3600 RPM		1800 RPM		1200 RPM		900 RPM		720 RPM		600 RPM	
	KVAR	%R	KVAR	%R	KVAR	%R	KVAR	%R	KVAR	%R	KVAR	%R
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3.5	41
5	2	12	2	13	2	17	3	25	4	32	4.5	37
7.5	2.5	11	2.5	13	2	15	4	22	5.5	30	6	34
10	3	10	3	11	3.5	14	5	21	6.5	27	7.5	31
15	4	9	4	10	5	13	6.5	18	8	23	9.5	27
20	5	9	5	10	5	11	7.5	18	10	20	10	25
25	5	6	5	8	7.5	11	7.5	13	10	20	10	21
30	5	5	5	8	7.5	11	10	15	15	22	15	25
40	7.5	8	10	8	10	10	15	16	15	18	15	20
50	10	7	10	8	10	9	15	12	20	15	25	22
60	10	6	10	8	15	10	15	11	20	15	25	20
75	15	7	15	8	15	9	20	11	30	15	40	20
100	20	8	20	8	25	9	30	11	40	14	45	18
125	20	6	25	7	30	9	30	10	45	14	50	17
150	30	6	30	7	35	9	40	10	50	17	60	17
200	40	6	40	7	45	8	55	11	60	12	75	17
250	45	5	45	6	60	9	70	10	75	12	100	17
300	50	5	50	6	75	9	75	9	80	12	105	17

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

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

HP Rating	3600 RPM		1800 RPM		1200 RPM		900 RPM		720 RPM		600 RPM	
	KVAR	%R	KVAR	%R	KVAR	%R	KVAR	%R	KVAR	%R	KVAR	%R
3	1.5	14	1.5	23	2.5	28	3	38	3	40	4	40
5	2	14	2.5	22	3	26	4	31	4	40	5	40
7.5	2.5	14	3	20	4	21	5	28	5	38	6	45
10	4	14	4	18	5	21	6	27	7.5	36	8	38
15	5	12	5	18	6	20	7.5	24	8	32	10	34
20	6	12	6	17	7.5	19	9	23	10	29	12	30
25	7.5	12	7.5	17	8	19	10	23	12	25	18	30
30	8	11	8	16	10	19	14	22	15	24	22.5	30
40	12	12	13	15	16	19	18	21	22.5	24	25	30
50	15	12	18	15	20	19	22.5	21	24	24	30	30
60	18	12	21	14	22.5	17	26	20	30	22	35	28
75	20	12	23	14	25	15	28	17	33	14	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	36	12	35	12	42	14	45	15	50	17
150	30	10	42	12	40	12	52.5	14	52.5	14	60	17
200	35	10	50	11	50	10	65	13	68	13	90	17
250	40	11	60	10	62.5	10	82	13	87.5	13	100	17
300	45	11	68	10	75	12	100	14	100	13	120	17
350	50	12	75	8	90	12	120	13	120	13	135	15
400	75	10	80	8	100	12	130	13	140	13	150	15
450	80	8	90	8	120	10	140	12	160	14	160	15
500	100	8	120	9	150	12	160	12	180	13	180	15

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

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.*

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

Motor Reference Tables, *continued*

NEMA Class 2B Open Squirrel Cage Motors
Normal Starting Torque - Normal Running Current

HP Rating	3600 RPM KVAR	3600 RPM %R	1800 RPM KVAR	1800 RPM %R	1200 RPM KVAR	1200 RPM %R	900 RPM KVAR	900 RPM %R	720 RPM KVAR	720 RPM %R	600 RPM KVAR	600 RPM %R
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3.5	41
5	2	12	2	13	2	17	3	25	4	32	4.5	37
7.5	2.5	11	2.5	12	3	15	4	22	5.5	30	6	34
10	3	10	3	11	3.5	14	5	21	6.5	27	7.5	31
15	4	9	4	10	5	13	6.5	18	8	23	9.5	27
20	5	9	5	10	6.5	12	7.5	16	9	21	12	25
25	6	9	6	10	7.5	11	9	15	11	20	14	23
30	7	8	7	9	9	11	10	14	12	18	16	22
40	9	8	9	9	11	9	12	13	15	16	20	20
50	12	8	11	9	13	10	15	12	19	15	24	19
60	14	8	14	8	15	10	18	11	22	15	27	19
75	17	8	16	8	18	10	21	10	26	14	32.5	18
100	22	8	21	8	25	9	27	10	32.5	13	40	17
125	27	8	26	8	30	9	32.5	10	40	13	47.5	16
150	32.5	8	30	8	35	9	37.5	10	47.5	12	52.5	15
200	40	8	37.5	8	42.5	9	47.5	10	60	12	65	14
250	50	8	45	7	52.5	8	57.5	9	70	11	77.5	13
300	57.5	8	52.5	7	60	8	65	9	80	11	87.5	12
350	65	8	60	7	67.5	8	75	9	87.5	10	95	11
400	70	8	65	6	75	8	85	9	95	10	105	11
450	75	8	67.5	6	80	8	92.5	9	100	9	110	11
500	77.5	8	72.5	6	82.5	8	97.5	9	107.5	9	115	10

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

NEMA Class C, D, and Wound-Rotor Motors

Induction Motor Rating (HP)	Design C Motor		Design D Motor	
	1800 & 1200 RPM	900 RPM	1200 RPM	Wound-Rotor Motor
15	5	5	5	5.5
20	5	6	6	7
25	6	6	6	7
30	7.5	9	10	11
40	10	12	12	13
50	12	15	15	17.5
60	17.5	18	18	20
75	19	22.5	22.5	25
100	27	27	30	25
125	35	37.5	37.5	33
150	37.5	45	45	40
200	45	60	60	50
250	54	70	70	75
300	65	90	75	85

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

Motor Reference Tables, *continued*

Recommended Wire Sizes, Switches and Fuses

KVAR	240 VAC				480 VAC				600 VAC			
	Current (Amps)	Wire Size	Fuse (Amps)	Switch (Amps)	Current (Amps)	Wire Size	Fuse (Amps)	Switch (Amps)	Current (Amps)	Wire Size	Fuse (Amps)	Switch (Amps)
2	4.8	14	10	30	2.4	14	6	30	1.9	14	6	30
2.5	6.0	14	10	30	3.0	14	6	30	2.4	14	6	30
3	7.2	14	15	30	3.6	14	6	30	2.9	14	6	30
4	9.6	14	20	30	4.8	14	10	30	3.8	14	10	30
5	12	14	20	30	6.0	14	10	30	4.8	14	10	30
6	14	14	25	30	7.2	14	15	30	5.8	14	10	30
7.5	18	12	30	30	9.0	14	15	30	7.2	14	15	30
8	19	10	35	60	9.6	14	20	30	7.7	14	15	30
10	24	10	40	60	12	14	20	30	9.6	14	20	30
12.5	30	8	50	60	15	14	25	30	12	14	20	30
15	36	8	60	60	18	12	30	30	14	14	25	30
17.5	42	6	80	100	21	10	40	60	17	12	30	30
20	48	6	80	100	24	10	40	60	19	10	35	60
22.5	54	4	100	100	27	10	50	60	22	10	40	60
25	60	4	100	100	30	8	50	60	24	10	40	60
30	72	3	125	200	36	8	60	60	29	8	50	60
35	84	2	150	200	42	6	80	100	34	8	60	60
40	96	1	175	200	48	6	80	100	38	6	80	100
45	108	1/0	200	200	54	4	100	100	43	6	90	100
50	120	2/0	200	200	60	4	100	100	48	6	100	100
60	144	3/0	250	400	72	2	125	200	58	4	100	100
75	180	250M	300	400	90	1/0	150	200	72	3	125	200
80	192	300M	350	400	96	1/0	175	200	77	3	150	200
90	216	350M	400	400	108	1/0	200	200	86	1	150	200
100	241	400M	400	400	120	2/0	200	200	96	1	175	200
120	289	(2)3/0	500	600	144	3/0	200	200	115	2/0	200	200
125	300	(2)3/0	500	600	150	3/0	250	400	120	2/0	200	200
150	361	(2)250M	600	600	180	250M	300	400	144	3/0	250	400
180	432	(2)350M	750	800	216	350M	400	400	173	250M	300	400
200	481	(2)400M	800	800	241	400M	400	400	192	300M	350	400
240	—	—	—	—	289	(2)3/0	500	600	231	400M	400	400
250	—	—	—	—	300	(2)3/0	500	600	241	400M	400	400
300	—	—	—	—	361	(2)250M	600	600	289	(2)3/0	500	600
360	—	—	—	—	432	(2)350M	750	800	246	(2)250M	600	600
400	—	—	—	—	480	(2)500M	800	800	284	(2)300M	650	800

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.

> *"Automatic switched capacitor banks should be checked regularly, and periodic maintenance should be performed."*

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

Capacitance Tolerance	-5%, +10%
Discharge Resistors	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.
Continuous Operation	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.
Dielectric Strength Test	Twice the rated AC voltage, or a DC voltage 4.3 times the AC rating for non-metalized systems.
Overcurrent Protection	Fusing between 1.65 and 2.5 times the rated current to protect case from rupture. *Exception: 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.*

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.

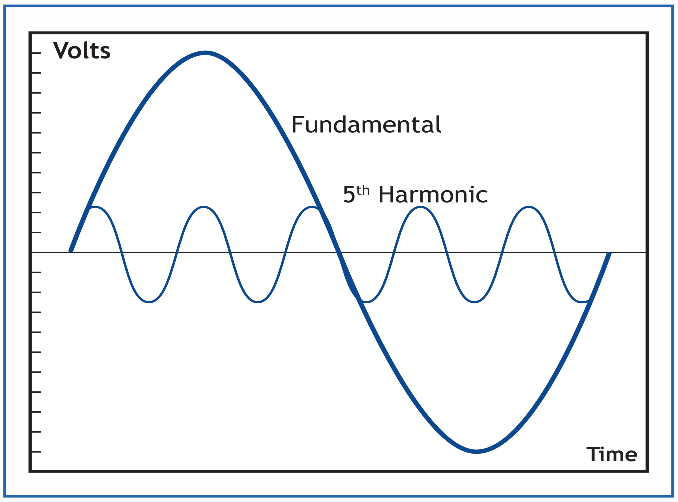


Figure 10. *Fundamental sinewave compared to the 5th order harmonic wave.*

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.

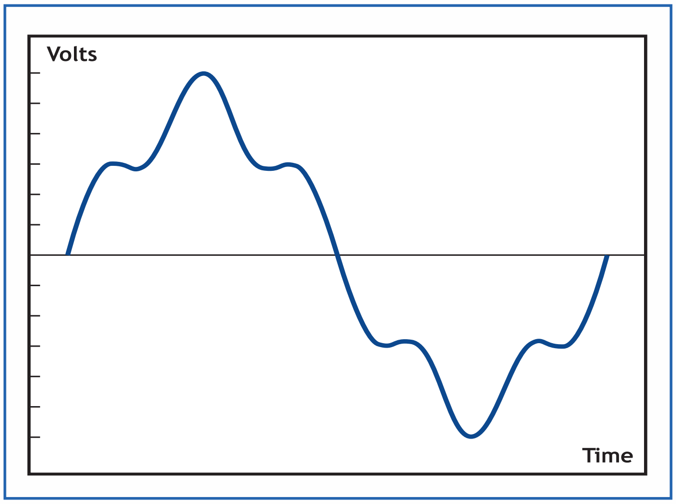


Figure 11. *Sinewave with 5th order harmonic present.*

> *“Harmonics is a term used to explain currents and voltages that have multiplied within an electrical 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)						
Ratio	h<11	11< h<17	17< h<23	23< h<35	35<h	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of odd harmonic limits						

Table 9. *IEEE 519 current distortion limits*

Bus Voltage at PCC	Individual Harmonic	THD (%)
69 KV & Below	3.0	5.0
69.001-161-161 KV	1.5	2.5
161 KV and Up	1.0	1.5

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*

[Harmonic Mitigation]

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 switch-gear
- Tripped or arcing circuit breakers
- Inaccurate readings from meters and instruments
- Overheated motors
- Breakdown of insulation
- Reversed torque on AC motors
- Reduced equipment life

“Certain orders of harmonics may cause serious equipment and system problems.”

Harmonic Distortions and Your Power Distribution System

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

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

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.

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

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)

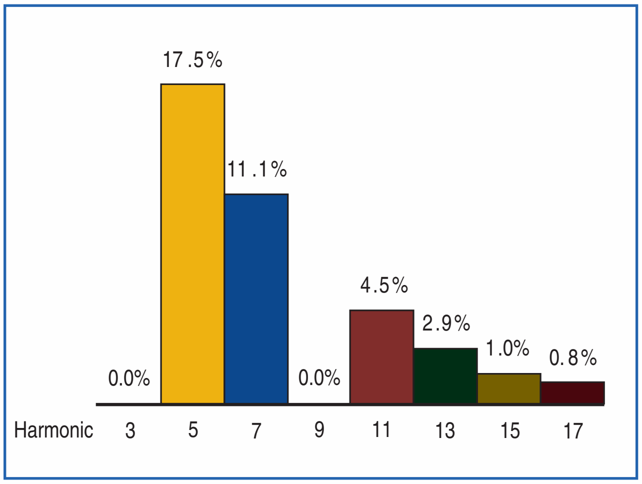


Figure 12: *Harmonic orders generated by a UPS system with a 6-pulse rectifier.*

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, how fusing, minimum power factor present, maximum power factor, utility limit, and desired power factor, if applicable

____

Communications: Interface, tele/data, satellite

____

> ***"A requirements review should include current usage information, plans for capital equipment upgrades or installations and facility expansion or improvements."***

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

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 of 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.

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

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.

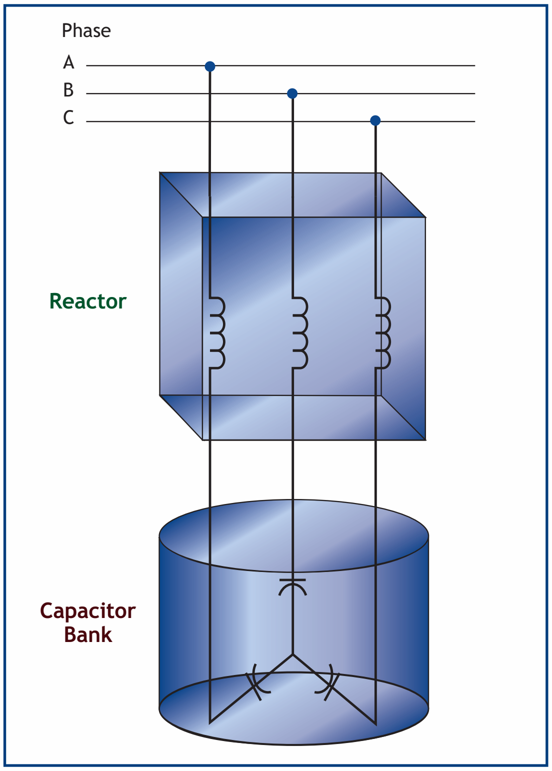


Figure 13. *Passive capacitor bank harmonic filter installation*

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.

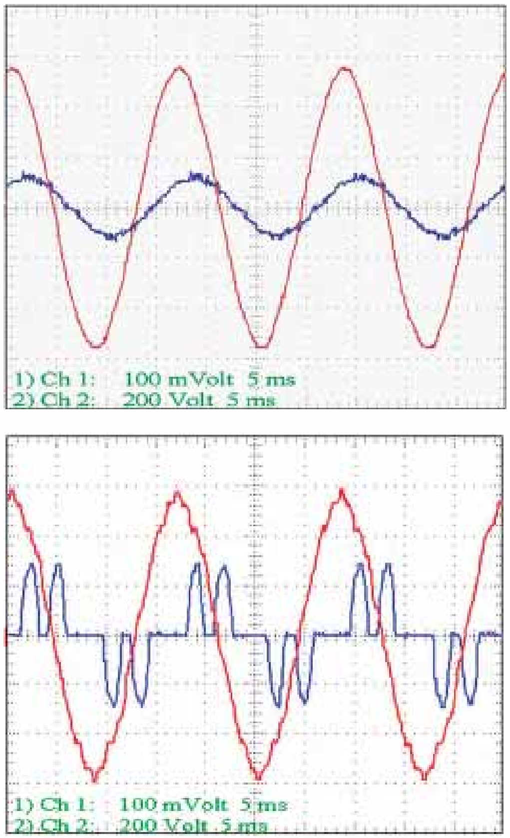


Figure 14. *Compensating sinewave from an active harmonic filter.*

“A notable feature of active filters is that you do not need an expensive site survey or application engineering before installing them.”

Active Harmonic Filters

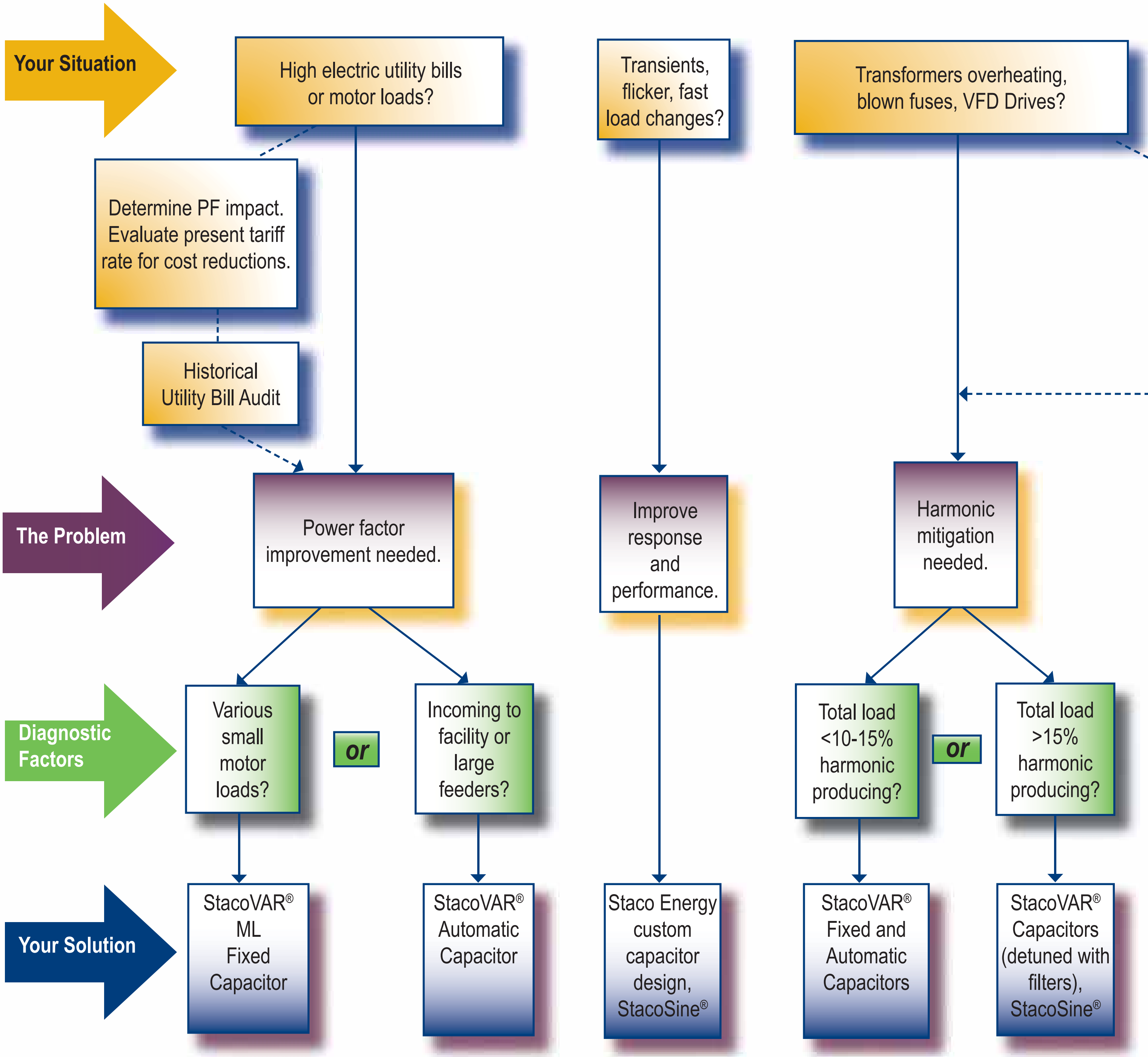
Active harmonic filters monitor and dynamically correct a wide range of harmonic orders, such as the 3rd to the 51st. They work by injecting a “mirror image” compensating current to restore the waveform. They can dramatically reduce distortion to less than 5% TDD, meeting IEEE 519 and international standards.

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.

StacoSine®
Active Harmonic Filter

Section 3: Staco Energy Products Co. Guide to Product Selection



Your Situation

High electric utility bills or motor loads?

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

Historical Utility Bill Audit

Transients, flicker, fast load changes?

Transformers overheating, blown fuses, VFD Drives?

The Problem

Power factor improvement needed.

Improve response and performance.

Harmonic mitigation needed.

Diagnostic Factors

Various small motor loads?

or

Incoming to facility or large feeders?

Total load <10-15% harmonic producing?

or

Total load >15% harmonic producing?

Your Solution

StacoVAR® ML Fixed Capacitor

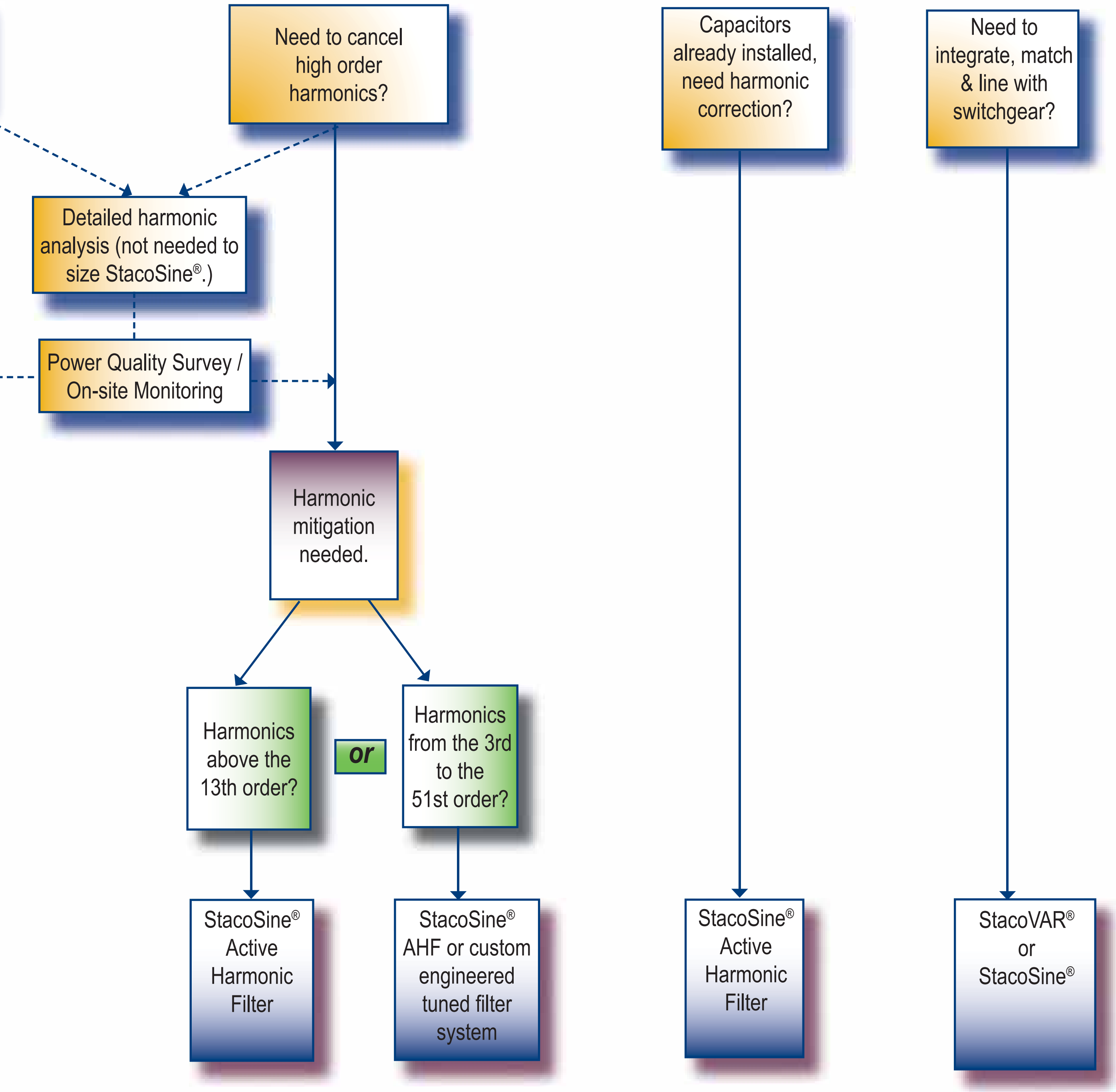
StacoVAR® Automatic Capacitor

Staco Energy custom capacitor design, StacoSine®

StacoVAR® Fixed and Automatic Capacitors

StacoVAR® Capacitors (detuned with filters), StacoSine®

"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:	Dynamic Compensation
Auto Bank:	Reactive Compensation
Switched Bank:	Capacitor Rack
Rack of Capacitors:	VAR Regulation
Reactive Power Compensation:	VAR Compensation

Terminology for Power Factor Correction Equipment with Reactors

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

Fixed Power Factor Correction

StacoVAR® PF

Motor load fixed capacitor products include liquid-filled long life single phase power capacitors (standard) or heavy duty, dry type three phase power capacitors (available), both types include discharge resistors and over pressure protection. Consult the factory when reactors are required for harmonic filtering.

Fixed and Automatic StacoVAR® Products

StacoVAR® Designation	Product Background — Application	CAP TYPE	TYPE OF SWITCH Contactor	Thyristor	TYPE OF CONTROLLER .5 - 300 ms	16-20 ms	REACTOR Detuned
StacoVAR® PF	Power factor correction, fixed only, no switching, no control, located at individual motor loads. PFH provides reactors for harmonic filtering.	Heavy Duty					
StacoVAR® PA	Power factor correction, automatically switched (contactors), basic, economical. Product accommodates most requirements.	Heavy Duty	Y		Y		
StacoVAR® PH	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.	Heavy Duty Derated	Y		Y		Y
StacoVAR® ZXR PR	VAR compensation, power factor correction, automatically switched, where load changes occur constantly. Use of thyristor switches, iron-core reactor for detuning and a fast response power factor controller. Controller, coordinated with the switches provides 16ms, sub-cycle switching. Due to power electronics and control, this product represents a greater cost than other PFC solutions. This product is more “niche” related for applications such as flicker, voltage sags, surges, load fluctuations.	Heavy Duty Derated		Y		Y	Y

Table 12. *StacoVAR® product features.*

[Selection Guide]

StacoVAR® 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.

StacoVAR® PA
Automatic Power Factor Correction

Additional Standard Features:

- *Type of Switching:* Electro-mechanical contactors with damping resistors to reduce switching inrush currents
- *Controller:* Adjustable (0.5 to 300 sec.) response microprocessor based controller (twelve-step regulation) with front panel LED display

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

Consult the factory for the availability of zero voltage cross thyristor switched capacitors and real time dynamic-VAR power factor correction systems.

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 strip. 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® automatic switched systems have optional circuit breakers, TVSS surge protection and current transformers."

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	41 = 415 Vac
24 = 240 VAC	48 = 480 Vac
38 = 380 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.Top Entry Option:

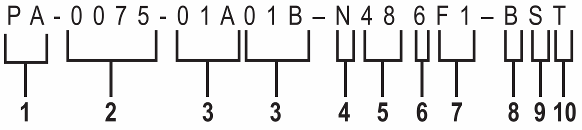
T = Top Entry Input/Output connection location
(consult factory)

11. Current Transformer (CT) Option:

Split-core, multi-tap, Part #712-1470

Part Numbering System

Part Number Example:



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

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 requirments.

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 300 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
- Open-chassis type for mounting in MCC and switchgear equipment

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.

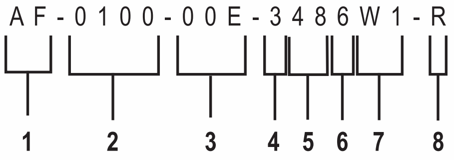
StacoSine's power electronics platform has been designed to operate at levels that continuously adapt to rapid load fluctuations. With its efficient operation and small physical size, it is ideal for a wide variety of industrial and commercial environments.

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:



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

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

Part Number Designation Guide

1:	Product Type	AF StacoSine® Active Harmonic Filter
2:	Amp Rating	Total amps required, four digit field
3:	Not Used	00E = Not used
4:	3 Wire	3 = 3 wire configuration 4 = 4 wire, consult factory
5:	Voltage Rating	20 = 208 VAC 24 = 240 VAC 38 = 380 VAC 40 = 400 VAC 41 = 415 VAC 48 = 480 VAC
6:	Frequency	6 = 50 or 60 Hz.
7:	Enclosure Type	W1 = Wall Mounted/Free Standing NEMA 1 (**standard**) F1 = Freestanding NEMA 1 (**standard**) C1 = Chassis Mounted, Open Type ** 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.*
8:	Communication	R = Communication Option

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

[Appendix A]

Useful Capacitor Formulas

Nomenclature:
A = Current
C = Capacitance in µF
F = Frequency
K = 1000
PF = Power Factor
V = Voltage

1. Power Factor = Cos θ = $\frac{KW}{KVA}$

	Single-Phase	Three-Phase
2. KW =	$\frac{V \times A \times PF}{10^3}$	$\frac{\sqrt{3} \times V \times A \times PF}{10^3}$
3. KVA =	$\frac{V \times A}{10^3}$	$\frac{\sqrt{3} \times V \times A}{10^3}$
4. Line Current = (Amperes)	$\frac{KVA \times 10^3}{V}$	$\frac{KVA \times 10^3}{\sqrt{3} \times V}$

5. Capacitor Current = $(2\pi f)\, CV \times 10^{-6}$
(Amperes)

Also: $\frac{KVAR \times 10^3}{V}$ $\quad \frac{KVAR \times 10^3}{\sqrt{3} \times V}$

6. Capacitors connected in parallel
$C_{total} = C_1 + C_2 + C_3 + - -$

7. Capacitors connected in series
$C_{total} = \frac{C_1 \times C_2}{C_1 \times C_2}$ For two capacitors in series

$$C_{total} = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \text{—} \ \text{—}}$$

8. Reactance -X_c (Capacitive)
A. $X_c = \frac{10^6}{(2\pi f)C}$
B. $X_c = \frac{2653}{C}$ @ 60 HZ (1µF = 2653 Ω)
C. $X_c = \frac{KV^2 \times 10^3}{KVAR}$

9. Capacitance — C
A. $C = \frac{10^6}{(2\pi f)X_c}$ $\qquad$ B. $X_c = \frac{KVAR \times 10^3}{(2\pi f)(KV)^2}$

10. Capacitive Kilovars
A. $KVAR = \frac{(2\pi f)C\,(KV)^2}{10^3}$ $\qquad$ B. $KVAR = \frac{10^3\,(KV)^2}{X_C}$

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:
$\%\ V.R. = \frac{\text{KVAR (Cap.) x \% transformer reactance}}{\text{KVA (transformer)}}$

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

15. KVA = $\frac{KW}{PF}$ (KW Motor Input)

16. KW (Motor Input) = $\frac{hp \times 0.746}{\text{efficiency}}$

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)

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.

As a leading power quality resource, we offer our customers world-class support; from our thorough applications assessment, to our ability to design and deliver a solution that is tailored to the specific needs of our customers; through delivery and commissioning.

Our professional, factory trained service team is in place to ensure that our customers' revenues are protected, and their investment provides them with many years of trouble free operation.

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

In addition to the StacoVAR line of power factor correction and harmonic mitigation equipment, we offer a wide array of power quality products, including:

- ***Uninterruptible Power Supplies***
- ***Power Conditioners***
- ***Voltage Regulators***
- ***Power Factor Correction and Harmonic Mitigation***
- ***Active Harmonic Filters***
- ***Variable Transformers***
- ***Custom Engineered Test Sets***

Represented locally by:

Your tailored power solutions provider™

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