Power Factor Tutorial

APQ, LLC.
16964 West Victor Road
New Berlin, WI 53151
Ph: 1-262-754-3883 Fax: 1-262-754-3993
www.apqpower.com

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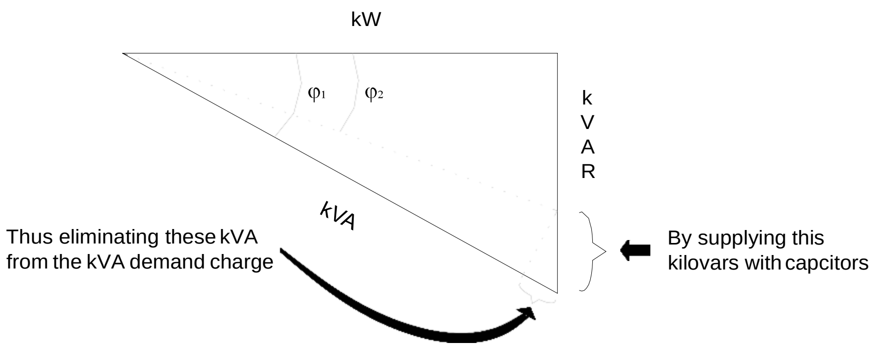
As with any equipment, an electrical system performs with some degree of efficiency rating from poor to excellent. One measure of efficiency compares the kW or work produced with the kVA of apparent power that is demanded from the power source for the purpose of performing that work. This measure of electrical efficiency is known as **Power Factor (PF)**.

Motors and other inductive equipment in a plant require two kinds of electric power. One type is working power, measured by the kilowatt (kW). This is what powers the equipment and performs useful work. Secondly, inductive equipment needs magnetizing power to produce the flux necessary for the operation of inductive devices. The unit of measure of magnetizing or reactive power is the kilovar (kVAR). The working power (kW) and reactive power (kVAR) together make up apparent power which is measured in kilovolt-amperes (kVA).

Most AC power systems require both kW (kilowatts) and kVAR (kilovars). Capacitors installed near the loads in a plant are the most economical and effective way of supplying these kilovars. If not supplied by local capacitors, then these kilovars will need to be provided by the electric utility. Low voltage capacitors are considered a low cost, high reliability and maintenance free means of providing the needed kilovars.

If magnetizing current is provided by capacitors to inductive loads, then those kilovars do not have to be sent all the way from the utility generator to the inductive loads. This relieves both your electrical system and your utility of the cost of carrying these extra kilovars. The utility charges you for this reactive power through either a direct or indirect power factor penalty charge. Capacitors can reduce your utility bill, gain system capacity, improve voltage and reduce power losses.

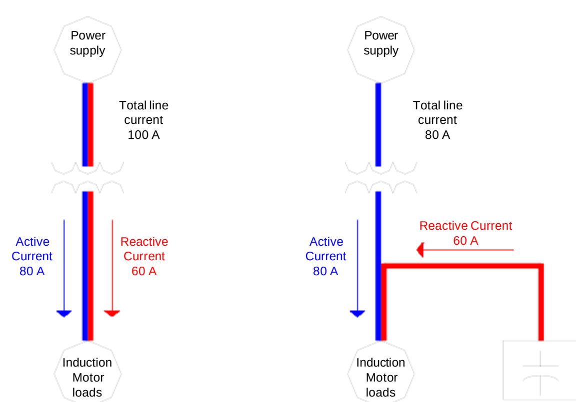
Induction motors, transformers and many other electrical loads require magnetizing current (kVAR) as well as working power (kW). By representing these components of apparent power (kVA) as the sides of a right triangle, we can determine the apparent power from the right triangle rule: $kVA^2 = kW^2 + kVAR^2$. To reduce the kVA required for any given load, you must shorten the line that represents the kVAR. This is precisely what capacitors do.



By supplying kVAR right at the load, the capacitor relieves the utility of the burden of carrying the extra kVAR. This makes the utility transmission/distribution system more efficient, reducing cost for the utility and their customers. The ratio of actual power and apparent power is usually expressed in percentage and is called power factor.

$$PF = \frac{kW}{kVA} = \cos \varphi$$

In the illustration below, addition of the capacitors has improved line power factor and subtracted the non-working current from the lines. This reactive current is now supplied by the capacitor rather than the utility.



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To properly select the amount of kVAR required to correct the lagging power factor of a 3-phase motor or other inductive loads you must have three pieces of information:

- KW (kilowatts)
- Original power factor in percent
- Desired power factor in percent

The formula to calculate the required kVAR is:

*Factor from Table 1 below x kW = kVAR of capacitor required

	DESIRED POWER FACTOR IN PERCENT																				
ORIGINAL POWER FACTOR IN PERCENT	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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	1.590	1.732
51	0.937	0.963	0.989	1.015	1.041	1.067	1.093	1.120	1.147	1.174	1.202	1.231	1.261	1.291	1.324	1.358	1.395	1.436	1.484	1.544	1.687
52	0.893	0.919	0.945	0.971	0.997	1.023	1.049	1.076	1.103	1.130	1.158	1.187	1.217	1.247	1.280	1.314	1.351	1.392	1.440	1.500	1.643
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	1.458	1.600
54	0.809	0.835	0.861	0.887	0.913	0.939	0.965	0.992	1.019	1.046	1.074	1.103	1.133	1.163	1.196	1.230	1.267	1.308	1.356	1.416	1.559
55	0.768	0.794	0.820	0.846	0.873	0.899	0.925	0.952	0.979	1.006	1.034	1.063	1.092	1.123	1.156	1.190	1.227	1.268	1.315	1.376	1.518
56	0.729	0.755	0.781	0.807	0.834	0.860	0.886	0.913	0.940	0.967	0.995	1.024	1.053	1.084	1.116	1.151	1.188	1.229	1.276	1.337	1.479
57	0.691	0.717	0.743	0.769	0.796	0.822	0.848	0.875	0.902	0.929	0.957	0.986	1.015	1.046	1.079	1.113	1.150	1.191	1.238	1.299	1.441
58	0.655	0.681	0.707	0.733	0.759	0.785	0.811	0.838	0.865	0.892	0.920	0.949	0.979	1.009	1.042	1.076	1.113	1.154	1.201	1.262	1.405
59	0.618	0.644	0.670	0.696	0.723	0.749	0.775	0.802	0.829	0.856	0.884	0.913	0.942	0.973	1.006	1.040	1.077	1.118	1.165	1.226	1.368
60	0.583	0.609	0.635	0.661	0.687	0.714	0.740	0.767	0.794	0.821	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
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	1.157	1.299
62	0.515	0.541	0.567	0.593	0.620	0.646	0.672	0.699	0.726	0.753	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123	1.265
63	0.483	0.509	0.535	0.561	0.587	0.613	0.639	0.666	0.693	0.720	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
64	0.451	0.477	0.503	0.529	0.555	0.581	0.607	0.634	0.661	0.688	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
66	0.388	0.414	0.440	0.466	0.492	0.519	0.545	0.572	0.599	0.626	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
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	0.966	1.108
68	0.328	0.354	0.380	0.406	0.432	0.459	0.485	0.512	0.539	0.566	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
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	0.907	1.049
70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
71	0.242	0.268	0.294	0.320	0.346	0.372	0.398	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
72	0.214	0.240	0.266	0.292	0.318	0.344	0.370	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
73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.370	0.396	0.424	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
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
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
76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
77	0.079	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.289	0.316	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
78	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.263	0.290	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
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	0.634	0.776
80		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	0.608	0.750
81			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
82				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	0.556	0.698
83					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	0.530	0.672
84						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
85							0.026	0.053	0.080	0.107	0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
86								0.027	0.054	0.081	0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
87									0.027	0.054	0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
88										0.027	0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
89											0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
90												0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484
91													0.030	0.060	0.093	0.127	0.164	0.205	0.253	0.313	0.456
92														0.031	0.063	0.097	0.134	0.175	0.223	0.284	0.426
93															0.032	0.067	0.104	0.145	0.192	0.253	0.395
94																0.034	0.071	0.112	0.160	0.220	0.363
95																	0.037	0.078	0.126	0.186	0.329
96																		0.041	0.089	0.149	0.292
97																			0.048	0.108	0.251
98																				0.061	0.203
99																					0.142

* Factors result from: $Factor = [Tan(\cos^{-1} OPF) - Tan(\cos^{-1} EPF)]$

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The previous chart makes it easier to find the amount of kVAR needed to improve your power factor from its present level to any desired value. Find your original power factor in the left side vertical column, then follow this row to the right until you reach the column of your desired power factor. This resulting figure multiplied times your kW = kVAR of capacitors required to improve from the present power factor to the desired power factor.

EXAMPLE: A small machine tool plant uses an average of 100 kW with an existing power factor of 80%. Desired power factor is 95%. The kVAR of capacitors necessary to raise the power factor to 95% is found by using Table 1, which in this case gives 0.421 as the factor needed to complete the formula referenced above:

0.421 X 100 kW = 42 kVAR

If kW or present power factor are not known you can calculate from the following formulas to get the three basic pieces of information required to calculate kVAR:

$$PF = \frac{kW}{kVA} \qquad kVA = \frac{1.73xIxE}{1000} \qquad kW = \frac{1.73xIxExPF}{1000} \quad \text{or} \quad kW = \frac{HPx\,746}{eff.}$$

Where:

I = Full load current in amps
E = Power supply
PF = Present power factor as a decimal (80% = 0.80)
HP = Rated horsepower of motor
eff = Rated efficiency of motor as a decimal (83% = 0.83)

If desired Power Factor is not provided, 95% is a good economical power factor for calculation purposes.

The application of shunt capacitors to industrial power systems has several benefits. Among these are:

- **Reduce power bills**

In areas where a kVA demand clause or some other form of low power factor penalty is incorporated in the electric utility's power rate structure, capacitors reduce power bill by reducing the kVA and kVAR demand.

- **Release in Systems Capacity**

In thermally-limited equipment, such as transformers or cables, capacitors release capacity and thus allow a greater payload. By furnishing the necessary magnetizing current for induction motors and transformers, capacitors reduce the current drawn from the power supply. Less current means less loading on transformers and feeder circuits. If a system has an existing overload, the capacitor may eliminate it. If the system is not overloaded, capacitors can release capacity and postpone or avoid an investment in more expensive transformers, switchgear and cable, otherwise required to serve additional loads.

- **Improve Voltage Conditions**

Excessive voltage sags can make your motors sluggish, and cause them to overheat. Low voltage also interferes with lighting, the proper operation of motor controls and electrical and electronics instruments. Capacitors will raise your plant voltage level, and can maintain it all along your feeders, right out to the last motors. Motor performance is improved and so is productivity.

- **Reduce line losses**

By supplying kilovars at the point where they are needed, capacitors will relieve the system of transmitting reactive current. Since the electrical current in the lines is reduced, I^2R losses also decrease. Therefore, fewer kilowatt-hours need to be purchased from the utility.

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