

Power Factor Tutorial



Arteche PQ, Inc.
16964 West Victor Road
New Berlin, WI 53151
Ph: 1-262-754-3883 Fax: 1-262-754-3993
www.artechepq.com

Power Factor Tutorial

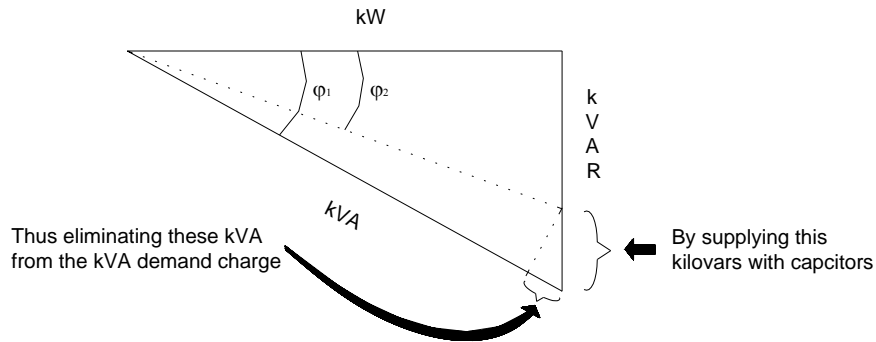
As with any equipment, an electrical system performs with some degree of efficiency rating from poor to excellent. One measure of efficiency compares the kW or work produced with the kVA of apparent power that is demanded for the power source for the purpose of performing that work. This measure of electrical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

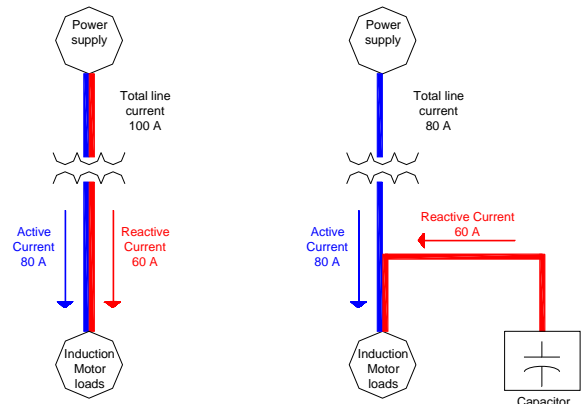
Induction motors, transformers and many other electrical loads require magnetizing current (kVAR) as well as working power (kW). By representing these components of apparent power (kVA) as the sides of a right triangle, we can determine the apparent power from the right triangle rule: $kVA^2 = kW^2 + kVAR^2$. 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.

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

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.



Power Factor Tutorial



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																				
		80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
ORIGINAL POWER FACTOR IN PERCENT	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: $Factor = [Tan(\cos^{-1} OPF) - Tan(\cos^{-1} EPF)]$

Power Factor Tutorial



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:

$$0.421 \times 100 \text{ kW} = 42 \text{ kVAR}$$

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:

$$PF = \frac{kW}{kVA} \quad kVA = \frac{1.73 \times I \times E}{1000} \quad kW = \frac{1.73 \times I \times E \times PF}{1000} \quad \text{or} \quad kW = \frac{HP \times 746}{eff}$$

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, $I^2 R$ losses also decrease. Therefore, fewer kilowatt-hours need to be purchased from the utility.