POWER QUALITY

POWER FACTOR—WIRING AND SERVICE

SCOPE

Power factor is a major consideration in efficient building or system operation. It is the measure of how effectively your equipment is converting electric current from BC Hydro's system to useful power output. Your business can save money—and gain other benefits—when your power factor is high enough to avoid power factor surcharges on your electricity bill. This brochure explains what is meant by power factor, why BC Hydro has a surcharge, and what you can do to improve power factor.

INTRODUCTION

Power factor is the ratio of real power to voltage times current. Power factor decreases with the installation of non-resistive loads, such as motors, transformers, lighting ballasts (especially magnetic ballasts) and other power electronics.

BC Hydro will add a surcharge to the electrical bill of commercial and industrial customers supplied at distribution voltage who do not maintain a power factor of at least 90 per cent. Customers can correct their low power factor through the proper selection, sizing and installation of capacitors.

The benefits of maintaining a high power factor include released system capacity and improved voltage.

BACKGROUND

Electricity consumption is determined by voltage (V), current (I) and power (P). For a purely resistive load the power is $P = VI$, but for most real loads there is a reactive current Ir. This reactive current flows in the circuit without dissipating power, so that $P \leqslant VI$.

BC Hydro charges for power, not current, but many of the costs of generation and transmission infrastructure are related to the supplied current, rather than the power. Therefore, we measure the power factor in order to apply a surcharge.

The power factor is never greater than one, and is usually given as a percentage where a power factor of one is stated as 100 per cent. A surcharge is applied to commercial and industrial distribution voltage accounts when power factor is below 90 per cent. The surcharge amount increases as power factor drops, ensuring that customers pay their fair share of the costs. Understanding power factor allows you to make corrections and avoid surcharges.

MEASUREMENT OF POWER FACTOR

Under normal conditions, the current in a circuit can be split into real component (Ip), and a reactive component (Ir). Because of the way these are related, the total current is calculated as follows:

$$I = \sqrt{I_p^2 + I_r^2}$$

Use the following formula to calculate power factor:

$$PF = \frac{VI_p}{VI} = \frac{VI_p}{\sqrt{V^2 I_p^2 + V^2 I_r^2}}$$

VIp is the real power, measured in watts, while VIr is the reactive power, measured in volt-amps reactive (VARs). BC Hydro traditionally used rotary meters, called watt-hour meters or VAR-hour meters to measure these quantities. The dials read kilowatt hours (kWh) or kilovar hours (kVARh).

At the end of the measuring period, the average power factor is calculated as follows:

$$PF = \frac{kWh}{\sqrt{kWh^2 + kVARh^2}}$$

Some equipment draws current that is heavily distorted from the ideal 60 Hz sine wave. This generates harmonics, which increase the current by another component, the harmonic current Ih. These harmonic currents reduce the power factor according to:

$$PF = \frac{VI_p}{\sqrt{V^2 I_p^2 + V^2 I_r^2 + V^2 I_h^2}}$$

Rotary meters do not measure harmonic currents properly, and their effect on the power factor often goes unnoticed. Newer electronic power meters now available can accurately measure power, current and voltage, even with distorted currents, providing a true power factor measure.

In the future, more of these meters will be installed at harmonics-rich sites (companies with large adjustable speed drives, for instance), and the customer will be responsible for either correcting the power factor or paying the true power factor.

UNDERSTANDING POWER FACTOR

The power factor of a system may be described as lagging if the reactive current is inductive, or leading if the reactive current is capacitive. Lagging power factor can be corrected by connecting capacitors in parallel with the system. The current in a capacitor produces a leading power factor. When the two circuits are combined, the effect of capacitance tends to cancel that of the inductance.

Most customer loads (particularly motors, but also many lighting circuits) are inductive. A low power factor can generally be corrected by connecting appropriate capacitors. This is not the case if the low power factor is caused by harmonics, in which case the installation of capacitors will not help, and may cause a serious problem. In high harmonic situations, expert help should be obtained before attempting to correct power factor problems.

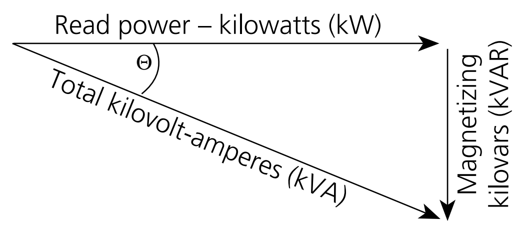

Figure 1: Power factor before adding capacitors.

Figures 1 and 2 show the before-and-after effects of adding capacitors. Note the smaller resultant kVAR with the capacitors added, but real power (kW) does not change.

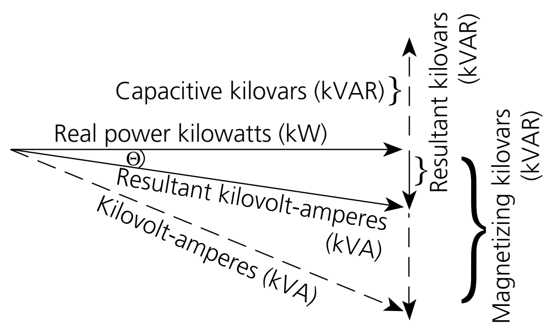

Figure 2: Power factor after adding capacitors.

A properly chosen capacitance value will neutralize the inductance and produce unity power factor. Too little or too much capacitance must be avoided. Too little will not correct to a sufficiently high power factor to eliminate a surcharge, and too much will result in leading power factor with possible undesirable effects.

BC HYDRO POWER FACTOR POLICY

POWER FACTOR REQUIREMENTS

BC Hydro's conditions of service require equipment to have a power factor of at least 90 per cent. On most non-residential service, a charge is applied to cover the extra service needs, determined by the degree of power factor. Following is a summary the power factor requirements.

LIGHTING

All new installations or connections of neon, mercury vapour, fluorescent or other types of lamps, lighting devices, or display facilities, served by BC Hydro, shall be equipped at the customer's expense with auxiliaries designed and installed to the satisfaction of BC Hydro that assure a lagging power factor of not less than 90 per cent.

GENERAL POWER AND INDUSTRIAL SERVICES

The average lagging power factor shall not be less than 90 per cent. BC Hydro may take continuous tests of power factor or may test the customer's power factor at any reasonable time. If the customer's power factor is lower than 90 per cent, the customer will be required to install power factor corrective equipment satisfactory to BC Hydro, at the customer's expense.

Measuring power factor on a branch circuit.

In the case where maximum demand is measured in kVA, it is strongly recommended that the power factor be maintained as close to unity as practical, as the customer is implicitly paying a surcharge for any amount of lagging power factor. This is the case for large customers (typically industrial) serviced at transmission voltage (greater than 69 kV).

SURCHARGES AND GRACE PERIOD

For new or existing customers requiring kVARh metering for the first time, BC Hydro allows 135 days, if necessary, for correcting the power factor after installation of measuring equipment.

Customers with kVARh metering who are making a significant change in their load are expected to assess, in advance, the needed correction. These customers will not automatically be allowed a further 135 days. The appropriate Customer Services manager may, in such circumstances, allow "reasonable time" during the testing or commissioning period to avoid problems that can arise during this time.

Where kVARh metering is not installed, should a customer with a low power factor neglect or refuse to install power factor corrective equipment as required, BC Hydro may do one of three things: disconnect service; require payment of an additional 50¢ per month per 100 watts (or fraction thereof) of the connected load; or apply a surcharge to the total bill.

Use the following formula and graph to determine the surcharge for average power factor based on monthly measurements of kWh and kVARh:

$$PF = \frac{kWh}{\sqrt{\{(kWh)^2 + (kVARh)^2\}}}$$

For example, if kVARh consumption is 17,460 and kWh consumption is 25,000, then the power factor is 82 per cent.

Figure 3 shows the surcharge versus BC Hydro's percentage power factor. In the previous example, with a power factor of 82 per cent, the surcharge is 9 per cent.

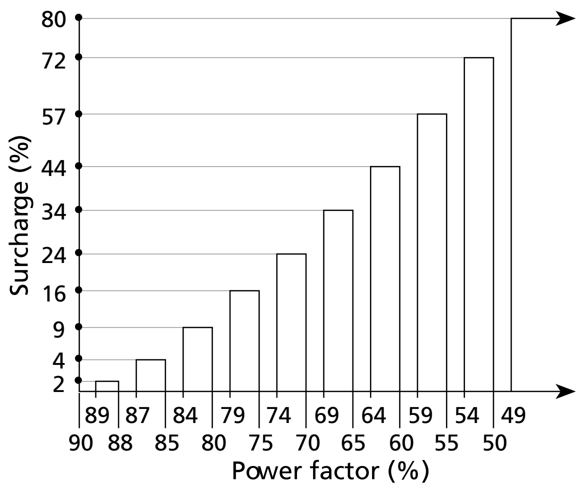

Figure 3: Power factor/surcharge relationship.

Figure 4 allows a quick estimation of power factor if kWh and kVARh are known.

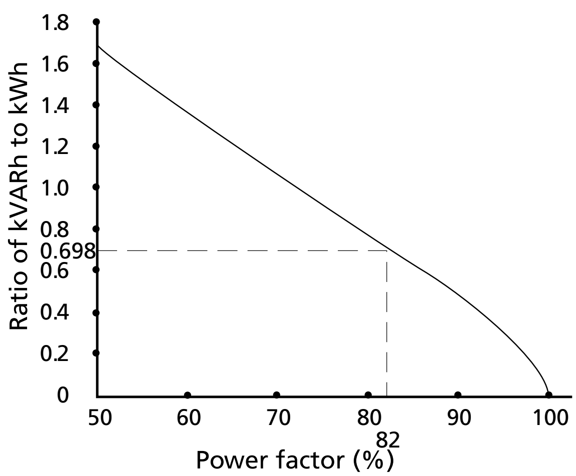

Figure 4: Power factor—kVARh/kWh relationship.

POWER FACTOR CORRECTION APPLIED BY BC HYDRO

BC Hydro uses power factor correction equipment throughout its system to maintain required voltage levels and system stability. Because of operational limits to the amount of correction that BC Hydro can apply additional power factor correction by the customer will be required.

CORRECTING POWER FACTOR

SOURCES

Motors, transformers, welding machines, induction heating coils and lighting ballasts are the major sources of lagging power factor.

Factors affecting the power factor of an induction motor are size, speed and load. The larger the motor and faster its speed, the higher the full-load power factor. The power factor of a motor varies according to its load. The higher the percentage of the rated load, the higher the power factor.

DIAGNOSIS

If your system is found to have a low power factor, check first that there are no blown fuses or tripped breakers for any existing capacitor banks. After confirming this, call in an expert to check installed equipment, sizes, loads and locations. Utility bills should be examined for the average power factor experienced. It can then be determined what amount of capacitance is required, the type of control needed, and the desirable location for the application.

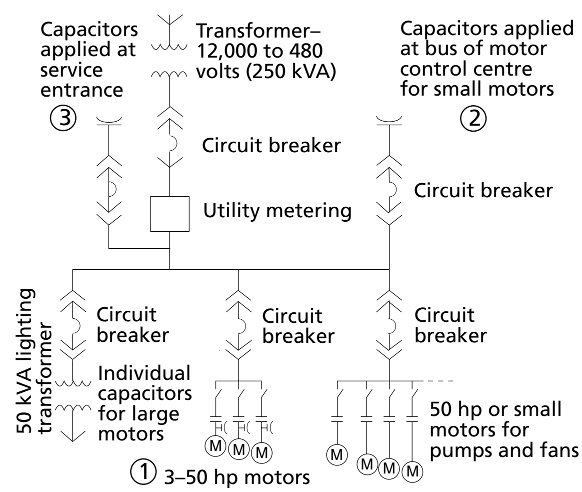

Figure 5: Single-line electrical system showing typical locations for capacitors.

METHODS OF CORRECTION

1. For motors of 50 hp and above, it is best to install power factor correction capacitors at the motor terminals (Figure 5, ①) since distribution circuit loading is reduced. Refer to manufacturer's instructions for recommended maximum capacitance ratings. When this is done, motor settings that are over current protection relays must be adjusted down accordingly.

2. The second arrangement (Figure 5, ②) shows capacitor banks connected at the bus for each motor control centre. This compromise to Method 1 will reduce installation costs.

3. The least expensive method (Figure 5,③) shows capacitor banks connected at the service entrance. However, the disadvantage is that higher feeder currents still flow from the service entrance to the end of line equipment.

4. For primary metered services, primary connected capacitance may be considered with the approval of BC Hydro.

USE OF SYNCHRONOUS MOTORS

Synchronous motors can be operated at power factors from unity to 20 per cent leading and are sometimes used for plant power factor correction. The motors are usually designed to operate at a particular power factor, often between 100 per cent and 90 per cent leading. When operated near 20 per cent power factor leading, synchronous motors are referred to as synchronous condensers.

ESTIMATING AMOUNT OF KILOVARS OF CAPACITANCE

The table on page 6 shows the kW multipliers used to determine capacitor kilovars required for power factor correction. Figure 6 is a graphical representation.

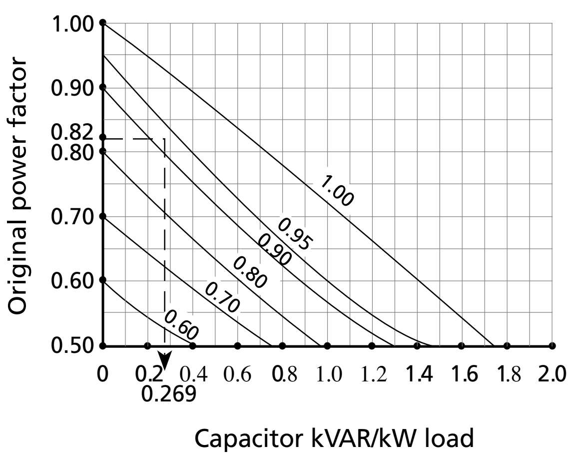

Figure 6: Capacitor for power factor improvement.

It is essential that the proper voltage rating of capacitors be used in order to achieve the nameplate kVAR rating. The kVAR rating is proportional to the square of the voltage. For example, if a 240 V capacitor is used on a 208 V system, the kVAR rating will be equal to (208)2/(240)2 times the nameplate value, that is, 0.75 times the nameplate value. This means that the required kVAR must be increased by one-third (33 per cent) to achieve the desired level of power factor correction.

EFFECTS OF CAPACITORS

When capacitors are used to correct low power factor, the following effects should be anticipated:

- Capacitors consume power at the rate of about 0.5 watts per kVAR.
- A slight increase in voltage can be expected.
- There is a chance that resonance may occur between the capacitors and any silicon-controlled rectifier (SCR) and rectifier circuits in the system. The presence of harmonics generated by rectifier circuits can be amplified because of this resonance, resulting in blown fuses and damage to capacitor banks and other electrical equipment. In the event that the frequent blowing of fuses occurs, apparently without reason, expert help should be called in to assist in resolving the problem. If harmonics are the source of the problem, the addition of the appropriate size of inductor, connected in series with the capacitor banks, will filter the harmonics and de-tune the resonant circuit.

BENEFITS OF INCREASED POWER FACTOR

Customers now paying a power factor surcharge can, at present costs, expect a payback period of under two years when power factor correction is properly applied.

For example, if the maximum demand for the previous year's electrical history is 80 kW and the maximum power factor is 82 per cent, then you can see from Figure 3 that the surcharge payable will be 9 per cent. If the annual surcharge amounts to $900, then by following the procedure below, the capacitance required and the associated payback period can be estimated.

Refer to the table on page 6 to determine the multiplier to be used to estimate the kVAR of capacitance required to correct the power factor. For example, to correct from 82 per cent to, 92 per cent, the multiplier is 0.269. For a demand of 80 kW, the amount of capacitance required is about 22 kVAR. Figure 6 shows this information in dotted lines.

POWER FACTOR IMPROVEMENT

Desired power factor (%)

Original power factor (%)	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
50	.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	1.442	1.481	1.529	1.590	1.732
51	.937	.962	.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
52	.893	.919	.945	.971	.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
53	.850	.876	.902	.928	.954	.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
54	.809	.835	.861	.887	.913	.939	.966	.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
55	.769	.795	.831	.847	.873	.899	.926	.952	.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1.377	1.519
56	.730	.756	.782	.808	.834	.860	.887	.913	.940	.968	.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
57	.692	.718	.744	.770	.796	.822	.849	.875	.902	.930	.958	.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
58	.655	.681	.707	.733	.759	.785	.812	.838	.865	.893	.921	.949	.976	1.010	1.042	1.076	1.114	1.154	1.202	1.263	1.405
59	.618	.644	.670	.696	.722	.748	.775	.801	.828	.856	.884	.912	.939	.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
60	.584	.610	.636	.662	.688	.714	.741	.767	.794	.822	.850	.878	.905	.939	.971	1.005	1.043	1.083	1.131	1.192	1.334
61	.549	.575	.601	.627	.653	.679	.706	.732	.759	.787	.815	.843	.870	.904	.936	.970	1.008	1.048	1.096	1.157	1.299
62	.515	.541	.567	.593	.619	.645	.672	.698	.725	.753	.781	.809	.836	.870	.902	.936	.974	1.014	1.062	1.123	1.265
63	.483	.509	.535	.561	.587	.613	.640	.666	.693	.721	.749	.777	.804	.838	.870	.904	.942	.982	1.030	1.091	1.233
64	.450	.476	.502	.528	.554	.580	.607	.633	.660	.688	.716	.744	.771	.805	.837	.871	.909	.949	.997	1.058	1.200
65	.419	.445	.471	.497	.523	.549	.576	.602	.629	.657	.685	.713	.740	.774	.806	.840	.878	.918	.966	1.027	1.169
66	.388	.414	.440	.466	.492	.518	.545	.571	.598	.626	.654	.682	.709	.743	.775	.809	.847	.887	.935	.996	1.138
67	.358	.384	.410	.436	.462	.488	.515	.541	.568	.596	.624	.652	.679	.713	.745	.779	.817	.857	.905	.966	1.108
68	.329	.355	.381	.407	.433	.459	.486	.512	.539	.567	.595	.623	.650	.684	.716	.750	.788	.828	.876	.937	1.079
69	.299	.325	.351	.377	.403	.429	.456	.482	.509	.537	.565	.593	.620	.654	.866	.720	.758	.798	.840	.907	1.049
70	.270	.296	.322	.348	.374	.400	.427	.453	.480	.508	.536	.564	.591	.625	.657	.691	.729	.769	.811	.878	1.020
71	.242	.268	.294	.320	.346	.372	.399	.425	.452	.480	.508	.536	.563	.597	.629	.663	.701	.741	.783	.850	.992
72	.213	.239	.265	.291	.317	.343	.370	.396	.423	.451	.479	.507	.534	.568	.600	.634	.672	.712	.754	.821	.963
73	.186	.212	.238	.264	.290	.316	.343	.369	.396	.424	.452	.480	.507	.541	.573	.607	.645	.685	.727	.794	.936
74	.159	.185	.211	.237	.263	.289	.316	.342	.369	.397	.425	.453	.480	.514	.546	.580	.618	.658	.700	.767	.909
75	.132	.158	.184	.210	.236	.262	.289	.315	.342	.370	.398	.426	.453	.487	.519	.553	.591	.631	.673	.740	.882
76	.105	.131	.157	.183	.209	.235	.262	.288	.315	.343	.371	.399	.426	.460	.492	.526	.564	.604	.652	.713	.855
77	.079	.105	.131	.157	.183	.209	.235	.262	.289	.317	.345	.373	.400	.434	.466	.500	.538	.578	.620	.687	.829
78	.053	.079	.105	.131	.157	.183	.210	.236	.263	.291	.319	.347	.374	.408	.440	.474	.512	.552	.594	.661	.803
79	.026	.052	.078	.104	.130	.156	.183	.209	.236	.264	.292	.320	.347	.381	.413	.447	.485	.525	.567	.634	.776
80	–	.026	.052	.078	.104	.130	.157	.183	.210	.238	.266	.294	.321	.355	.387	.421	.459	.499	.541	.608	.750
81	–	–	.026	.052	.078	.104	.131	.157	.184	.212	.240	.268	.295	.329	.361	.395	.433	.473	.515	.582	.724
82	–	–	–	.026	.052	.078	.105	.131	.158	.186	.214	.242	.269	.303	.335	.369	.407	.447	.489	.556	.698
83	–	–	–	–	.026	.052	.079	.105	.132	.160	.188	.216	.243	.277	.309	.343	.381	.421	.463	.530	.672
84	–	–	–	–	–	.026	.053	.079	.106	.134	.162	.190	.217	.251	.283	.317	.355	.395	.437	.504	.645
85	–	–	–	–	–	–	.027	.053	.080	.108	.136	.164	.191	.225	.257	.291	.329	.369	.417	.478	.620
86	–	–	–	–	–	–	–	.026	.053	.081	.109	.137	.167	.198	.230	.265	.301	.343	.390	.451	.593
87	–	–	–	–	–	–	–	–	.027	.055	.082	.111	.141	.172	.204	.238	.275	.317	.364	.425	.567
88	–	–	–	–	–	–	–	–	–	.028	.056	.084	.114	.145	.177	.211	.248	.290	.337	.398	.540
89	–	–	–	–	–	–	–	–	–	–	.028	.056	.086	.117	.149	.183	.220	.262	.309	.370	.512
90	–	–	–	–	–	–	–	–	–	–	–	.028	.058	.089	.121	.155	.192	.234	.281	.342	.484
91	–	–	–	–	–	–	–	–	–	–	–	–	.030	.061	.093	.127	.164	.206	.253	.314	.456
92	–	–	–	–	–	–	–	–	–	–	–	–	–	.031	.063	.097	.134	.176	.223	.284	.426
93	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.032	.066	.103	.145	.192	.253	.395
94	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.034	.071	.113	.160	.221	.363
95	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.037	.079	.126	.187	.328
96	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.042	.089	.150	.292
97	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.047	.108	.251
98	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.061	.203
99	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.142

The numbers inside this table are the kW multipliers used to determine capacitor kilovars required for power factor correction.

To determine the linear payback period for this installation, consider the following example. Note that these figures should not be used for estimates; consult your electrician for actual costs.

Example

Survey cost and advice (location and quantity of capacitance to be installed)	$500
Capacitance (22 kVAR at $30/kVAR)	$660
Labour (2 people, 1 day = $250 a day x 2)	$500
Total cost of installation	$1,660

$$\text{Payback period (years)} = \frac{\text{total cost of installation}}{\text{annual savings}}$$

In this sample $\frac{\$1,660}{\$900}$ = 1.84 years payback

RELEASED SYSTEM CAPACITY

When a system's power factor is improved, the amount of reactive current flowing is lowered, thus reducing transformer and distribution circuit loads, and releasing system capacity. Figure 7 shows the amount of capacity released for various amounts of correction. For the example given previously, the dotted lines indicate that the system capacity released is 0.13 times the kilowatt load, which in this case is 10.4 kVA.

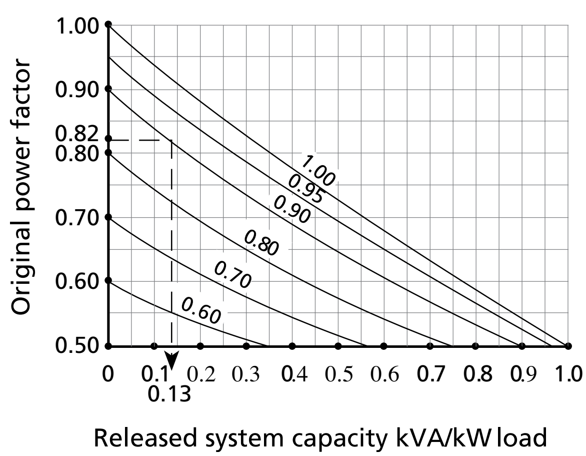

Figure 7: Released system capacity for various amounts of correction.

IMPROVED VOLTAGE

A low power factor results in a higher current flowing for a given load. As power factor decreases, line current increases, causing greater voltage drops in the conductors. Greater voltage drops result in poor voltage at equipment. With improved power factor, the voltage drops are reduced and the voltage at the equipment is improved.

IMPROVED EFFICIENCY

The voltage drop in supply conductors is a resistive loss, and wastes power heating the conductors. A 5 per cent drop in voltage means that 5 per cent of your power is wasted as heat before it even reaches the motor. Improving the power factor, especially at the motor terminals, can improve your efficiency by reducing the line current and the line losses.

POWER FACTOR OF HIGH-EFFICIENCY MOTORS

The high-efficiency or energy-efficient motors that are currently being marketed in Canada exhibit power factor characteristics that are superior to those of industry average motors. Figure 8 compares full-load high-efficiency and industry average or standard power factors for motors in the 1 to 25 horsepower (hp) range. Note that full-load power factors for all of the energy-efficient motors are above 82 per cent.

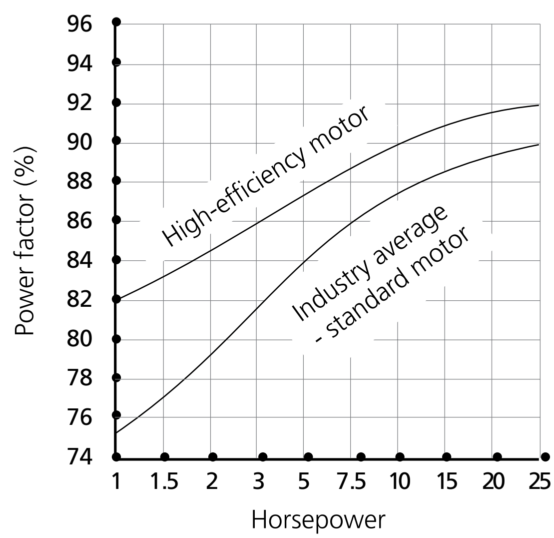

Figure 8: Power factor comparison.

SUMMARY OF RECOMMENDATIONS

- Maintain system power factor at 90 per cent lagging or better.
- Size electric motors to match mechanical loads to increase the overall system power factor.
- Consider using leading power factor synchronous motors for slow-speed high-horsepower applications to raise the overall system power factor.
- Use banks of capacitors at motor control centres or service entrances to facilitate switching for varying load conditions.
- Consider using automatically switched power factor correction capacitors to prevent leading power factor during periods of light loading and undesirable over-voltages.

INSTALLATION

This Power Quality brochure is designed as a general guide. Please ensure that installations meet your requirements, manufacturers' instructions and all applicable codes, standards and regulations. BC Hydro is not responsible for installations.

ABBREVIATIONS

C	=	capacitance in μF (see below)
f	=	frequency in Hz
F	=	farad–unit of capacitance
hp	=	horsepower
I	=	current in amperes
k	=	kilo or 1000
kA	=	kiloamp
kVAR	=	kilovar
kVARh	=	kilovar hours
PF	=	power factor
V	=	voltage in volts
μ	=	micro or 10^{-6}

FORMULAS

		SINGLE PHASE	THREE PHASE
kW = kilowatts	=	$\frac{V \times I \times PF}{1,000}$	$\frac{\sqrt{3} \times V \times I \times PF}{1,000}$
kVA = kilovolt amperes	=	$\frac{V \times I}{1,000}$	$\frac{\sqrt{3} \times V \times I}{1,000}$
I = line current in amperes	=	$\frac{kVA \times 1,000}{V}$	$\frac{kVA \times 1,000}{\sqrt{3} \times V}$
Capacitor current in amperes	=	$\frac{kVAR_{cap} \times 1,000}{V}$	$\frac{kVAR_{cap} \times 1,000}{\sqrt{3} \times V}$
kW (input)	=	$\frac{\text{rated hp} \times 0.746}{\text{efficiency}}$	
PF (instantaneous)	=	$\frac{kW}{kVA}$	
PF (average)	=	$\frac{kWh}{\sqrt{\{(kWh)^2 + (kVARh)^2\}}}$	

FOR MORE INFORMATION CONTACT:

Your Key Account Manager.
Or phone 604 522 4713 in the Lower Mainland or 1 866 522 4713 elsewhere in BC.

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