Vol. 14 SEPTEMBER, 1949 No. 9

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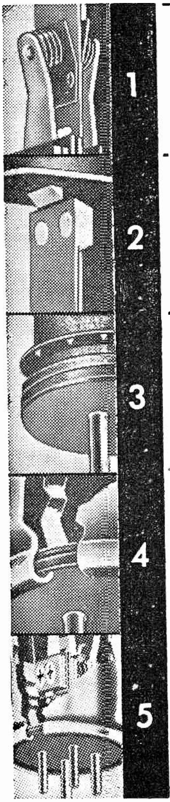

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POWER FACTOR CORRECTION

It is a well-known fact that current and voltage are not in phase in an a.c. circuit unless the circuit contains resistance only. If there is capacitance in the circuit, the current leads the voltage. And if there is inductance in the circuit, the current lags the voltage. A typical circuit containing pure resistance only might be one in which are connected incandescent lamps or ordinary electric heaters. An example of a circuit containing inductance only (with negligible resistance, of course) is one in which motors are connected. Capacitance is seldom encountered by itself in industrial circuits.

Figures 1 and 2 illustrate these phase relations. In Figure 1, vectors are used. The voltage vector is longer than the current vector in each case to show that the voltage value is higher than the current value (for example, 115 volts and 5 amperes). The vectors are assumed to rotate in a counter-clockwise direction; that is, from right to left. Thus, in Figure 1(A) the current vector (I) is moving ahead of the voltage vector (E), or current is leading voltage. In Figure 1(B), the current vector is trailing the voltage vector (current lags voltage). The angle of separation of these vectors (angle of lead or lag) is termed the **phase angle** and is designated by the Greek letter **theta** which resembles the English capital O with a horizontal cross-bar.

In Figure 2, the same phase relations are shown, using a.c. sine wave patterns for illustration. In Figure 2(A), note that the current (dotted line) has been flowing for an appreciable interval and reaches its peak value before the voltage (solid line) even leaves zero. Also, the current stops flowing before the voltage again reaches zero. Just as in Figure 1(A), this condition represents leading current. In Figure 2(B), the opposite condition holds. The voltage has reached its maximum (peak) value before the current begins to flow. And after the voltage has cut off, the current continues to flow for an interval

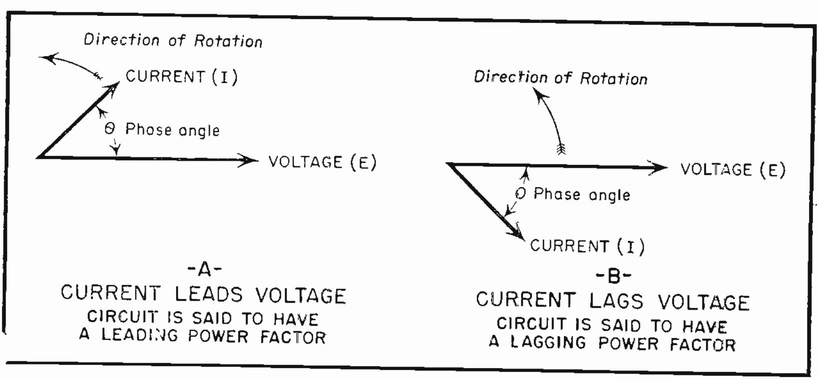

Fig. 1. Phase relationship vectors.

CHART 2.

Power Factor	Multiplier	Power Factor	Multiplier	Power Factor	Multiplier
.150	6.586	.450	1.984	.725	0.949
.160	6.163	.455	1.957	.730	0.936
.170	5.798	.460	1.930	.735	0.922
.180	5.466	.465	1.903	.740	0.909
.190	5.169	.470	1.878	.745	0.896
.200	4.900	.475	1.852	.750	0.882
.205	4.773	.480	1.828	.755	0.867
.210	4.658	.485	1.803	.760	0.855
.215	4.542	.490	1.779	.765	0.842
.220	4.431	.495	1.755	.770	0.829
.225	4.331	.500	1.732	.775	0.815
.230	4.230	.505	1.709	.780	0.802
.235	4.139	.510	1.686	.785	0.789
.240	4.045	.515	1.664	.790	0.779
.245	3.957	.520	1.642	.795	0.763
.250	3.871	.525	1.621	.800	0.750
.255	3.789	.530	1.600	.805	0.737
.260	3.714	.535	1.579	.810	0.724
.265	3.639	.540	1.558	.815	0.711
.270	3.565	.545	1.539	.820	0.698
.275	3.495	.550	1.518	.825	0.685
.280	3.430	.555	1.496	.830	0.672
.285	3.361	.560	1.479	.835	0.659
.290	3.298	.565	1.460	.840	0.646
.295	3.237	.570	1.441	.845	0.633
.300	3.178	.575	1.423	.850	0.619
.305	3.121	.580	1.404	.855	0.607
.310	3.065	.585	1.386	.860	0.593
.315	3.012	.590	1.369	.865	0.580
.320	2.960	.595	1.351	.870	0.565
.325	2.909	.600	1.333	.875	0.553
.330	2.858	.605	1.316	.880	0.539
.335	2.813	.610	1.299	.885	0.526
.340	2.765	.615	1.282	.890	0.512
.345	2.720	.620	1.265	.895	0.498
.350	2.674	.625	1.249	.900	0.484
.355	2.627	.630	1.233	.905	0.469
.360	2.589	.635	1.217	.910	0.455
.365	2.549	.640	1.201	.915	0.441
.370	2.511	.645	1.185	.920	0.426
.375	2.471	.650	1.169	.925	0.411
.380	2.434	.655	1.154	.930	0.395
.385	2.396	.660	1.138	.935	0.379
.390	2.361	.665	1.123	.940	0.363
.395	2.326	.670	1.108	.945	0.346
.400	2.291	.675	1.093	.950	0.328
.405	2.257	.680	1.078	.955	0.310
.410	2.225	.685	1.064	.960	0.291
.415	2.192	.690	1.049	.965	0.272
.420	2.161	.695	1.033	.970	0.250
.425	2.130	.700	1.019	.975	0.227
.430	2.099	.705	1.006	.980	0.203
.435	2.070	.710	0.992	.985	0.175
.440	2.041	.715	0.977	.990	0.142
.445	2.013	.720	0.964	.995	0.100

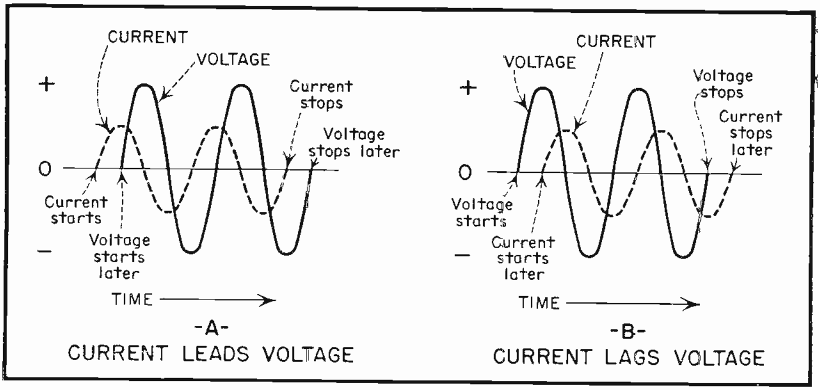

Fig. 2. Phase relationships shown with waveforms.

before it finally dies down to zero. Figure 2(B) corresponds to Figure 1(B) in showing a lagging current.

Since most a.c. circuits contain something more than resistance, current and voltage seldom are in phase in these circuits. In simple resistance circuits, a.c. power (watts) can be calculated exactly as for d.c. circuits simply by multiplying the current by the voltage. When the current and voltage are not in phase, as is the case in all reactive (inductive and capacitive) circuits, finding the a.c. power value is not so simple. We must multiply the current by the voltage and then multiply this product by the power factor. The true a.c. power value is somewhat less than the product of volts times amperes, since the power factor is a decimal in practical cases.

The best power factor would be 1. In practice, we try to keep it as close to 1 as possible. In a circuit with unity power factor, the power in watts would be equal to the simple product of volts times amperes. To illustrate the detrimental effect of low power factor, consider the example of 115 volts forcing 6 amperes through a circuit with power factor of 0.5. We ought to have 115 × 6, or 690 watts, available. But we must multiply E × I by the power factor, so our true power actually is only 115 × 6 × 0.5, or 345 watts. Economically, this means simply that we must force 12 amperes into such a circuit in order to do a 690-watt job. Heavier conductors must be installed to handle the higher current, and the voltage drop along such conductors will be proportionately larger.

Numerically, the power factor is equal to the actual power, as measured with a wattmeter, divided by the apparent power, obtained by multiplying E by I. Thus:

$$(1) \quad \text{p.f.} = \frac{\text{WATTS}}{E \times I}$$

Since the true a.c. watts in a reactive circuit will be lower in value than the apparent watts, it is easy to see from Equation (1) why the power factor will be less than 1. Numerically, the power factor is equal also to the cosine of the phase angle.

Capacitor circuits are said to have a leading power factor; inductive circuits a lagging power factor. Inductive circuits include motors which undoubtedly are the most widely used electrical machines. The leading power factor of capacitors (due to the leading current through these units) can be

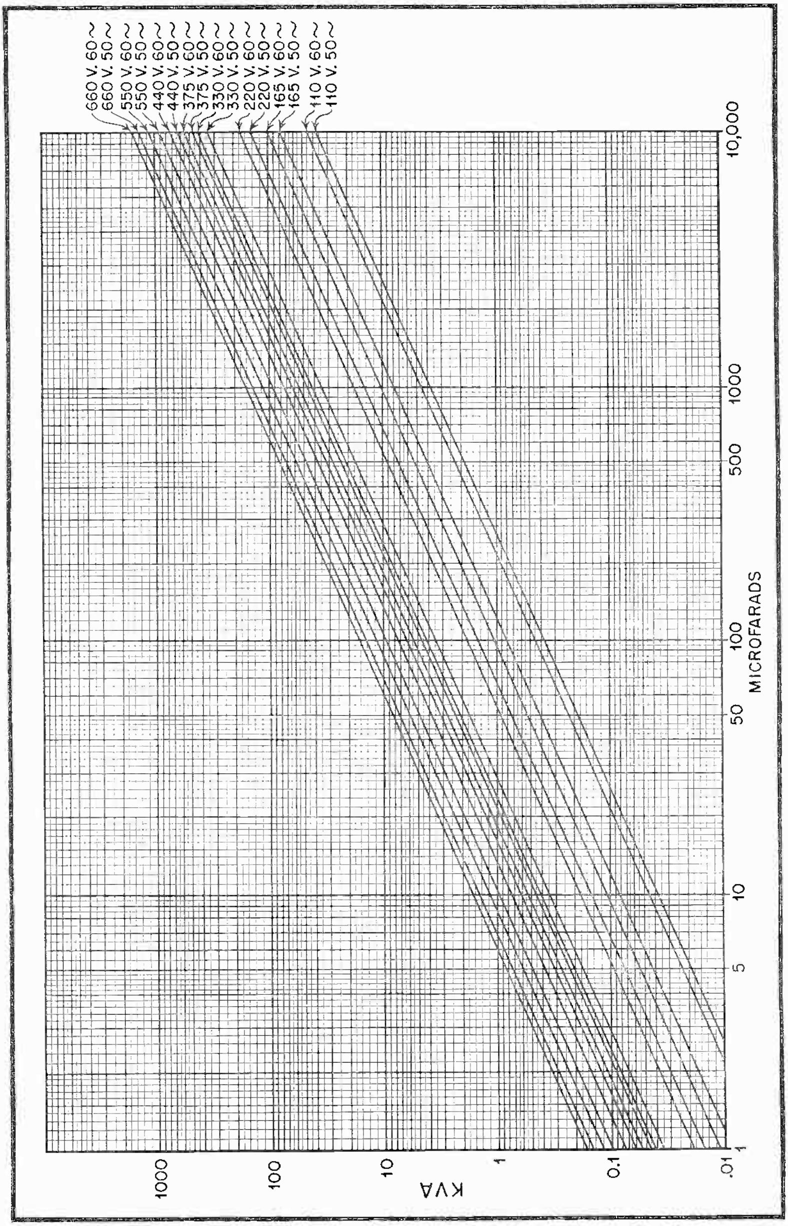

Chart 3 — KVA vs. MICROFARADS.

employed advantageously to counteract the detrimental lagging current in motors, fluorescent lamps, and other lagging-power-factor devices. The relatively simple connection of a capacitor of the proper rating in parallel with the power-line terminals at the motor will improve the motor power factor and, for a given work load, the motor will draw less current from the power line. This is beneficial both to the consumer and the electric power company. The consumer because, with power factor correction, he is able to increase the number of machines he can operate at a given total current drain and is not compelled to install heavier conductors to take care of the additional machines. The power company because it sells its product by the kilowatt hour, but must supply amperes as well, for which it does not bill. A customer with power factor correction will demand fewer unpaid amperes per kilowatt hour than the customer who does not have this improvement.

As an example of the current reduction afforded by power factor correction, consider the following illustrative example: A 220-volt, single-phase motor draws 10 amperes at full load. Its actual power drain measured with a wattmeter is 1500 watts, or 1.5 k. w. The apparent power in this case, obtained by multiplying E by I (220 × 10) is 2200 watts, or 2.2 k. w. The power factor of this machine, from Equation (1), is 1.5/2.2 = 0.682, or 68.2%. If we correct this power factor to 90% (it seldom is of any advantage to "over-correct," that is to shoot at 100%), the current drain for the same measured 1500 watts will be the watts divided by 0.90 × 220 = 1500/188 = 7.89 amperes. This new current value is 2.11 amperes lower than the first value before power factor correction. In other instances, the current saving would be even greater.

Determining the proper value of capacitance to correct the power factor of a given electrical machine requires a rather roundabout calculation involving the trigonometry of phase angles. In order to simplify these calculations to the point that they may be handled by non-technical personnel including sales people, we have prepared Charts 1, 2, and 3 which accompany this article. In Chart 2, the POWER FACTOR values are cosines of the phase angle, while the MULTIPLIER values are tangents of the phase angle.

To determine the proper value of capacitance for a given amount of power factor correction, proceed according to the following steps in the order in which they are given:

(1) Measure the voltage (E) and current (I) of the machine for which the power factor correction is desired.
(2) Multiply E × I × 0.001 to obtain the KVA.

(3) With a wattmeter, measure the power taken by the machine. This is the KW value which will be used later in calculations. (If the meter reads in WATTS instead of kilowatts, multiply its reading by 0.001 to obtain KW).

(4) Determine the power factor of the machine by dividing KW by KVA. Thus; p. f. = KW/KVA.

(5) Decide what amount of improvement in power factor you want (for example; decide to raise the present power factor of the machine to 90%, or 0.90).

(6) On Chart 2, find first the multiplier corresponding to the present power factor you calculated in Step 4. Then, find the multiplier corresponding to the improved power factor you desire.

(7) Subtract the smaller of these multipliers from the larger one. Call this difference the "final multiplier."
(8) Multiply the KW by this final multiplier. The result is the capacitor KVA required for correction.

(9) The required capacitance in microfarads then may be found by multiplying the capacitor KVA (obtained in Step 8) by the proper figure selected from Chart 1. The Chart 1 figure, for

(Continued on page 10)

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example, will be 201 if the machine is operated at 125 volts 50 cycles. Or it will be 8.76 if the machine is operated at 550 volts 60 cycles; etc., etc.

(10) The required capacitance also may be determined from the graph in Chart 3, by following to the right the line corresponding to the capacitor KVA (obtained in Step 8) until it intersects with the applicable voltage-frequency line, and then following the vertical line of intersection downward to read the capacitance on the horizontal MICROFARADS scale.

CHART 1.

Volts	Microfarads per KVA 50 cycles	60 cycles
110	260	219
115	238	200
125	201	170
165	115	97.5
220	65	55
330	28.8	24.3
375	22.3	18.8
440	16.2	13.7
550	10.4	8.76
660	7.2	6.09

ILLUSTRATIVE EXAMPLE. A 110-volt 60-cycle motor is found (by Steps 1 and 3) to draw 0.7 k. w. and 8.5 amperes. By Step 1, KVA = 110 × 8.5 × 0.001 = 0.935. By Step 4, the power factor = 0.700/0.935 = 0.750. Let us decide to improve this power factor to 0.950 (95 per cent).

By Step 6, the mutiplier corresponding to the original power factor of 0.750 is 0.882. And the multiplier corresponding to a power factor of 0.950 is 0.328. By Step 7, the final multiplier is 0.882 — 0.328 = 0.554.

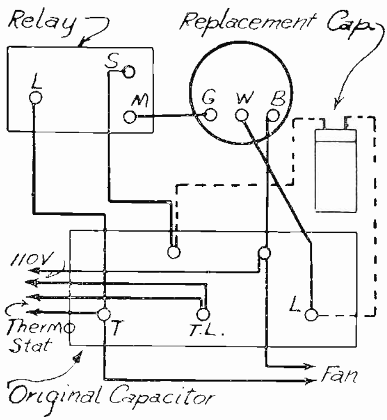
0.7 k. w. (obtained in Step 3) multiplied by 0.554 = 0.338, which is the required capacitor KVA.

Since the motor is 110 volts 60 cycles, we multiply the 110 v.-60 cycle value (219) from Chart 1 by the final multiplier (0.554) to obtain 121.3 microfarads, which is the required capacitance for correction to 95 per cent.

We also can find the capacitance value directly from the intersection of the 110-volt, 60-cycle line (in Chart 3) with the 0.554 line, reading our value on the MICROFARADS scale.

Replacement Capacitor on Kelvinator Unit

Here is a tip on replacing a 5 terminal capacitor on a Kelvinator ice cream cabinet having a sealed condensing unit that was submitted by Chas. H. Bricknell, Plympton, Mass., in "The Refrigeration Service Engineer." If the capacitor fails and you do not have a replacement capacitor with the 5 terminals, use a conventional 2 terminal capacitor as per diagram.



If the original capacitor is open circuited, as is usually the case, it may be used for binding posts connections, but if it is short circuited, make connections with a small bolt, connecting the new capacitor to "S" on the relay and "W" from the compressor.