POWER FACTOR CORRECTION

A GUIDE FOR THE PLANT ENGINEER

What is power factor?

Special electrical requirements of inductive loads

Most loads in modern electrical distribution systems are inductive. Examples include motors, transformers, gaseous tube lighting ballasts and induction furnaces. Inductive loads need an electromagnetic field to operate.

Inductive loads require two kinds of current:

- working power (KW) to perform the actual work of creating heat, light, motion, machine output, etc.
- reactive power (KVAR) to sustain the electromagnetic field

Working power consumes watts and can be read on a wattmeter. It is measured in kilowatts (KW). Reactive power doesn't do useful "work" but circulates between the generator and the load. It places a heavier drain on the power source, as well as on the power source's distribution system. Reactive power is measured in kilovolt-amperes reactive (KVAR).

Working power and reactive power together make up apparent power. Apparent power is measured in kilovolt-amperes (KVA).

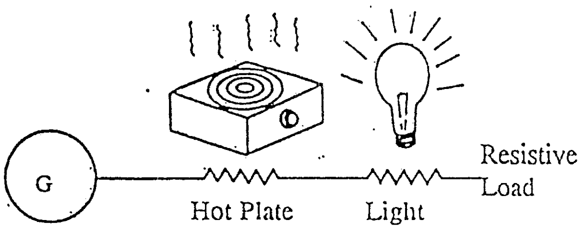


Figure 1
KW Power

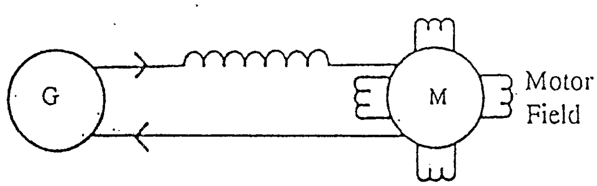


Figure 2
KVAR Power

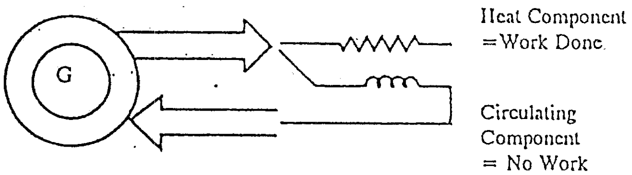
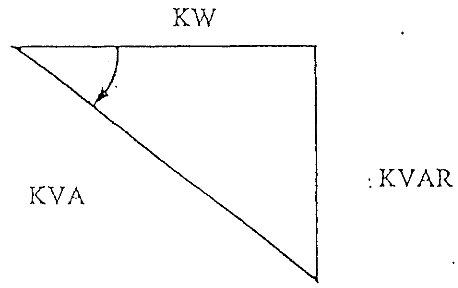


Figure 3
KVA Power

A right "power" triangle is often used to illustrate the relationship between KW, KVAR, KVA.



$$\text{COS}\,\theta = \frac{\text{KW}}{\text{KVA}} = \text{PF}$$

Figure 4
Right Power Triangle

Note: For a discussion on power factor in non-linear, non-sinusoidal systems, turn to page 15.

Fundamentals of power factor

Power factor is the ratio of working power to apparent power. It measures how effectively electrical power is being used. A high power factor signals efficient utilization of electrical power, while a low power factor indicates poor utilization of electrical power.

To determine power factor (PF), divide working power (KW) by apparent power (KVA). In a linear or sinusoidal system, the result is also referred to as the cosine θ.

$$\text{PF} = \frac{\text{KW}}{\text{KVA}} = \text{cosine }\theta$$

For example, if you had a boring mill that was operating at 100 KW and the apparent power consumed was 125 KVA, you would divide 100 by 125 and come up with a power factor of 0.80.

$$\frac{(\text{KW})\,100}{(\text{KVA})\,125} = (\text{PF})\ 0.80$$

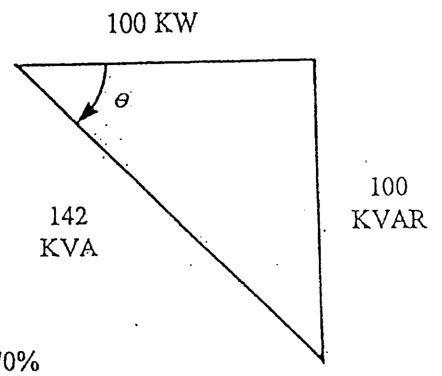
Note: Power factor in a non-linear environment will not hold to the presented formulas or tables without filters or chokes installed on the harmonic generators.

Why should I be concerned about low power factor?

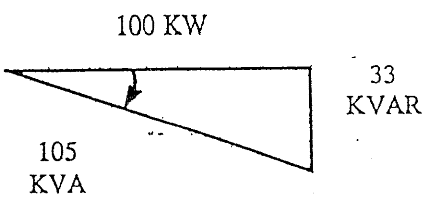
Low power factor means you're not fully utilizing the electrical power you're paying for. In the example above, with a power factor of 80%, your boring mill would be utilizing only 80% of the energy supplied by the utility. That means only 80% of the incoming current is being used to produce useful work.

As the triangle relationships in Figure 5 demonstrate, KVA decreases as power factor increases. At 70% power factor, it requires 142 KVA to produce 100 KW. At 95% power factor, it requires only 105 KVA to produce 100 KW. Another way to look at it is that at *70% power factor, it takes 35% more current to do the same work.*

Figure 6 illustrates the effects of various power factors on an electrical system of 100 KW demand at 480 volts. As the chart shows, the wire size requirement on the system with 100% power factor is no. 1/0. The same system with a 60% power factor requires a no. 4/0 conductor. Actual wire diameters are shown.

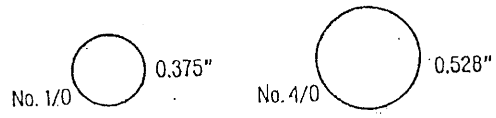


$$PF = \frac{100}{142} = 70\%$$

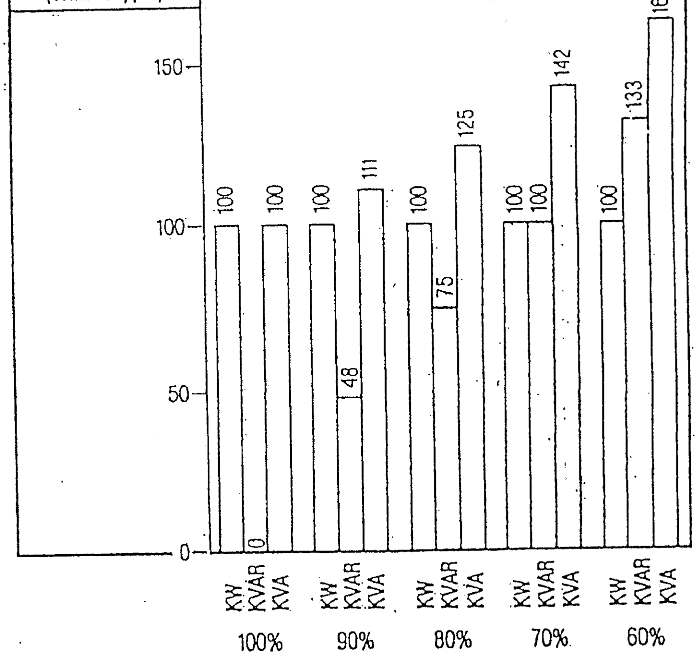


$$PF = \frac{100}{105} = 95\%$$

Figure 5
Typical Power Triangles



Load (Amperes)	120	133.7	150.5	170	201
Transformer	100 KVA	125 KVA	125 KVA	150 KVA	200 KVA
NEC Wire Size	1/0	1/0	2/0	2/0	4/0
Wire Diameter (THHN Copper)	0.375	0.375	0.419	0.419	0.528



POWER FACTOR

Figure 6
Characteristics of Power Factor on 100 KW Loads

What can I do to improve power factor?

You can improve power factor by adding power factor correction capacitors to your plant distribution system.

When apparent power (KVA) is greater than working power (KW), the utility must supply the excess reactive current *plus* the working current. Power capacitors act as reactive current generators. By providing the reactive current, they reduce the total amount of current your system must draw from the utility.

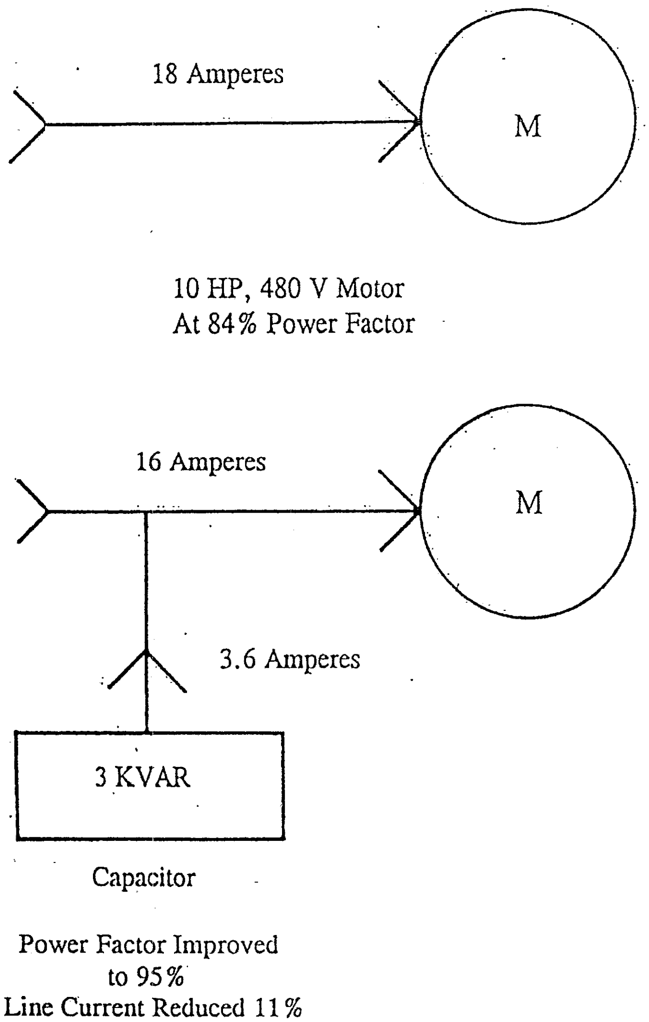


Figure 7
Capacitors as KVAR Generators

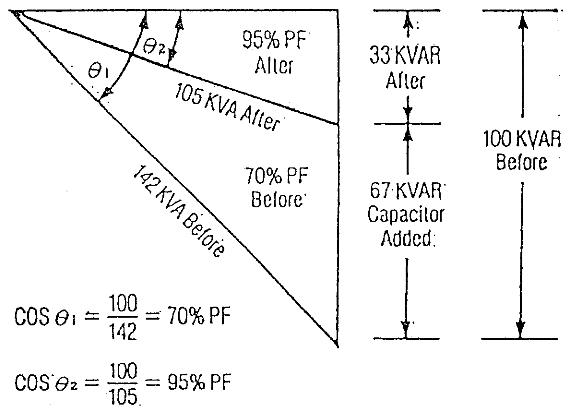


Figure 8
Required Apparent Power Before
and After Adding Capacitors

95% power factor provides maximum benefit

Theoretically, capacitors could provide 100% of needed reactive power. In practical usage, however, *power factor correction to approximately 95% provides maximum benefit.* The power triangle in Figure 8 shows apparent power demands on a system before and after adding capacitors. By installing power capacitors and increasing power factor to 95%, apparent power is reduced from 142 KVA to 105 KVA - *a reduction of 35%.*

How much can I save by installing power capacitors?

Power capacitors provide many benefits:

- Reduced electric utility bills
- Increased system capacity
- Improved voltage
- Reduced losses

Reduced utility bills

Your electric utility provides working (KW) and reactive power (KVAR) to your plant in the form of apparent power (KVA). While reactive power (KVAR) doesn't register on KW demand or KW hour meters, the utility's transmission and distribution system must be large enough to provide it. Utilities have various ways of passing along the expense of larger generators, transformers, cables, switches, etc. to you.

As shown in the following case histories, capacitors can save you money no matter how your utility bills you for power.

KVA billing

The utility measures and bills every amp of current, including reactive current.

CASE I

Assume an uncorrected 460 KVA demand, 480 volt, 3-phase @ 87% power factor (normally good.)

BILLING:
$4.75/KVA demand Correct to 97% Power Factor.

SOLUTION:
KVA x Power Factor = KW
460 x 0.87 = 400 KW Actual Demand

$$\frac{KW}{PF} = KVA \qquad \frac{400}{0.97} = 412 \text{ Corrected Billing Demand}$$

From Table 3 KW Multipliers, to raise the Power Factor from 0.87 to 0.97 requires capacitor:

multiplier 0.316 x KW
 0.316 x 400 = 126 KVAR
 (Use 130 KVAR)

Uncorrected original billing:	Corrected new billing:
460 KVA x $4.75	412 KVA x $4.75
= $2185/mo.	= $1957/mo.
- $1957	

$ 228/mo. saving x 12 = $2736 annual saving

130 KVAR, 480 volt capacitor cost in 1988, $1750.00 (installation extra). This capacitor pays for itself in less than eight months.

CASE 2

Assume the same conditions except that:
400 KW @ 87% = 460 KVA
400 KW @ 97% = 412 KVA Corrected Billing

KVA Demand Charge: $1.91/KVA/month
(112,400 KWH/month energy consumed.)

Energy Charge:
$0.0286/KWH (first 200 KWH/KVA of demand).
$0.0243/KWH (next 300 KWH/KVA of demand).
$0.021/KWH (all over 500KWH/KVA of demand).

Uncorrected:	Corrected:
Demand:	
460KVA x $1.91	412 KVA x $1.91
= $878.60	= $786.92
- $786.92	

$ 91.68 Savings in demand charge.

Energy:

KWH = 112,400	KWH = 112,400
460x200 = 92,000KWH	412x200 = 82.400KWH
@ $0.0286 = $2631.20	@ $0.0286 = $2356.64
460 x 30 = 138,000	412 x 300 = 123,600
but balance only = 20,400	but balance only = 30,000
@ $0.0243 = $ 495.72	@ $0.0243 = $ 729.00
$2631.20	$2356.64
+ $ 495.72	+ $ 729.00
$3126.92 Uncorrected Energy Charge	$3085.64 Corrected Energy Charge

- $3085.64
$ 41.28 saving in energy charge due to rate change.

(9600 KWH in first step reduced by $0.0043)

NOTE: This is not a reduction in energy consumed, but in billing only.

Saving:
 $ 41.28 Energy
 +$ 91.68 Demand
 $ 132.96 Monthly total saving
 x 12
 $1595.52

A 130 KVAR capacitor can be paid for in less than 14 months.

KW demand billing with power factor adjustment

The utility bills according to KW demand and adds a surcharge or adjustment for power factor. The adjustment may be a multiplier applied to KW demand. The following formula shows a billing based on 90% power factor:

$$\frac{\text{KW demand x 0.90}}{\text{actual power factor}}$$

If power factor was 0.84, the utility would require 7% increase in billing, as shown in this formula:

$$\frac{KW \times 0.90}{0.84} = 1.07 \text{ multiplier}$$

Some utilities charge for low power factor but give a credit or bonus for power factor above a certain level.

CASE 1

Assume a 400 KW Load, 87% power factor with the following Utility tariff:

A. Demand Charges:

First 40 KW	@ $10.00/KW monthly billing demand
Next 160 KW	@ $ 9.50/KW
Next 800 KW	@ $ 9.00/KW
All over 1 000 KW	@ $ 8.50 KW

B. Power Factor Clause.

Rates based on power factor of 90% or higher. When power factor is less than 85%, the demand will be increased 1 % for each 1 % that the power factor is below 90%. If the power factor is higher than 95%, the demand will be decreased 1 % for each 1 % that the power factor is above 90%. *(Note that there would be no penalty for 87% power factor. However, a bonus could be credited if the power factor were raised to 96%.)*

To raise an 87% power factor to 96%, refer to Table 3. Find 0.275 x 400 KW =110KVAR (Select 120 KVAR to assure the maintenance of the 96% level).

To Calculate savings:

Normal 400KW billing demand

First 40KW @ $10.00 =	$ 400.00
Next 160KW @ $ 9.50 =	$1520.00
Bal. 200KW @ $ 9.00 =	$1800.00
Total 400KW	$3720.00 Normal Monthly Billing

New Billing:

KWx0.90 =

New Power Factor

$$\frac{400 \times 0.90}{96} = 375 \text{ KW demand}$$

First 40KW @ $10.00	= $ 400.00
Next 160KW @ $ 9.50	= $1520.00
Bal. 175KW @ $ 9.00	= $1575.00
	$3495.00
	Power Factor Adjusted Billing

CASE 2

With the same 400KW load, the power factor is only 81%. In this example, the customer will pay an adjustment based on:

$$\frac{400}{0.81} \times .90 = 444 \text{ Billing KW Demand}$$

(From Case 1. When the Power Factor = 96%, the Billing demand is 375 KW = $3495.00 per month)

First 40KW	@ $10.00	= $ 400.00
Next 160KW	@ $ 9.50	= $1520.00
Next 244KW	@ $ 9.00	= $2196.00
Total 444KW		$4116.00 - $3495.00
		+$621.00 x 12 = $7452.00
		yearly savings if corrected to 96%.

$4116.00	Charge at 81%
-$3720.00	Normal KW Demand Charge
$ 396.00	Power Factor Adjustment for 81% Power Factor*

To raise 81% power factor to 96%, select the multiplier from Table 3. 0.432 x 400KW = 173KVAR. Use 180KVAR to assure a 96% power factor.

The cost of a 180 KVAR capacitor is $2070.00, and the payoff is less than four months.

*55KVAR would eliminate the penalty by correcting power factor to 85%.

KVAR reactive demand charge

The utility imposes a direct charge for the use of magnetizing power, usually a waiver of some percentage of KW demand. For example, if this charge was 60 cents per KVAR for everything over 50% of KW, and a 400 KW load existed at the time, the utility would provide 200 KVAR free.

CASE 1

Assume a 400KW load demand at 81 % power factor.

Tariff Structure:

Demand Charge is

$635.00 for the first 200 KW demand

$ 2.80 per KW for all addition

Reactive demand charge is:

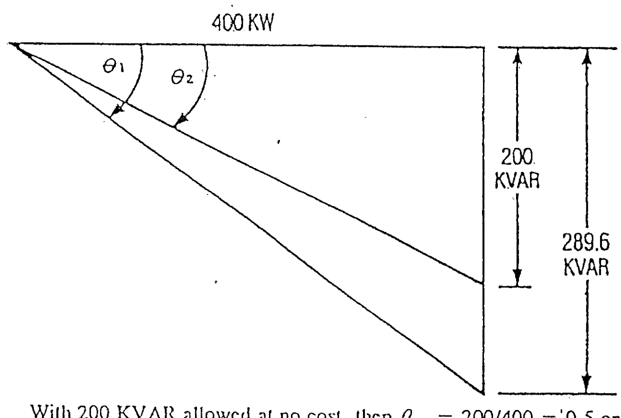
$ 0:60 per KVAR in excess of 50% of KW demand.

In this example, KW demand = 400KW, therefore 50% = 200 KVAR which will be furnished at no cost.

$$\cos \theta = PF = \frac{KW}{KVA} \text{ or } \frac{ADJ}{HYP}$$

$$\text{Also } \tan \theta = \frac{KVAR}{KW} = \frac{OPP}{ADJ}$$

This ratio is the basis of the Table of Multipliers. (Table 3).



With 200 KVAR allowed at no cost, then θ_2 = 200/400 = 0.5 or 50% of KW. From 1.0 or unity power factor column. Table 3, note that 0.500 falls between 89% and 90% power factor. The billing for excess KVAR is above that level. 81% power factor Tan θ_1 = 0.724 KVAR = KW x Tan θ_1 = 400 x 0.724 = 289.6 KVAR.

Since 200 KVAR is allowed, the excess KVAR is 89.6 (round to 90) x $0.60 = $54.00 per month billing for reactive demand.

SOLUTION:

To correct 400 KW from 81% to 90% requires 400 x 0.240 (from Table 3) 96 KVAR. (Use 100 KVAR). The 1985 cost for this capacitor is $1250.00. The payoff is about 23 months. NOTE: KVAR charges vary from about 15 cents to a dollar and free KVAR ranges from 25% (97% power factor) to 75% (80% power factor) of KW demand.

Increased system capacity

Power capacitors increase system current-carrying capacity. Raising the power factor on a KW load reduces KVA. Therefore, by adding capacitors, you can add additional KW load to your system without altering the KVA.

A plant has a 500KVA transformer operating near capacity. It draws 480KVA or 578 amperes at 480 volts. The present power factor is 75%, so the actual working power available is 360KW.

It is desired to increase production by 25%, which means that about 450KW output must be obtained. How is this accomplished? A new transformer would certainly be one solution. For 450KW output, the transformer would be rated at 600KVA to handle 75% power factor load. More likely, the next size standard rating would be needed. (750KVA).

Perhaps a better solution would be to improve the power factor and release enough capacity to accommodate the increased load.

To correct 450KW from 75% to 95% power factor requires 450 x 0.553 (from Table 3) 248.8KVAR use 250KVAR at about $3400.00.

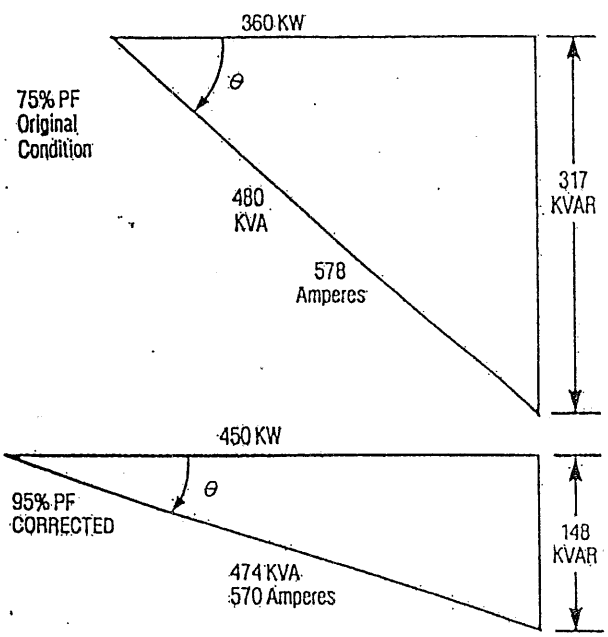


Figure 9

Correcting Power Factor Increases Transformer Output

The same principle holds true for reducing current on overloaded facilities. Increasing power factor from 75% to 95% on the same KW load results in 21% lower current flow. Put another way, it takes 26.7% more current for a load to operate at 75%, and 46.2% more current to operate at 65%.

Industries with low power factors benefit most from capacitors

Low power factor results when motors are operated at less than full load. This often occurs in cycle processes such as those using circular saws, ball mills, conveyors, compressors, grinders, punch presses, etc.- where motors are sized for the heaviest load. Examples of situations where low power factors (from 30% to 50%) occur include a surface grinder performing a light cut, an unloaded air compressor and a circular saw spinning without cutting.

The following industries typically exhibit low power factors:

Industry	*Uncorrected power factor*
saw mills	45%-60%
plastics (esp. extruders)	55%-70%
machine tools, stamping	60%-70%
plating, textiles, chemicals, breweries	65%-75%
hospitals, granaries, foundries	70%-80%

Include power capacitors in new construction/ expansion plans

Including power capacitors in your new construction and expansion plans can reduce the size of transformers, busses, switches, etc. and bring your project in at lower cost.

Figure 10 shows how much system KVA can be released by improving power factor. Raising the power factor from 70% to 90% releases 0.32 KVA per KW. On a 400 KW load, 128 KVA are released.

Improved voltage conditions

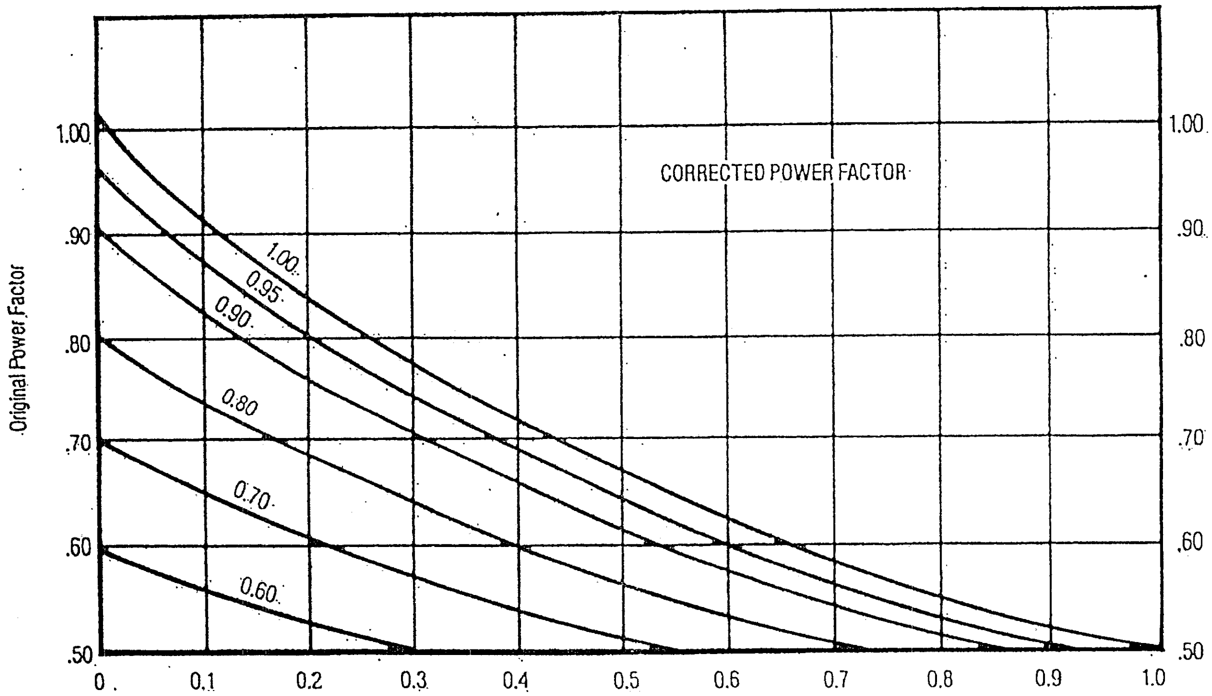
Low voltage, resulting from excessive current draw, causes motors to be sluggish and overheated. As power factor decreases, total line current increases, causing further voltage drop. By adding capacitors to your system and improving voltage, you get more efficient motor performance and longer motor life.

Reduced losses

Losses caused by poor power factor are due to reactive current flowing in the system. These are watt-related charges and can be eliminated through pwer factor correction.

Power loss (watts) in a distribution system is calculated by squaring the current and multiplying it by the circuit resistance (I^2R). To calculate loss reduction:

$$\%\text{ reduction losses} = 100 - 100 \times \left(\frac{\text{Original Power Factor}}{\text{New Power Factor}}\right)^2$$



KVA of System Capacity Released Per Kilowatt of Load

Figure 10
Corrected Power Factor Releases System KVA

How can I select the right capacitors for my specific application needs?

Once you've decided that your facility can benefit from power factor correction, you'll need to choose the optimum type size and number of capacitors for your plant.

There are two basic types of capacitor installations: individual capacitors on linear or sinusoidal loads and banks of fixed or automatically switched capacitors at the feeder or substation.

Individual vs. banked installations

Advantages of individual capacitors at the load:

- Complete control. Capacitors can't cause problems on the line during light load conditions.
- No need for separate switching. Motor always operates with capacitor.
- Improved motor performance due to more efficient power utilization and reduced voltage drops.
- Motors and capacitors can be easily relocated together.
- Easier to select the right capacitor for the load.
- Reduced line losses.
- Increased system ampacity

Advantages of bank installations at the feeder or substation:

- Lower cost per KVAR.
- Lower installation costs.
- Total plant power factor improved - reduces or eliminates all forms of KVAR charges.
- Automatic switching ensures exact amount of power factor correction, eliminates overcapacitance resulting overvoltages.

TABLE 1: SUGGESTED MAXIMUM CAPACITOR RATINGS— USED FOR HIGH EFFICIENCY MOTORS AND OLDER DESIGN (PRE "T-FRAME") MOTORS*

No. of Poles and Nominal Motor Speed in RPM

Induction Motor Horsepower Rating	2 3600 RPM		4 1800 RPM		6 1200 RPM		8 900 RPM		10 720 RPM		12 600 RPM	
	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3	41
5	2	12	2	13	2	17	3	25	4	32	4	37
7.5	2.5	11	2.5	12	3	15	4	22	5	30	6	34
10	3	10	3	11	3	14	5	21	6	27	7.5	31
15	4	9	4	10	5	13	6	18	8	23	9	27
20	5	9	5	10	6	12	7.5	16	9	21	12.5	25
25	6	9	6	10	7.5	11	9	15	10	20	15	23
30	7	8	7	9	9	11	10	14	12.5	18	17.5	22
40	9	8	9	9	10	10	12.5	13	15	16	20	20
50	12.5	8	10	9	12.5	10	15	12	20	15	25	19
60	15	8	15	8	15	10	17.5	11	22.5	15	27.5	19
75	17.5	8	17.5	8	17.5	10	20	10	25	14	35	18
100	22.5	8	20	8	25	9	27.5	10	35	13	40	17
125	27.5	8	25	8	30	9	30	10	40	13	50	16
150	30	8	30	8	35	9	37.5	10	50	12	50	15
200	40	8	37.5	8	40	9	50	10	60	12	60	14
250	50	8	45	7	50	8	60	9	70	11	75	13
300	60	8	50	7	60	8	60	9	80	11	90	12
350	60	8	60	7	75	8	75	9	90	10	95	11
400	75	8	60	6	75	8	85	9	95	10	100	11
450	75	8	75	6	80	8	90	9	100	9	110	11
500	75	8	75	6	85	8	100	9	100	9	120	10

*For use with 3-phase, 60 hertz NEMA Classification B Motors to raise full load power factor to approximately 95%.

TABLE 2: SUGGESTED MAXIMUM CAPACITOR RATINGS— "T-FRAME" NEMA "DESIGN B" MOTORS*

No. of Poles and Nominal Motor Speed in RPM

Induction Motor Horsepower Rating	2 3600 RPM		4 1800 RPM		6 1200 RPM		8 900 RPM		10 720 RPM		12 600 RPM	
	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %
2	1	14	1	24	1.5	30	2	42	2	40	3	50
3	1.5	14	1.5	23	2	28	3	38	3	40	4	49
5	2	14	2.5	22	3	26	4	31	4	40	5	49
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	12.5	30
25	7.5	12	7.5	17	8	19	10	23	12.5	25	17.5	30
30	8	11	8	16	10	19	15	22	15	24	20	30
40	12.5	12	15	16	15	19	17.5	21	20	24	25	30
50	15	12	17.5	15	20	19	22.5	21	22.5	24	30	30
60	17.5	12	20	15	22.5	17	25	20	30	22	35	28
75	20	12	25	14	25	15	30	17	35	21	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	35	12	35	12	40	14	45	15	50	17
150	30	10	40	12	40	12	50	14	50	13	60	17
200	35	10	50	11	50	11	70	14	70	13	90	17
250	40	11	60	10	60	10	80	13	90	13	100	17
300	45	11	70	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

*For use with 3-phase, 60 hertz NEMA Classification B Motors to raise full load power factor to approximately 95%.

Summary of Advantages/Disadvantages
of Individual, Fixed Banks, Automatic Banks, Combination

Method	Advantages	Disadvantages
Individual capacitors	Most technically efficient, most flexible	Higher installation cost
Fixed bank	Most economical, fewer installations	Less flexible, requires switches and/or circuit breakers
Automatic bank	Best for variable loads, prevents overvoltages, low installation cost	Higher equipment cost
Combination	Most practical for larger numbers of motors	Least flexible

Consider the particular needs of your plant

When deciding which type of capacitor installation best meets your needs, you'll have to weigh the advantages and disadvantages of each and consider several plant variables, including load type, load size, load constancy, load capacity, motor starting methods and manner of utility billing.

Load type

If your plant has many large motors, 25 hp and above, it is usually economical to install one capacitor per motor and switch the capacitor and motor together. If your plant consists of many small motors, ½ to 10 hp, you can group the motors and install one capacitor at a central point in the distribution system. Often, the best solution for plants with large and small motors is to use both types of capacitor installations.

Load size

Facilities with large loads benefit from a combination of individual load, group load and banks of fixed and automatically-switched capacitor units. A small facility, on the other hand, may require only one capacitor at the control board.

Sometimes, only an isolated trouble spot requires power factor correction. This may be the case if your plant has welding machines, induction heaters or D-C drives. If a particular feeder serving a low power factor load is corrected, it may raise overall plant power factor enough that additional capacitors are unnecessary.

Load constancy

If your facility operates around-the-clock and has a constant load demand, fixed capacitors offer the greatest economy. If load is determined by eight-hour shifts five days a week, you'll want more switched units to decrease capacitance during times of reduced load.

Load capacity

If your feeders or transformers are overloaded, or if you wish to add additional load to already loaded lines, correction must be applied at the load. If your facility has surplus amperage, you can install capacitor banks at main feeders. If load varies a great deal, automatic switching is probably the answer.

Utility billing

The severity of the local electric utility tariff for power factor will affect your payback and ROI. In many areas, an optimally designed power factor correction system will pay for itself in less than one year.

How much KVAR do I need?

The unit for rating power factor capacitors is a KVAR, equal to 1000 volt-amperes of reactive power. The KVAR rating signifies how much reactive power the capacitor will provide.

Sizing capacitors for individual motor loads

To size capacitors for individual motor loads, use Tables 1 and 2. Simply look up the type of motor frame, RPM and horsepower. The charts indicate the KVAR rating you need to bring power factor to 95%. The charts also indicate how much current is reduced when capacitors are installed.

Sizing capacitors for entire plant loads

If you know the total KW consumption of your plant, its present power factor and the power factor you're aiming for, you can use Table 3 to select capacitors.

TABLE 3: MULTIPLIERS TO DETERMINE CAPACITOR KILOVARS REQUIRED FOR POWER FACTOR CORRECTION

Original Power Factor	Corrected 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
060	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

Instructions: 1. Find the present power factor in column 1 2. Read across to optimum power factor column 3. Multiply that number by KW demand

Example: If your plant consumed 410 KW, was currently operating at 73% power factor and you wanted to correct power factor to 95%, you would:

1. Find 0.73 in column 1 2. Read across to 0.95 column 3. Multiply 0.607 by 410 = 249 (round to 250)
4. You need 250 KVAR to bring your plant to 95% power factor

If you don't know the existing power factor level of your plant, you will have to calculate it before using Table 3. To calculate existing power factor: KW divided by KVA = Power Factor

USA Customer

TABLE 4: RECOMMENDED WIRE SIZES, SWITCHES, AND FUSES FOR 3-PHASE, 60 Hz CAPACITORS

(These wire sizes are based on 135% of rated current in accordance with the 1987 National Electrical Code, Article 460)

	240 VOLTS				480 VOLTS				600 VOLTS			
KVAR	Current* (Amps)	Wire Size 90°C-Type THHN XHHW* or Equiv.†	Fuse (Amps)	Switch (Amps)	Current* (Amps)	Wire Size 90°C-Type THHN XHHW* or Equiv.†	Fuse (Amps)	Switch (Amps)	Current* (Amps)	Wire Size 90°C-Type THHN XHHW* or Equiv.†	Fuse (Amps)	Switch (Amps)
.5	1.2	14	3	30	—	—	—	—	—	—	—	—
1	2.4	14	6	30	1.2	14	3	30	1.0	14	3	30
1.5	3.6	14	6	30	1.8	14	3	30	1.4	14	3	30
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	250	400	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	346	(2)250M	600	600
400					480	(2)500M	800	800	384	(2)300M	650	800

*Rated current based on operation at rated voltage, frequency and KVAR.

† Consult National Electrical Code for other wire types. Above size based on 35°C Ambient Operation. (Refer to NEC table 310-16.)

Note: Fuses furnished within Capacitor Assembly may be rated at higher value than shown in this table. The table is correct for field installations and reflects the manufacturer's suggested rating for over current protection and disconnect means in compliance with the National Electrical Code.

TABLE 2

(See Rules 4-004, 8-104, 12-2212, 26-000, 26-744, 42-008, 42-016 and Tables 5 A, 19 and D3)

ALLOWABLE AMPACITIES FOR NOT MORE THAN 3 COPPER CONDUCTORS IN RACEWAY OR CABLE

Based on Ambient Temperature of 30° C*

Size AWG kcmil	Allowable Ampacity†‡‡					
	60° C ‡	75° C ‡	85 – 90° C ‡	110° C ‡	125° C ‡	200° C ‡
	Type TW	Types RW75, TW75	Types R90, RW90, T90 NYLON / Paper / Mineral-insulated Cable**	See Note (1)	See Note (1)	See Note (1)
14	15	15	15	30	30	30
12	20	20	20	35	40	40
10	30	30	30	45	50	55
8	40	45	45	60	65	70
6	55††	65	65	80	85	95
4	70	85	85	105	115	120
3	80	100	105	120	130	145
2	100	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	265	315	335	—
300	240	285	295	345	380	—
350	260	310	325	390	420	—
400	280	335	345	420	450	—
500	320	380	395	470	500	—
600	355	420	455	525	545	—
700	385	460	490	560	600	—
750	400	475	500	580	620	—
800	410	490	515	600	640	—
900	435	520	555	—	—	—
1000	455	545	585	680	730	—
1250	495	590	645	—	—	—
1500	520	625	700	785	—	—
1750	545	650	735	—	—	—
2000	560	665	775	840	—	—
Col. 1	**Col. 2**	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7

**See Table 5 A for the correction factors to be applied to the values in Columns 2 to 7 for ambient temperatures over 30° C.*

† The ampacity of aluminum-sheathed cable is based on the type of insulation used on the

Where should I install capacitors in my plant distribution system?

At the load

Since capacitors are KVAR generators, the most efficient place to install them is directly at the motor, where KVAR is consumed. Three options exist for installing capacitors at the motor. Use Figures 11, 12 and 13, and the information below to determine which option is best for each motor.

Location A- motor side of overload relay

- New motor installations in which overloads can be sized in accordance with reduced current draw
- Existing motors when no overload change is required

Location B -between the starter and overload relay

- Existing motors when overload rating surpasses code (see Appendix for NEC code requirements)

Location C- line side of starter

- Motors that are jogged, plugged, reversed
- Multi-speed motors
- Starters with open transition and starters that disconnect/reconnect capacitor during cycle
- Motors that start frequently
- Motor loads with high inertia, where disconnecting the motor with the capacitor can turn the motor into a self
- excited generator

At the service feeder

When correcting entire plant loads, capacitor banks can be installed at the service entrance, if load conditions and transformer size permits. If the amount of correction is too large, some capacitors can be installed at individual motors or branch circuits.

When capacitors are connected to the bus, feeder, motor control center or switchboard, a disconnect and over-current protection must be provided.

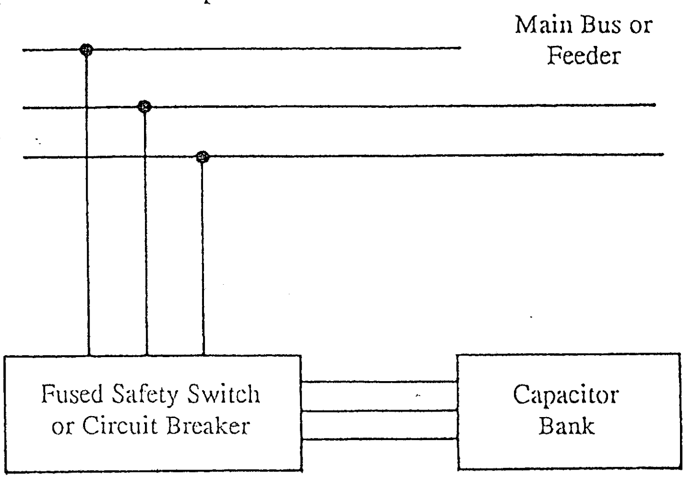


Figure 11
Installing Capacitors On-Line

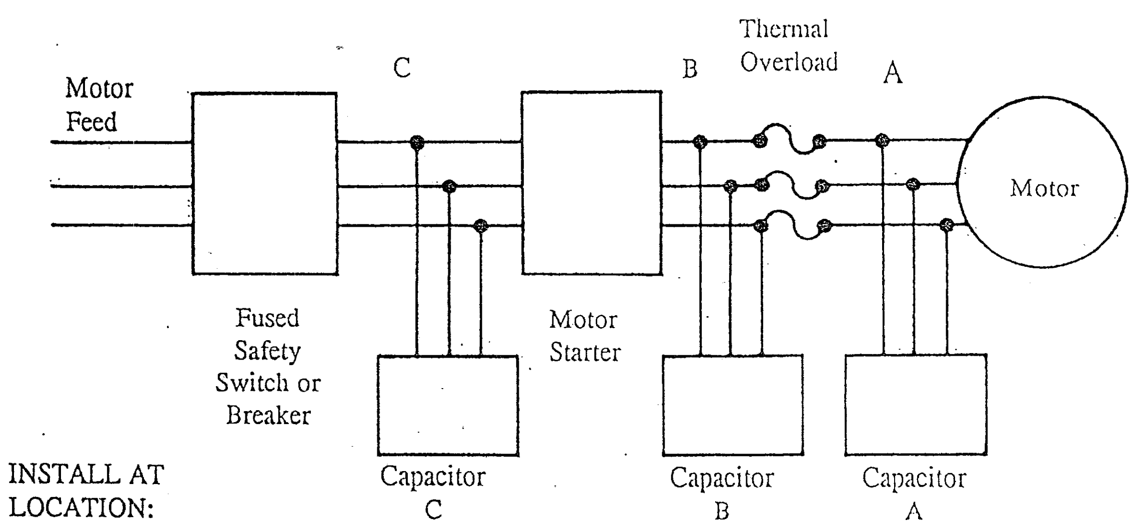
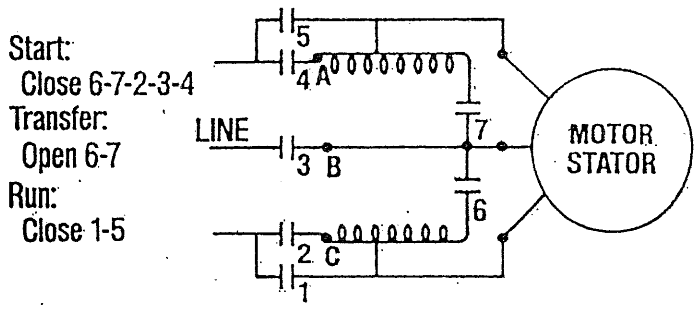
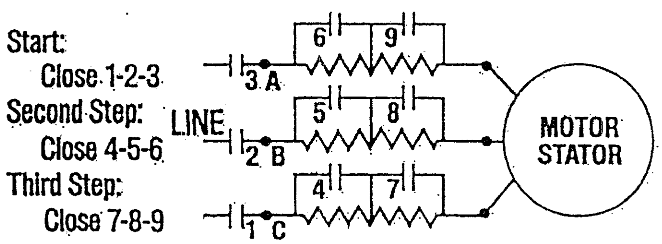


Figure 12
Locating Capacitors on Motor Circuits

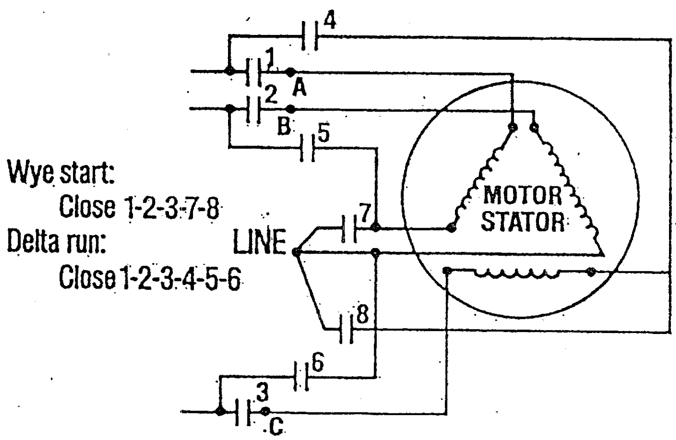
Figure 13
Locating Capacitors on Reduced Voltage and Multi-Speed Motors



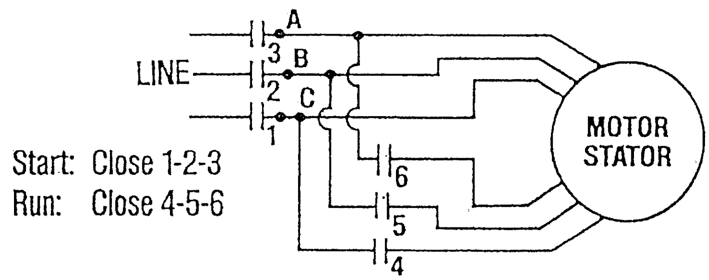
AUTOTRANSFORMER-CLOSED TRANSITION
Connect capacitor on motor side of starting contacts (2,3,4) at points A-B-C



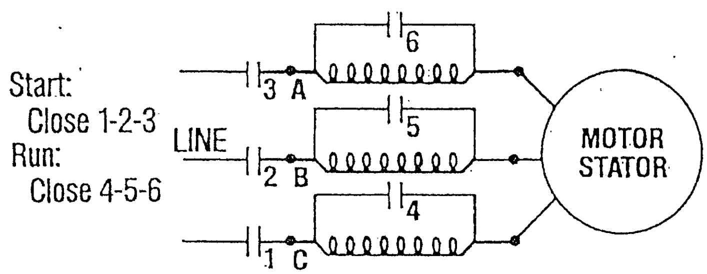
SERIES RESISTANCE STARTING
Connect capacitor on motor side of starting contactor (1,2,3) at points A-B-C.



WYE-DELTA STARTING
Connect capacitor on motor side of starting contacts (1,2,3) at points A-B-C.



PART-WINDING STARTING
Connect capacitor on motor side of starting contacts (1,2,3) at points A-B-C.



REACTOR STARTING
Connect capacitor on motor side of starting contactor (1,2,3) at points A-B-C.

What about maintenance?

Capacitors have no moving parts to wear out and require very little maintenance. Check fuses on a regular basis. If high voltages, harmonics, switching surges or vibration exists, fuses should be checked more frequently.

Our capacitors operate warm to the touch. If the case is cold, check for blown fuses, open switches or other power losses. Also check for bulging cases and puffed up covers, which signal operation of the capacitor interrupter.

Code requirements for capacitors:

Nameplate KVAR: Tolerance + 15, -0%

Discharge resistors: Capacitors rated at 600 volts and 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 (121% KVAR), 15% capacitance tolerance and harmonic voltages over the fundamental frequency (60 Hz).

Dielectric strength test. Twice the rated A-C voltage (or a D-C voltage 4.3 times the A-C rating for non-metallized systems).

Overcurrent protection: Fusing between 1.65 and 2.5 times rated current to protect case from rupture. Does not preclude NEC requirement for overcurrent protection in all 3 ungrounded conductors. (Exception: when capacitor is connected to the load side of the motor overcurrent protection, fused disconnects or breaker protection is not required. However, *we highly recommend fusing for all indoor applications whenever employees may be working nearby.)*

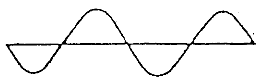
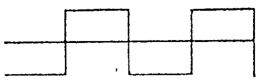
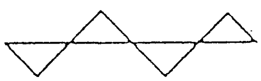
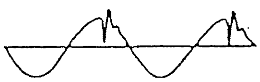
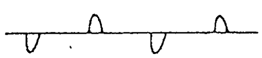
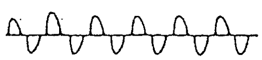
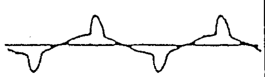
Waveform	Description	Average (RMS calibrated)	Peak (RMS calibrated)	True RMS
	Sine wave	100.0 Amps	100.0 Amps	100.0 Amps
	Square wave	100.0 Amps	63.6 Amps	90.0 Amps
	Triangle wave	100.0 Amps	125.7 Amps	103.3 Amps
	Sine wave with exponentially damped impulse	100.0 Amps	129.2 Amps	100.8 Amps
	Single-phase electronic load current	100.0 Amps	400.1 Amps	199.4 Amps
	3-phase wye electronic load neutral current	100.0 Amp	156.5 Amps	115.4 Amps
	Single-phase electronic load plus 30° linear load	100.0 Amps	201.2 Amps	119.9 Amps

Figure 14
RMS Equivalent Heating for Various Wave Shapes

Can capacitors be used in non-linear, non-sinusoidal environments?

Until recently, almost all loads were linear, with the current wave-form closely matching sinusoidal voltage wave-form and changing in proportion to the load. Lately, non-linear loads-which use current in pulses and at a load frequency other than 60 Hz-have increased dramatically.

Examples of linear and non-linear devices are as follows:

Linear devices	*Non-linear devices*
Motors	DC drives
Incandescent lighting	Variable frequency drives
Heating loads	Programmable controllers
	Induction furnaces
	Arc-type lighting
	Personal computers
	Uninterruptible power supplies (UPS)

The increase in non-linear loads has led to harmonic distortion in electrical distribution systems. *Although capacitors do not cause harmonics aggravate existing conditions.*

The existence of harmonic currents is a site-specific problem. It results from the complex interrelationship between all the electrical electronic equipment in a facility and, thus, is difficult to predict and model.

A discussion on Variable Frequency Drives (VFD) will help explain the problems associated with harmonics. A VFD uses switching power supplies to control output. In a six-step VFD, the control switches six times per cycle in an effort to simulate a sine wave. As the time between switches changes, the motor receives varying apparent frequencies and changes synchronous speed accordingly.

These changes in apparent frequencies lead to two problems: large voltage spikes and distorted current wave shapes. The voltage spikes are short and generally won't affect equipment that doesn't use a zero crossing of the voltage wave shape for timing. The distorted current wave shape is the "harmonic generator."

Harmonics cause additional noise on the line, and this noise generates heat. The increase in heat can cause nuisance tripping of circuit breakers. Power factor capacitors experience the same problem. Under thermal overload, their fuses blow. Thus, they provide an early warning signal that harmonic currents exist in the facility.

Capacitor banks and transformers cause resonance

Capacitors and transformers can create dangerous resonance conditions when capacitor banks are installed at the service entrance. Under these conditions harmonics produced by non-linear devices can be amplified many fold.

You can estimate the resonant harmonic by using the following formula:

$$h = \sqrt{\frac{KVA_{sys}}{KVAR}}$$

KVA_{sys} = short circuit capacity of the system
KVAR = amount of capacitor KVAR on the line
h = the harmonic number referred to a 60Hz base

If h is near the values of the major harmonics generated by a non-linear device- i.e., three, five, seven, eleven, ... - then the resonance circuit will greatly increase harmonic distortion.

For example, if the plant has a 1,500 KVA transformer with 5½% impedance and the short circuit rating of the utility is 48,000 KVA, then KVA_{sys} would equal 17,391 KVA.

If 350 KVAR of capacitors were used to improve power factor, h would be:

$$h = \sqrt{\frac{17{,}391}{350}} = \sqrt{49.7} = 7.0$$

Because h falls right on the 7th harmonic, these capacitors could create a harmful resonance condition if non-linear devices were present in the factory. In this case the capacitors should be applied only as harmonic filtering assemblies. For further information, see Harmonics Publication.

Reducing harmonic distortion

It's possible for non-linear equipment and power capacitors to co-exist. You don't have to give up the benefits of power correction if your plant uses many types of electronic power controls and computers.

To reduce harmonics:

- Avoid odd-number harmonics: 5,7, 11 and 13
- Size reactors to filter site-specific harmonic problems
- Use proper filtering and chokes

We offer harmonic analysis services to identify harmful harmonic currents and their sources in your facility. We'll work with you to make sure your power factor capacitors benefit you for years to come, despite harmonics generated by electronic equipment.

Useful capacitor formulas

Nomenclature: C = Capacitance in μF
V = Voltage
A = Current
K = 1000

A. Capacitors connected in parallel:

$$C_{Total} = C_1 + C_2 + C_3 + \cdots$$

B. Capacitors connected in series:

$$C_{Total} = \frac{C_1 \times C_2}{C_1 + C_2}$$

For two capacitors in series

$$C_{Total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots}$$

For more than two in series

C. Reactance - X_c (Capacitive)

1. $X_c = \frac{10^6}{(2\pi f)X_c}$
2. $X_c = \frac{2653}{C}$ @ 60 HZ ($1\mu F = 2653\Omega$)
3. $X_c = \frac{KV^2 \times 10^3}{KVAR}$

D. Capacitance-C

1. $C = \frac{10^6}{(2\pi f)X_c}$
2. $C = \frac{KVAR \times 10^3}{(2\pi f)(KV)^2}$

E. Capacitive Kilovars

1. $KVAR = \frac{(2\pi f)C(KV)^2}{10^3}$
2. $KVAR = \frac{10^3 (KV)^2}{X_c}$

F. Miscellaneous

1. Power Factor $= \cos\theta = \frac{KW}{KVA}$

$\tan\theta = \frac{KVAR}{KW}$ (see Table 3)

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

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

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

8. Approx. Motor KVA = Motor HP (at full load)

G. Additional Data

1. Simplified voltage rise:

$$\%V.R. = \frac{KVAR\ (Cap.) \times \%\ transformer\ reactance}{KVA\ (Transformer)}$$

2. Losses Reduction:

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

3. Operation at other than rated voltage and frequency:

NOTE: Use of voltages and frequencies *above* the rated values can be dangerous. Consult the factory for any unusual operating conditions.

a. Reduced voltage:

$$Actual\ KVAR\ (output) = Rated\ KVAR\left(\frac{Actual\ Voltage}{Rated\ Voltage}\right)^2$$

b. Reduced frequency:

$$Actual\ KVAR = Rated\ KVAR\left(\frac{Actual\ Freq.}{Rated\ Freq.}\right)$$

c. 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

$$KVAR\ (50Hz.) = KVAR\ (60Hz.)\left(\frac{50}{60}\right) = 0.83$$

(60 KVAR @ 480V 60 Hz = 50 KVAR, 480V, 50Hz)

H. Standard data

	μF/KVAR Total	AMP/KVAR Single Phase	AMP/KVAR Three Phase
208V	61.3	4.81	2.78
240V	46.0	4.17	2.41
480V	11.5	2.08	1.20
600V	7.37	1.67	0.96
2400V	0.46	-	0.24
4160V	0.153	-	0.139

(Above is at nominal voltage @ 60Hz = nominal KVAR μF and current)