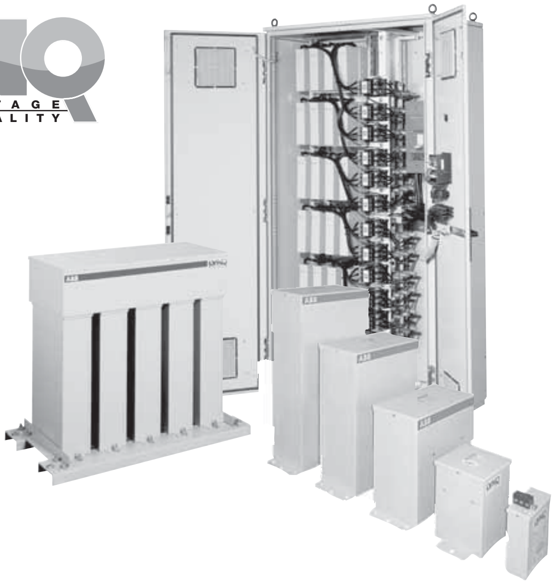
Application manual
Dry type power factor correction capacitors

LVNQ
LOW VOLTAGE NETWORK QUALITY



Index

General information

Basic Concepts

Most loads on an electrical distribution system can be categorized into three types:

- Resistive
- Inductive
- Capacitive

On modern systems, the most common is the inductive load. Typical examples include transformers, fluorescent lighting and AC induction motors.

A common characteristic of these inductive loads is that they utilize a winding in order to operate. This winding produces an electromagnetic field which allows the motor or transformer to function and requires a certain amount of electrical power to maintain this electromagnetic field.

All inductive load require two kinds of power to function properly:

• Active power (kW)	- actually performs the work
• Reactive power (kvar)	- sustains the electro–magnetic field

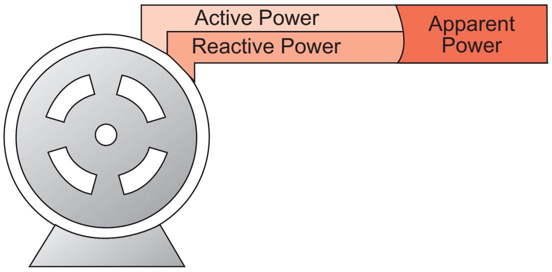


Fig. 1

One common example of reactive power can be seen in an unloaded AC motor. When all load is removed from the motor, one might expect the no-load current to drop near zero. In truth, however, the no-load current will generally show a value between 25% and 30% of full load current. This is because of the continuous demand for magnetizing current by any inductive load.
Active power is the total power indicated on a wattmeter. Apparent power is the combination of reactive and active power.

What is Power Factor?

Power factor is the relationship between working (active) power and total power consumed (apparent power). Essentially, power factor is a measurement of how effectively electrical power is being used. The higher the power factor, the more effectively electrical power is being used.

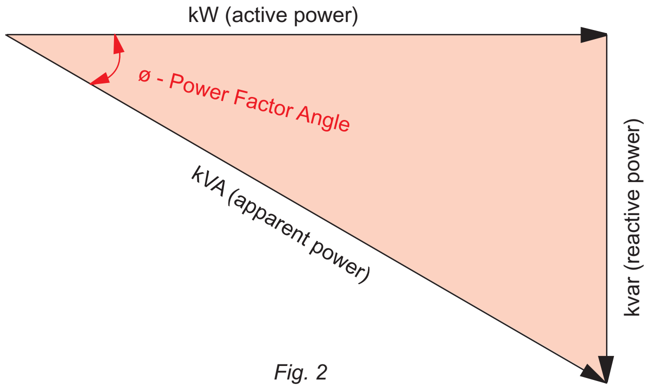


Fig. 2

Fig. 2

A distribution system's operating power is composed of two parts: Active (working) power and reactive (non-working magnetizing) power. The ACTIVE power performs the useful work . . . the REACTIVE power does not. It's only function is to develop magnetic fields required by inductive devices.

Generally, power factor decreases (phi increases) with increased motor load. This geometric relationship of apparent power to active power is traditionally expressed by the right triangle relationship of:

Cos phi = p.f. = kW/kVA

Why Improve Low Power Factor?

Low power factor means poor electrical efficiency. The lower the power factor, the higher the apparent power drawn from the distribution network.

When low power factor is not corrected, the utility must provide the nonworking reactive power IN ADDITION to the working active power. This results in the use of larger generators, transformers, bus bars, wires, and other distribution system devices that otherwise would not be necessary. As the utility's capital expenditures and operating costs are going to be higher, they are going to pass these higher expenses to industrial users in the form of power factor penalties.

Advantages of Improving Low Power Factor — Saving Money!!

- High power factor eliminates utility power factor penalties.
- High power factor reduces the heating losses of transformers and distribution equipment, prolonging life of the equipment.
- High power factor stabilizes voltage levels.
- Increased system capacity

Figure 3 illustrates the relationship of power factor to total current consumed. With a power factor of 1.0 given a constant load, the 100% figure represents the required useful current.

As the power factor drops from 1.0 to .9, power is used less effectively. Therefore, 10% more current is required to handle the same load.

A power factor of .7 requires approximately 43% more current; and a power factor of .5 requires approximately 100% (twice as much!!) to handle the same load.

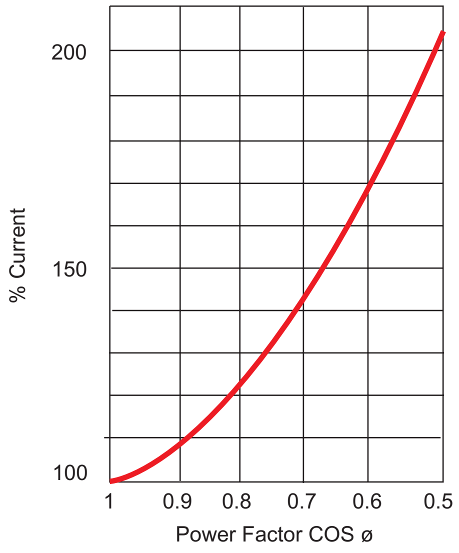


Fig. 3

How Power Factor Correction Capacitors Solve the Problem of Low Power Factor

Lower power factor is a problem that can be solved by adding power factor correction capacitors to the plant distribution system. As illustrated in Fig. 4, power factor correction capacitors work as reactive current generators “providing” needed reactive power (kvar) to the power supply. By supplying their own source of reactive power, the industrial user frees the utility from having to supply it; therefore, the total amount of apparent power (kVA) supplied by the utility will be less.

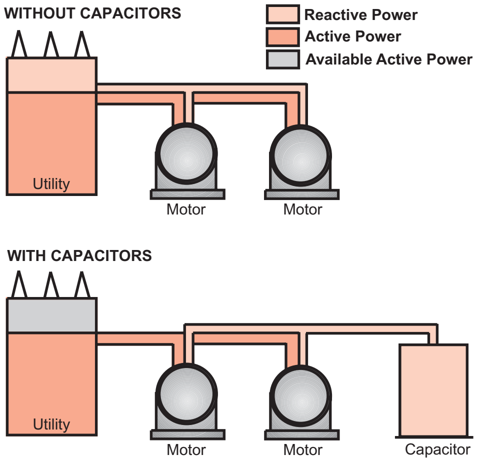


Fig. 4

Power factor correction capacitors reduce the total current drawn from the distribution system and subsequently increase system capacity by raising the power factor level.

Capacitor Rating

Power factor correction capacitors are rated in electrical units called “vars”. One var is equivalent to one volt ampere of reactive power. Vars are units of measurement for indicating how much reactive power the capacitor will supply.

As reactive power is usually measured in thousands of vars, the letter “k” (abbreviation for “kilo”, meaning thousands) precedes the var creating the more familiar “kvar” term.

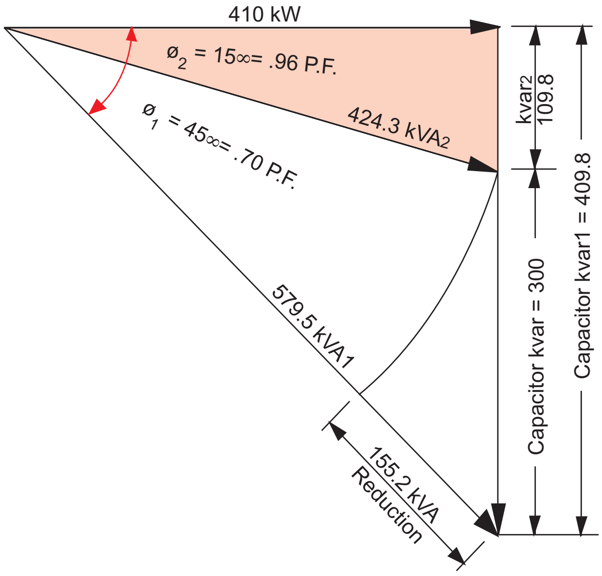


Fig. 5

The capacitor kvar rating shows how much reactive power the capacitor will supply. Each unit of the capacitor’s kvar will decrease the inductive reactive power demand (magnetizing demand) by the same amount.

EXAMPLE:

A low voltage network requires 410 kW active power at full load, and the power factor is measured to be .70. Therefore, the system’s full load consumption of apparent power is 579.5 kVA. If 300 kvar of capacitive reactive power is installed, the power factor will rise to .96 and the kVA demand will be reduced from 579.5 to 424.3 kVA. See Fig. 5.

Capacitor installation locations

Where Should Power Factor Correction Capacitors Be installed in a distribution system?

As shown in Fig. 6, several options exist for the connection of power factor correction capacitors on the low voltage distribution system.

Option A: On the secondary of the overload relay
Advantages: This is the most efficient location since the reactive power (kvar) is produced at the same spot where it is consumed. Line losses and voltage drop are minimized. The capacitor is switched automatically by the motor starter, so it is only energized when the motor is running. No separate switching device or overcurrent protection is required because of the presence of the motor starter components.

Care must be taken in setting the overload relay since the capacitor will bring about a reduction in amps through the overload. Therefore, to give the same protection to the motor, the overload relay's trip setting should be readjusted or the heater elements should be resized. Refer to page 6.12 for line current reduction in percent of FLA.

Option B: Between the contactor and the overload relay
The advantages are the same as Option A except the overload relay can now be set to the full load amps as shown on the motor nameplate. This mounting location is normally preferred by motor control center and switchgear builders since the overload setting is simplified.

Option C: Between the circuit breaker and the contactor
Advantages: Since the capacitor is not switched by the contactor, it can act as a central kvar source for several motors fed by the same circuit breaker. This location is recommended for jogging, plugging and reversing applications.

Since the capacitor remains energized even when the motor or motors are not running, there exists the possibility of overcorrection and leading power factor during lightly loaded periods. Losses are higher than with Options A & B as the reactive current must be carried further.

LOCATIONS FOR CAPACITORS IN MOTOR CIRCUITS

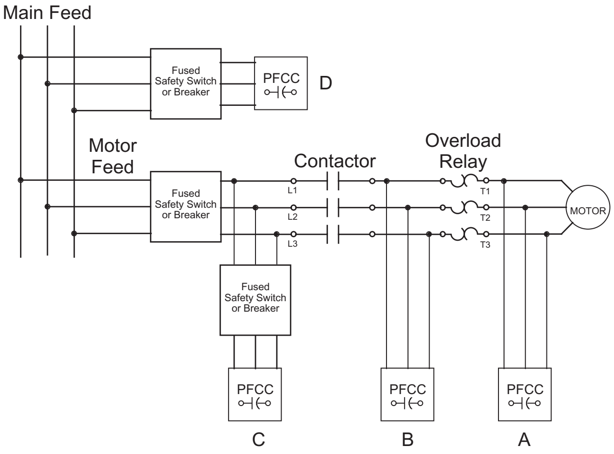


Fig. 6

Option D: As a central compensation source connected to the main distribution bus
Advantages: Of the four options, this is the most cost efficient because it uses a few large kvar capacitors rather than many small units.

A primary disconnect must be provided for switching and overcurrent protection. As with Option C, a real possibility of overcompensation exists during lightly loaded periods unless some form of automatic control is incorporated. Automatic control can be provided by ABB automatic capacitor banks.

Application and Installation

Temperature and Ventilation

Capacitors should be located in areas where the surrounding ambient temperature does not exceed 40^{o} C and where there is adequate ventilation. As capacitors always operate at full load and generate heat of their own, maximum heat dissipation must be provided to ensure long operating life.

Line frequency and operating voltage are factors that can cause capacitor temperature to rise.

- **Line Frequency** - Assuming the line frequency of the capacitor matches the frequency of the incoming service, line frequency is not a concern since it is constant in modern power systems.

- **Operating Voltage** - Capacitor overheating at a normal operating voltage and with adequate ventilation seldom occurs. However, when the voltage exceeds 110% of the capacitor rating, overheating and resultant damage can happen.

When the operating voltage exceeds 110% of the capacitor's rated voltage, the line voltage should be reduced or the capacitor taken off line.

This overvoltage problem is exactly why, when determining the required kvar capacitance for a distribution system, a person should always "undersize" a capacitor's kvar rating... too much capacitance means overvoltage... too much overvoltage means excessive heat... and excessive heat can be damaging to the capacitor unit!!!

Special Applications

Care should be taken when power factor correction capacitors are used in the following applications:

- Plugging and jogging applications
- Frequent starts
- Crane or elevator motors where the load may drive the motor
- Multi-speed motors
- Motors involving open transition reduced voltage starting
- Reversing starters if they reverse more frequently than once per minute

Discharging Time

Power factor capacitors need a minimum of one minute to discharge. Afterwards, it is always recommended that the terminals be short-circuited to ground before touching.

Typical Capacitor Specifications

The following guidelines can be used when specifying capacitors.

SPECIFICATIONS FOR CAPACITORS

600 Volts and Below

Furnish and install where indicated power factor correction capacitors of the size, voltage rating, and enclosure type shown on the drawings.

(OPTIONAL) All motors of _____ horsepower and above shall have individual power factor correction capacitors energized with the motor.

All capacitors shall be the self healing metallized-film type filled with vermiculite, a dry NONFLAMMABLE filler material; oil-filled capacitors will not be acceptable. Discharge resistors shall be provided to automatically discharge the capacitor to less than 50 volts within one minute after de-energization. An internal ground lug shall be provided. The capacitors shall withstand 135% of rated current continuously, 110% of rated voltage continuously; and an ambient temperature range of -40°C to +40°C.

Losses shall be less than 0.5 watts per kvar. Each element shall be individually protected and the enclosure shall be filled with a dry, non-toxic, nonflammable insulating material. The capacitors shall be UL Listed and CSA approved. Capacitors shall be ABB or equivalent.

ABB contactor kvar ratings

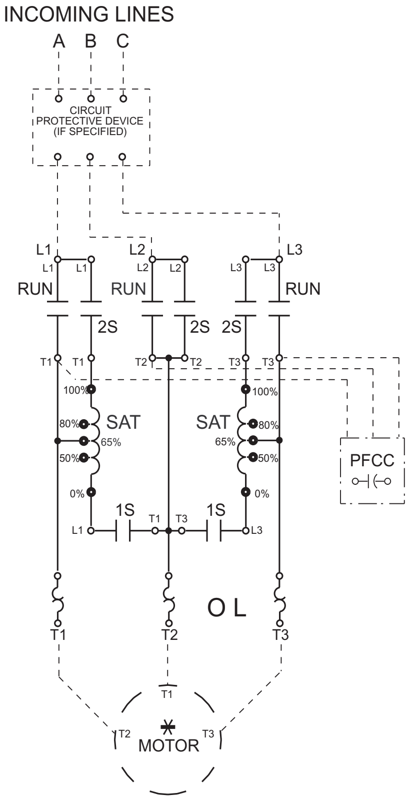
Contactor	208V	240V	480V	600V	Max amps
UA26	3.5	4.0	8.0	10.0	10
UA30	7.0	8.0	16.5	20.5	20
UA50	10.5	12.5	25.0	31.0	30
UA75	21.5	25.0	50.0	62.0	60
UA95	25.0	29.0	58.0	72.0	70
UA110	28.5	33.0	66.0	83.0	80
A145	43	50	100	125	120
A185	57	66	133	166	160
A210	66	77	153	192	185
A260	75	87	174	218	210
A300	88	101	203	254	245
AF400	119	137	274	343	330
AF460	142	164	329	410	396
AF580	178	205	411	514	495
AF750	214	247	495	618	595

Application and installation

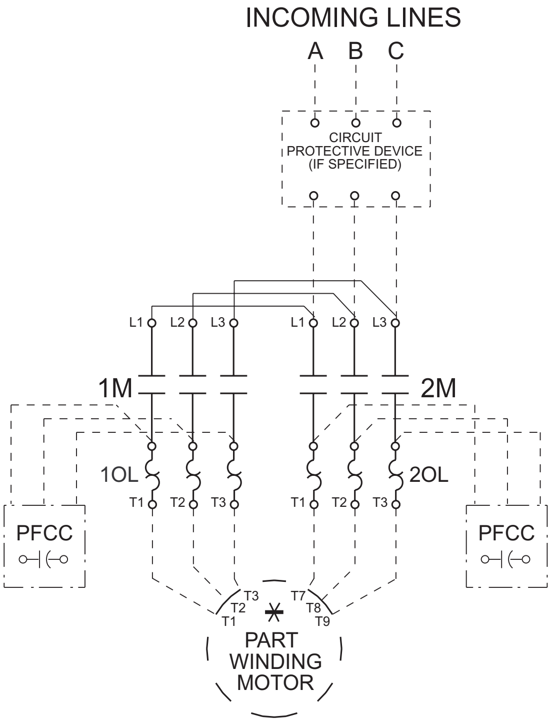
Wiring diagrams for Autotransformer, part-winding, wye-delta, multi-speed

Power Factor Correction Capacitor connection locations

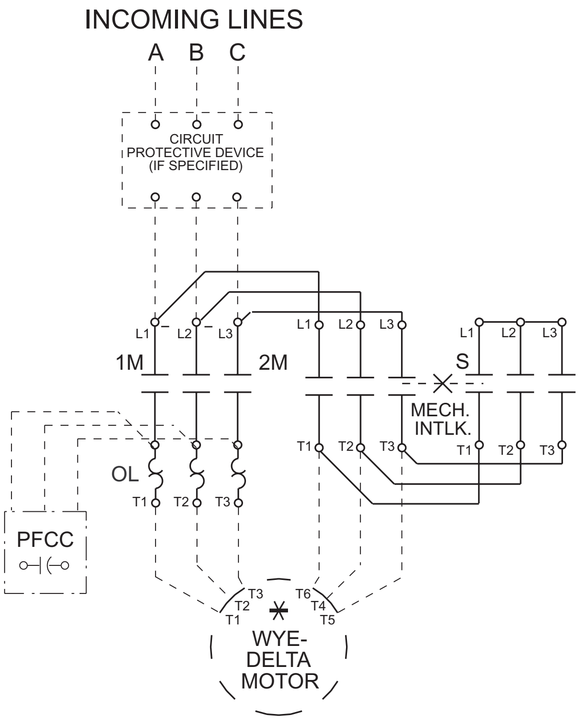
Autotransformer



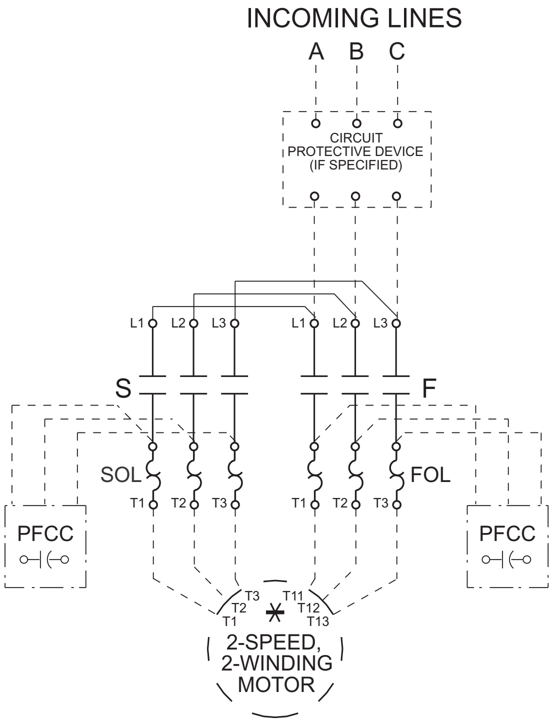
Part-winding



Wye-delta

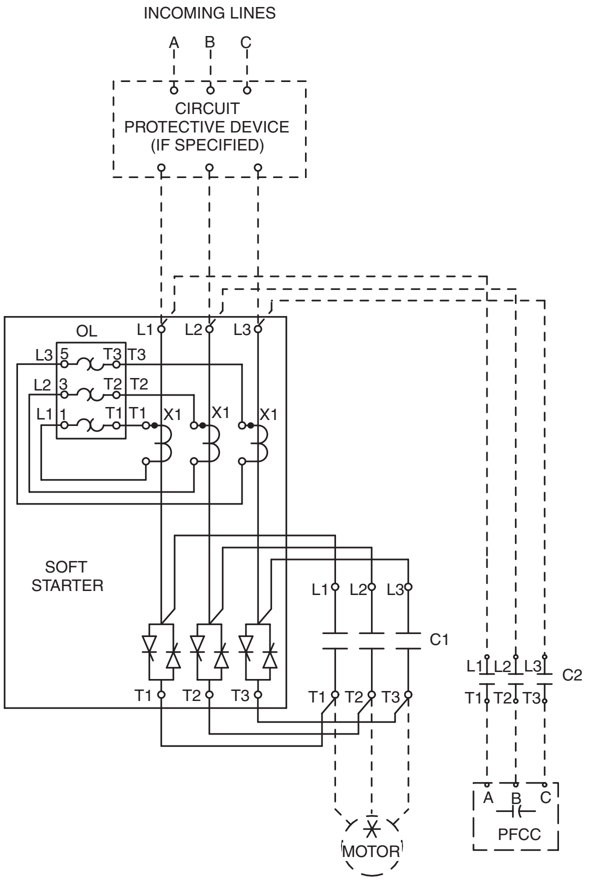


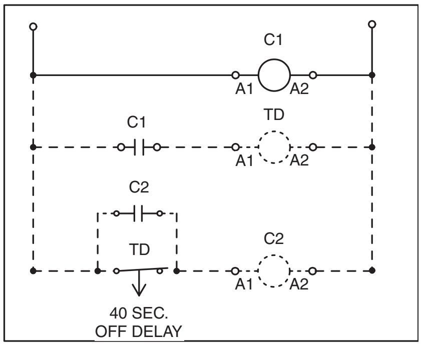
2 Speed, 2 winding



Application and installation
Wiring diagrams for Softstarters

Softstarter





BYPASS CONTACTOR CONTROL CIRCUIT

Harmonic phenomena

Problems Created by Harmonics

- Excessive heating and failure of capacitors, capacitor fuses, transformers, motors, fluorescent lighting ballasts, etc.
- Nuisance tripping of circuit breaker or blown fuses
- Presence of the third harmonic & multiples of the 3rd harmonic in neutral grounding systems may require the derating of neutral conductors
- Noise from harmonics that lead to erroneous operation of control system components
- Damage to sensitive electronic equipment
- Electronic communications interference

Any device with non-linear operating characteristics can produce harmonics in your power system. If you are currently using equipment that can cause harmonics or have experienced harmonic related problems, capacitor reactor or filter bank equipment may be the solution. The following is a discussion of harmonics; the characteristics of the problem; and a discussion of our solution.

Origins of Harmonic Distortion

The ever increasing demand of industry and commerce for stability, adjustability and accuracy of control in electrical equipment led to the development of relatively low cost power diodes, thyristors, SCRs and other power semi-conductors. Now used widely in rectifier circuits for U.P.S. systems, static converters and A.C. & D.C. motor control, these modern devices replace the mercury arc rectifiers of earlier years and create new and challenging conditions for the power engineer of today.

Although solid state devices, such as the thyristor, have brought significant improvements in control designs and efficiency, they have the disadvantage of producing harmonic currents.

Harmonic currents can cause a disturbance on the supply network and adversely affect the operation of other electrical equipment including power factor correction capacitors.

We are concentrating our discussions on harmonic current sources associated with solid state power electronics but there are actually many other sources of harmonic currents. These sources can be grouped into three main areas:

1. Power electronic equipment: Variable speed drives (AC VFD's, DC drives, PWM drives, etc.); UPS systems, rectifiers, switch mode power supplies, static converters, thyristor systems, diode bridges, SCR controlled induction furnaces and SCR controlled systems.

2. Arcing equipment: Arc furnaces, welders, lighting (mercury vapor, fluorescent)

3. Saturable devices: Transformers, motors, generators, etc. The harmonic amplitudes on these devices are usually insignificant compared to power electronic and arcing equipment, unless saturation occurs.

Waveform

Harmonics are sinusoidal waves that are integral multiples of the fundamental 60 Hz waveform (i.e., 1st harmonic = 60 Hz; 5th harmonic = 300 Hz). All complex waveforms can be resolved into a series of sinusoidal waves of various frequencies, therefore any complex waveform is the sum of a number of odd or even harmonics of lesser or greater value. Harmonics are continuous (steady-state) disturbances or distortions on the electrical network and are a completely different subject or problem from line spikes, surges, sags, impulses, etc., which are categorized as transient disturbances.

Transient problems are usually solved by installing suppression or isolation devices such as surge capacitors, isolation transformers or M.O.V.s. These devices will help solve the transient problems but will not affect the mitigation of low order harmonics or solve harmonic resonance problems.

Harmonic Content

Thyristor and SCR converters are usually referred to by the number of DC current pulses they produce each cycle. The most commonly used are 6 pulse and 12 pulse.

There are many factors that can influence the harmonic content but typical harmonic currents, shown as a percentage of the fundamental current, are given in the below table. Other harmonics will always be present, to some degree, but for practical reasons they have been ignored.

Order of harmonic	Typical percentage of harmonic current	
	6 Pulse	12 pulse
1	100	100
5	20	–
7	14	–
11	9	9
13	8	8
17	6	–
19	5	–
23	4	4
25	4	4

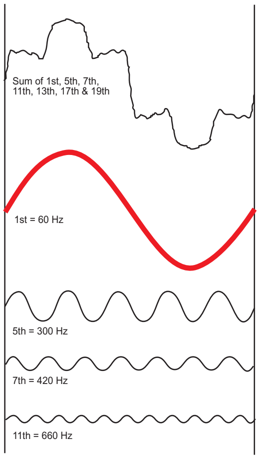


Fig. 7

Harmonic Overloading of Capacitors

The impedance of a circuit dictates the current flow in that circuit. As the supply impedance is generally considered to be inductive, the network impedance increases with frequency while the impedance of a capacitor decreases. This causes a greater proportion of the currents circulating at frequencies above the fundamental supply frequency to be absorbed by the capacitor, and all equipment associated with the capacitor.

In certain circumstances, harmonic currents can exceed the value of the fundamental (60 Hz) capacitor current. These harmonic problems can also cause an increased voltage across the dielectric of the capacitor which could exceed the maximum voltage rating of the capacitor, resulting in premature capacitor failure.

Harmonic Resonance

The circuit or selective resonant frequency is reached when the capacitor reactance and the supply reactance are equal.

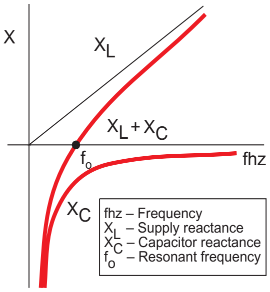


Fig. 8

Whenever power factor correction capacitors are applied to a distribution network, which combines capacitance and inductance, there will always be a frequency at which the capacitors are in parallel resonance with the supply.

If this condition occurs on, or close to, one of the harmonics generated by solid state control equipment, then large harmonic currents can circulate between the supply network and the capacitor equipment. These currents are limited only by the damping resistance in the circuit. Such currents will add to the

Harmonic phenomena

harmonic voltage disturbance in the network causing an increased voltage distortion.

This results in a higher voltage across the capacitor and excessive current through all capacitor components. Resonance can occur on any frequency, but in general, the resonance we are concerned with is on, or close to, the 5th, 7th, 11th and 13th harmonics for 6 pulse systems. See Fig. 8.

Avoiding Resonance

There are a number of ways to avoid resonance when installing capacitors. In larger systems it may be possible to install them in a part of the system that will not result in a parallel resonance with the supply. Varying the kvar output rating of the capacitor bank will alter the resonant frequency. With capacitor switching there will be a different resonant frequency for each step. Changing the number of switching steps may avoid resonance at each step of switching. See Fig. 9.

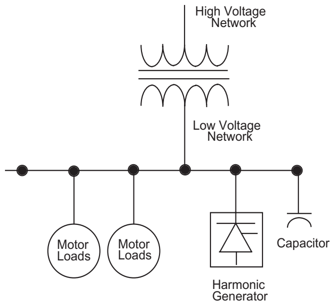
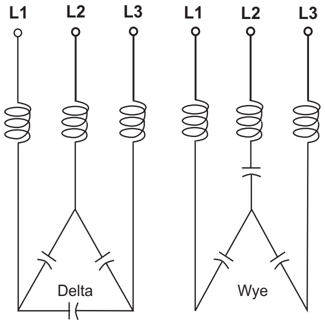


Fig. 9

Overcoming Resonance

If resonance cannot be avoided, an alternative solution is required. A reactor must be connected in series with each capacitor such that the capacitor/reactor combination is inductive at the critical frequencies but capacitive at the fundamental frequency. To achieve this, the capacitor and series connected reactor must have a tuning frequency below the lowest critical order of harmonic, which is usually the 5th. This means the tuning frequency is in the range of 175 Hz to 270 Hz, although the actual frequency will depend upon the magnitude and order of the harmonic currents present.



Detuned Capacitor/Reactor Systems

Fig. 10

The addition of a reactor in the capacitor circuit increases the fundamental voltage across the capacitor. Therefore, care should be taken when adding reactors to existing capacitors. See Fig. 10.

Reduction of Harmonic Distortion

Harmonic currents can be significantly reduced in an electrical system by using a harmonic filter.

In its basic form, a filter consists of a capacitor connected in series with a reactor tuned to a specific harmonic frequency. In theory, the impedance of the filter is zero at the tuning frequency; therefore, the harmonic current is absorbed by the filter. This, together with the natural resistance of the circuit, means that only a small level of harmonic current will flow in the network.

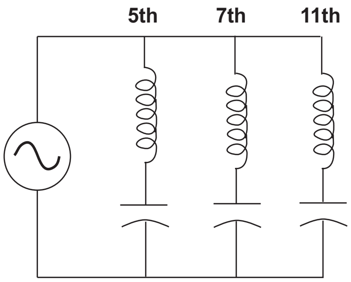
Types of Filters

The effectiveness of any filter design depends on the reactive output of the filter, tuning accuracy and the impedance of the network at the point of connection.

Harmonics below the filter tuning frequency will be amplified. The filter design is important to ensure that distortion is not amplified to unacceptable levels. Where there are several harmonics present, a filter may reduce some harmonics while increasing others. A filter for the 7th harmonic creates a parallel resonance in the vicinity of the 5th harmonic with magnification of the existing 5th harmonic; therefore, a 7th harmonic filter requires a 5th harmonic filter. See Fig. 11. Consequently, it is often necessary to use a multiple filter design where each filter is tuned to a different frequency. Experience is extremely important in the design of such filters to ensure:

(a) the most efficient and cost effective solution is selected;

(b) no adverse interaction between the system and the filter.



Shunt Filters

Fig. 11

Load Alteration

Whenever load expansion is considered, the network is likely to change and existing filter equipment should be evaluated in conjunction with the new load condition. It is not recommended to have two or more filters tuned to the same frequency connected on the same distribution system. Slight tuning differences may cause one filter to take a much larger share of the harmonic distortion. Or, it may cause amplification of the harmonic order which the equipment has been designed to reduce. When there is a need to vary the power factor correction component of a harmonic filter, careful consideration of all load parameters is necessary.

Harmonic Analysis

The first step in solving harmonic related problems is to perform an analysis to determine the specific needs of your electrical distribution system. To determine capacitor and filter requirements, it is necessary to establish the impedance of the supply network and the value of each harmonic current. Capacitor, reactor and filter bank equipment are then specified under very detailed and stringent computer analysis to meet your needs.

Your ABB Solution to Harmonics

ABB is the world's largest manufacturer of dry type low voltage capacitors! ABB Control Inc. utilizes this experience in recommending three options to solve the problems associated with applying capacitors to systems having harmonic distortion:

1. Apply the correct amount of capacitance (kvar) to the network to avoid resonance with the source. This may be difficult, especially in automatic systems as the capacitance is always changing. This solution usually means connecting less capacitance to the system than is actually needed for optimum power factor correction.

2. Install reactors in series with capacitors to lower the resonance below critical order harmonics; i.e., 5th, 7th, 11th & 13th. This design tunes the resonant frequency of the system well below the critical harmonic and is called an anti-resonance bank. This solution allows the capacitors to operate in a harmonic environment.

Harmonic phenomena

3. Filters are recommended if a problem exists with harmonic distortion before the application of power factor correction, or if the harmonic distortion is above the limits recommended in IEEE 519, "Guide for Harmonic Control and Reactive Compensation of Static Power Converters". (The recommended limits for voltage distortion in IEEE 519 are presently 5% for general applications.) Tuned filters sized to reduce the harmonic distortion at critical frequencies have the benefits of correcting the power factor and improving the network power quality.

With our knowledge of harmonics, ABB provides a complete range of products from individual capacitors, fixed banks and automatic banks, to power filter systems. All these products utilize dry type low voltage ABB power factor correction capacitor elements which are self-healing for internal faults.

To maintain stringent quality control standards, most control components found in automatic and anti-resonance filter bank products are also ABB products. These products include contactors, circuit breakers, control relays, disconnect switches, power factor relays and pushbutton devices.

ABB Capacitor Features & Services

Every ABB Control low voltage capacitor product incorporates our unique dry type design. Therefore, environmental and personnel concerns associated with leakage or flammability of conventional oil-filled units are eliminated. Other features include:

- Patented Sequential Protection System includes dry, self-healing design; internally protected elements; and dry, non-flammable vermiculite filler
- Individual units, fixed and automatic capacitor bank designs, 208-600V
- Automatic and fixed tuned or anti-resonance capacitor banks
- Power factor and harmonic studies
- UL and CSA

Sizing Capacitors at the Motor Load

When the determination is made that power factor correction capacitors ARE a good investment for a particular electrical system, you need to know:

- How many capacitors are needed?
- What sizes are appropriate?

The capacitor provides a local source of reactive current. With respect to inductive motor load, this reactive power is the magnetizing or “no-load current“ which the motor requires to operate.

A capacitor is properly sized when its full load current rating is 90% of the no-load current of the motor. This 90% rating avoids overcorrection and the accompanying problems such as overvoltages.

One Selection Method: Using Formulas

If no-load current is known . . .

The most accurate method of selecting a capacitor is to take the no-load current of the motor, and multiply by .90 (90%). Take this resulting figure, turn to the appropriate catalog page, and determine which kvar size is needed, catalog number, enclosure type, and price.

EXAMPLE: Size a capacitor for a 100hp, 460V 3-phase motor which has a full load current of 124 amps and a no-load current of 37 amps.

1. Multiply the no-load current figure of 37 amps by 90%.

37 no load amps X 90% = 33 no load amps

2. Turning to the catalog page for 480 volt, 3-phase capacitors, find the closest amp rating to, but NOT OVER 33 amps. See Table 1, sample catalog pricing chart. Per the sample chart the closest amperage is 32.5 amps. The proper capacitor unit, then is 27 kvar and the appropriate catalog number depends on the type enclosure desired.

NOTE

The formula method corrects power factor to approximately .95

If the no load current is not known . . .

If the no-load current is unknown, a reasonable estimate for 3-phase motors is to take the full load amps and multiply by 30%. Then take that figure and multiply times the 90% rating figure being used to avoid overcorrection and overvoltages.

EXAMPLE: Size a capacitor for a 75hp, 460V 3-phase motor which has a full load current of 92 amps and an unknown no-load current.

1. First, find the no-load current by multiplying the full load current times 30%.

92 (full load amps) X 30% = 28 estimated no-load amps

2. Multiply 28 no-load amps by 90%.

28 no-load amps X 90% = 25 no-load amps

3. Now examine the capacitor pricing and selection chart for 480 volt, 3-phase capacitors. Refer again to Table 1. Here it will be seen that the closest capacitor to 25 amps full load current without going over is a 20 kvar unit, rated at 24.1 amps.

4. The correct selection, then, is 20 kvar!

TABLE 1
480 VOLT, 60 Hz., 3-Phase

Enclosure Size	kvar Rating	Rated Current Per Phase	Approx. Shipping We ight (Lbs.)	Indoor – Nema 1	Outdoor – Nema 3R	Indoor – Nema 12
				Catalog Number	Catalog Number	Catalog Number
	1.5	1.8	8	C484G1.5	C484R1.5	C484D1.5
	2	2.4	8	C484G2	C484R2	C484D2
	2.5	3.0	8	C484G2.5	C484R2.5	C484D2.5
	3	3.6	[illegible]	[illegible]	C484R2	C484D3
	[illegible]	4.8	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	13	C484G17.5	[illegible]	[illegible]
	18	21.7	13	C484G18	C484R18	[illegible]
	19	22.8	13	C484G19	C484R19	C484D19
	20	24.1	13	C484G20	C484R20	C484D20
	21	25.3	13	C484G21	C484R21	C484D21
	22	26.5	13	C484G22	C484R22	C484D22
	22.5	27.1	13	C484G22.5	[illegible]	[illegible]
	24	28.9	[illegible]	C484G24	[illegible]	[illegible]
	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Sizing capacitors at the motor load

Using charts

An Alternate Selection Method — Using Charts

TABLE 2: Suggested Maximum Capacitor Ratings for T-Frame NEMA Class B Motors

Induction motor rating (HP)	NOMINAL MOTOR SPEED											
	3600 R/Min		1800 R/Min		1200 R/Min		900 R/Min		720 R/Min		600 R/MIN	
	Capacitor rating (kvar)	Line current reduction (%)	Capacitor rating (kvar)	Line current reductions (%)	Capacitor rating (kvar)	Line current reduction (%)	Capacitor rating (kvar)	Line current reduction (%)	Capacitor rating (kvar)	Line current reduction (%)	Capacitor rating (kvar)	Line current reduction (%)
3	1.5	14	1.5	23	2.5	28	3	38	3	40	4	40
5	2	14	2.5	22	3	26	4	31	4	40	5	40
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	12	25	18	30
25	7.5	12	7.5	17	8	19	10	23	12	25	18	30
30	8	11	8	16	10	19	14	22	15	24	22.5	30
40	12	12	13	15	16	19	18	21	22.5	24	25	30
50	15	12	18	15	20	19	22.5	21	24	24	30	30
60	18	12	21	14	22.5	17	26	20	30	22	35	28
75	20	12	23	14	25	15	28	17	33	14	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	36	12	35	12	42	14	45	15	50	17
150	30	10	42	12	40	12	52.5	14	52.5	14	60	17
200	35	10	50	11	50	10	65	13	68	13	90	17
250	40	11	60	10	62.5	10	82	13	87.5	13	100	17
300	45	11	68	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

Applies to three-phase, 60Hz motors when switched with capacitors as a single unit.

Another method of selecting the proper capacitor employs the use of only a selection chart shown in Table 2 or 3. These tables take other variables such as motor RPM into consideration in making recommendations for capacitor applications. They are convenient because they only require that the user know the horsepower and RPM of the motor. Both tables estimate the percentage reduction in full load current drawn by the motor as a result of the capacitor's installation.

WARNING!

NEVER OVERSIZE CAPACITORS OR EXCEED 1.0 POWER FACTOR OR RESULTING PROBLEMS WITH THE MOTOR CAN OCCUR!!

If calculations or a kvar determination chart indicate a kvar rating not found in a pricing and selection chart, always refer to the next lower kvar rating!

EXAMPLE: A manufacturer needs to determine the proper capacitors required for a 1200 RPM, 75HP T-Frame NEMA class B motor.

1. First find 75 in the horsepower column of the chart.
2. Locate the 1200 RPM capacitor rating (kvar) column. Note the figure of 25 kvar.
3. Now refer to the appropriate pricing and selection chart Table 1, page 6.11. The appropriate kvar rating is 25 kvar. Depending on the desired enclosure, the price and catalog number can then be easily determined.

NOTE

Using the above charts for selecting capacitors will correct power to approximately .95.

TABLE 3: Suggested Maximum Capacitor Ratings for U-Frame NEMA Class B Motors

NEMA Motor Design A or B Normal Starting Torque Normal Running Current												
H.P. Rating	3600 RPM		1800 RPM		1200 RPM		900 RPM		720 RPM		600 RPM	
	kvar	%AR	kvar	%AR	kvar	%AR	kvar	%AR	kvar	%AR	kvar	%AR
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3.5	41
5	2	12	2	13	2	17	3	25	4	32	4.5	37
7.5	2.5	11	2.5	13	2	15	4	22	5.5	30	6	34
10	3	10	3	11	3.5	14	5	21	6.5	27	7.5	31
15	4	9	4	10	5	13	6.5	18	8	23	9.5	27
20	5	9	5	10	5	11	7.5	18	10	20	10	25
25	5	6	5	8	7.5	11	7.5	13	10	20	10	21
30	5	5	5	8	7.5	11	10	15	15	22	15	25
40	7.5	8	10	8	10	10	15	16	15	18	15	20
50	10	7	10	8	10	9	15	12	20	15	25	22
60	10	6	10	8	15	10	15	11	20	15	25	20
75	15	7	15	8	15	9	20	11	30	15	40	20
100	20	8	20	8	25	9	30	11	40	14	45	18
125	20	6	25	7	30	9	30	10	45	14	50	17
150	30	6	30	7	35	9	40	10	50	17	60	17
200	40	6	40	7	45	8	55	11	60	12	75	17
250	45	5	45	6	60	9	70	10	75	12	100	17
300	50	5	50	6	75	9	75	9	80	12	105	17

Applies to three-phase, 60Hz motors when switched with capacitors as a single unit.

Sizing capacitors at the motor load

Using charts

Power factor correction chart

Original power factor in percent	DESIRED CORRECTED POWER FACTOR IN PER CENT																				
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.442	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	1.669
55	.769	.795	.821	.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	.907	.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	.907	.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	.368	.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	.686	.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	.538	.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	.616	.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	.236	.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	.000	.026	.052	.078	.104	.130	.157	.183	.210	.238	.266	.294	.321	.355	.387	.421	.459	.499	.541	.608	.750
81	-	.000	.026	.052	.078	.104	.131	.157	.184	.212	.240	.268	.295	.329	.361	.395	.433	.473	.515	.582	.724
82	-	-	.000	.026	.052	.078	.105	.131	.158	.186	.214	.242	.269	.303	.335	.369	.407	.447	.489	.556	.698
83	-	-	-	.000	.026	.052	.079	.105	.132	.160	.188	.216	.243	.277	.309	.343	.381	.421	.463	.530	.672
84	-	-	-	-	.000	.026	.053	.079	.106	.134	.162	.190	.217	.251	.283	.317	.355	.395	.437	.504	.645
85	-	-	-	-	-	.000	.027	.053	.080	.108	.136	.164	.191	.225	.257	.291	.329	.369	.417	.478	.620
86	-	-	-	-	-	-	.000	.026	.053	.081	.109	.137	.167	.198	.230	.265	.301	.343	.390	.451	.593
87	-	-	-	-	-	-	-	.000	.027	.055	.082	.111	.141	.172	.204	.238	.275	.317	.364	.425	.567
88	-	-	-	-	-	-	-	-	.000	.028	.056	.084	.114	.145	.177	.211	.248	.290	.337	.398	.540
89	-	-	-	-	-	-	-	-	-	.000	.028	.056	.086	.117	.149	.183	.220	.262	.309	.370	.512
90	-	-	-	-	-	-	-	-	-	-	.000	.028	.058	.089	.121	.155	.192	.234	.281	.342	.484
91	-	-	-	-	-	-	-	-	-	-	-	.000	.030	.061	.093	.127	.164	.206	.253	.314	.456
92	-	-	-	-	-	-	-	-	-	-	-	-	.000	.031	.063	.097	.134	.176	.223	.284	.426
93	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.032	.066	.103	.145	.192	.253	.395
94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.034	.071	.113	.160	.221	.363
95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.037	.079	.126	.87	.328
96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.042	.089	.150	.292
97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.047	.108	.251
98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.061	.203
99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.000	.142

Sizing Capacitors for Improving System Power Factor

Sizing and selecting capacitors for system power factor correction is calculated using a Power Factor Correction Chart. Before this chart can be used, however, the total kW requirement needs to be known for the ENTIRE system in addition to the PRESENT and DESIRED power factors.

EXAMPLE: A plant has a present power factor level of .75; a load draws 806 amps at 480V; average power consumption of 500kW; and a desired power factor level of .90. Compute the necessary capacitance required and select the proper automatic and fixed bank unit.

1. First, look at the left hand column of the Power Factor Correction chart entitled “Original Power Factor”. Find your current power factor level of .75.

2. Second, follow the column of figures to the right of the .75 figure until you come to the column entitled “.90” (your desired power factor level).

3. The number in that row is .398. Now multiply this figure by the total plant kW of 500:

.398 X 500kW = 199 kvar

4. The resulting total of 199 represents the amount of capacitive power (kvar) required to bring the power factor to the desired level of .90.

5. Referring to the sample selection charts (See Table 4 or Table 5, next page), select the appropriate kvar rating.

NOTE: When selecting automatic bank units, select the closest kvar rating to the amount of kvar desired based on present and future applications. If the desired rating is not listed, the next higher kvar rating should be selected. When selecting fixed bank units, however, select the kvar rating WITHOUT GOING OVER (See Warning, page 6.12) the desired capacitance level.

In this example for the automatic capacitor bank, 200 kvar is the closest to the desired 199 kvar. For the fixed capacitor bank, 180 kvar should be selected without going over the desired kvar of 199.

Sizing capacitors at the motor load

Using charts

What if Present Power Factor Cannot Be Determined Because kVA is Unknown?

1. First, find the apparent power (kVA). kVA demand on a 3-phase system is equal to:

kVA = VOLTS x AMPS x√3 ÷ 1000

2. The voltage and amperage of the distribution system will be known. Again, using the above example, we know that the distribution system is 480 volts and draws 806 amps. Therefore:

480 VOLTS x 806 AMPS x√3 ÷ 1000 = 670kVA

3. Now power factor can be solved for:

500kW / 670kVA = .746 pf

4. With the power factor now known, the Power Factor Improvement chart can be used as before.

How is the Power Factor Correction Chart Used if Existing Power Factor Level is Unknown?

1. First, power factor has to be calculated. Power factor is equal to active power (kW) divided by apparent power (kVA). kW will be known because it is the total amount of power consumed over a given period of time and is the amount shown on a utility bill. Therefore:

pf = kW / kVA

2. Using the above example, 500kW divided by 670kVA equals a present power factor (pf) of .746.

500kW / 670kVA = .746 pf

3. When DETERMINING power factor, always round off to the next higher rating. Therefore, the .746 power factor figure is rounded off to .75.

NOTE: Don't confuse rounding UP a power factor figure that is manually calculated with the warning on page 46 that tells you to round DOWN when using a catalog selection chart!

4. Now that present power factor is known, the above problem can be solved as before.

FINAL EXAMPLE: A manufacturer has a 480 volt, 3-phase metered demand of 460kW. An ammeter on the system shows total current draw of 770 amps. Existing power factor and apparent power (kVA) are unknown. What is the existing system power factor and how much capacitance is required to correct to .92?

1. First, solve for kVA.

480 VOLTS x 770 AMPS x√3 ÷ 1000 = 640kVA

2. Next, solve for Power Factor.

460kW / 640kVA = .72 POWER FACTOR

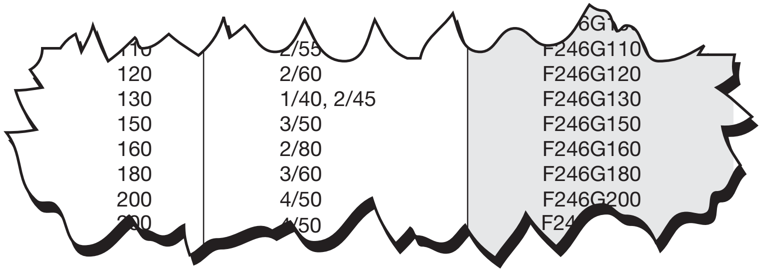
3. To correct the power factor from .72 to .92 refer to the Power Factor Correction Chart on page 47. A factor of .534 will be determined.

4. The final step is to multiply the 460kW figure by the correction factor of .534.

460kW X .534 = 245 kvar

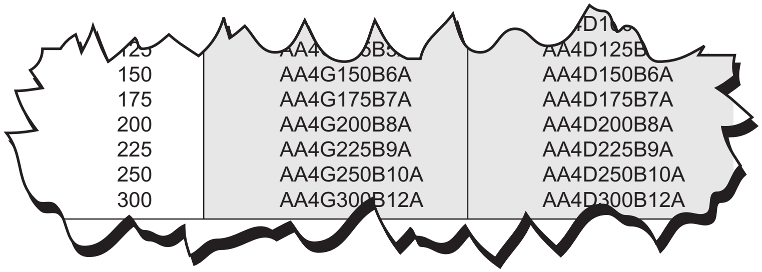
This system would require the installation of 245 kvar of capacitance to improve the power factor to .92. Refer to the appropriate automatic or fixed bank catalog pages, select the proper voltage and phase, then identify the proper catalog number.

TABLE 4 - Fixed Capacitor Banks



110	2/55	F246G110
120	2/60	F246G120
130	1/40, 2/45	F246G130
150	3/50	F246G150
160	2/80	F246G160
180	3/60	F246G180
200	4/50	F246G200

TABLE 5 - Automatic Capacitor Banks



150	AA4G150B6A	AA4D150B6A
175	AA4G175B7A	AA4D175B7A
200	AA4G200B8A	AA4D200B8A
225	AA4G225B9A	AA4D225B9A
250	AA4G250B10A	AA4D250B10A
300	AA4G300B12A	AA4D300B12A

Typical recommended ratings of cables & protected devices

Typical recommended ratings of cables and protected devices

3- Phase Capacitor kVar	Rated Current Per Phase (amps)	Minimum Copper Cable Size for 75oC Insulation	Recommended fuse amps Type Class RK5 (Time Delay)	Recommended Disconnect Switch Amps	Recommended MCCB Trip Amps
240 Volt					
2.5	6	#14	10	30	15
3.5	8.4	#14	15	30	15
5	12	#14	20	30	20
7.5	18	#12	30	30	30
10	24	#10	40	60	40
15	36	#6	60	60	60
20	48	#4	80	100	80
25	60	#4	100	100	90
30	72	#2	125	200	110
40	96	#1	175	200	150
50	120	1/0	200	200	200
60	144	2/0	250	400	225
75	180	250 kcmil	300	400	300
100	241	400 kcmil	400	400	400
125	301	(2) - 4/0	500	600	500
150	361	(2) - 250 kcmil	600	600	600
200	481	(2) - 400 kcmil	800	800	750
250	601	(3) - 300 kcmil	1000	1000	900
300	722	(3) - 400 kcmil	1200	1200	1100
480 Volt					
1.5	1.8	#14	3	30	15
2	1.8	#14	3	30	15
2.5	3	#14	6	30	15
3	3.6	#14	6	30	15
3.5	4.2	#14	10	30	15
4	4.8	#14	10	30	15
5	6	#14	10	30	15
6	7.2	#14	15	30	15
6.5	7.8	#14	15	30	15
7.5	9	#14	15	30	15
10	12	#14	20	30	20
15	18	#12	30	30	30
20	24	#10	40	60	40
25	30	#8	50	60	50
30	36	#6	60	60	60
35	42	#6	70	100	70
40	48	#4	80	100	80
45	54	#4	90	100	90
50	60	#4	100	100	90
60	72	#2	125	200	110
70	84	#1	150	200	150
75	90	#1	150	200	150
80	96	#1	175	200	150
90	108	1/0	200	200	175
100	120	2/0	200	200	200
150	180	250 kcmil	300	400	300
200	241	400 kcmil	400	400	400
250	301	(2) - 4/0	500	600	500
300	361	(2) - 250 kcmil	600	600	600
350	421	(2) - 300 kcmil	700	800	650
400	481	(2) - 400 kcmil	800	800	750
500	601	(3) - 300 kcmil	1000	1000	902

Typical recommended ratings of cables & protected devices

Typical recommended ratings of cables and protected devices

3-Phase Capacitor kvar	Rated Current Per Phase (amps)	Minimum Copper Cable Size for 75oC Insulation	Recommended fuse amps Type RK5 (Time Delay)	Recommended Disc Switch Amps	Recommended MCCB Trip Amps
600 Volt					
2	2	#14	3	30	15
3	3	#14	6	30	15
4	4	#14	6	30	15
5	5	#14	10	30	15
7.5	7	#14	15	30	15
10	10	#14	20	30	15
15	14	#14	25	30	25
20	19	#10	35	60	30
25	24	#10	40	60	40
30	29	#8	50	60	50
35	34	#8	60	60	60
40	38	#6	70	100	60
45	43	#6	80	100	70
50	48	#4	80	100	80
60	58	#4	100	100	90
70	67	#2	125	200	110
80	77	#2	150	200	125
90	87	#1	150	200	150
100	96	#0	175	200	150
150	144	3/0	250	400	225
200	192	300 kcmil	350	400	300
250	241	400 kcmil	400	400	400
300	289	(2) - 3/0	500	600	450
350	337	(2) - 4/0	600	600	550
400	385	(2) - 300 kcmil	650	800	600
500	481	(2) - 400 kcmil	800	800	750

NOTE: Cable sizes are derived from Article 310, Table 310-16 of 2002 ***NEC*** ®

The above table gives recommended ratings of cables, disconnect switches, and/or molded case circuit breakers for use with capacitor loads. For requirements not covered in the table, the following application guidelines may be used for capacitor switching duty:

• Power Cable Sizing	135% of Capacitor Current
• Disconnect Switch	165% of Capacitor Current
• Molded Case Circuit Breaker	135% of Capacitor Current

Note: For specific applications, refer to the *NEC*®.

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Extract from *NEC* ®
Separate overcurrent protection

Extract from 2002 *NEC* ® Code Requirements

460-8. Conductors.

(A) Ampacity. The ampacity of capacitor circuit conductors shall not be less than 135 percent of the rated current of the capacitor. The ampacity of conductors that connect a capacitor to the terminals of a motor or to motor circuit conductors shall not be less than one third the ampacity of the motor circuit conductors and in no case less than 135 percent of the rated current of the capacitor.

(B) Overcurrent Protection. An overcurrent device shall be provided in each ungrounded conductor for each capacitor bank. The rating or setting of the overcurrent device shall be as low as practicable.

Exception: A separate overcurrent device shall not be required for a capacitor connected on the load side of a motor overload protective device.

(C) Disconnecting Means. A disconnecting means shall be provided in each ungrounded conductor for each capacitor bank and shall meet the following requirements.

(1) The disconnecting means shall open all ungrounded conductors simultaneously.

(2) The disconnecting means shall be permitted to disconnect the capacitor from the line as a regular operating procedure.

(3) The rating of the disconnecting means shall not be less than 135 percent of the rated current of the capacitor.

Exception: A separate disconnecting means shall not be required where a capacitor is connected on the load side of a motor controller.

460-9. Rating or Setting of Motor Overload Device. Where a motor installation includes a capacitor connected on the load side of the motor overload device, the rating or setting of the motor overload device shall be based on the improved power factor of the motor circuit.

The effect of the capacitor shall be disregarded in determining the motor circuit conductor rating in accordance with Section 430-22.

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Separate overcurrent protection

A separate overcurrent device is not necessary when an ABB capacitor is electrically connected on the load side of the motor starter fused safety switch or breaker. Personnel and facility short circuit protection is provided within the capacitor by ABB's patented Sequential Protection System. Short circuit protection between the main feed and the capacitor is provided by the motor starter fused safety switch or breaker. A disconnect switch can be provided when the capacitor is connected as illustrated in Option C (See Fig. 12). When the capacitor is connected as shown in Option C, the capacitor remains energized when the motor is off. The optional disconnect switch provides a means to disconnect the capacitor when the motor is not in operation.

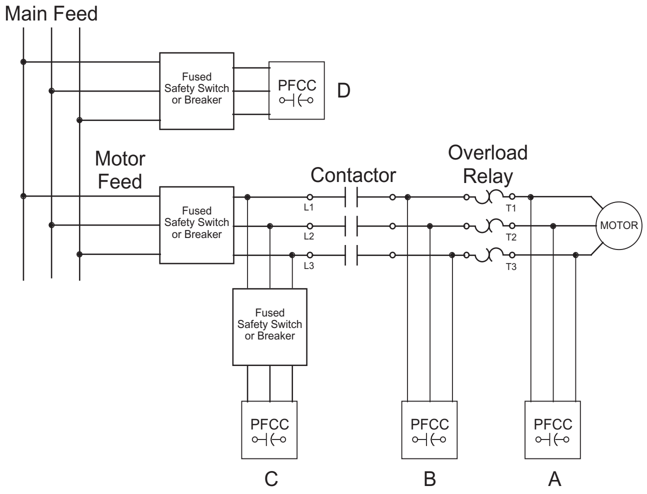

Fig. 12

Notes