Power Factor.

Power factor is the ratio between the KW and the KVA drawn by an electrical load where the KW is the actual load power and the KVA is the apparent load power. It is a measure of how effectively the current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system.

All current will causes losses in the supply and distribution system. A load with a power factor of 1.0 results in the most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system.
A poor power factor can be the result of either a significant phase difference between the voltage and current at the load terminals, or it can be due to a high harmonic content or distorted/discontinuous current waveform.
Poor load current phase angle is generally the result of an inductive load such as an induction motor, power transformer, lighting ballasts, welder or induction furnace.
A distorted current waveform can be the result of a rectifier, variable speed drive, switched mode power supply, discharge lighting or other electronic load.

A poor power factor due to an inductive load can be improved by the addition of power factor correction, but, a poor power factor due to a distorted current waveform requires an change in equipment design or expensive harmonic filters to gain an appreciable improvement. Many inverters are quoted as having a power factor of better than 0.95 when in reality, the true power factor is between 0.5 and 0.75. The figure of 0.95 is based on the Cosine of the angle between the voltage and current but does not take into account that the current waveform is discontinuous and therefore contributes to increased losses on the supply.

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Power Factor Correction.

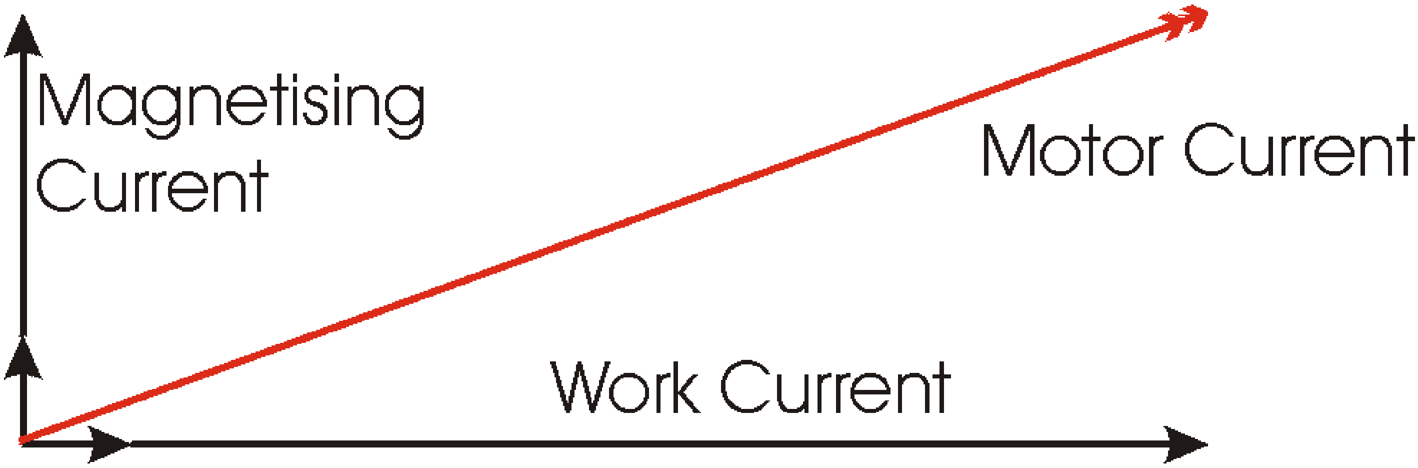
Capacitive Power Factor correction is applied to circuits which include induction motors as a means of reducing the inductive component of the current and thereby reduce the losses in the supply. There should be no effect on the operation of the motor itself.

An induction motor draws current from the supply, that is made up of resistive components and inductive components. The resistive components are:

1) Load current.
2) Loss current.

and the inductive components are:

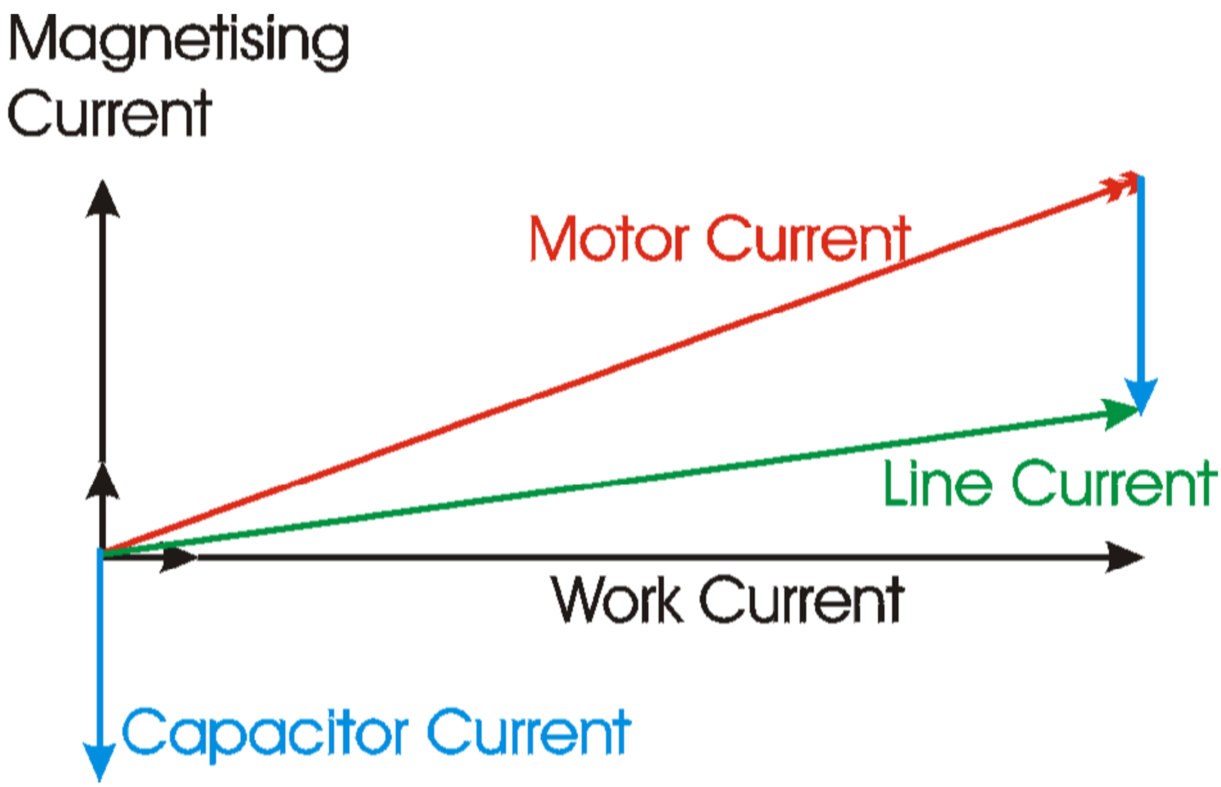
3) Leakage reactance.
4) Magnetizing current.



The current due to the leakage reactance is dependant on the total current drawn by the motor, but the magnetizing current is independent of the load on the motor. The magnetizing current will typically be between 20% and 60% of the rated full load current of the motor. The magnetizing current is the current that establishes the flux in the iron and is very necessary if the motor is going to operate. The magnetizing current does not actually contribute to the actual work output of the motor. It is the catalyst that allows the motor to work properly. The magnetizing current and the leakage reactance can be considered passenger components of current that will not affect the power drawn by the motor, but will contribute to the power dissipated in the supply and distribution system. Take for example a motor with a current draw of 100 Amps and a power factor of 0.75 The resistive component of the current is 75 Amps and this is what the KWh meter measures. The higher current will result in an increase in the distribution losses of (100 x 100) /(75 x 75) = 1.777 or a 78% increase in the supply losses.

In the interest of reducing the losses in the distribution system, power factor correction is added to neutralize a portion of the magnetizing current of the motor. Typically, the corrected power factor will be 0.92 - 0.95 Some power retailers offer incentives for operating with a power factor of better than 0.9, while others penalize consumers with a poor power factor. There are many ways that this is metered, but the net result is that in order to reduce wasted energy in the distribution system, the consumer will be encouraged to apply power factor correction.

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the starter, or applied at the switchboard or distribution panel. The resulting capacitive current is leading current and is used to cancel the lagging inductive current flowing from the supply.



Capacitors connected at each starter and controlled by each starter is known as *"Static Power Factor Correction"* while capacitors connected at a distribution board and controlled independently from the individual starters is known as *"Bulk Correction".*

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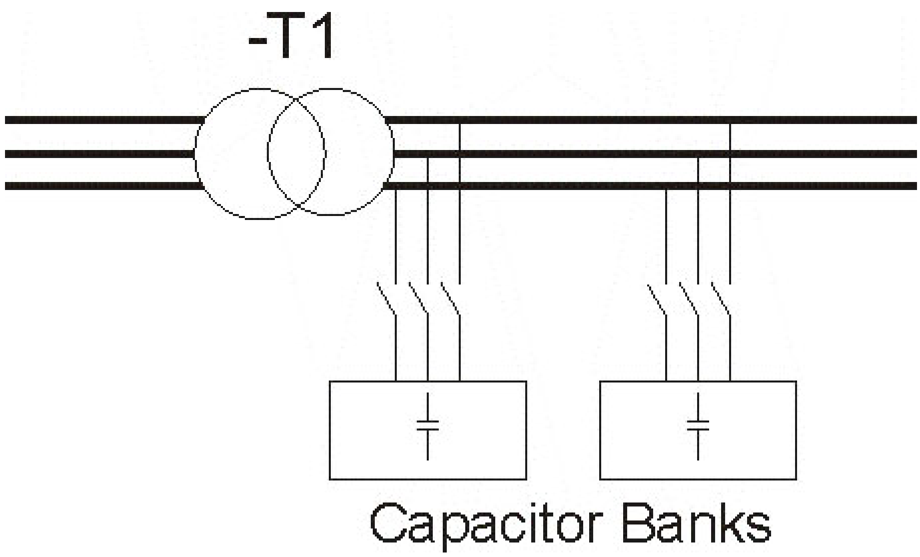
Bulk Correction.

The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks In a fashion to maintain a power factor better than a preset limit. (Typically 0.95) Ideally, the power factor should be as close to unity as possible. There is no problem with bulk correction operating at unity.



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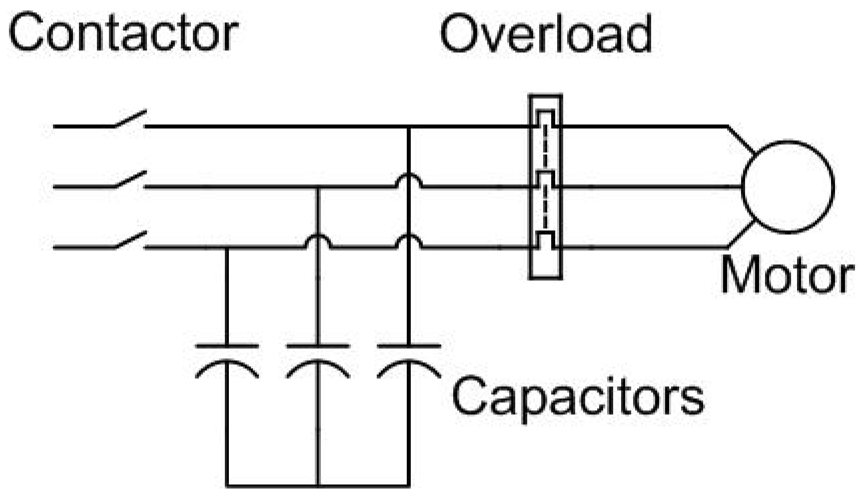
Static Correction.

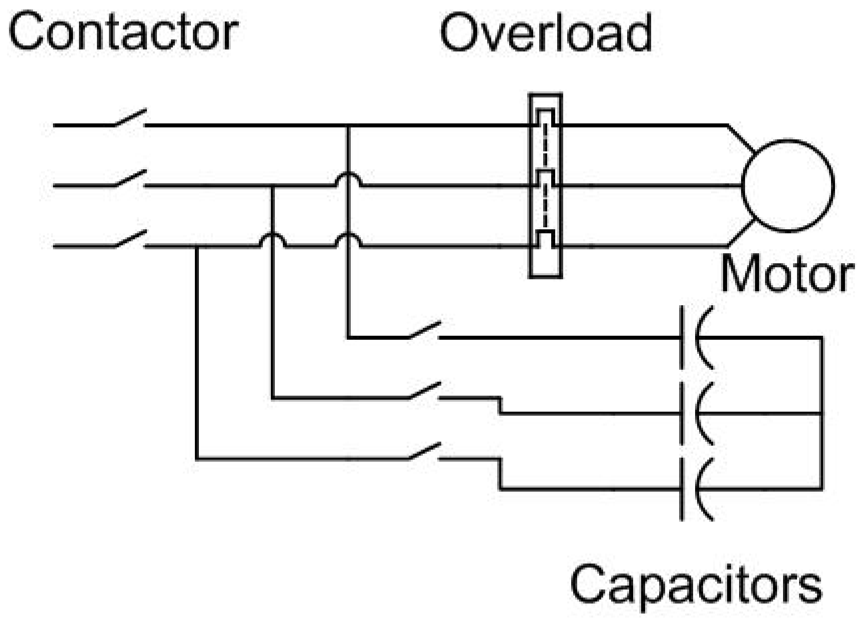
As a large proportion of the inductive or lagging current on the supply is due to the magnetizing current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters. With static correction, it is important that the capacitive current is less than the inductive magnetizing current of the induction motor. In many installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is Off Line, the capacitors are also Off Line. When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment. In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator which induces current into the rotor. When the motor is disconnected from the supply, there is for a period of time, a magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is related to it's speed. The capacitors connected across the motor terminals, form a resonant circuit with the motor inductance. If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency. If the motor is over corrected, the resonant frequency will be below the line frequency. If the frequency of the voltage generated by the decelerating motor passes through the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit. This can result in severe damage to the capacitors and motor. It is imperative that motors are never over corrected or critically corrected when static correction is employed.

Static power factor correction should provide capacitive current equal to 80% of the **magnetizing current**, which is essentially the open shaft current of the motor.

The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor. It is not practical to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Tables result in under correction on most motors but can result in over correction in some cases. Where the open shaft current can not be measured, and the magnetizing current is not quoted, an approximate level for the maximum correction that can be applied can be calculated from the half load characteristics of the motor. It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in over correction under no load, or disconnected conditions.



Static correction is commonly applied by using on e contactor to control both the motor and the capacitors. It is better practice to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors.



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Inverter.

Static Power factor correction **must not be** used when the motor is controlled by a variable speed drive or inverter. The connection of capacitors to the output of an inverter can cause serious damage to the inverter and the capacitors due to the high frequency switched voltage on the output of the inverters.
The current drawn from the inverter has a poor power factor, particularly at low load, but the motor current is isolated from the supply by the inverter. The phase angle of the current drawn by the inverter from the supply is close to zero resulting in very low inductive current irrespective of what the motor is doing. The inverter does not however, operate with a good power factor. Many inverter manufacturers quote a cos Ø of better than 0.95 and this is generally true, however the current is non sinusoidal and the resultant harmonics cause a power factor (KW/KVA) of closer to 0.7 depending

on the input design of the inverter. Inverters with input reactors and DC bus reactors will exhibit a higher true power factor than those without.
The connection of capacitors close to the input of the inverter can also result in damage to the inverter. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the input circuits of the inverter, and the energy behind the impulses is much greater due to the energy storage of the capacitors. It is recommended that capacitors should be at least 75 Meters away from inverter inputs to elevate the impedance between the inverter and capacitors and reduce the potential damage caused.
Switching capacitors, Automatic bank correction etc, will cause voltage transients and these transients can damage the input circuits of inverters. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.

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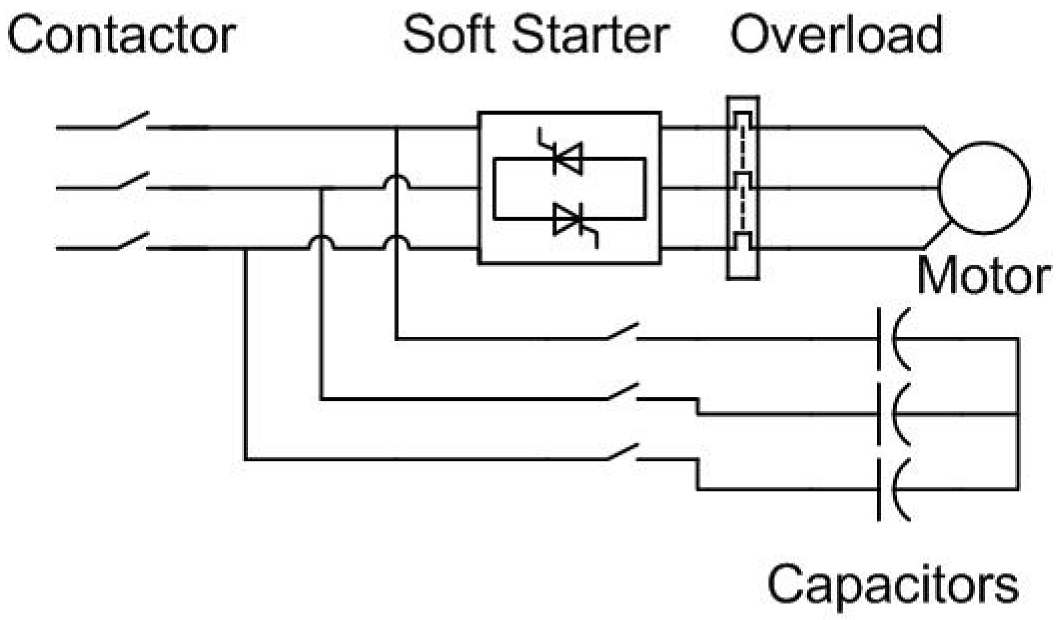
Solid State Soft Starter.

Static Power Factor correction capacitors **must not** be connected to the output of a solid state soft starter. When a solid state soft starter is used, the capacitors must be controlled by a separate contactor, and switched in when the soft starter output voltage has reached line voltage. Many soft starters provide a *"top of ramp"* or *"bypass contactor control"* which can be used to control the power factor correction capacitors.
The connection of capacitors close to the input of the soft starter can also result in damage to the soft starter if an isolation contactor is not used. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the SCRs of the Soft Starter, and the energy behind the impulses is much greater due to the energy storage of the capacitors. It is recommended that capacitors should be at least 50 Meters away from Soft starters to elevate the impedance between the inverter and capacitors and reduce the potential damage caused.
Switching capacitors, Automatic bank correction etc, will cause voltage transients and these transients can damage the SCRs of Soft Starters if they are in the Off state without an input contactor. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.



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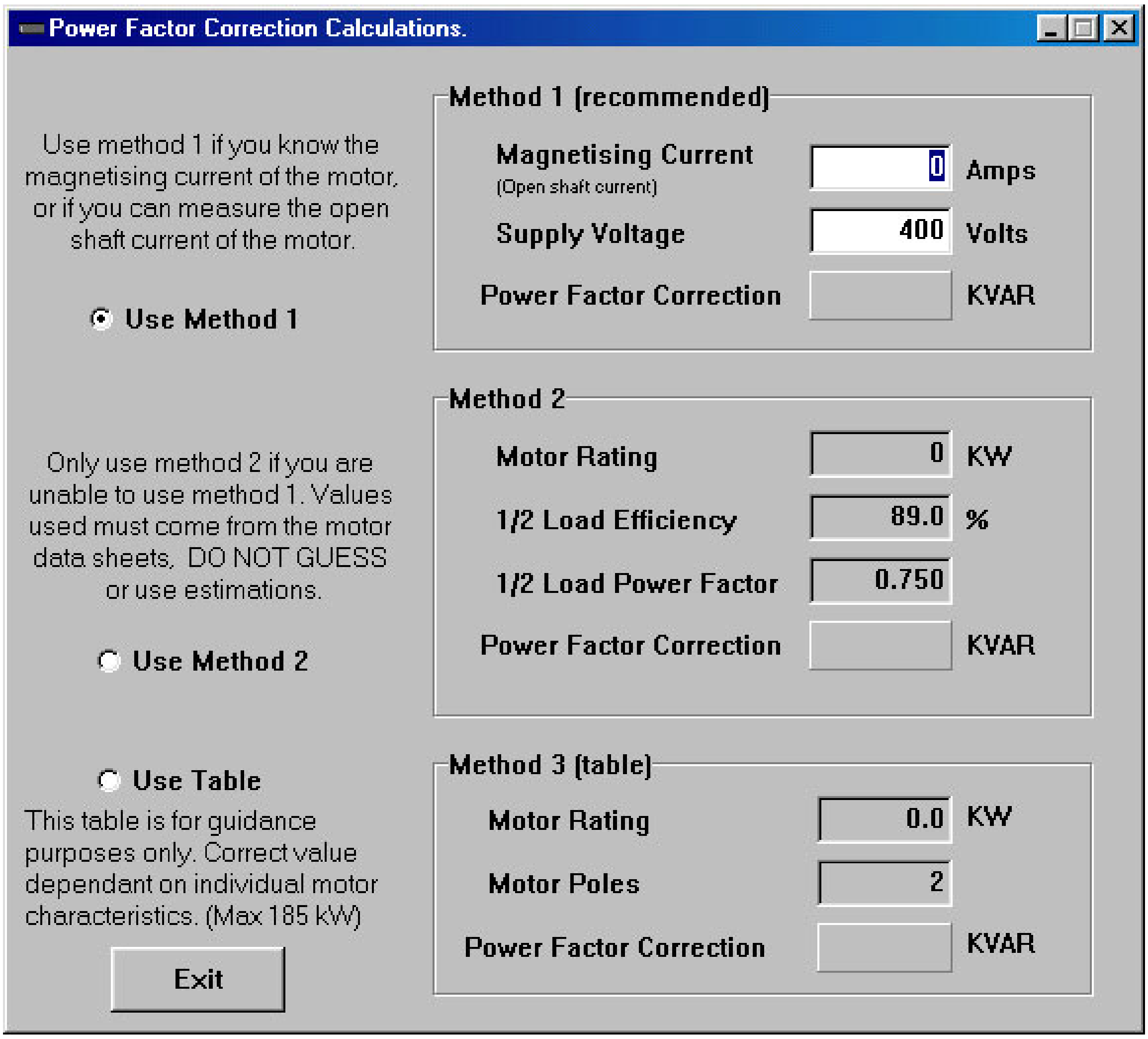
Capacitor selection.

Static Power factor correction must neutralize no more than 80% of the magnetizing current of the motor. If the correction is too high, there is a high probability of over correction which can result in equipment failure with severe damage to the motor and capacitors. Unfortunately, the magnetizing current of induction motors varies considerably between different motor designs. The magnetizing current is almost always higher than 20% of the rated full load current of the motor, but can be as high as 60% of the rated current of the motor. Most power factor correction is too light due to the selection based on tables which have been published by a number of sources. These tables assume the lowest magnetizing current and quote capacitors for this current. In practice, this can mean that the correction is often less than half the value that it should be, and the consumer is unnecessarily penalized.
Power factor correction must be correctly selected based on the actual motor being corrected. The Electrical Calculations software provides two methods of calculating the correct value of KVAR correction to apply to a motor. The first method requires the magnetizing current of the motor. Where this figure is available, then this is the preferred method. Where the magnetizing current is not available, the second method is employed and is based on the half load power factor and efficiency of that motor. These figures are available from the motor data sheets.

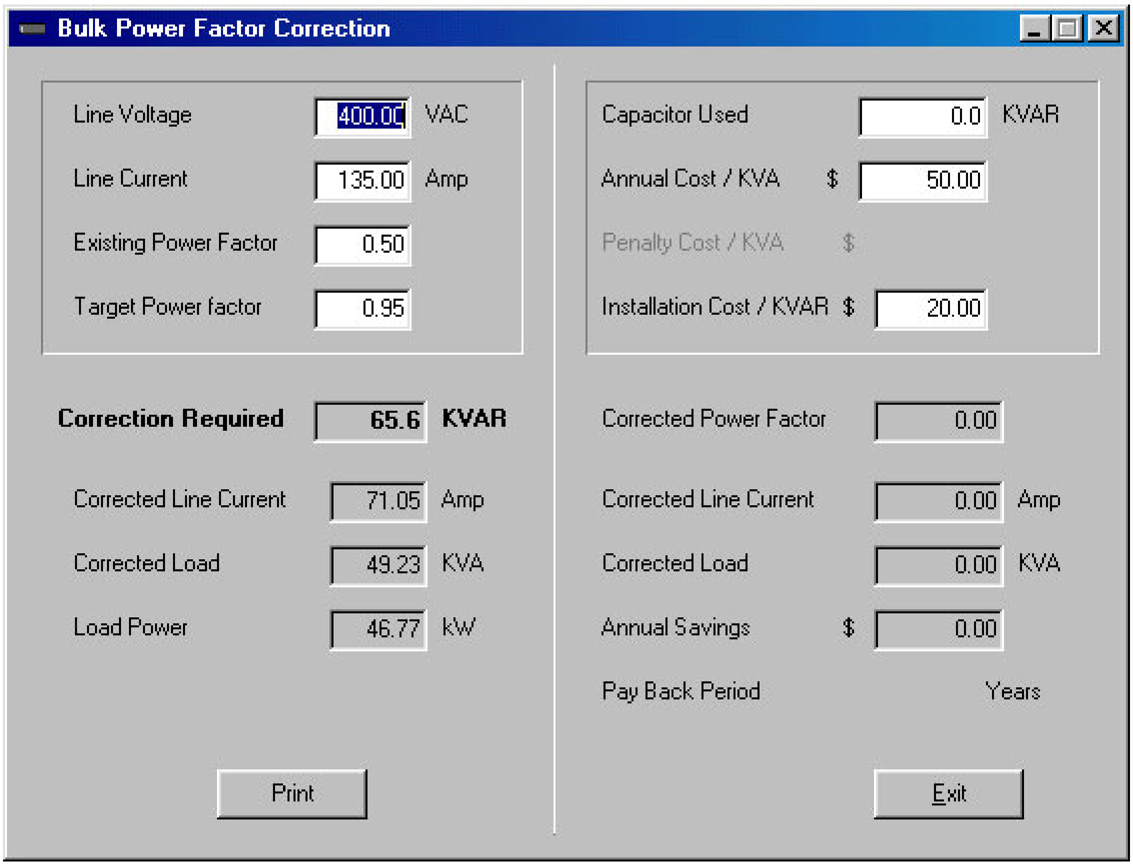
For example:
Motor A is a 200 KW 6 pole motor with a magnetizing current of 124A. From tables, the correction applied would be 37KVAR. From the calculations, this would require a correction of 68.7 KVAR
Motor B is a 375KW 2 pole motor with a half load efficiency of 93.9% and a half load power factor of 0.805, the correction recommended by the tables is 44 KVAR while the calculations reveal that the correction should be 81.3KVAR

Electrical Calculations is a shareware program which means that you can try it before you buy it. You can freely distribute copies to anyone you please, but if you find it to be useful, as I'm sure you will, then you must purchase it at $NZ35.00 Registered copies of Busbar will be eligible for continued updates, and registered users will be advised of all major upgrades as they become available.

Static Power factor correction can be calculated from known motor characteristics for any given motor, either the magnetizing current and supply voltage (method 1) or half load efficiency and half load power factor(method 2), or, as a last resort, table values can be used. These will almost always result in under correction.



Bulk power factor correction can be calculated from known existing power factor, required new powerfactor, line voltage and line current.



Click here to download Electrical Calculations including the power factor calculations.

Downloads

The Purchase Price for Electrical Calculations is $NZ35 or $US22.

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Supply Harmonics.

Harmonics on the supply cause a higher current to flow in the capacitors. This is because the impedance of the capacitors goes down as the frequency goes up. This increase in current flow through the capacitor will result in additional heating of the capacitor and reduce it's life. The harmonics are caused bu many non linear loads, the most common in the industrial market today, are the variable speed controllers and switchmode power supplies. Harmonic voltages can be reduced by the use of a harmonic compensator, which is essentially a large inverter that cancells out the harmonics. This is an expensive option. Passive harmonic filters comprising resistors, inductors and capacitors can also be used to reduce harmonic voltages. This is also an expensive exersize.
In order to reduce the damage caused to the capacitors by the harmonic currents, it is becomming common today to install detuning reactors in series with the power factor correction capacitors. These reactors are designed to make the correction circuit inductive to the higher frequency harmonics. Typically, a reactor would be designed to create a resonant circuit with the capacitors above the third harmonic, but sometimes it is below. (Never tuned to a harmonic frequency!!) Adding the inductance in series with the cpacitors will reduce their effective capacitance at the supply frequency.

Reducing the resonant or tuned frequency will reduce the the effective capacitance further. The object is to make the circuit look as inductive as possible at the 5th harmonic and higher, but as capacitive as possible at the fundemental frequency. Detuning reactors will also reduce the chance of the tuned circuit formed by the capacitors and the inductive supply being resonant on a supply harmonic frequency, thereby reducing damage due to supply resonances amplifying harmonic voltages caused by non linear loads.

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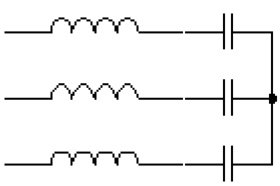
Detuning Reactors.

Detuning reactors are connected in series with power factor correction capacitors to reduce harmonic currents and to ensure that the series resonant frequency does not occur at a harmonic of the supply frequency.
The reactors are usually chosen and rated as either 5% or 7% reactors. This means that at the line frequency, the capacitive reactance is reduced by 5% or 7%.
Using detuning reactors results in a lower KVAR, so the capacitance will need to be increased for the same level of correction.
When detuning reactors are used in installations with high harmonic voltages, there can be a high resultant voltage across the capacitors. This necessitates the use of capacitors that are designed to operate at a high sustained voltage. Capacitors designed for use at line voltage only, should not be used with detuning reactors. Check the suitability of the capacitors for use with line reactors before installation.
The detuning reactors can dissipate a lot of heat. The enclosure must be well ventillated, typically forced air cooled.
The detuning reactor must be specified to match the KVAR of the capacitance selected. The reactor would typically be rated as 12.5KVAR 5% meaning that it is a 5% reactor to connect to a 12.5KVAR capacitor.



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Supply Resonance.

Capacitive Power factor correction connected to a supply causes resonance between the supply and the capacitors. If the fault current of the supply is very high, the effect of the resonance will be minimal, however in a rural installation where the supply is very inductive and can be a high impedance, the resonances can be very severe resulting in major damage to plant and equipment. Voltage surges and transients of several times the supply voltage are not uncommon in rural areas with weak supplies, especially when the load on the supply is low. As with any resonant system, a transient or sudden change in current will result in the resonant circuit ringing, generating a high voltage. The magnitude of the voltage is dependant on the 'Q' of the circuit which in turn is a function of the circuit loading. One of the problems with supply resonance is that the 'reaction' is often well removed from the 'stimulus' unlike a pure voltage drop problem due to an overloaded supply. This makes fault finding very difficult and often damaging surges and transients on the supply are treated as 'just one of those things'.

To minimize supply resonance problems, there are a few steps that can be taken, but they do need to be taken by all on the particular supply.
1) Minimize the amount of power factor correction, particularly when the load is light. The power factor correction minimizes losses in the supply. When the supply is lightly loaded, this is not such a problem.
2) Minimize switching transients. Eliminate open transition switching - usually associated with generator plants and alternative supply switching, and with some electromechanical starters such as the star/delta starter.
3) Switch capacitors on to the supply in lots of small steps rather than a few large steps.
4) Switch capacitors on o the supply after the load has been applied and switch off the supply before or with the load removal.

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Harmonic Power Factor correction is not applied to circuits that draw either discontinuous or distorted current waveforms.

Most electronic equipment includes a means of creating a DC supply. This involves rectifying the AC voltage, causing harmonic currents. In some cases, these harmonic currents are insignificant relative to the total load current drawn, but in many installations, a large proportion of the current drawn is rich in harmonics. If the total harmonic current is large enough, there will be a resultant distortion of the supply waveform which can interfere with the correct operation of other equipment. The addition of harmonic currents results in increased losses in the supply.

Power factor correction for distorted supplies can not be achieved by the addition of capacitors. The harmonics can be reduced by designing the equipment using active rectifiers, by the addition of passive filters (LCR) or by the addition of electronic power factor correction inverters which restore the waveform back to its undistorted state. This is a specialist area requiring either major design changes, or specialized equipment to be used.

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