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Improving Power Quality of Induction Motors using Capacitor Bank

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Abstract: In this paper, the improvement in power factor of induction motor by using capacitor bank is represented with the help of MATLAB simulation model. When power factor is improved, automatically energy will be saved A power factor is the goal of any electrical utility company since if the power factor is less than one, they have to supply more current to the user for a given amount of power use. In so doing they occur more line losses. Induction motors are the most widely used electrical motors due to their reliability, low cost and robustness. For industrial and mining applications, 3- phase AC induction motors are the prime movers for the vast majority of machines. It has been estimated that 70% to 80% of all electricity in the world is consumed by these motors. At no load induction motor has very low power factor. It improves at increasing load from no load to full Load. 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.

Keywords: Power Factor Improvement, Capacitor Bank, Induction Motor

I. INTRODUCTION

The main objective of this project is to design an energy saving scheme for an industrial distribution network. This can be achieved by decreasing the network losses and improving the main electric load operation to a better efficiency level. The designed scheme is concerned with improving the power factor of the distribution network by adding shunt capacitors to the network at optimal size and location. Industrial power distribution networks encounters increase in power losses and increase in the type of load is accompanied with low power factor which leads to huge transfer of reactive power from the utility through the network. When power factor is improved, automatically energy will be saved A power factor is the goal of any electrical utility company since if the power factor is less than one, they have to supply more current to the user for a given amount of power use. In so doing they occur more line losses. Induction motors are the most widely used electrical motors due to their reliability, low cost and robustness. For industrial and mining applications, 3-phase AC induction motors are the prime movers for the vast majority of machines. It has been estimated that 70% to 80% of all electricity in the world is consumed by these motors. At no load induction motor has very low power factor. It improves at increasing load from no load to full load. 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 main drawback of this problem is increase in the network losses and reduction in the voltage level. It can result in poor reliability, safety problems and higher energy costs. The lower our power factor, the less economically our system operates. The actual amount of power being used or dissipated in a circuit is called true power. Reactive loads such as inductors and capacitors make up what is called reactive power. The linear combination of true power and reactive power is called apparent power. Power system loads consist of resistive, inductive, and capacitive loads. Examples of resistive loads are incandescent lighting and electric heaters. Inductive loads are induction motors, transformers, and reactors and capacitive loads are capacitors, variable or fixed capacitor banks, motor starting capacitors, generators, and synchronous motors. Low power factor is not that much problem in domestic's area, but it becomes a problem in industry where multiple large motors are used so there is requirement to correct the power factor. Thus Power factor correction (PFC) is usually achieved by adding capacitive load to offset the inductive load present in the power system. There are many benefits to having power factor correction.

Power Factor: The power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit, and is a dimensionless number in the closed interval of -1 to 1. A power factor of less than one means In electrical engineering that the voltage and current waveforms are not in phase, reducing the instantaneous product of the two waveforms (V X 1). Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power. A negative power factor occurs when the device (which is normally the load) generates power, which then flows back towards the source, which is normally considered the generator. In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor. Linear loads with low power factor (such as induction motors) can be corrected with a passive ! network of capacitors or inductors. Non-linear loads, such as rectifiers, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise the power factor. The devices for correction of the power factor may be at a central substation, spread out over a distribution system, or built into power consuming equipment.

Power Factor in Terms of Power

AC power flow has two components:
1. Real power or active power (P) (sometimes called average power), expressed in watts (W)
2. Reactive power (Q), usually expressed in reactive volt-amperes (VAR)

These are combined to the complex power (S) expressed volt-amperes (VA). The magnitude of the complex power is the apparent power (S), also expressed in volt-amperes (VA).

The VA and VAR are non-SI units mathematically identical to the watt, but are used in engineering practice instead of the watt in order to state what quantity is being expressed. The SI explicitly disallows using units for this purpose or as the only source of information about a physical quantity as used. The power factor (is defined as the ratio of real power to apparent power. As power is transferred along a transmission line, it does not consist purely of real power that can do work once transferred to the load, but rather consists of a combination of real and reactive power, called apparent power. The power factor describes the amount of real power transmitted along a transmission line relative “to the total apparent power flowing in the line.

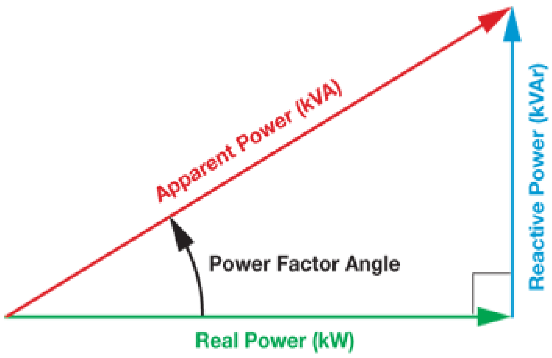

Figure 1. Power triangle

One can relate the various components of AC power by using the power triangle. Real power extends horizontally in the i direction as it represents a purely real component of AC power. Reactive power extends in the direction of j as it represents a purely imaginary component of AC power. Complex power (and its magnitude, Apparent power) represents a combination of both real and reactive power, and therefore can be calculated by using the vector sum of these two components. We can conclude that the mathematical relationship between these components is:

As the power factor (Le. cos ϴ) increases, the ratio of real power to apparent power (which = cos ϴ), increases and approaches unity (1), while the angle ϴ decreases and the reactive power decreases. [As cos φ, its maximum possible value, as the load becomes less reactive and more purely resistive].

As the power factor decreases, the ratio of real power to apparent power also decreases, as the angle increases and reactive power increases.

Lagging and leading power factors: There is also a difference between a lagging and leading power factor. The terms refer to whether the phase of the current is leading or lagging the phase of the voltage. A lagging power factor signifies that the load is inductive, as the load will consume reactive power, and therefore the reactive component is positive as reactive power travels through the circuit and IS “consumed” by the inductive loud A leading power factor signifies that

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the load is capacitive, as the load “supplies" reactive power, and therefore the reactive component is negative as reactive power is being supplied to the circuit.

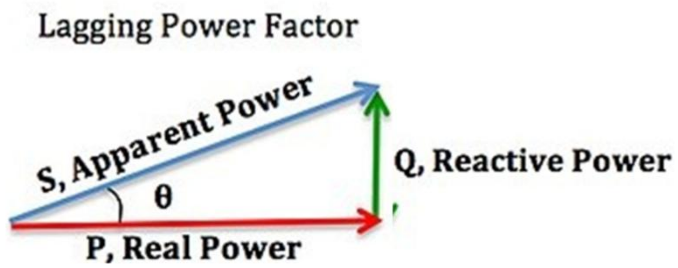

Figure 2. Lagging power factor.

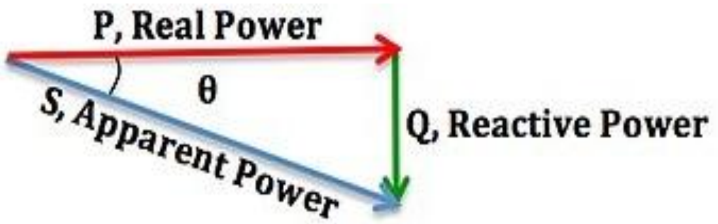

Figure 3. Leading power factor.

If φ is the phase angle between the current and voltage, then the power factor is equal to the cosine of the angle, Since the units are consistent, the power factor is by definition dimensionless number between -l and 1, When power factor is equal to O, the energy flow is entirely reactive and stored energy in the load returns to the source on each cycle. When the power factor is I, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading” or “lagging" to show the sign of the phase angle. Capacitive loads are leading (current leads voltage), and inductive loads are lagging (current lags voltage).

If a purely resistive load is connected to a power supply, current and voltage ‘will change polarity to step, the power factor will be 1 and the electrical energy flows in a single direction across the network in each cycle, inductive loads such as induction motors (any type of wound coil) consume power with current waveform lagging the voltage. Capacitive loads such as capacitor banks or buried. cable generate reactive power with correct phase loading the voltage, both types of loads will absorb energy during part of the AC cycle, which is stored to the device magnetic or electric field, only to return this energy back to the source during the rest of the cycle.

For example, to get 1 kW of real power, if the power factor is unity, l kVA of apparent power needs to be transferred (1 kW -11 = l kVA). At low values of power factor, more apparent power needs to be transferred to get the same real power. To get 1 kW of real power at 0.2 power factor, 5 kVA of apparent power needs to be transferred (1 kW + 0.21 = 5 kVA). This apparent power must be produced and transmitted to the load, and is subject to the losses in the production and transmission processes.

Electrical loads consuming alternating current power consume both real power and reactive power. The vector sum of real and reactive power is the apparent power. The presence of reactive power causes the real power to be less than the apparent power, and so, the electric load has a power factor of less than 1.

A negative power factor (0 to ~-l) can result from returning power to the source, such as in the case of a building fitted with solar panels when surplus power is fed back into the supply. ' r

The of 3 phase induction motor is simple, robust construction, and high reliability factor in the sea environment. A 3 phase induction motor can be used for different applications with various speed and load requirements. Electric motors can be found in almost every production process today. Getting the most out of your application is becoming more and more important in order to ensure cost-effective operations. The three-phase induction motors are the most widely used electric motors in industry. They run at essentially constant speed from no-load to full-load. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control. We usually prefer dc motors when large speed variations are required. ‘Nevertheless, the 3-phase. induction motors are simple, rugged, low-priced, easy to maintain and can be manufactured with characteristics to suit most industrial' requirements. Like any electric motor, a 3-phase induction motor has a stator and a rotor. The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator w1nd1ng through electromagnetic induction and hence the name.

The Operation of the motor can be explained as under: (i) When 3-phase stator winding is energized froni a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed NS = 120 f/P). (ii) The rotating field passes through the air gap and cuts the rotor conductors, which as yet, are stationary. Due to the relative speed between the rotating flux and the stationary rotor, emfs are induced in the rotor conductors. Since the rotor circuit is short-circuited, currents start flowing in the rotor conductors. (iii) The current-carrying rotor conductors are placed in the magnetic field produced by the stator. Consequently, mechanical force acts on the rotor conductors. The sum of the mechanical forces on all the rotor conductors produces a torque which tends to move the rotor in the same direction as the rotating field. (iv) The fact that rotor is urged to follow the stator field (La, rotor moves in the direction of stator field) can be explained by Lenz's law. According to this law, the direction of rotor current; will be such that they tend to oppose the cause producing them. Now, the cause producing the rotor currents is the relative speed between the rotating field and the stationary rotor conductors. Hence to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it.

Total Current of an Induction Motor: By the increased real-power requirements with increasing load. The presence of air-gap between the stator and rotor of an induction motor greatly increases the reluctance of the magnetic circuit. Consequently, an induction motor draws a large magnetizing current (1m) to produce the required flux in the air gap. The total current is composed of two parts l.Load current 2. Magnetizing current.

Magnetizing current: Magnetizing current establishes the magnetic field so the motor will spin. Magnetizing current is constant. It uses no energy, what it uses in one half cycles and it returns in next half cycle. When voltage is applied to motor (it's a sine wave) the magnetizing current (also a sine wave) doesn't rise until 90 degrees after the voltage rises. This represent to as lagging current, magnetizing current lags voltage by 90 degrees.

Load current: Load current develop when something tries to prevent the motor from spinning and the resistance to the spinning is load. Load current increases with increase in load, It uses energy this is what doing the work. When voltage is applied to motor, the load current rises and falls perfectly in steps with the voltage it doesn't lag at all, this is referred to a being in phase i.e. 0 degree difference. Load current is in phase with voltage.

Total current: Now the total motor current is the sum of magnetizing current and load V current. Magnetising current lags voltage by 90 degrees and load current is in phase with voltage. So the sum of these two, in which the motor current delivered by cable should be offset from voltage somewhere between 0 and 90 depending on amount of load current being drawn. The power factor represents the delay or offset between voltage and current being delivered and is defined as cosine of that delay we said 'it lagging because the current lags behind the voltage. If delay was 0 degree means voltage and current are in phase and power factor would be 1. If delay were a full 90 degrees then the power factor would be zero and this is all about magnetizing current, under no load condition the total no load current is equal to magnetizing current, an induction motor draws large magnetizing current hence power factor of induction motor is low. When motor is loaded, the total motor current increases and it gets closer and closer to being in phase with voltage hence power factor of motor increases near to unity power factor.

Power Factor of Induction Motor: The only possible source of excitation in an induction machine is the stator input. The induction motor therefore must operate at a lagging power factor. This power factor is very low at no load and increases to about 85 to 90 percent at full load, the improvement being caused Consider a portion of 3-phase induction motor.

(i) At no load, an induction motor draws a large magnetizing current and a small active component to meet the no-load losses. Therefore, the induction motor takes a high no-load current lagging the applied voltage by a large angle. Hence the power factor of an induction motor on no load is low i.e., about 0.1 lagging.

(ii) When an induction motor is loaded, the active component of current increases while the magnetizing component remains about the same Consequently, the power factor of the motor is increased. However, "because of the large value of magnetizing current, which is present regardless of load, the power factor of an induction motor even at full load seldom exceeds 0.9 lagging.

II. POWER FACTOR IMPROVEMENT

Power Factor Correction: Power factor correction is the term given to a technology that has been used since the turn of the 20th century to restore the power factor to as close to unity as is economically viable. This is normally achieved by the addition of capacitors to the electrical network which compensate for the reactive power demand of the inductive load and thus reduce the burden on the supply. There should be no effect on the operation of the equipment. To reduce losses in the distribution system, and to reduce the electricity bill, power factor correction, usually 1n the form of capacitors, is added to neutralize as much of the magnetizing current as possible. Capacitors contained in most power factor correction equipment draw current that leads the voltage, thus producing a leading power factor. If capacitors are connected to a circuit that operates at a nominally lagging power factor, the extent that the circuit lags is reduced proportionately. Typically, the corrected power factor will be 0.92 to 0.95. Some power distributors offer incentives for operating with a power factor of better than 0.9, for example, and some 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 is encouraged to apply power factor correction. Most Network Operating companies now penalize for power factors below 0 95 or 0.9.

Why Power Factor needs to be improved?
In case of low power factor, current will be increased and this high current will cause the following disadvantages: -

Large Copper Loss
We know that, the copper losses are directly proportional to the square of current

$$\text{Copper loss} = I^2 R$$

Therefore, larger the current, greater the copper losses.
In other words,

$$\text{Power loss} = I^2 R = 1/(\text{COS}\,\Phi 2)$$

Therefore,

$$I \,\alpha\, 1/(\text{Cos}\ \Phi 2\ )$$

Thus, if power factor is 0.8 then losses on this power factor

$$1/(\text{Cos}\ \Phi 2\ ) = 1/(0.8)2$$

= 1.56 times will be greater than losses on unity

Large KVA Rating: We know that almost all electrical machinery rated in KVA, but it is clear from the following formula that power factor is inversely proportional to KVA.

$$\text{Cos}\ \Phi = KW/KVA$$

Therefore, lower the power factor, the larger the KVA rating of machine larger the KVA rating, greater the size of machine and greater the size of machine larger the cost of machine.

Poor Voltage Regulation and Large Voltage Drop

$$\text{Voltage drop} = V = IR$$

Now in case of low PF, current will be increased. So the larger the current, the larger the voltage drop.
Also voltage Regulation,

$$VR = (VNL-VFL)/VFL$$

In case of low PF (lagging PF) there would be large voltage drop which causes low voltage regulation. Keeping voltage drop in particular limit, we need to install extra regulation equipments
i.e. voltage regulators

Penalty from Electric Power Supply Company On Low PF: Electrical power Supply Company imposes a penalty of power factor below 0.95 lagging in electrical power bill. So it is must to improve PF above 0.95.

Use of Capacitor Bank: A Capacitor Bank is a group of several capacitors of the same rating that are connected in series or parallel with each other to store electrical energy. The resulting bank is then used to counteract or correct a power factor lag or phase shift. An inductive load. Current flows when voltage is applied, but inductors impede the change in current" such that the current waveform lags behind the voltage waveform.

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The amount that it lags is the power factor (e. g. 0.8 lagging) that is seen by the power supply(A capacitor does the opposite it stores charge such that its current leads voltage (e.g. power factor 0.7 leading). When you put a shunt capacitor between the supply and the motor, it provides some of the lagging current required by the motor. So the power supply does not see as much; lagging current, so; its power factor is better (closer to 1) over that than at the motor. Alternating current (AC) power supply. They can also ‘be used in a direct current (DC) power supply to increase the ripple current capacity of the power supply or to increase the overall amount of stored energy So in an Inductive load (Induction Motor) when you connect a Capacitor Bank, then the. Reactive power demand by the

Inductive load (Induction Motor) is supplied by the Capacitor Bank not from the: Source. So for the system the reactive power demand is reduced and the Power factor is improved by reducing the angle gap between the Voltage vector and the Current Vector.

How capacitor works to improve pf of induction motor: In the graphic below I show a very lightly loaded motor. It has a power factor of less than 0.3. Notice there is a lot of magnetizing current compared to the load current; we know that the load current is the one that delivers the power, so if we could eliminate the magnetizing current the total current delivered to the motor would be less.

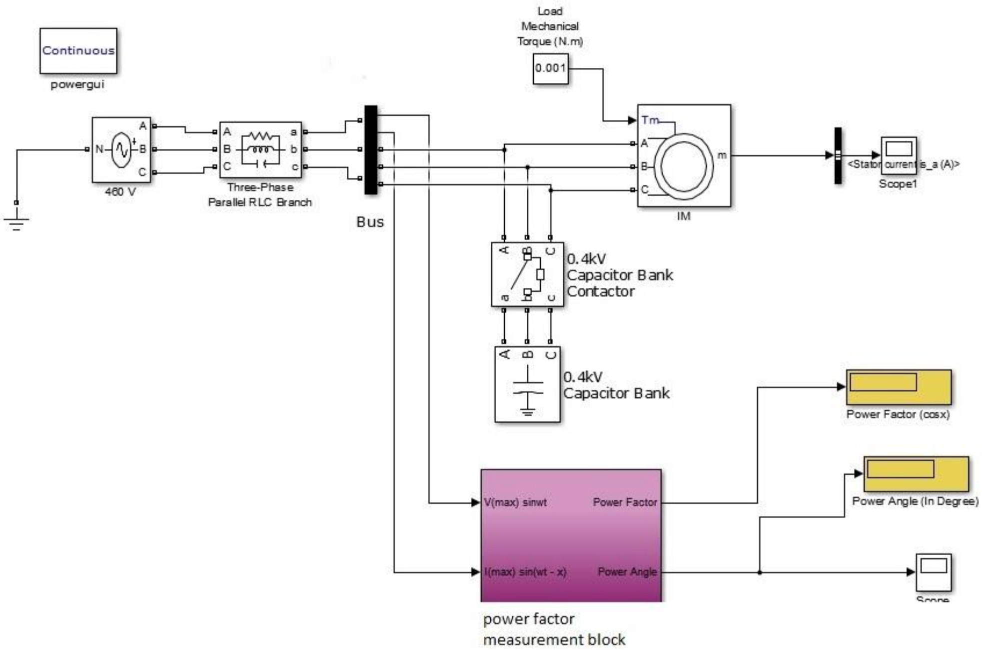

Figure 4. Simulink Model

1. In the graphic below is the same motor with no magnetizing current being delivered thus the total motor current equals the load current and the power factor on this line 1.0 or unity.

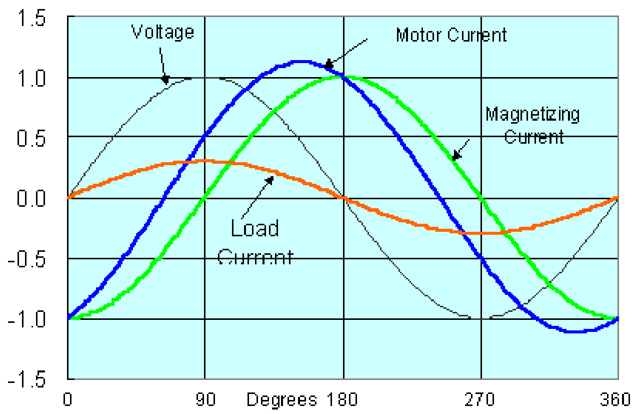

Figure 5. Motor with no magnetizing current being delivered thus the total motor current equals the load current and the power factor on this line 1.0 or unity.

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2. The following graphic which shows two curves; one is magnetizing current and the other is that of a power factor correction capacitor which draws a current of equal magnitude.

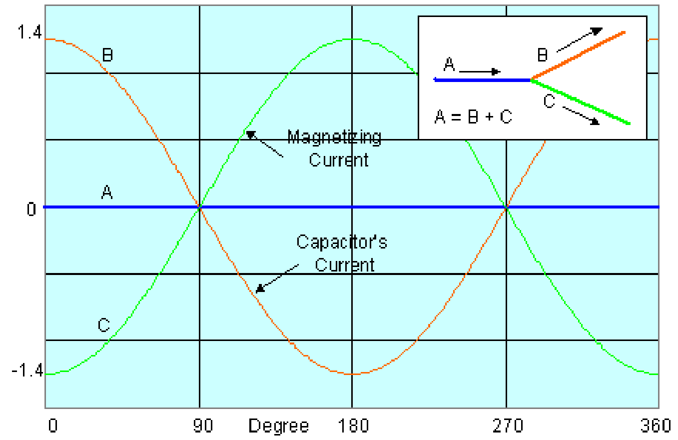

Figure 6. Curve one is magnetizing current and curve two is that of a power factor correction capacitor which draws a current of equal magnitude.

The currents are 180 degrees apart from each other. Comparing them to system voltage, the magnetizing current lags the voltage by 90 degrees and the power factor correction capacitor current leads the voltage by 90 degrees. Anyhow, they complement each other, when the magnetic field is build up, it is demanding current. During that time the capacitor is discharging and supplying current. On the flip side, in the magnetic field is collapsing and kicking current back into the system, the capacitor is demanding current and building a charge.

III. ADVANTAGES

- Increase in efficiency of system and devices.
- Low voltage drop.
- Line losses (copper losses) I2R is reduced.
- Appropriate size of electrical machines (T/F & Generator etc.)
- Eliminate the penalty of low power factor from the electric supply company.
- Low kwh
- Saving in the energy bill.
- Better usage of power system lines and generation etc.
- Saving in energy as well as rating and the cost of electrical devices and equipment is reduced.

CONCLUSION

In this paper we have improved power quality of induction motors using capacitor bank At no load induction motor has very low power factor. It improves at increasing load from no load to full Load. 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. 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.

FUTURE SCOPE

- To improve the power factor by using capacitor bank using microcontroller base system.
- It is also improving the power factor by using microcontroller based GSM service.
- Automatic power factor controller to improve power factor automatically to connected to input of bus bar.

APPLICATION

- Industrial application for improvement of power factor.
- Regenerative loads where load may drive the motor (costing etc.)
- Multi-speed motor involving open transition reduce –voltage starting.
- Frequent starts, plugging and jogging application.

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