Minimize Penalty Industrial Power Consumption by APFC Unit

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ABSTRACT:

The project is designed to minimize penalty for industrial units by using automatic power factor correction unit. Power factor is defined as the ratio of real power to apparent power. This definition is often mathematically represented as KW/KVA, where the numerator is the active (real) power and the denominator is the (active + reactive) or apparent power. Reactive power is the non working power generated by the magnetic and inductive loads, to generate magnetic flux. The increase in reactive power increases the apparent power, so the power factor also decreases. Having low power factor, the industry needs more energy to meet its demand, so the efficiency decreases. This project report represents one of the most effective automatic power factor improvements by using static capacitors which will be controlled by a Microcontroller with very low cost although many existing systems are present which are expensive and difficult to manufacture. In this study, many small rating capacitors are connected in parallel and a reference power factor is set as standard value into the microcontroller IC. Suitable number of static capacitors is automatically connected according to the instruction of the microcontroller to improve the power factor close to unity. Some tricks such as using resistors instead of potential transformer and using one of the most low cost Microprocessor IC (ARM) which also reduce programming complexity that make it one of the most economical system than any other controlling system. In this proposed system the time lag between the zero voltage pulse and zero current pulse duly generated by suitable operational amplifier circuits in comparator mode are fed to two interrupt pins of the ARM Processor. It displays the time lag between the current and voltage on an Mobile Display. The program takes over to actuate appropriate number of relays from its output to bring shunt capacitors into the load circuit to get the power factor till it reaches near unity. The Node MCU ESP32 used in the project belongs to ARM family. Further the project can be enhanced by using thyristor control switches instead of relay control to avoid contact pitting often encountered by switching of

capacitors due to high in rush current. This project report represents one of the most effective automatic power factor improvements by using static capacitors which will be controlled by a Microcontroller with very low cost although many existing systems are present which are expensive and difficult to manufacture.

1. INTRODUCTION:

Before venturing into the details in the design of power factor correction systems, we would first like to present a brief refresher of basic alternating current circuit theory. In any AC system the current, and therefore the power, is made up of a number of components based on the nature of the load consuming the power. These are resistive, inductive and capacitive components. In the case of a purely resistive load, for example, electrical resistance heating, incandescent lighting, etc., the current and the voltage are in phase that is the current follows the voltage[1]. Whereas, in the case of inductive loads, the current is out of phase with the voltage and it lags behind the voltage. Except for a few purely resistive loads and synchronous motors , most of the equipment and appliances in the present day consumer installation are inductive in nature, for example, inductive motors of all types, welding machines, electric arc and induction furnaces, choke coils and magnetic systems , transformers and regulators, etc. In the case of a capacitive load the current and voltage are again out of phase but now the current leads the voltage. The most common capacitive loads are the capacitors installed for the correction of power factor of the load. The inductive or the capacitive loads are generally termed as the reactive loads. The significance of these different types of loads is that the active (or true or useful) power can only be consumed in the resistive portion of the load, where the current and the voltage are in phase. (Watt less or) reactive power which is necessary for energizing the magnetic circuit of the equipment (and is thus not available for any useful work). Inductive loads require two forms of power - Working/Active power (measured in kW) to perform the actual work of creating heat, light, motion, machine output, etc., and Reactive power (measured in kVAr) to sustain the electromagnetic field. The current known as wattles current is required to produce the magnetic field around an electric motor. If there was no watt-less current then an electric motor would not turn. The problems arise due to the fact that we can sometimes have too much watt-less current, in those cases we need to remove some of it[2]. The vector combination of these two power components (active and reactive) is termed as Apparent Power (measured in kVA), the value of which varies considerably for the same active power depending upon the reactive power drawn by the equipment. The ratio of the active power (kW) of the load to the apparent power (kVA) of the load is known as the power factor of the load.

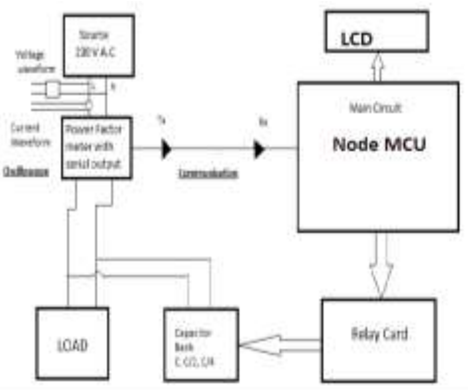


Fig 1: APFC Block Diagram

1.2. Power factor correction:

The various conventional methods for the power factor correction are the using static capacitors, synchronous condensers, phase advancers, etc. Doing so will increase the power factor The advantages of an improved power factor[3]:

1.3. Higher power factors result in:

a) Reduced system losses, and the losses in the cables, lines, and feeder circuits and hence lower sizes could be opted.

b) Improved system voltages, thus enable maintaining rated voltage to motors, pumps and other equipment. The voltage drop in supply conductors is a resistive loss, and wastes power heating the conductors. A 5% drop in voltage means that 5% of your power is wasted as heat before it even reaches the motor. Improving the power factor, especially at the motor terminals, can improve your efficiency by reducing the line current and the line losses.

c) Increased system capacity, by release of kVA capacity of transformers and cables for the same kW, thus permitting additional loading without immediate augmentation.

d) Reduce power cost due to reduced kVA demand charge and so also by reduced power factor charge[4].

1.4. Active power:

With a purely resistive load with no inductive or capacitive components, such as in an electric heater, the voltage and current curves intersect the zero coordinate at the same point The voltage and current are said to be ‗in phase'. The power (P) curve is calculated from the product of the momentary values of voltage (V) and current (I). It has a frequency which is double that of the voltage supply, and is entirely in the positive area of the graph, since the product of two negative numbers is positive, as, of course, is the product of two positive numbers[5].

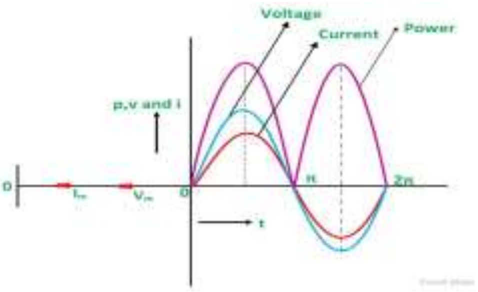


Fig2: Current, voltage and power waveform of purely resistive load[6].

1.5. Active and reactive power:

In practice, however, it is unusual to find purely resistive loads, since an inductive component is also present. This applies to all consumers that make use of a magnetic field in order to function, e.g. induction motors, chokes and transformers. Power converters also require reactive current for commutation purposes. The current used to create and reverse the magnetic field is not dissipated but flows back and forth as reactive current between the generator and the consumer. As Fig.: 1. 2 shows, the voltage and current curves no longer intersect the zero coordinate at the same points. A phase displacement has occurred. With inductive loads the current lags behind the voltage, while with capacitive loads the current leads the voltage. If the momentary values of power are now calculated with the formula (P) = (V) · (I), a negative product is obtained whenever one of the two factors is negative.

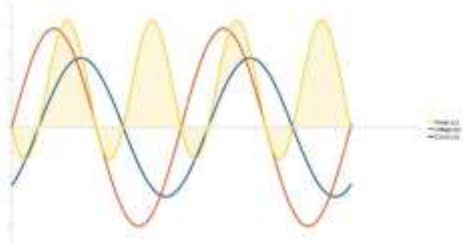


Fig 3: Current, voltage, power waveform of partial reactive load. The active power in this case is given by the Formula: P = V. I cosϕ

1.6. Reactive power:

Inductive reactive power occurs in motors and transformers when running under no-load conditions if the copper, iron and, where appropriate, frictional losses are ignored[7]. If the voltage and current curves are 90° out of phase, one half of the power curve lies in the positive area, with the other half in the negative area. The active power is therefore zero, since the positive and negative areas cancel each other out. Reactive power is defined as that power which flows back and forth between the generators And the consumer at the same frequency as the supply voltage in order for the magnetic/electric field to build up and decay . Q = V. I sin ϕ

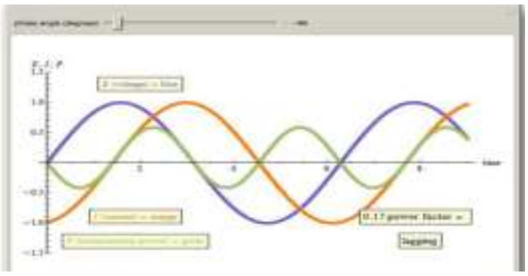


Fig 4: Current, voltage, power waveform of pure reactive load.

1.7.Apparent power:

The apparent power is critical for the rating of electric power networks. Generators, transformers, switchgear, fuses, circuit breakers and conductor cross sections must be adequately dimensioned for the apparent power that results in the system[8]. The apparent power is the product obtained by multiplying the voltage by the current without taking into account the phase displacement. S = V. I

The apparent power is given by the vector addition of active power and reactive power[9]

: $S = \sqrt{P^2+Q^2}$

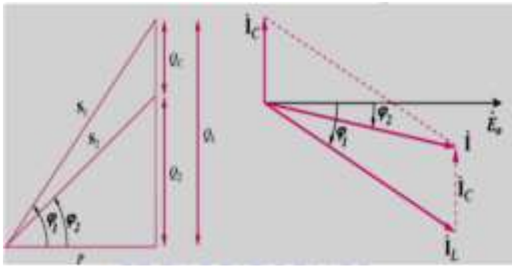


Fig 5: Reactive power compensation

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

P.F = kW / kVA = cosine ϕ

1.8. To Improve Power Factor:

We can improve power factor by adding power factor correction capacitors to your plant distribution system[11]. 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:

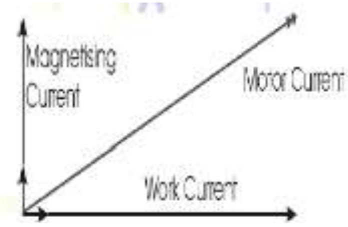
I. Load current

II. Loss current

The inductive components are

I. Leakage reactance

II. Magnetizing current



The current due to the leakage reactance is dependent 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[10].

2. EXISTING SYSTEM :

A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved .This figure is said to be a synchronous condenser used for power factor control .It consist of various faults Such as If the rated voltage increases, then it causes damage to it. This figure is said to be a synchronous condenser used for power factor control .It consist of various faults, S u c h as If the rated voltage increases, then it causes damage to it. Once the capacitors spoiled, then repairing is costly, there are considerable losses in the motor, maintenance c o s t is high, It produces noise, These are the various difficulties faced in the existing system

3. PROPOSED SYSTEM:

The proposed method is facilitated with Node MCU is mainly used to get an accurate and automatic correction of power factor values, this method is enhanced due to eradicate the faults or difficulties faced in existing system. Here the transformer is acts as a input module , from the transformer ac current is converted in to dc by using rectifier, then it is given to the micro controller through zero crossing detector with required input , then it passes to the PLC, which control the entire process ,it continuously monitoring the inductive loads ,if the power factor lags means it passes the instruction to switch on the capacitor in order to maintain almost to unity power factor A power supply is a device that supplies electrical energy to one or more electric loads. The term is most commonly applied to the devices that convert one form of electrical energy in to another, This system provides +12v and 12v with maximum 2amps and +5v with maximum of 1amps.We connect rectifier to the transformer to convert AC in to DC. This method requires DC supply to operate the system

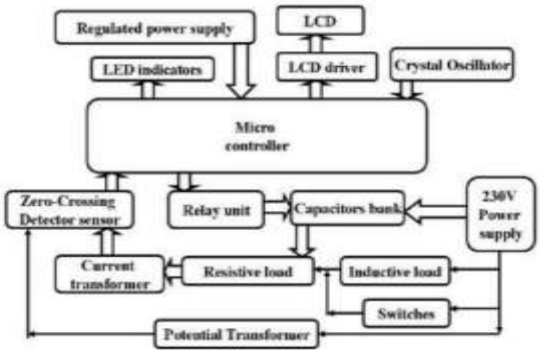


Fig.6. APFC system

4. WORKING METHODOLOGY:

4.1. 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.

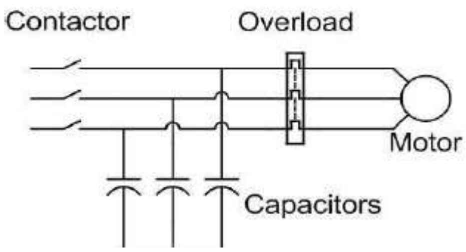


Fig.7: Capacitors for compensation of reactive power in motor circuit.

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.

4.2. 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 its life. The harmonics are caused by many non linear loads; the most common in the industrial market today, are the variable speed controllers and switch mode power supplies. Harmonic voltages can be reduced by the use of a harmonic compensator, which is essentially a large inverter that cancels out the harmonics[12].

4.3. 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 high impedance, the resonance can be very severe resulting in major damage to plant and equipment.

4.4. Improving your power factor include:

1) Lower utility fees by:

a. Reducing peak KW billing demand

Recall that inductive loads, which require reactive power, caused your low power factor. This increase in required reactive power (KVAR) causes an increase in required apparent power (KVA), which is what the utility is supplying. So, a facility's low power factor causes the utility to have to increase its generation and transmission capacity in order to handle this extra demand.

By raising your power factor, you use less KVAR. This results in less KW, which equates to

a dollar savings from the utility.

b. Eliminating the power factor penalty

4.5. Correction methods

Individual power factor correction

In the simplest case, an appropriately sized capacitor is installed in parallel with each individual inductive consumer. This completely eliminates the additional load on the cabling,

including the cable feeding the compensated consumer. The disadvantage of this method, however, is that the capacitor is only utilized during the time that its associated consumer is in operation. Additionally, it is not always easy to install the capacitors directly adjacent to the machines that they compensate (space constraints, installation costs).

5.COMPILER:

Compiler used in the project is WinAVR. It is a suite of executable, open source software

development tool for Atmel AVR series of RISC microprocessors hosted on WINDOWS

platform. It includes the GNU GCC compiler for AVR target for C and C++.

5.1. BURNER:

Extreme Burner – AVR is used in the project. It is a full graphical user interface (GUI) AVR

series of MCU that supports several types of clock sources for various applications. It enables

us to read and write a RC oscillator or a perfect high speed crystal oscillator.

6. SYSTEM DESIGN AND IMPLEMENTATION:

6.1. ALGORITHM FOR THE PRINCIPLE OF APFC

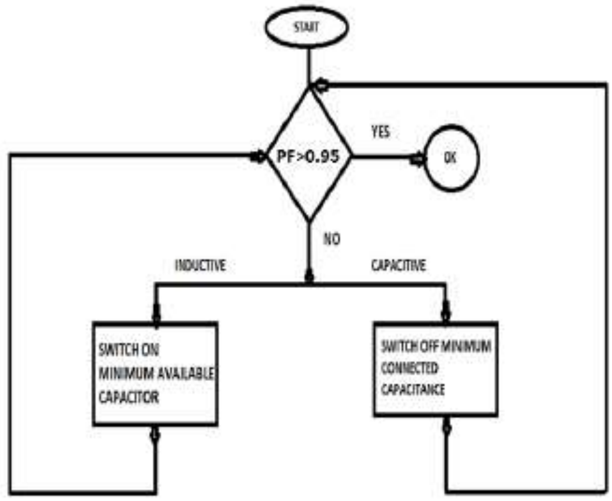


Fig.8: Algorithm for APFC

The following diagram shows the algorithm of the working method of the project. Reference

power factor has been chosen as 0. 95. If the power factor as read by power factor meter is greater than or equal to the reference value i.e. 0.95 then the system does not require any

compensation and hence the microcontroller won‘t actuate the relay. Now when the power

factor is less than the reference value two cases arise:

The load is either 1) inductive or 2) capacitive

When the load is inductive, power factor would be less than reference value as read by PF

meter and hence the microprocessor would actuate the relay and firstly minimum available

capacitor would be switched on. If this does not bring power factor to reference value the

microcontroller would send signal to second relay and hence more capacitance is introduced

in circuit and so on till the desired power factor of 0.95 is displayed.

In case of capacitive load, the microcontroller would first switch off the minimum connected

capacitance and go on taking out capacitances till we get the desired power factor of 0.95.

7. HARDWARE DESCRIPTION:

7.1. CAPACITOR BANKS AND LOAD:

Capacitor banks are automatically inserted into the circuit or out of it using respective relays.

We are using 3 capacitor banks, each of rating, C/2 and C/4. The relays with the best combination of capacitor banks provide an improved power factor. The loads we are using are incandescent bulbs (for resistive load), and cooler pump (for inductive load).

Fig.9: Capacitor bank

Fig.10: Different types of loads that have been used in APFC project.

7.2. ESP32 controller : ESP32 is a chip that provides Wi-Fi and (in some models) Bluetooth connectivity for embedded devices – in other words, for IoT devices. While ESP32 is technically just the chip, the modules and development boards that contain this chip are often also referred to as "ESP32" by the manufacturer. The ESP32 uses a Tensilica Xtensa 32-bit LX6 microprocessor. This typically relies on a dual core architecture, with the exception of one module, the ESP32-S0WD, which uses a single-core system. The clock frequency reaches up to 240MHz and it performs up to 600 DMIPS (Dhrystone millions of instructions per second). Moreover, its low power consumption allows for analog to digital conversions as well as computation and level thresholds, even while the chip is in deep sleep mode.

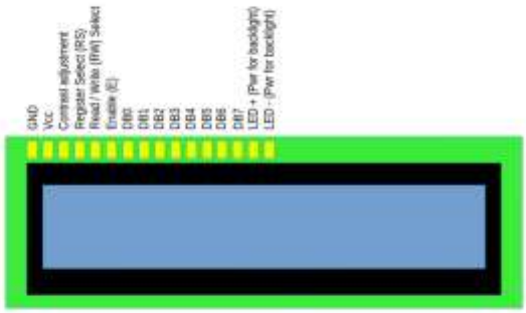
Fig.11. ESP32 controller

ESP32 is the SoC (System on Chip) microcontroller which has gained massive popularity recently. Whether the popularity of ESP32 grew because of the growth of IoT or whether IoT grew because of the introduction of ESP32 is debatable. If you know 10 people who have been part of the firmware development for any IoT device, chances are that 7−8 of them would have worked on ESP32 at some point.

7.3. LIQUID CRYSTAL DISPLAY:

8051 program must interact with the outside world using input and output devices that communicate directly with a human being. One of the most common devices attached to an 8051 is an LCD display. Some of the most common LCDs connected to the 8051 are 16x2 and 20x2 displays. This means 16 characters per line by 2 lines and 20 characters per line by 2 lines, respectively. LCD (Liquid Crystal Display) screen is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on[13].

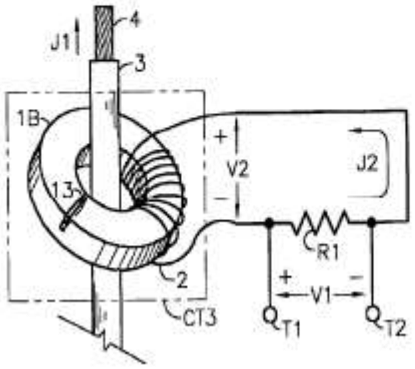
Fig. 12: **Pin Diagram:**



7.4. INDUCTIVE LOAD:

A load that is predominantly inductive, so that the alternating load current lags behind the alternating voltage of the load. Also known as lagging load. Any devices that have coils of wire in there manufacture can be classed as inductive loads.

7.5. CURRENT TRANSFORMER



In electrical engineering, a current transformer (CT) is used for measurement of electric currents. Current transformers, together with voltage transformers (VT) (potential transformers (PT)), are known as instrument transformers. When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. A current transformer also isolates the measuring instruments from what may be very high voltage in the monitored circuit. Current transformers are commonly used in metering and protective relays in the electrical power industry[14].

7.6. SHUNT CAPACITORS:

Shunt capacitor banks are used to improve the quality of the electrical supply and the efficient operation of the power system. Studies show that a flat voltage profile on the system can significantly reduce line losses. Shunt capacitor banks are relatively inexpensive and can be easily installed anywhere on the network.

7.7.**Zero crossing detection using op amp**

ARM Processor PIC16F877A read zero crossings of voltage and current waveform and start timer according to zero crossing detection of current and voltage wave form. PC16F877A ARM Processor is main part of this project. In reads zero crossing detection. measures time difference and calculate power factor according to above given formula's.After calculating power factor, ARM Processor displays it on 16 X2 LCD.

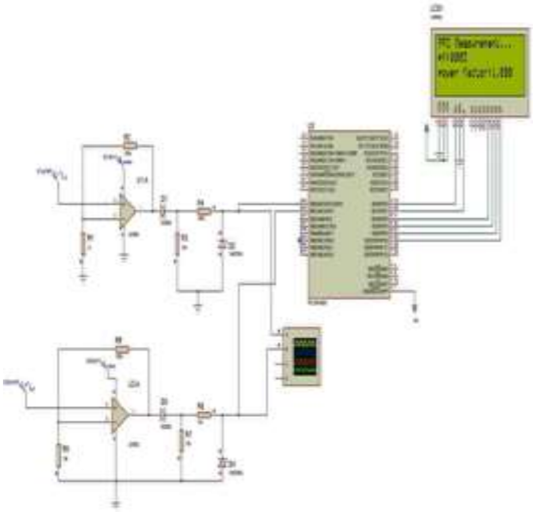


Fig .13: Simulation results in Proteus

List of components for power measurement circuit:

List of components for power measurement circuit using ARM Processor is given below:

Category,Reference,Value,Order Code

Resistors,"R1",2k,

Resistors,"R2",4k,

Resistors,"R3",4k,

Resistors,"R4",4k,

Resistors,"R5",4k,

Integrated Circuits,"U1",ARM,

Miscellaneous,"AC SOURCE",,

Miscellaneous,"CURRENT TRANSFORMER" It can be wind according to requirement,

Miscellaneous,"POTENTIAL TRANSFORMER" 220V AC to 12V AC step down transformer,

Liquid crystal display: ,"LCD1",LM016L,

Variable resistor: ,"RV1",10k,

Current Amplifier

Fig 14:Circuit showing Darlington amplifier used in project.

A current of sufficiently high value is required to energise the coils of a relay, but the output

current received via the optocoupler cannot serve the purpose. Thus, we require a current

amplifier for in series with the optocoupler for each relay. The amplifier we are using is

ULN2803APG.

Relays

A relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts (there are two in the relay pictured). The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relay in the picture also has a wire connecting the armature to the yoke. This ensures continuity of the circuit between the moving contacts on the armature, and the circuit track on the printed circuit board (PCB) via the yoke, which is soldered to the PCB. When an electric current is passed through the coil it generates a magnetic field that activates the armature and the consequent movement of the movable contact either makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de-energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters.

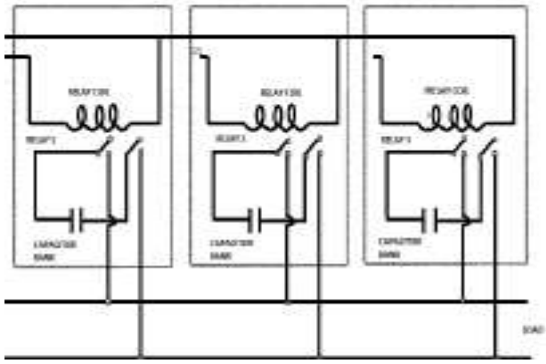


Fig15: Relay connections with the capacitor bank and the line.

We are using Leone SC5-S type relay. It operates on 6V dc, and can handle an ac voltage of 300V and current of 7A. When the current is amplified by an amplifier, it is sent to the coils of the relay, which get energised, thereby leading to the closing of NO contacts. Thus the relay operates and brings the respective capacitor bank in parallel with it. When a particular relay operates, an LED connected to it also glows for the user to know which relay is functional at that load to improve the current power factor.

8. ADVANTAGE OF IMPROVED POWER FACTOR

- Reactive power decreases
- Avoid poor voltage regulation
- Over loading is avoided
- Copper losses decrease
- Transmission loss decrease

- Improved voltage regulation
- Efficiency of supply system

9. Software Description

9.1.Arduino IDE:

Arduino is an open-source prototyping platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing. Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers - students, hobbyists, artists, programmers, and professionals - has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and experts alike.

10. Conclusion and Future Scope:

It can be concluded that power factor correction techniques can be applied to the industries, power systems and also households to make them stable and due to that the system becomes stable and efficiency of the system as well as the apparatus increases. The use of microcontroller reduces the costs. Due to use of microcontroller multiple parameters can be controlled and the use of extra hard wares such as timer, RAM, ROM and input output ports reduces. Care should be taken for overcorrection otherwise the voltage and current becomes more due to which the power system or machine becomes unstable and the life of capacitor banks reduces. This project has proposed the advanced method of the power factor correction by using the microcontroller which has the many advantages over the various conventional methods of the power factor compensation. The switching of capacitors is done automatically by using the relay and thus the power factor correction is more accurate. Thus we have presented the possible advanced method for the correction of the power factor. Installation capacitor bank for power factor correction will obtain profitable both sides consumer and electric flow. Installation of capacitor bank can reduce reactive current consumption further minimize a losses. By observing all aspects of the power factor it is clear that power factor is the most significant part for the utility company as well as for the consumer. Utility companies get rid from the power losses while the consumers are free from low power factor penalty charges. The automotive power factor correction using capacitive load banks is very efficient as it reduces the cost by decreasing the power drawn from the supply. As it operates automatically, manpower are not ,required and this Automated Power factor Correction using capacitive load banks can be used for the industries purpose in the future.

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