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"Automatic Power Factor Correction"

1)Mr. Prashant Bhagat, 2)Prof. Tejal Y. Kharche, 3) Mr. Ganesh Adhao
4) Mr. Umakant Gawande, 5) Mr. Rudra Sangale, 6) Mr. Ajinkya Chavan
Department of Electrical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur

Abstract- *With the mining industry moving from traditional manual methods to the advanced mechanised mining, the focus is also shifting to the energy efficiency of the equipment and system being employed. Most of the equipment used in mining like shovel, drill, elevator, continues miner, conveyor, pumps etc. runs on electricity. Electric energy being the only form of energy which can be easily converted to any other form plays a vital role for the growth of any industry. The Power Factor gives an idea about the efficiency of the system to do useful work out of the supplied electric power. A low value of power factor leads to increase is electric losses and also draws penalty by the utility. Significant savings in utility power costs can be realized by keeping up an average monthly power factor close to unity. To improve the power factor to desired level, reactive power compensators are used in the substations. The most common used device is capacitor bank which are switched on and off manually based on the requirement. If automatic switching can be employed for the correction devices, not only it will improve the response time but also removes any scope for error. The work carried out is concerned with developing power factor correction equipment based on embedded system which can automatically monitor the power factor in the mining electrical system and take care of the switching process to maintain a desired level of power factor which fulfils the standard norms. The Automatic Power Factor Correction (APFC) device developed is based on embedded system having 89S52 microcontroller at its core. The voltage and current signal from the system is sampled and taken as input to measure the power factor and if it falls short of the specified value by utility, then the device automatically switch on the capacitor banks to compensate for the reactive power.*

Keywords*:- Automatic, Power factor, Single phase, Domestic, TRIAC, Capacitor Bank etc.*

I. INTRODUCTION

The thirst for new sources of energy is unquenchable, but we seldom realize that we are wasting a part of the electrical energy everyday due to the lagging power factor in the inductive loads we use. Hence, there is an urgent need to avoid this wastage of energy. Before getting into the details Power Factor Correction, let us just brush our knowledge about the term power factor. In simple words, power factobasically states how far the energy provided has been utilized. The maximum value of power factor is unity. So the closer the value of power factor to unity, better is the utility of energy or lesser is the wastage. In electrical terms, power factor is basically defined as the ratio of active power to reactive power or it is the phase difference between voltage and current. Active power performs useful work while reactive power does no useful work but is used for developing the magnetic field required by the device. Most of the devices we use have power factor less than unity. Hence, there is a requirement to bring this power factor close to unity. Here we are presenting a prototype for automatic power factor correction using the 8-bit AVR microcontroller Atmega328. Power factor correction using capacitor banks reduces reactive power consumption which will lead to minimization of losses and at the same time increases the electrical system's efficiency. Power saving issues and reactive power management has brought about the development of single phase capacitor banks for domestic applications. The development of this project is to enhance and upgrade the operation of single phase capacitor banks by developing a microprocessor based control system. The control unit will be able to control the individual capacitors in the capacitor bank and will operate in steps based on the variation in power factor. Current transformer and a Voltage transformer are used for sampling of the circuit current and voltage, so as to determine the power factor. An Automatic power factor correction device reads power factor from line voltage and line current by

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determining the delay in the arrival of the current signal with respect to voltage signal from the source with high accuracy by using an internal timer. It determines the phase angle lag (Φ) between the voltage and current signals and then determines the corresponding power factor (cosΦ). Then the microcontroller calculates the compensation requirement and accordingly switches on the required number of capacitors from the capacitor bank until the power factor is normalized to about unity. Automatic power factor correction techniques can be applied to industrial units, power systems and also households to make them stable. As a result the system becomes stable and efficiency of the system as well as of the apparatus increases. Therefore, the use of microcontroller based power factor corrector results in reduced overall costs for both the consumers and the suppliers of electrical energy. Power factor correction using capacitor banks reduces reactive power consumption which will lead to minimization of losses and at the same time increases the electrical system‘s efficiency. Power saving issues and reactive power management has led to the development of single phase capacitor banks for domestic and industrial applications. The development of this project is to enhance and upgrade the operation of single phase capacitor banks by developing a micro-processor based control system. The control unit will be able to control capacitor bank operating steps based on the varying load current. Current transformer is used to measure the load current for sampling purposes. Intelligent control using this micro-processor control unit ensures even utilization of capacitor steps, minimizes number of switching operations and optimizes power factor correction. The Choke used in the Compact Fluorescent Lamp (CFL) will be used as an Inductive load.

II. LITERATURE REVIEW

- **Oommen and Kohler (1988)** explored the advantages that can be accomplished by proper implementation of power factor compensation. Different compensators along with the sizing and strategic location was also considered. A brief study on the economic analysis was carried out to show the economic viability of compensation.
- **Jiang et al. (1993)** proposed a novel single-phase power factor correction scheme based on parallel power factor correction concept which was described to be more efficient than convention two-cascade stage scheme.
- **Qureshi and Aslam (1995)** outlined the different methods for power factor correction and carried out an experimental case study to explore the areas which will be suitable for compensation. After a practical demonstration to have a significant improvement in power factor was completed, they found that it would release the capacity of distribution transformer and the problem of over voltage under condition of low load was avoided.
- **Novak and Kohler (1998)** pointed out the importance of power factor improvement for technological innovation and advancement in deep coal mine power systems. Different protection equipment to check the inherent electrical faults in the mining system were argued. The power factor correction near loads for improved voltage regulation was emphasized within the constraints of high voltage distribution in underground coal mines.
- **Shwehdi and Sultan (2000)** suggested some mathematical calculations for power factor and reactive power requirement of the system along with the capacitor size estimation methods. Different problems associated accompanied by essentials and cautions for capacitor used for correction purpose were discussed in details.
- **Celtekligil (2008)** discussed the application of a method for dynamic power factor correction and voltage regulation in light rail transportation system. Main reactors have been switched on through thyristors using automatic power controllers by sensing the power factor and constantly monitoring the current and voltage, calculating the power factor and switching inductance banks as required. The system proposed connects inductive loads in parallel with the capacitive system to improve the power factor.
- **Choudhury (2008)** gave a design and implementation of a low cost power factor improvement device for small

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signal low power loads. The design involved designing of a small signal model load, selecting appropriate capacitors, and designing appropriate switching circuits to select proper combination of capacitors.

- **Shahid and Anwar (2013)** offered the design of a power factor improvement circuit using PIC (Programmable Interface Controller) chip with reduced parts count to achieve desired efficiency and low cost. The solution involves ensuring the power factor value from the load and uses an algorithm to determine and trigger switching capacitors in order to compensate for excessive reactive components to increase power factor value.
- **Sharma and Haque (2014)** carried out a simulation and analysis study for power factor correction for metal halide high intensity discharge lamps. A modified boost converter using active devices was proposed along with PI controller to stabilize the control loops. The capacitor and inductor with voltage and current ripple with minimum ripple values was designed and to absorb sinusoidal input current to reduce total harmonic distortion (THD) in the input current with output voltage regulation.

III. HARDWARE IMPLEMENTATION

1. **Potential Transformer:-** Transformers convert AC electricity from one voltage to another with a little loss of power. The potential transformer (PT) essentially uses a step-down transformer to reduce the dangerously high voltage to a safer low voltage (typically 110 Volts) in any substation. The PT used here steps-down the supply voltage of 230 Volts to 12 Volts as required by the circuit to operate. The output of a PT is used for all measurement and monitoring purposes in conjunction with relay operation

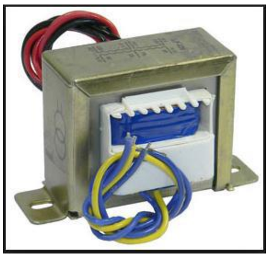

Fig. A. 230/12 Volt Transformer

The ratio of the number of turns on each coil, called the turn's ratio, determines the ratio of the voltages. A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.

B. Current Transformer:- In an electrical circuit, 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.

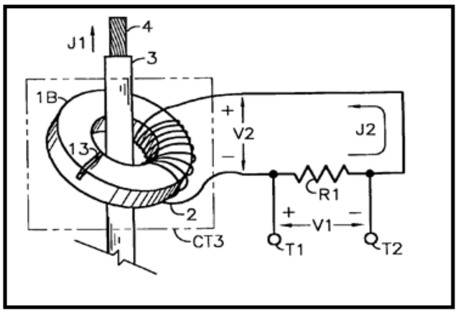

Fig. B. Schematic working of a Current Transformer

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. It also isolates the measuring instruments from what may be very high voltage in the monitored circuit. They are commonly used in metering and protective relays in the electrical power industry.

C. Zero Crossing Detector:- The zero crossing detector is a sine-wave to square-wave converter. To calculate the phase lag between the voltage and current, two detectors are used to find the arrival instance of each signal. Then the difference in the arrival instance calibrated to angle gives the phase angle lag. By taking the cosine of this phase lag, power factor of the circuit is calculated. The reference voltage in this case is set to zero. The output voltage waveform shows when and in what direction an input signal crosses zero volts. If input voltage is a low frequency signal, then output voltage will be less quick to switch from one saturation point to another. And if there is noise in between the two input nodes, the output may fluctuate between

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positive and negative saturation voltage Vsat. The LM339 IC is used as the comparator circuit to function as zero crossing detector.

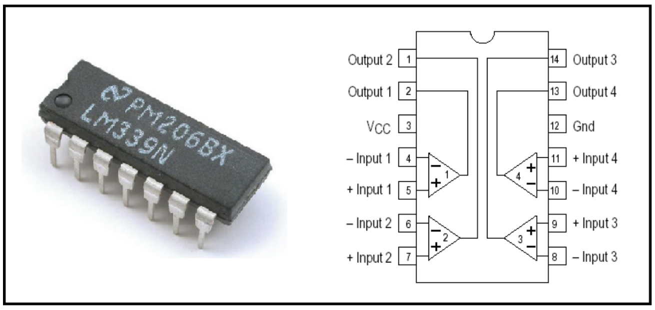

Fig. C. LM339 IC and its Pin Diagram

D. Power Supply For Circuit:- The embedded system circuit typically uses 12 volt and 5 volt DC as its operating voltage. Therefore, there is a need to convert the 230 Volt AC supply to the required DC supply. In the 1st stage the 230 V AC is step-down to 12 V AC by using a transformer. In this case the output from the potential transformer (PT) can be utilized instead of going for another step-down transformer. The 2nd stage is the rectification process. By using a full bridge rectifier circuit, the 12 V AC is rectified to a 12V pulsating DC voltage. This pulsating DC is passed through a capacitive filter for smoothening in the 3rd stage and gives a normal 12V DC as output. The 4th stage consists of using a 12 V and a 5 V voltage regulator for generating the required stable supply voltage to be used in the control circuit.

E. Rectifier:- A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), current that flows in only one direction, a process known as rectification. It converts A.C. into pulsating D.C. The rectifier may be a half wave or a full wave rectifier. Most of the cases, a bridge rectifier is used because of its merits like good stability and full wave rectification. In positive half cycle only two diodes (1 set of parallel diodes) will conduct, in negative half cycle remaining two diodes will conduct and they will conduct only in forward bias only.

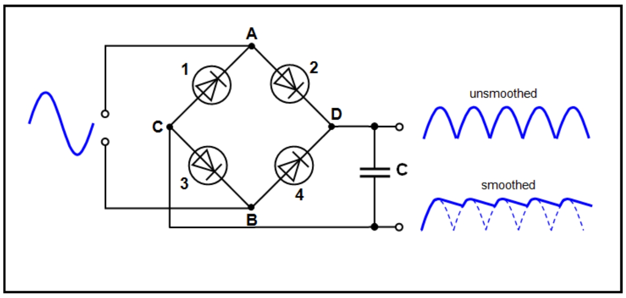

Fig. D. A Full Bridge Rectifier with Input and Output

F. Filter:- Capacitive filter is used in this project. It removes the ripples from the output of rectifier and smoothens the D.C. Output received from this filter is constant until the mains voltage and load is maintained constant. The simple capacitor filter is the most basic type of power supply filter.

G. Voltage Regulator:- The LM78XX/LM78XXA series of three-terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shutdown and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output Current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents. In the LM78XX, the output voltage is specified by the last 2 digits XX. The output of LM7805 will be 5 Volts and the same for 7812 will be 12 volts.

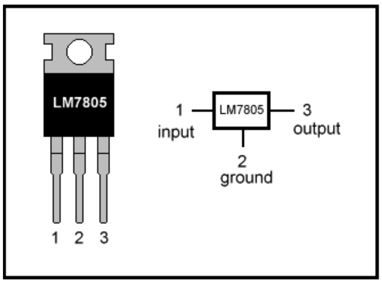

Fig. E. LM7805 and its Connection Diagram

H. Display Unit:- In an embedded system, the microcontroller interacts with the outside world using input and output devices that communicate directly with a human being. One of the most common devices attached to the microcontroller is an LCD display. Some of the most common LCDs connected to the microcontroller are 16x2 and 20x4 displays. This means there will be 16 characters per line by

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2 lines and 20 characters per line by 4 lines, respectively available to use. In this project a 16x2 LCD, model JHD 162A which shows the power factor and the phase lag between voltage and current in milliseconds.

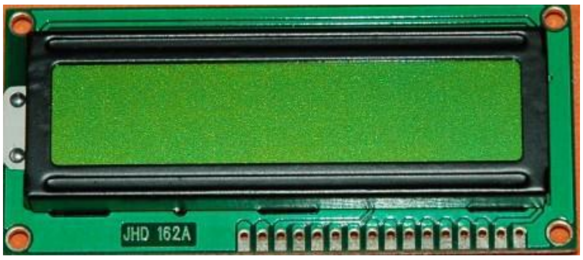

Fig. F. 16x2 LCD Display

I. Microcontroller :- The heart of any embedded system is a microcontroller which is responsible for all the logical processing. It takes input, processes it according to the program written to it and then gives the processed output. It also has some on chip memory which is utilized to store some temporary variables during processing is going on. The microcontroller used here is AT89S52 which is a 8-bit controller. The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry standard instruction set and pin out. The on-chip flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer.

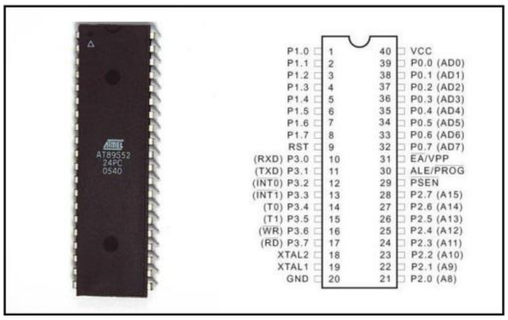

Fig. G. 89S52 Microcontroller and its Pin Diagram

By combining a versatile 8-bit CPU with in-system programmable flash on a monolithic chip, the Atmel AT89S52 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications. The AT89S52 provides the following standard features: 8K bytes of flash, 256 bytes of RAM, 32 I/O lines, watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry.

J. Relay Unit:- This unit consists of a relay driver and some relays. As the output of the microcontroller cannot control the switching of capacitors directly, this unit is responsible for controlling the high power circuit from a low power circuit. A relay is an electrically operated switch. 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. Current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts. The relay's switch connections are usually labelled COM, NC and NO:

- COM = Common, always connect to this; it is the moving part of the switch.
- NC = Normally Closed, COM is connected to this when the relay coil is off.
- NO = Normally Open, COM is connected to this when the relay coil is on.

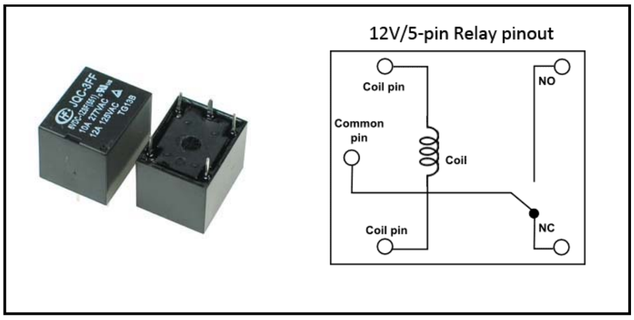

Fig. H. 12 Volt Relay and its Internal Connection

K. Relay Driver:- As the current supplied by the output pin of microcontroller is not sufficient for the relay coil to operate the relay, a relay driver ULN2003 is used. ULN2003 is a high voltage and high current Darlington transistor array. The ULN2003 is a monolithic high voltage and high current Darlington transistor arrays.

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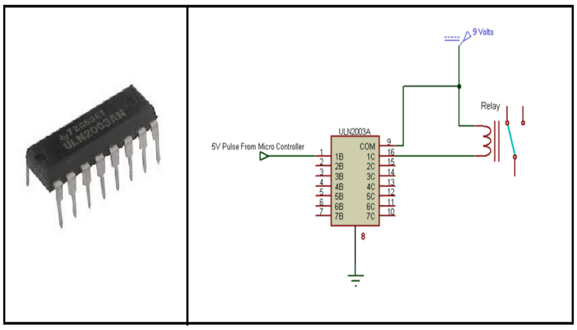


Fig. I. ULN2003 Relay Driver and its Pin Connection Diagram

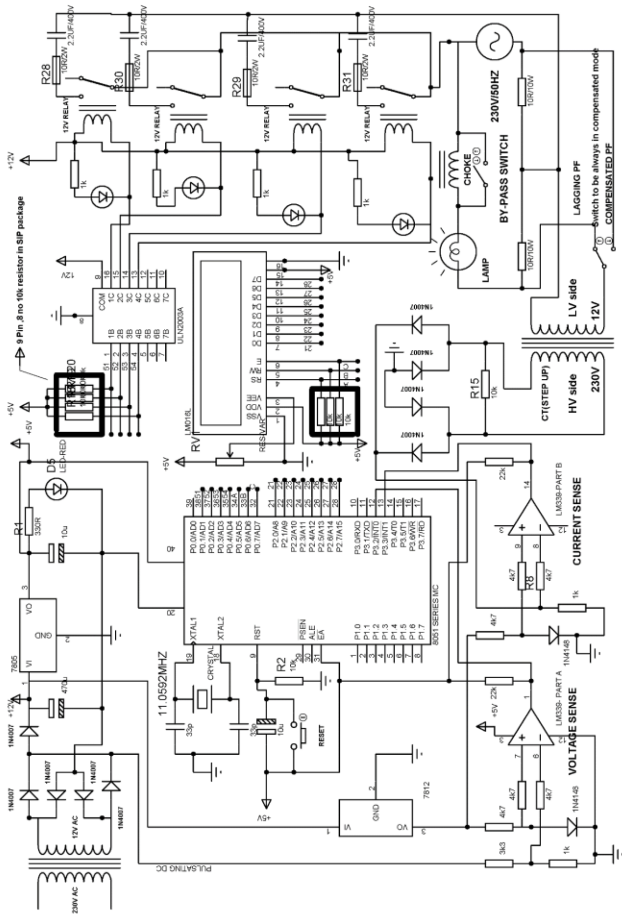
It consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode Clamp diode for switching inductive loads. The collector-current rating of a single Darlington pair is 500mA. The Darlington pairs may be paralleled for higher current capability. Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED gas discharge), line drivers, and logic buffers.

L. Capacitor Bank :- 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. The capacitor bank consists of number of shunt capacitors which are switched ON or OFF depending on the reactive power requirement. The switching of capacitors can be done manually or automatically by using relays.

Fig. J Shunt Capacitors

Shunt capacitors, either at the customer location for power factor correction or on the distribution system for voltage control, dramatically alter the system impedance variation with frequency. Capacitors do not create harmonics, but severe harmonic distortion can sometimes be attributed to their presence. A shunt capacitor at the end of a feeder results in a gradual change in voltage along the feeder. Ideally, the percent voltage rise at the capacitor would be zero at no load and rise to maximum at full load. However, with shunt capacitors, percent voltage rise is essentially independent of load. Thus, automatic switching is often employed in order to deliver the desired regulation at high loads, but prevent excessive voltage at low loads. Moreover, capacitor switching may result in transient overvoltage inside customer facilities.

IV. BLOCK DIAGRAM



V. IMPLEMENTATION

The P C B was made-up as per the diagram and then all the components were soldered. The Potential transformer, Current Transformer, capacitor bank was soldered properly

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at their respective places. Microcontroller was programmed by using a burner. The C T is connected in series with load and capacitor bank. Ardiuno determines both magnitudes and phase difference of AC voltage and current. Based on the measured values using formula P F of load is calculated. The liquid crystal display is used to display the improved P.F.

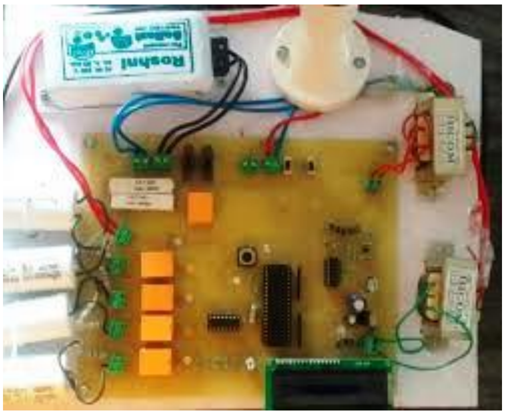

Fig K. Hardware of Automatic Power Factor Control

Figure shows the whole hardware of Automatic Power Factor Control Unit used for improving power factor. One of the results is discussed below. Figure when inductive load was applied i.e. Choke is used in this case the measured P.F was found to be 0.85 Lagging and the P F is increased to 0.99 by adding capacitor in parallel. The result shows the working and idea of Automatic Power Factor Correct ion by using capacitors.

Fig 4 Measured power factor

Fig 5. Showing corrected power factor on LCD

VI. CONCLUSION

Increasing pollution and rapid depletion of fossil fuels has a paved a way to the entry of EV's in the market. But charging of E-Vehicle through conventional/Non renewable energy sources will can make the pollution. The development of the E-Vehicle represents a significant advancement in E-Vehicle is a new bridge between the E-Vehicle and Petrol and diesel Vehicles. The capable of fast charging with the help of Solar and Wind plant must adopted to short time require for charging of Vehicle. The Device now works with a limited connection but there are many types of charging and in a future we can increase the connections.

Advantages of APFC

- Advantages which can be achieved by employing the proper power factor correction scheme are:
- Increase in efficiency due to Reduction of power consumption.
- Reduction in power consumption leads to a reduction in greenhouse gasses.
- Reduction of electricity bills.
- Availability of extra KVA from the same existing supply.
- Reduction of I^2R losses in transformers and distribution equipment.

Disadvantages of APFC

- They have a short service life ranging from 8 to 10 years
- They are easily damaged if the voltage exceeds the rated value
- Once the capacitors are damaged, their repair is uneconomical

VI. CONCLUSION

Power factor correction equipment designed based on microcontroller and capacitor banks was used for measurement and monitoring of modeled electrical load and the following deductions were obtained:

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- The power factor correction device designed was able to improve the power factor from 0.76 to 0.97 under the test load conditions.
- The average savings in energy consumption was about 1.7% for the designed load and different load patterns.
- With the proper amount of reactive power compensation, the system capacity is released as there is a reduction in current drawn.
- The economic analysis suggested the payback period to be around 9 months with a significant amount of savings in energy cost.

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