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# An Efficient Penalty Factor using Automatic Power Factor Correction and Detection by Arduino Uno

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## ABSTRACT

***The main aim of the Power generating stations is to provide uninterrupted power supply (UPS) to the loads. The loads based on their consumption classified as main three types namely industrial, commercial and domestic loads. When we consider the industrial loads power consumption is huge. So, protection of industrial power grid and minimization of power loss & penalty is also to be consideredat mostly. This new technique equipment minimizes the energy consumption and thus reduce the power loss in industries and establishments by making use of a number of shunt capacitors. This substantially reduces the electricity bill in industries and establishments. The power factor is also known as the ratio of real power to apparent power. It is also represented as KW/KVA, in the equation KW stands for the active or real power whereas KVA stands for reactive + active or apparent power. The power generated by inductive as well as magnetic loads in order to create a magnetic flux is known as reactive power which is a non-working power. An increase in the reactive power increases the apparent power, thus decreasing the power factor. With low power factor there is an increase in the need of energy to meet industry demands, this decreases the efficiency. This works by feeding the time lag between zero voltage pulse and zero current pulse produced by suitable operation amplifier circuit working in comparator mode is connected to Arduino digital pins. The project program controls the working and actuates required number of relays from the output that will get shunt capacitors into load circuit in order to get good power factor until it reaches unity.An Arduino uno with atmega328 microcontroller on its board is required to fulfils this process. The data of the power factor is shown on LCD.***

## 1. INTRODUCTION

In the present technological revolution, power is very precious and the power system is becoming more and more complex with each passing day. As such it becomes necessary to transmit each unit of power generated over increasing distances with minimum loss of power. However, with increasing number of inductive loads, large variation in load etc. the losses have also increased manifold. Hence, it has become prudent to find out the causes of power loss and improve the performance of the power system. Due to increasing use of inductive loads, the load power factor decreases considerably which increases the losses in the system and hence power system losses its efficiency and leads to Voltage instability of the power system.

An Automaticpower factor correction device reads power factor from line voltage and line current by 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 an Arduino uno with atmega328 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, commercial loads 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 Arduino uno based power factor corrector results in reduced overall costs for both the consumers and the suppliers of electrical energy and moreover to the industrial loads where the utilisation of the power is very huge.

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 main aim for the development of this project is to enhance and upgrade the operation of single-phase capacitor banks manually by developing a Arduino 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 Arduino based control unit ensures even utilization of capacitor steps, minimizes number of switching operations and optimizes power factor correction.

## 2.POWER FACTOR

Power factor is defined as the cosine of the angle between the voltage and current. The power factor is also known as the ratio of real power to apparent power. It is also represented as KW/KVA, in the equation KW stands for the active or real power where as KVA stands for reactive + active or apparent power

**Pavg = VIcosϕ**

Where, ϕ is the phase angle between the voltage and current. The termcosϕ is called the power factor.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. A load with a power factor of 1.0 result 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.

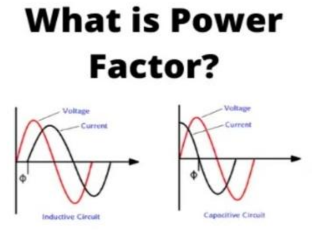



Fig. 2.1. VOLTAGE & CURRENT WAVE FORMS OFINDUCTIVE ANCAPACITIVE LOAD

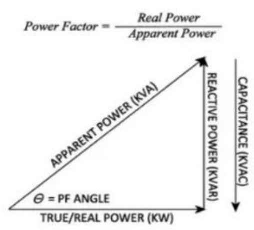



Fig. 2.2.POWERTRIANG

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 a change in equipment design or expensive harmonic filters to gain an appreciable improvement.

## 3.NEED OF POWER FACTOR CONTROLLER

Power factor correction is a technique of counteracting the undesirable effects of electric loads that create a power factor less than one. Power factor correction may be applied either by an electrical power transmission utility to improve the stability and efficiency of the transmission network or correction may be installed by individual electrical customers to reduce the costs charged to them by their electricity supplier.

An electrical load that operates on alternating current requires apparent power, which consists of real power plus reactive power. Real power is the power actually consumed by the load. Reactive power is repeatedly demanded by the load and returned to the power source i.e., which remains unused in the power system circuit, and it is the cyclic effect that occurs when alternating current passes through a load that contains a reactive component. The presence of reactive power causes the real power to be less than the apparent power, and so, the electrical load has a power factor of less than unity (1.0).

The reactive power increases the current flowing between the power source and the load, which increases the power losses through transmission and distribution lines. This results in operational and financial losses for the power companies. Therefore, power companies require their customers, especially those with large loads, to maintain their power factors above a specified value (usually 0.90 or higher) or be subjected to additional charges.

The electric utilities therefore put a limit on the power factor of the loads that they will supply. The ideal figure for load power factor is unity (1), that's a pure resistive load, because it requires the smallest current to transmit a given amount of real power. Real loads deviate from this ideal condition. Electric motor loads are phase lagging (inductive), therefore requiring capacitor banks to counter their inductance.

Sometimes, when the power factor is leading due to capacitive loading, inductors (also known as reactors in this context) are used to correct the power factor. In the electric industry, inductors are said to consume reactive power and capacitors are said to supply it, even though the reactive power is actually just moving back and forth between each AC cycle.

Electric utilities measure reactive power used by high demand customers and charge higher rates accordingly. Some consumers install power factor correction schemes at their factories to cut down on these higher costs.

**Table 3.1. PENALTY RATE BASED ON THEPOWER FACTOR RANGE**

**Power Factor Penalty**

**Example of DTE penalty rates (issued January 1994)**

| Power Factor | Penalty |
|---|---|
| .850 and higher | None |
| .800 to .849 | 1% |
| .750 to .799 | 2% |
| .700 to .749 | 3% |
| <.700 | 25% |

- •Penalty is applied to all metered quantities
- •Power Factor less than .700 is not permitted and corrective equipment must be installed.
- •25% penalty applied after two consecutives months below .700

$$\text{Penalty factor } \lambda_\alpha = \frac{1}{1 - \frac{dP_L}{dP}}$$

Where,

$dP_L/dP$ = Incremental transmission loss

Penalty factor = 1

If $dP_L/dP = 0$

**Table 9-31: Power Factor Penalty approved for FY 2018-19 and FY 2019-20**

| Sr. No. | Range of Power Factor | Power Factor Level | Penalty |
|---|---|---|---|
| 1 | 0.895 to 0.900 | 0.90 | 0% |
| 2 | 0.885 to 0.894 | 0.89 | 1.0% |
| 3 | 0.875 to 0.884 | 0.88 | 1.5% |
| 4 | 0.865 to 0.874 | 0.87 | 2.0% |
| 5 | 0.855 to 0.864 | 0.86 | 2.5% |
| 6 | 0.845 to 0.854 | 0.85 | 3.0% |
| 7 | 0.835 to 0.844 | 0.84 | 3.5% |
| 8 | 0.825 to 0.834 | 0.83 | 4.0% |
| 9 | 0.815 to 0.824 | 0.82 | 4.5% |
| 10 | 0.805 to 0.814 | 0.81 | 5.0% |
| ... | ... | ... | ... |

All the above statistics depict that the impact and influence of the penalty factor and its effects on the power systems. When the power factor become poor and poor the penalty also increases. Due to this penalty mainly the industrial and commercial are paying the charges to the power that are they not utilizing. So, this penalty should be reduced by appointing the special automatic controllers to constantly monitor the power factor and correcting it by using the capacitor banks.

## 4.ARDUINO BASED ATMEGA328 MICROCONTROLLER

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

The Uno differs from all other boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. The Arduino

Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX).

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno from the Tools > Board menu (according to the microcontroller on our board). The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files). We can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header.

## 5.BLOCK DIAGRAM

The below block diagram represents the Automatic Power Factor detection and correction operates on the principal of constantly monitoring the power factor of the system and to initiate the required correction in case the power factor is less than the set value of powerfactor.

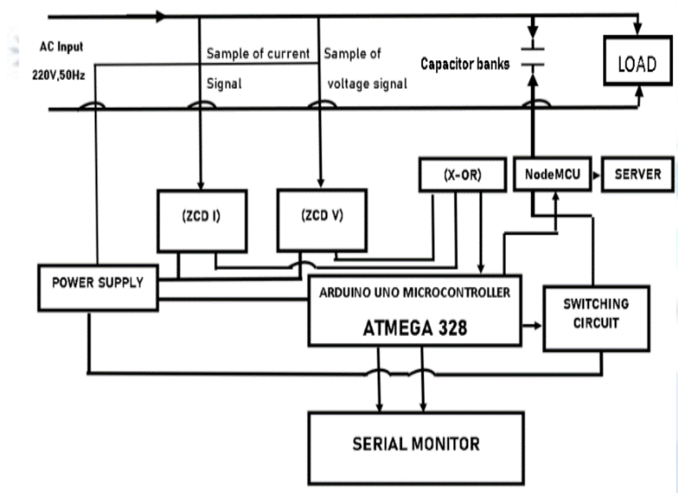



**Fig. 5.1. PROPOSED BLOCK DIAGRAM OF SIMULATION CIRCUIT**

The current and voltage signals are sampled by connecting terminal busesto ZCD in the circuit. The sampled Analog signals are converted to suitable digital signals by the zero crossing detectors, which changes state at each zero crossing of the current and voltage signals. The ZCD signals are then added in order to obtain pulses which represent the time difference between the zero crossing of the current and voltage signals. The time period of these signals is measured by the internal timer circuit of the Arduino by using the function pulseIn(), which gives the time period in micro seconds. The time period obtained is used to calculate the power factor of the circuit. If the calculated power factor is less than the minimum power factor limit set at about 0.98 or any other set value, then the Arduino based Atmega328 microcontroller switches on the require number of capacitors until the power factor is greater than or equal to the set value.

## 6.NODE MCU & SERVER: AN IOT EXTENSION

All the data regarding power factor,voltage,real &reactive power can be displayed on the remote LCD. But it is difficult to read out the data and making a record in case of the power systems. So, to avoid this drawback we came up with an IOT extension of this project. By using this IOT technology we can access the information regarding parameters of the particular area from any global location i.e., from substation, power plant Control room or any place needed by the user who is connected to the Authenticated server of the nodeMCU.

The information is accessible only when the electronic device is connected to the server when both are interfaced to same Wi-Fi or ethernet. In real time working we can use the blink app to access, monitor, control the unit of the APFC.But if you want to simulate the complete Automatic power factor correction system in proteus it is not possible to show the real time behaviour of the Wi-Fi module because the NodeMCU is not physically connected to Wi-Fi network or the Blynk server.

NodeMCU is a development board based on ESP8266 module.It includes components such as USB-to-serial converter,voltage regulator and GPIO pins.This is most easier to build IOT projects.The NodeMCU used in proteus for simulating the behaviour of the Wifi module and it is not possible to show the real time behaviour.In real time applications we have to create a server to receive the data sent by NodeMCU.This can be cloud paltform or local server.To simulate in proteus we use virtual server for representation where the data can be received from NodeMCU.

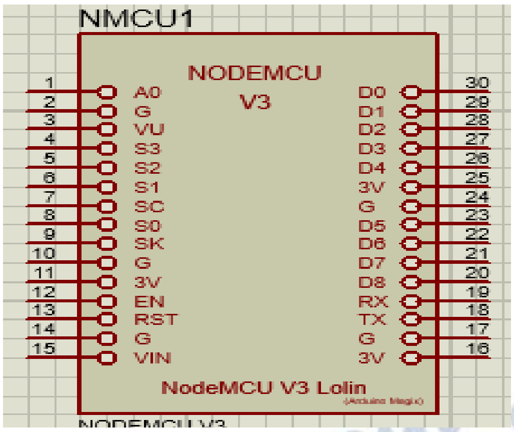



Fig.6.1. NODEMCU

To interface the NodeMCU with Arduino Uno we have to include some libraries in Arduino IDE to enable the NodeMCU interact with the server. When it is connected to server the data, we can use the wificlient.write() function to send data to the server. When we want to access the data, we have to connect with the same Authenticated server. When the data is sent, we can monitor and control the APFC circuit. By sending the data to a server. We can analyse and optimize the performance of the APFC circuit and ensure the efficient power consumption

## 7.SIMULATION AND RESULT

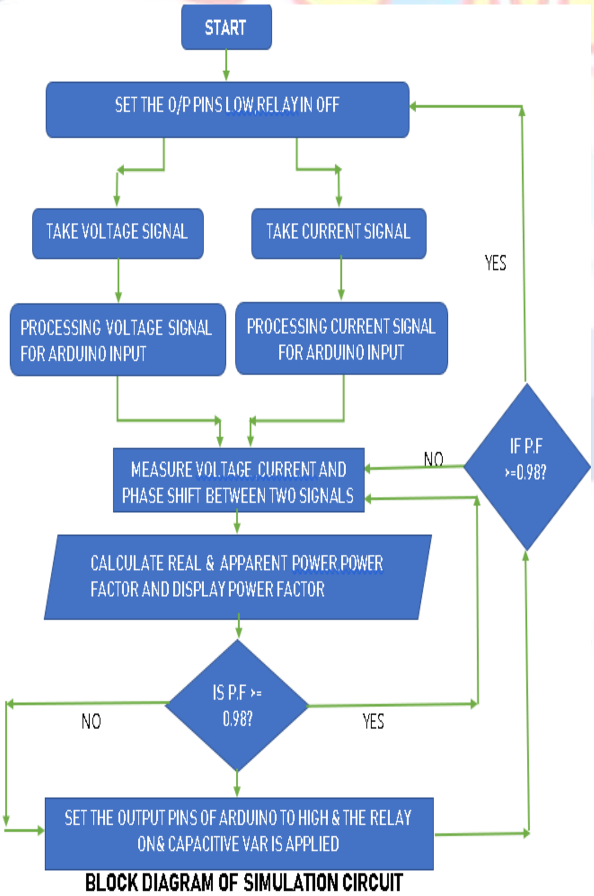



Fig. 7.1. SOFTWARE FLOW OF THE APFC UNIT

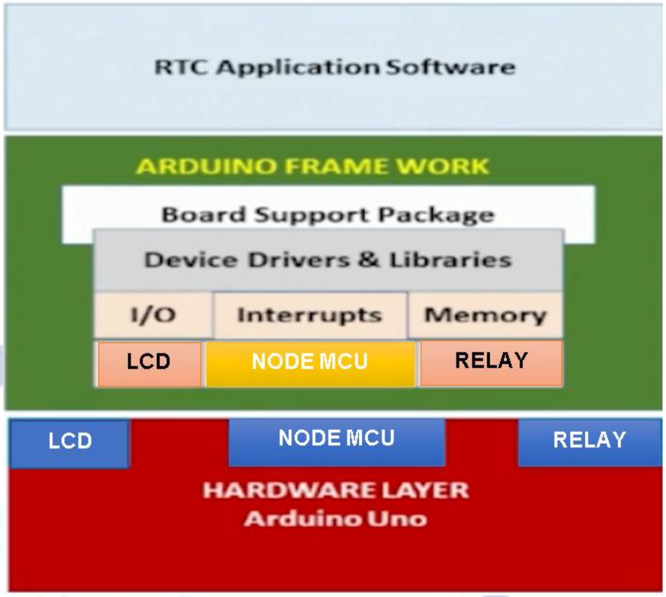
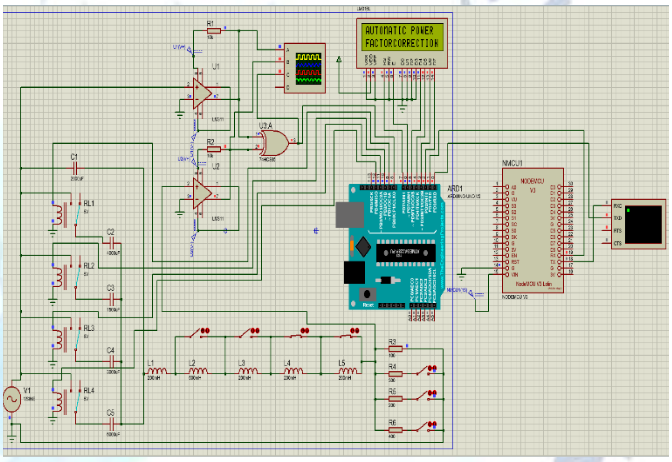
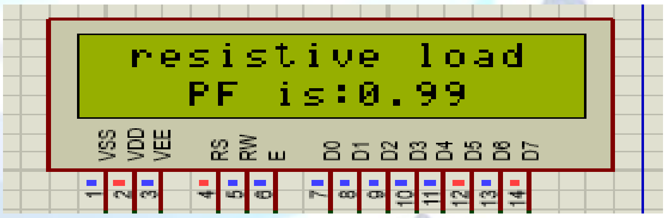
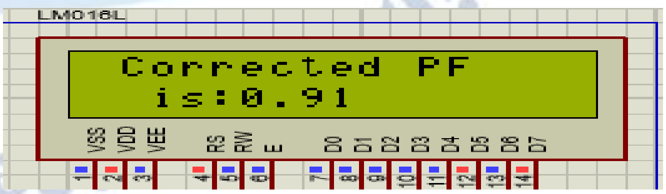
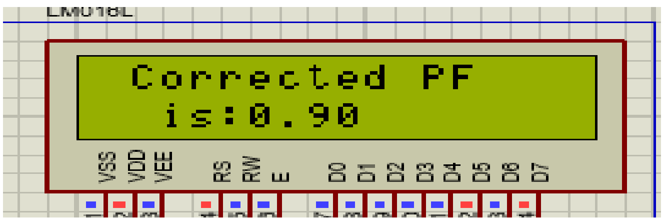



Fig. 7.2. HARDWARE BLOCK DIAGRAM



| Sr. No | LOAD | CALCUALTED | DETECTED | CORRECTED |
|---|---|---|---|---|
| 1. | Pure resistive load | 0.99 | 0.99 | 0.99 |
| 2. | RL load (700 mH) | 0.94 | 0.94 | 0.99 |
| 3. | RL load (900 mH) | 0.91 | 0.91 | 0.99 |
| 4. | RL load (1100 mH) | 0.90 | 0.90 | 0.99 |

**TABLE 7.1. RESULT COMPARISON**

## 8.CONCLUSION

By using Arduino based Atmega328 Microcontroller is made easy to detect the lag/lead power factor in the flow of power. The data can be displayed on the LCD and easy to access in remote and but in case of power systems the NodeMCU along with inbuilt WIFI Module also used to access the data from control room when the receiver is connected to server.

The results obtained with various load conditions are satisfactory and the system would make a cost-effective solution for automatic power factor improvement in industrial environment. Further the system can be modified using IOT technology i.e., the NodeMCU connected to the Arduino transmits data to server and that data can be monitored, accessed from any global location. Also, same data transferring techniques can be used for more scientific analysis of PF of a certain facility. The Automatic Power Factor Detection and Correction provides an efficient technique to improve the power factor of a power system by an economical way and allow to access the data from any global location using IOT technology.

### Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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