IOT-BASED AUTOMATIC POWER FACTOR CONTROLLER

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***Abstract*—Recently, the concern for power quality of ac systems is on rise due to considerable growth of large number of electronic equipment, power electronics, and high voltage power systems. The majority of commercial and industrial establishments of the country are having large electrical loads, and these loads are severally inductive in nature, thereby giving rise to lagging power factor, for which considerable penalties are being charged by the electricity board. It is for this purpose that Automatic Power Factor Correction is used. APFC device detects power factor using line voltage and line current by finding the phase delay of current signal change arrival time concerning voltage signal change arrival time using function generator with high accuracy by using an internal timer. The values are then calibrated as phase angle and corresponding power factor. The values are then displayed using 2x16 LCD modules. Then, using these values, the motherboard calculates how much compensation is required and then switches on different capacitor banks. The aim of this project is to create a system that will switch capacitor banks in and out of circuit when power factor drops below a certain point, thus preventing power company charges.**

***Keywords* — Power Factor , Capacitor Banks, Reactive Power, APFC, IoT**

I. 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 parallelly. Therefore, it becomes important to identify the causes of power loss and take measures to improve the efficiency of the power system. The increasing use of inductive loads significantly reduces the load power factor, which results in higher losses in the system and decreases the overall efficiency of the power network. An Automatic power factor correction device reads the power factor from line voltage and line current by finding the delay of the arrival of the current signal with respect to the voltage signal from the source using an inbuilt timer with high accuracy. It then finds the phase angle lag Ø between the volt age and current signals, followed by finding the corresponding power factor cos Ø. Then the microcontroller finds the amount of compensation required and hence switches on the number of capacitors required from the capacitor bank until the PF is normalized at about unity. The industrial units, power systems as well as households can be made stable using automatic power factor correction techniques. By doing so, the system becomes stable and efficiency of the system as well as of the apparatus increases.

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 has been realized to be able to reduce reactive power consumption using capacitor banks; this will lead to minimization of losses and at the same time increases the electrical system's efficiency. Development of single-phase capacitor banks for domestic and industrial applications has therefore been done due to power saving issues and management of reactive power. The development of the project involves improving the operation of single-phase capacitor banks with a more sophisticated microprocessor-based control system.

A. MOTIVATION

Today, with the increasing urban population, rapid growth in urban areas, and swift growth of industries, along with the usage of electrical equipment in daily life, the demand for electricity is increasing. Most of the equipment, such as motors, pumps, fans, transformers, and air conditioners, used in our daily life are inductive in nature and are used in both residential and commercial areas. These inductive loads have a low power factor, and it causes a reduction in the efficiency of the power system. If the power factor is low, it causes an increase in the flow of currents, line losses, voltage drop, and even overheating, and it might even lead to an increase in the electricity bill. In many small industries and commercial areas, the power factor is not being regulated properly. These industries are often penalized by the electricity boards for maintaining a low power factor, due to their carelessness. Since the load currents vary during the day, manual switching of the capacitor banks is required for the conventional method of power factor correction, which is not feasible.

The manual method requires constant human intervention, and it is a time-consuming process. A system that can automatically measure and control electrical parameters in real time can be designed with the development of microcontroller and Internet of Things technologies. It is because of these reasons that we were motivated to develop an Internet of Things-based automatic power factor controller, which can automatically switch capacitor banks if required and monitor the power factor in real time. The inclusion of IoT gives the system a modern look because it can be used by the user even if they are not near the panel.

Two other important reasons for the development of this project are cost and energy savings. The losses in the system can be minimized and efficiency maximized by maintaining the power factor at or near unity. This helps in increasing the lifespan of the electrical equipment and saving electricity by not stressing it unnecessarily.

B. LITERATURE REVIEW

In 2009 G. K. Singh did a thorough job of looking at harmonics in power systems. He explained where harmonics come from and how they move through networks. Harmonics in power systems also have some effects like making things overheat and causing problems with protection devices. G. K. Singh talked about ways to reduce harmonics in power systems. These methods include using filters, active filters and hybrid filters. The importance of controlling harmonics in power systems is very clear. Controlling harmonics in power systems helps keep them stable and working properly. Harmonics, in power systems need to be controlled [1].

In the year R. S. Bhuvaneswari and B. G. Singh worked on making power quality better using Automatic Power Factor Correction in industrial environments. They looked at how Automatic Power Factor Correction systems work and how they are designed. This includes the way capacitor banks are switched on and off and how they are controlled. The study found out that using Automatic Power Factor Correction helps make things work better reduces problems and keeps the voltage at the level. What R. S. Bhuvaneswari and B. G. Singh found out shows that we need to use automated systems, in industries where the load changes a lot. This is because Automatic Power Factor Correction helps a lot in these situations [2].

Later in 2021 N. P. Padhy and S. K. Dash talked about Artificial Intelligence and IoT in power systems. They said that Artificial Intelligence can be used in power systems. Artificial Intelligence is used for things like predicting how much power will be needed, finding faults and keeping the system running. The book also says that IoT devices are helpful because they collect information as things happen which makes it easier to keep an eye on things and make decisions, in modern smart grids that use Artificial Intelligence and IoT [3].

M. H. Rashid wrote a book in 2017 that really helps us understand power electronics. He explains how things, like SCRs and MOSFETs and IGBTs work. The book also talks about how to change power from one type to another and how to control things digitally. These ideas are really helpful when we are designing circuits that use capacitors to switch things on and off and when we want to make APFC systems work better. Power electronics is an important subject and M. H. Rashids book is a great resource to learn about power electronics and how to use power electronics in real life [4].

Later, the research in 1998 done by K.M. Passino found some intelligent control techniques in power system. In the study there were methods like fuzzy logics and neural networks which helps in voltage regulations and system stability. Which finally showed that how intelligent controllers can stabilize the system and improve power quality [5].

II. HARDWARE IMPLEMENTATION

A. AC Shunt Capacitor (2.5 µF, 440V)

Fig.1 Shunt Capacitor

The 2.5 µF/440V AC capacitor is the main component responsible for correcting the power factor in the Internet of Things-based APFC circuit. The ESP32 uses a relay to connect the capacitor to the circuit once it has identified that the inductive circuit is causing the power factor to lag. The capacitor supplies a leading reactive power component once it is connected in parallel to the circuit, thus reducing the phase difference between the voltage and the current and consequently increasing the power factor.

B. 2-Channal Relay Module

It is a two-channel relay module that is managed by an ESP32 microcontroller and functions similarly to a switch. It enables safe control of high-voltage AC or DC loads with a low-voltage signal. The external load is connected to the green terminals, and the controller is connected to the pins marked VCC, GND, IN1, and IN2.The relay responds to signals from the controller by turning ON or OFF. This module is used in the Internet of Things-based APFC system to automatically connect or disconnect the capacitor in order to increase the power factor.

Fig.2 Relay module

C. Step Transformer (230V/12V) AC

A step-down transformer (230V/12V AC) is used to supply isolated low-voltage power to the control and IoT circuitry of the APFC system.

In this project, this transformer is typically used to:
a) Provide low-voltage supply for control circuits
b) Power the microcontroller (through rectifier and regulator
c) For Isolation

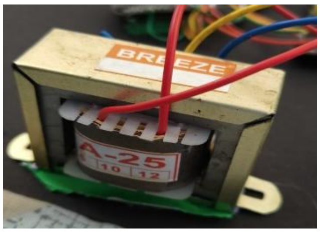

Fig.3 Stepdown Transformer

D. 16×2 LCD display module (JHD 162A) with I2C protocol

The 16×2 LCD interfaced using the I2C protocol communicates with the microcontroller through only two lines, SDA (data) and SCL (clock), reducing the number of required GPIO pins. An I2C interface module converts serial data from the microcontroller into parallel signals to control the LCD display.

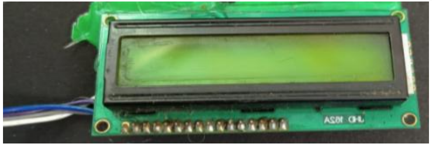

Fig.4 LCD with I2c

E. ESP32 WROOM 30 PIN

In this project, the ESP32 act as the main controller that controls the overall operation. It reads the current values from the sensor, analyzes the load condition, and switches the capacitor bank through a relay whenever power factor correction is required. The ESP32 also connects to Wi-Fi and sends real-time electrical data to the Blynk platform, allowing the system to be monitored remotely through an IoT interface.

Fig.5 ESP32

F. ACS712 Hall-Effect Current Sensor Module

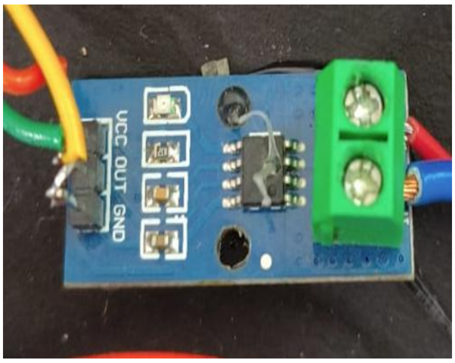

Fig.6 Current Sensor Module

In this project, the ACS712 current sensor is used to monitor the load current. The current sensor generates an analog voltage that is proportional to the current, which is read by the ESP32 to analyse load conditions and control capacitor switching for power factor correction.

G. Power supply Circuit

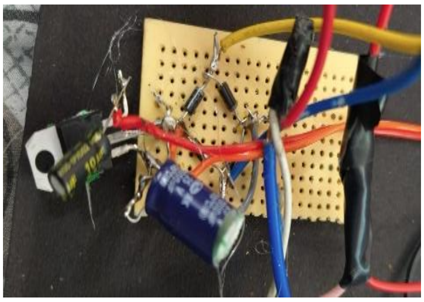

Fig.7 Power supply unit

The 1N4007 diodes are connected as a bridge rectifier to convert the AC voltage into DC volage from transformer. Voltage regulator (7805) provides a stable and constant DC output which is required by the ESP32 and other control components. The 1050 µF capacitor smooths the rectified output by reducing ripple, and the 10 µF capacitor further stabilizes the voltage to ensure a steady and reliable supply for the control circuit.

III. METHODOLOGY

The IoT-based Automatic Power Factor Correction (APFC) system proposed here allows for real-time monitoring and remote control of the system via the Blynk platform. The IoT-based APFC will execute its actions through a closed-loop control system wirelessly.

To support the ESP32 microcontroller (used for powering the relay module and the LCD) a 12-0-12 transformer regulates the AC voltage, 1N4007 diodes rectify it, 1025µf capacitors filter it and a 7805 voltage regulator produces 5V DC. The current is monitored continuously using an AC712 current sensor that transmits data to the ESP32 microcontroller for further processing. The controller will evaluate the power factor and determine how much additional reactive power must be added to achieve a desired power factor defined as

$Q_c = P(\tan\phi 1 - \tan\phi 2)$.

When the power factor is low and below a pre-determined limit (for example, a limit of 0.90

lagging), the ESP32 will command the relay module to close the capacitor bank so that the load current receives assisting leading VARs that will help improve the power factor. When the desired power factor value has been achieved, the capacitor bank will be disconnected from the circuit to prevent over-correction.

The ESP32 sends the real-time power factor data from the system to the Blynk IoT platform over the WiFi connection. This allows real-time monitoring and visualization of the power factor via a mobile app connected to the Blynk IoT platform.

VI. RESULT

The developed IoT-based Automatic Power Factor Correction (APFC) system was successfully designed and implemented using the ESP32 microcontroller, ACS712 Current Sensor, relay module, and capacitor bank. The system continuously monitored the load current and calculated the power factor of the connected load. When an inductive load such as a choke coil was connected, the power factor initially dropped to a lower value. The controller detected this condition and automatically activated the relay to connect the capacitor bank across the load. As a result, the leading reactive power supplied by the capacitor compensated for the lagging reactive power of the load, thereby improving the overall power factor.

Experimental observations showed that the power factor improved from approximately 0.20–0.30 (lagging) to around 0.91, depending on the load conditions. The corrected power factor and system status were also displayed on the LCD display and transmitted to the IoT platform through Wi-Fi for real-time monitoring.

Thus, the proposed APFC system effectively improved the power factor, reduced reactive power demand, and demonstrated the feasibility of remote monitoring using IoT technology.

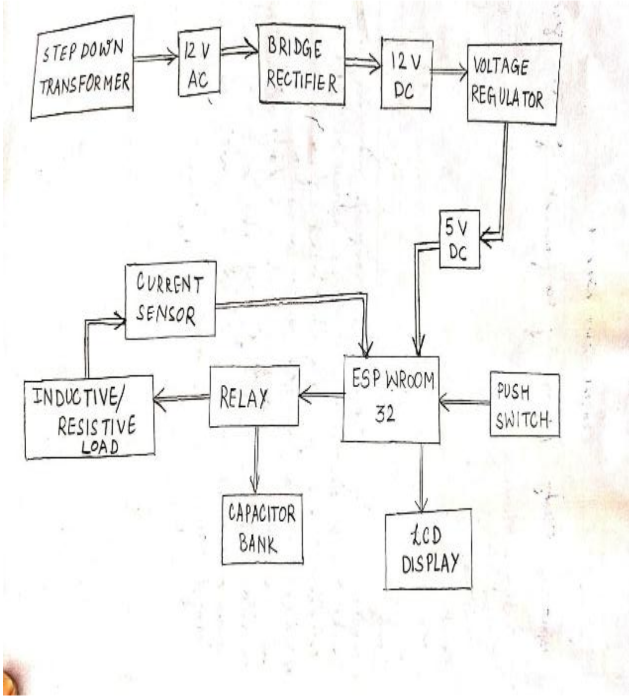

Fig. 8 Block Diagram

CALCULATION:-

Supply Voltage, $V = 230$Volts

Frequency, $f = 50$Hz

Resistive load = 529Ω

Capacitor bank = $2*2.5\mu F$

$C = 5\mu F$

Inductive load = 1.1 H

Inductive Reactance (X_L):-

$X_L = 2\pi fL$

$= 2 * 3.14 * 50 * 1.1$

$= 345.4\Omega$

Capacitive Reactance (X_C):-

$X_C = 1/(2*\pi*f*C)$

$= 1/(2 * 3.14 * 50 * 5 * 10^{-6})$

$= 636.6\ \Omega$

Net Reactance:-

$X = X_L - X_C$

$= 345.4 - 636.6$

$= -291\ \Omega$ [Capacitive compensation]

Impedance:-

$Z = \sqrt{(R^2 + X^2)}$

$R = V^2 / P = (230^2)/100$

$= 529\ \Omega$

$z = \sqrt{(529^2 + 291^2)}$

$= 603\ \Omega$

Theoretical Power Factor:-

$PF = R/Z$

$= 529/603$

$=0.87$

$PF \approx 0.87$

Practical Power Factor:-

$PF \approx 0.91$

V. CONCLUSION

Low power factor reduces power quality and may lead to penalty charges from the electricity board. To overcome this issue, an IoT-based automatic power factor correction system was developed using the ESP32, ACS712 Current Sensor, 2-Channel Relay Module, Capacitor bank, Step-Down Transformer, Bridge Rectifier, voltage regulator, and 16×2 LCD Display.

The system automatically monitors the load current and switches the capacitor bank through the relay module whenever the power factor decreases due to inductive loads. This automatic correction improves the overall power factor and maintains better power quality.

Additionally, IoT monitoring allows real-time observation of system parameters, making the system simple, reliable, and suitable for practical applications.

The project successfully combined the principles of power factor correction with the capabilities of modern IoT technologies. It has demonstrated that effective power quality control can be achieved using affordable hardware, intelligent programming, and cloud connectivity.

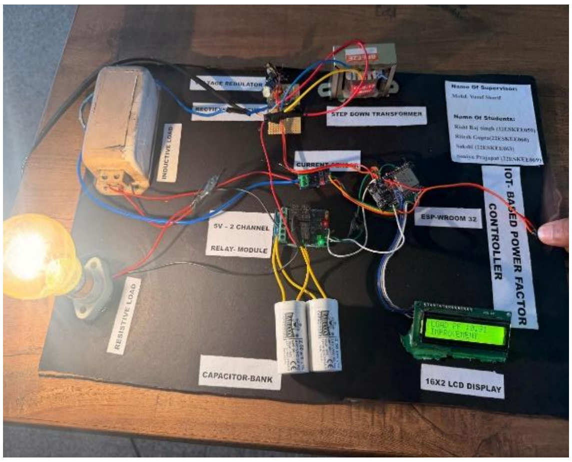

Fig.9 Complete Project

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