IoT-BASED AUTOMATIC POWER FACTOR CORRECTION

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A Thesis Presented to the University of Energy and Natural Resources in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

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IoT-BASED AUTOMATIC POWER FACTOR CORRECTION

A Thesis Presented to the University of Energy and Natural Resources in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Computer Engineering

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AUTHOR'S DECLARATION

We understand that copyright in our thesis is transferred to University of Energy and Natural Resources.

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ABSTRACT

Power quality of the AC system has become a great concern due to the rapidly increased use of inductive loads. Electrical energy is wasted everyday due to the lagging power factor in the inductive loads used in industries. Hence, the urgent need to avoid this wastage of energy in our power system. Poor power factor results in poor reliability, safety problems and high energy cost. Internet of Things (IoT) potentially enhance the quality of life in the energy sector is used monitoring and controlling of electrical sites remotely. Many control methods for the Power Factor Correction (PFC) were proposed where different types of devices performing similar work were used.

This paper aims to measure and correct power factor using capacitor banks. The results are then displayed on LCD as well as sending the results through wi-fi module to web page to be viewed remotely. The profit gained after correcting the power factor is also calculated and sent to the web page for viewing by the user. A prototype of the work is built for achieving the aim of this paper.

DEDICATION

This work is dedicated to our family, friends and loved ones.

ACKNOWLEDGEMENT

First and foremost, we like to thank the Almighty God for his mercies all through this period of our life for his grace shown to us. We would like to also thank Ing. Nana Twum Duah, our project supervisor, for giving us this opportunity to work on this project to enlighten more on our studies. We would also like to thank Mr. Quarshie for his support when we needed help during the course of the project.

Lastly, we would like to extend our heartfelt thanks to our parents for their immense support both emotionally and financial for this project to be a success.

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LIST OF ABBREVIATIONS

AC	Alternating Current
PF	Power Factor
PFC	Power Factor Correction
kW	Kilowatt
kVA	Kilovolt-Ampere
KVAR	Kilovolt-Ampere Reactance
PQ	Power Quality
IoT	Internet of Things
LAN	Local Area Network
GSM	Global System for Mobile
Wi-Fi	Wireless Fidelity
APFC	Automatic Power Factor Correction
DC	Direct Current
PLC	Programmable Logic Controller
PIC	Peripheral Interface Controller
LCD	Liquid Crystal Display
PT	Potential Transformer
CB	Capacitor Bank
LED	Light Emitting Diode
XAMPP	X-os-Apache-Mysql-Php-Perl
HTTP	Hypertext Transfer Protocol

VSCODE	Visual Studio Code
MySQL	My Structured Query Language

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Power is useful in the present scenario of technological revolution. Higher power factor (pf) improves the Power quality of power system which is essential for effective operation of machines. Power Factor Correction (PFC) plays a vital role in power system quality, stability control and protection. For efficient utilization of electrical power, PF should be high. PF is defined as the ratio of the real power (in kW) flowing to the load to the apparent power (in kVA) in the circuit [1]. The difference between the real power and the apparent power is the reactive power (in kVAR) which the power needed to generate magnetic fields in the inductive equipment. Even though the reactive power performs no useful work, it is however needed by the inductive equipment in the system to produce magnetic fields. At constant Real Power, the higher the reactive power, the higher the apparent power, therefore, the lower the power factor. A load with a low PF draws more current than a load with a high PF for the same amount of useful power transferred. High current increases the energy loss in the power systems, and require larger cables and other equipment [2]. Because of the costs of additional equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers, where there is a low PF. PFC is a process for compensating the lagging current by creating a leading current using a sufficient capacitance so that the PF is adjusted to be as close to unity as possible [3]. PFC is the capability of generating or absorbing reactive power to a load without consuming reactive power from the utility company. Employing PFC aims to improve PQ by enhancing PF. This increases energy efficiency and reduces electricity cost.

Internet of Things (IoT) interconnects a number of devices, people, data, and processes, by allowing them to communicate with each other seamlessly. IoT also helps in improving different processes to be more quantifiable and measurable by collecting and processing large amount of data [4]. In fields like medical services, smart cities, construction industry, agriculture, water management, and the energy sector, IoT can potentially enhance the quality of life [5]. In order for data transmission to be possible, IoT employs sensors and communication technologies for sensing and transmitting real-time data, which enables fast computations and optimal decision-making [6]. Moreover, IoT helps the energy sector to transform from a centralized to a distributed, smart, and integrated energy system. In terms of monitoring processes during manufacturing, IoT, and its enabling technology play a crucial role. Gateway devices, IoT hub networks, web servers, and cloud platforms, which are accessible with smart mobile devices (e.g., smart phones or personal computers), can be examples of monitoring equipment. Wireless communications such as Wi-Fi, Bluetooth or wired communications, such as Local Area Network (LAN) can be used to connect all pieces of equipment [7].

There are various methodologies proposed to correct the power factor. One of the simplest methods of PFC is switching on and switching off the capacitor banks. To obtain a desired power factor at various load conditions, the reactive power generation was done by switching on the capacitor banks. If any failure occurs in the capacitor banks, it can be identified by the microcontroller and alert the user with the help of GSM. Failure in capacitive banks affects the maximum demand in the industry and hence to keep within limits, automatic load switching has to be done. In an electrical power system, a load with a low power factor draws more current than a load with a unity power factor. The increase in number of industries and consumers primarily relying on inductive loads has made power quality one of the biggest concerns [8]. So many previous works have been done to improve the power factor. Notably among the researchers, [9] developed an optimization technique to improve the power factor level in the industries. In order to utilize the energy in an efficient manner many industries have adopted these kinds of techniques to improve the power factor level.

This project seeks to improve the existing power factor correction unit. It is geared towards economic analysis of the designed system and how important it is for the user.

1.2 PROBLEM STATEMENT

Loads with poor power factor draw high current resulting in high energy loss in the form of heat in the power system. This heat, over a period of time, contributes to heating of the equipment including cable, contactors, terminals, bus bar which can be damaged over a period of time [10]. High amount of apparent power is transmitted by the distribution companies to meet the power demands of industries with low power factor. Distribution companies, in order to avoid these challenges, place high penalty charges on industries with low factor. Industries also pay high fees for the high amount of apparent power transmitted to them by the distribution companies. Industries such as the production industries, increase the price of their commodities so as to avoid losses, increasing the cost of living in the country.

1.3 AIM AND OBJECTIVES OF STUDY

1.3.1 Aim

The aim of the project is to design and build an IoT-based Automatic Power Factor Correction Unit/Device.

1.3.2 Objectives

The objectives are summarized as follows:

I. Design a microcontroller-based PFC equipment to improve the pf of the system to a value not less than 0.95 by switching on the required capacitance.

II. Size a capacitor bank to improve the pf with motor rating not less than 600W.

III. Build web application to monitor the state of pf remotely.

IV. Carry out economic analysis for power factor correction.

1.4 SCOPE OF WORK

The project will be based on using capacitor bank in a microcontroller based APFC circuit. The objective of this project is to implement a PFC unit, which will improve the power factor automatically of varying lagging loads to 0.95 and display it on an LCD screen. It will also send information to the user's phone through mobile app with the help of Wi-Fi module. The proposed circuit will be designed step by step, starting from power supply unit and finally design the complete proposed project. In this project, the user would be privileged to know whether or not profit is gained before the circuit loses its significance.

In all the works reviewed, the IoT did not display merits of their system concerning the profits gained after using it as time goes by. This work will include that and the IoT will display the cost analysis at the end of every 6 months to the user. In addition, the IoT will display all the other information necessary to the user.

1.5 THESIS OUTLINE

This thesis is made up of five chapters and each of the chapter clearly describes the process taken to provide full details for our project work.

Chapter I presents the introduction of the project which include the background of study, aim and objectives, problem statement, scope of work and thesis outline.

Chapter II gives a literature review of existing work on this project grouped into sections such as switching devices, microcontrollers and mode of communication to the user.

Chapter III involves the proposed principle to design the correction equipment and the algorithm to work for achieving the required outcome along with the technique to measure and monitor. It also gives detail idea about construction and working of each component associated with the power factor correction equipment and the final hardware implementation.

Chapter IV shows the results obtained by measuring and monitoring the designed loads under different conditions and load patterns. It also involves the economic analysis

Chapter V provides conclusion and recommendation for future enhancement of the project work.

CHAPTER TWO

LITERATURE REVIEW

2. 1 INTRODUCTION

This chapter contains existing work which is categorized into switching devices, microcontrollers used and mode of communication to user or technician. The role of the switching device is to take instructions from the microcontroller. These switching devices open and close in order to inject the desired capacitance value into the system. Microcontrollers also play an important role in Power Factor Correction. In Automatic Power Factor Correction (APFC), the microcontroller controls the capacitor banks and give instructions to the switching devices. It also gives instructions to the LCD to display any information to the user. Internet of Things (IoT) interconnects a number of devices, people, data, and processes, by allowing them to communicate with each other seamlessly. Hence, IoT can help improving different processes to be more quantifiable and measurable by collecting and processing large amount of data.

2.1.1 Switching devices used

In the work of [11]-[14], relay acted as switching device in correcting power factor by switching on or off of the capacitor values to be injected into the system. Almost all the works regarding this switching device emphasized on the low cost of the device and how simple it is to be used. However, given its low speed of operation, the ability to change in its characteristics due to aging, some researchers preferred other switching devices for operation. Other demerits of Relay include its contact wear due to its design and not being able to be used at explosive/vibrative environment.

Authors [15] and [16] developed power factor correction device with thyristors being used to switched on the amount of capacitance needed by the system to improve the power factor of the system. Unlike the Relay, thyristors operate at high speed and hence the reason for their usage. It has no moving parts to cause wear, therefore has increasing lifetime even after activated many times. Despite how advantageous this device is, few works made use of the device owing to it higher cost.

2.1.2 Microcontrollers

Arduino has become one of the commonly used microcontrollers among students and researchers, because of its readiness to use structure and how effortless their functions are [11][12][16]. It is also preferred by many due to the affordable costs of its components [17][19]. Arduinos can be powered through the USB connection from the computer or from a 9V battery.

PIC microcontroller used by [13][19] has minimum power consumption and is less prone to fault occurrence. With this microcontroller, only a small set of instructions are to be learnt by the users. The 8-bit PIC microcontroller used are the most popular ones and are currently used in most low-cost low-speed microcontroller-based applications. The operation of PIC microcontroller is faster as well.

[20] used PLC in its operation where the PLC operated on 24V DC supply. The switch mode power supply is used to turn ON the PLC. Rack type delta PLC was used in the project because of its simplicity and easy to programming. The Ladder logic diagram is used for programming

the PLC. The ladder logic diagram method is the easiest way of programming. However, when a problem occurs, hold-up time is indefinite, usually long.

2.1.3 Mode of communication

Authors [11]- [15] and [21]-[23] used LCD as a mode of communicating relevant information to the users. This was done by displaying information on the LCD from time to time to the users. With the LCD, users will be updated on the situation regarding the PFC. This is done with the help of the microcontroller used. The microcontroller being the main controller of the work gives instructions to the LCD to display any information to the user. The users can obtain this information only by going on site. The main disadvantage of this mode of communication is the inability of the users to gain access to the information from the LCD when the user is not on site, making it difficult to control any situation that may occur especially when the device is not working.

As a result, authors [11], [21]-[23] introduced another mode of communication to the already existing one to their work to communicate the relevant information to the users on or off site by the introduction of Internet of Things. In author [21] work, a mobile app was used with the help of an IoT to disclose loads utilization to the customer. The percentage increment on amount to be paid was also displayed based on measured power factor to the user. The load causing poor power factor was also sent to the user by the help of the IoT in this work. This useful information sent to the user was from the micro controller through a mobile app on the user's device. In author [23] work, the information displayed on the LCD is also recorded on an SD card, connected to PC with MATLAB using a USB cable for data plotting and further analysis, or sent to a server using Wi-Fi shield when activated. Wi-Fi module was used to provide internet connection to the device for remote monitoring purposes but it was not made clear what information or data the user receives through the IoT. After LCD was attached for monitoring the output data, [11] also used a Wi-Fi module for monitoring over the internet; the data relayed to the users was the measured power factor, as well as the corrected power factor. [22] also explored IoT by sending messages to the user for response when there was a capacitor bank failure through Wi-Fi module to the user's PC or mobile phone. A text message was sent from the user to the Wi-Fi module which was also sent to the microcontroller to deactivate the relay circuit to disconnect the load from the system. After the failed capacitor was replaced to correct the power factor to the desired value, again by sending a text message from the user; the Wi-Fi module sent a signal to PIC microcontroller. The microcontroller then activated the relay circuit and the load was connected to the supply

CHAPTER THREE

SYSTEM DESIGN AND CONSTRUCTION

3.1 INTRODUCTION

This chapter provides details of the proposed system design. It shows the algorithm of the proposed system, the block diagram of the system, the circuit diagram and the construction of the system prototype as well as how the system was connected to the website. It also shows the orderly manner in which the system was designed.

3.2 BLOCK DIAGRAM OF PROPOSED SYSTEM

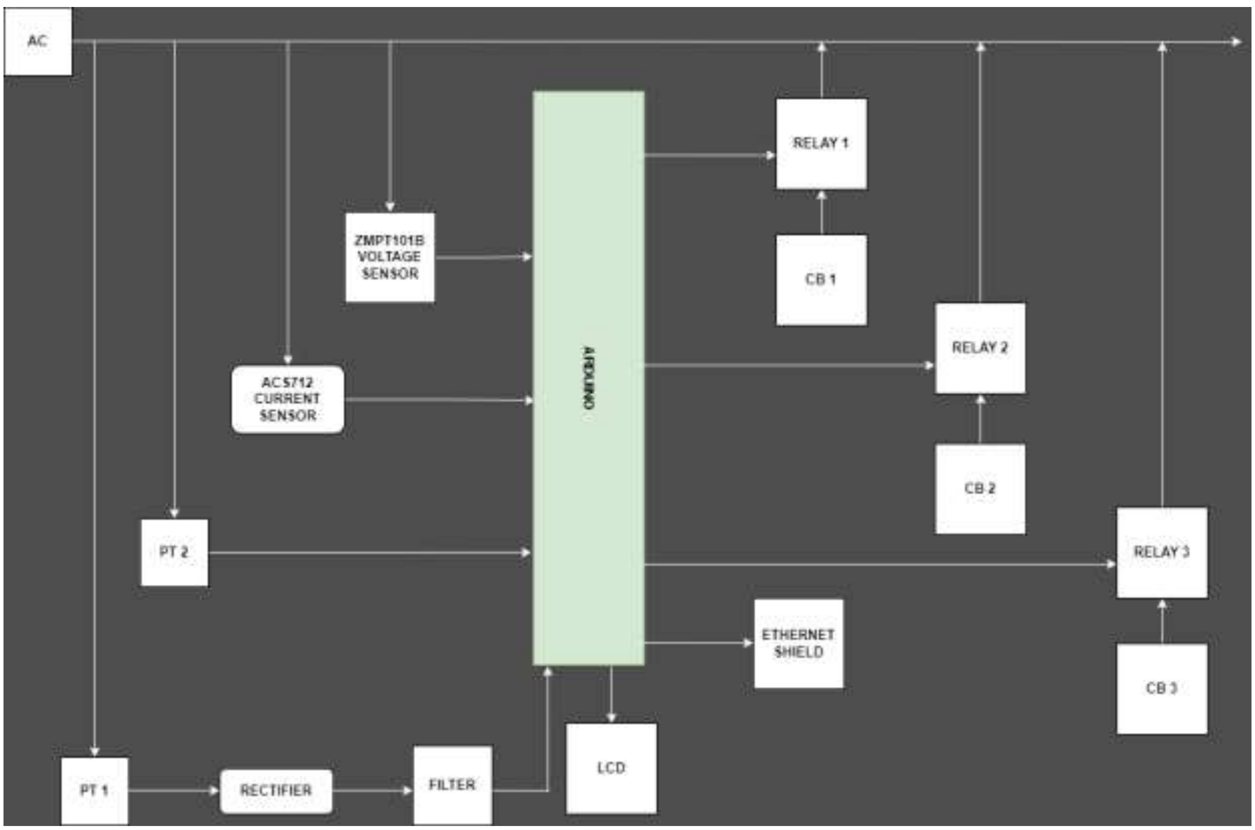

Fig 3.2.1: Block Diagram of proposed system

The block diagram in Fig. 3.2.1 shows how the components were connected and the role ech component plays to achieving the desired results.

The voltage from the AC source (220V – 240V) is stepped down to 6V by the potential transformer 1 (PT 1) which is transformed to a pulsating dc voltage with the help of the rectifier. The ripples in the pulsating dc are removed by the filter to a pure dc voltage. The output voltage is supplied to the arduino to power it. The liquid crystal display (LCD) and the relays are powered by tapping the source from the arduino.

The potential transformer 2 (Pt 2) steps down the source voltage and feeds it to the arduino for voltage measurement whiles the current sensor connected to the picks the current signal and sends it to the Arduino for current measurement. The voltage sensor as well as the current sensor sends the signal of the respective sensors to the arduino for power factor calculation. The display of the measured voltage, measured current and the calculated power factor is done on the LCD.

With a power factor of less than 0.95, the arduino calculates for the capacitance needed to be injected to the power system to correct it to 0.95 or above. Based on the capacitance value, the relay or relays are switched on by the arduino for the injection of the capacitors by either one, two or all three of the capacitor banks 1, 2 and 3 (CB 1, CB 2 and CB 3) into the system.

After the injection, the same process is repeated to measure the voltage, current and power factor and displayed to the LCD. The values displayed by the LCD is sent to the web data base by the ethernet shield to be viewed remotely. Profit gained is also calculated by the arduino based on the power factor calculated earlier and then sent to the data base as well through the shield.

3.3 CIRCUIT DIAGRAM OF PROPOSED SYSTEM

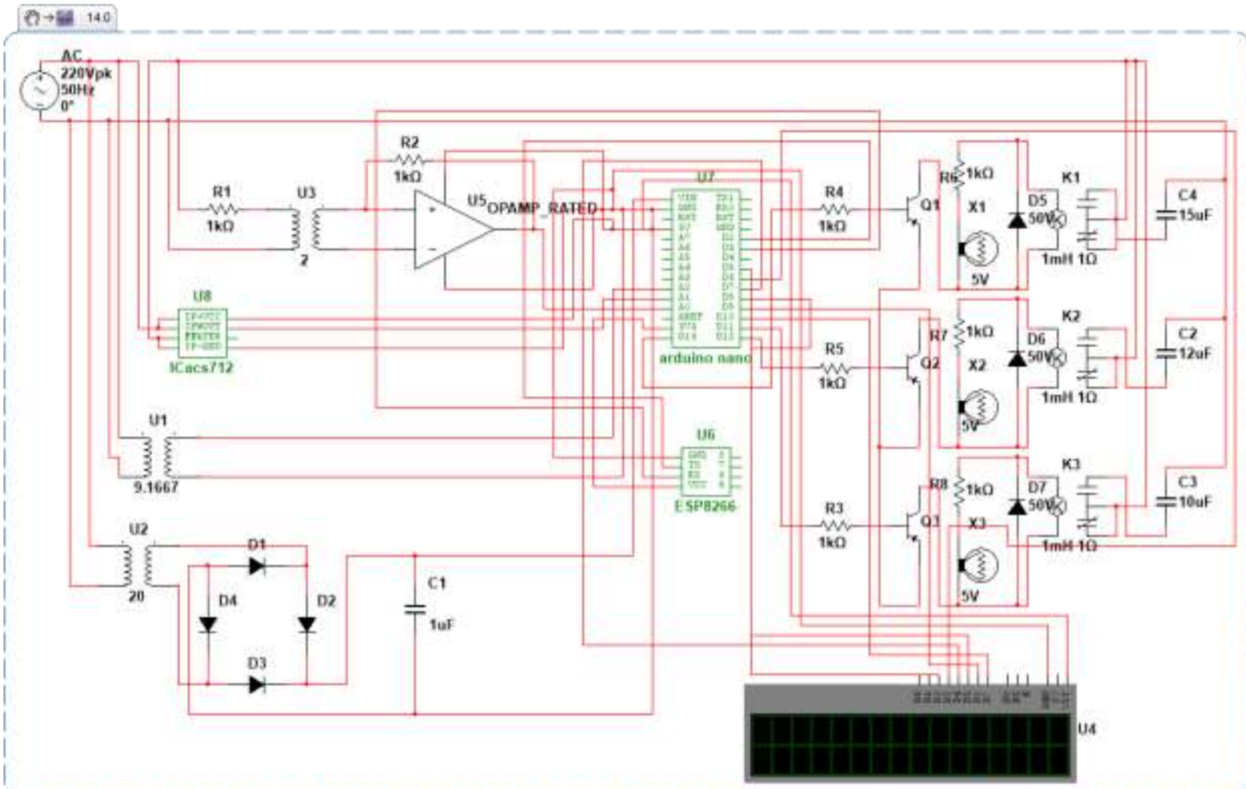

Fig.3.3.1: Circuit Diagram of proposed system

The voltage from the AC source (220V – 240V) is stepped down to 6V by the potential transformer (PT 2) which is transformed to a pulsating dc voltage with the help of the bridge rectifier. The ripples in the pulsating dc are removed by the filter (capacitor) connected in parallel to the rectifier to a pure dc voltage. The output voltage is supplied to the V_{IN} of the Arduino and is grounded to power it. The LCD and the relays are powered by tapping the 5V and the ground from the Arduino.

The potential transformer (PT 1) steps down the source voltage and feeds it to the analog side (A2) of the arduino for voltage measurement whiles the current sensor connected to the picks the current signal and sends it to A1 of the Arduino for current measurement. The voltage sensor connected to the A0 of the arduino as well as the current sensor sends the signal of the respective sensors to the arduino for power factor calculation. Both the current and voltage sensors are powered by connecting their VCC to 5V of the arduino and the ground to the Arduino's ground. The display of the measured voltage, measured current and the calculated power factor is done on the LCD.

With a power factor of less than 0.95, the arduino calculates for the capacitance needed to be injected to the power system to correct it to 0.95 or above. Based on the capacitance value, the relay or relays are switched on by the arduino for the injection of the capacitors into the system. This is done by switching on the transistor in front of the relay allow flow of current. The resistors in front of the transistors reduce the amount of current passing through the transistor to avoid damage to these transistors. The light emitting diode (LED) associated with the switched transistor is powered to be on to indicate which relay or relays are switched. The resistors in series with the LEDs prevent high flow of current from flowing though the LEDs. To prevent the back flow of current from the relays to the system, diodes are connected in parallel to the relays.

After the injection, the same process is repeated to measure the voltage, current and power factor and displayed to the LCD. The values displayed by the LCD is sent to the web data base by the ethernet shield to be viewed remotely. Profit gained is also calculated by the arduino based on the power factor calculated earlier and then sent to the data base as well through the shield.

3.4 POWER FACTOR CORRECTION CALCULATION

$$PF_1 = cos(\theta_1) = \frac{S_1}{P} ....eqn1$$

$$\theta_1 = cos^{-1}\left(PF_1\right) ....eqn2$$

$$PF_2 = cos(\theta_2) = \frac{S_2}{P} ....eqn3$$

$$\theta_2 = cos^{-1}\left(PF_2\right) ....eqn4$$

$$Tan(\theta_1) = \frac{Q_1}{P} ....eqn5$$

$$Q_1 = Ptan(\theta_1) ....eqn6$$

$$Tan(\theta_2) = \frac{Q_2}{P} ....eqn7$$

$$Q_2 = Ptan(\theta_2) ....eqn8$$

$$Q = Q_1 - Q_2$$

$$Q = P\tan(\theta_1) - P\tan(\theta_2)$$

$$Q = P\tan(\theta_1 - \theta_2)$$

Where;

PF = power factor

Ɵ = angle

S = apparent power (VA)

P = real power (W)

Q = reactive power (VAR)

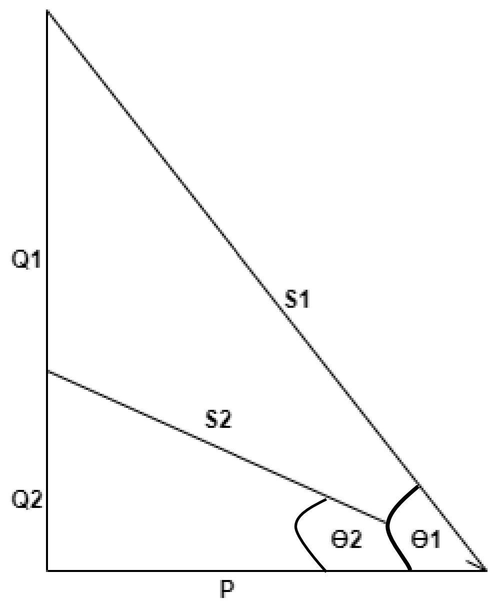

Fig 3.4.1: Power factor triangle

$$C = \frac{Q \times 10^6}{2\pi f v^2} \text{............} eqn9$$

Where;

C = capacitance value (µF)

Q = reactive power (VAR)

F = frequency (Hz)

V = voltage (V)

3.5 FLOW CHART OF PROPOSED SYSTEM

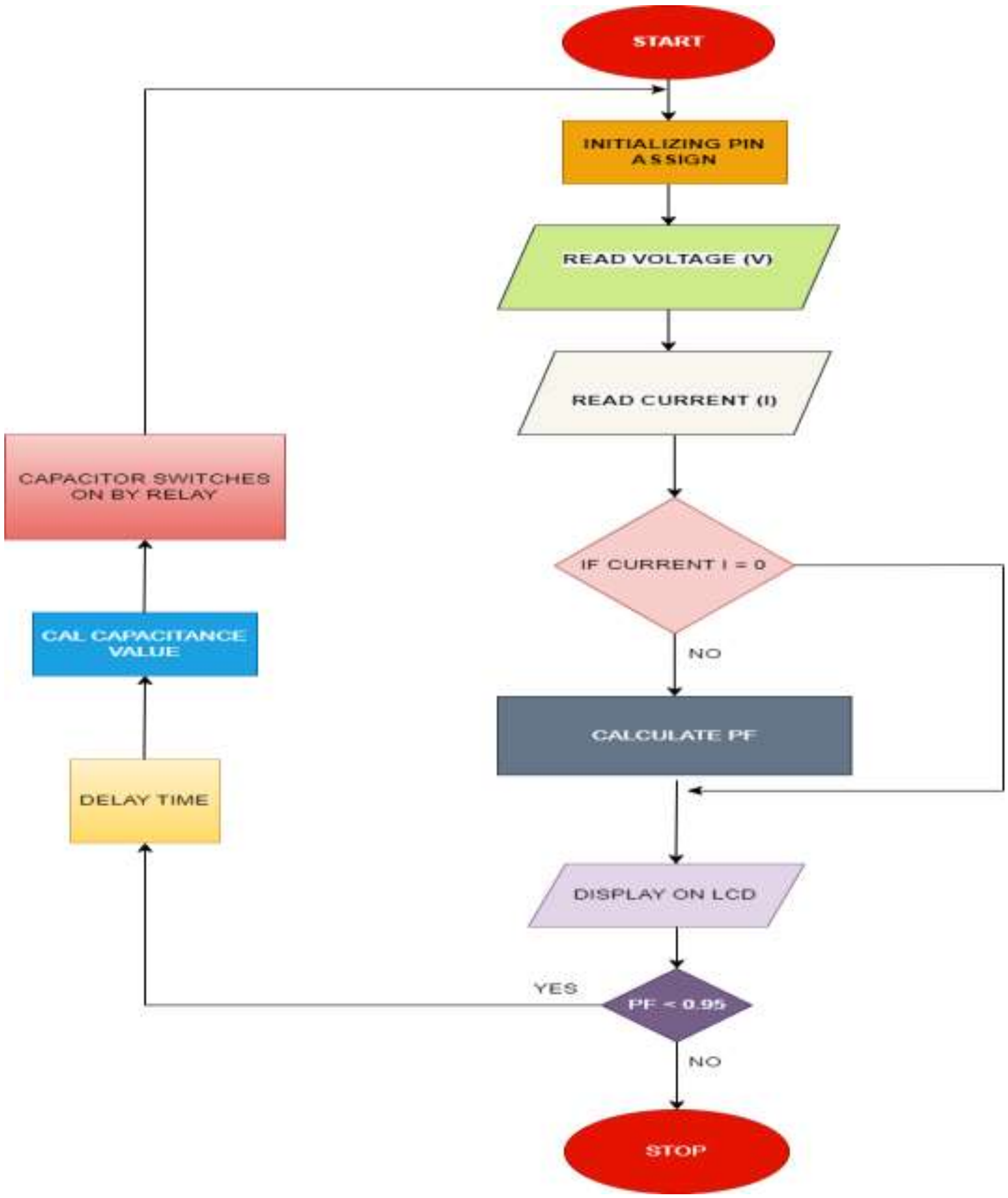

Fig. 3.5.1: Flow chart of proposed system

To display the voltage needed by the load, the current drawn by the load as well as measured power factor on the LCD through the Arduino, the voltage from the source was stepped down by the potential transformer (220:4.5) and it fed into the Arduino (A2). The current drawn by the load was measured by the current sensor and was fed into the Arduino (A1). The waveforms of the signals of both voltage (through the voltage sensor) and current which was received by the arduino to calculate the phase shit of the waveforms. The power factor is then calculated based on the phase shit. The measured voltage, current and the power factor of the load was displayed by the LCD.

With a power factor of the load being less than 0.95, the Arduino calculated the capacitance value needed to be injected by the capacitor bank to correct the power factor to a value greater than or equal to 0.95. Based on the capacitance value, the relay or relays were switched on to allowed the capacitor or capacitors to inject into the system. After the correction was made, the new current, voltage and the corrected power factor was displayed again on the LCD.

3.6 WEB PAGE DESIGN

Developed by Apache Friends, XAMPP is a free and open-source cross-platform web server consisting mainly of the Apache HTTP Server, MariaDB database, and interpreters for scripts written in the PHP (Personal Home Page) and Perl programming languages. [24][25] Most actual web server deployments use the same components as XAMPP; hence it makes transitioning from a local test server to a live server possible.

In this project, Xampp Control Panel v3.3.0 was used with VsCode as a text editor. The two main features that were used was the Apache side that shows the text written at the VsCode and the MySQL side that is used for creating database for the website. Before the Xampp can respond to showing the features of the text in VsCode, both the Apache and the MySQL must be turned on.

Visual Studio Code, also commonly referred to as VS Code,[26] is a source-code editor made by Microsoft for Windows, Linux and macOS. [27] Features include support for debugging, syntax highlighting, intelligent code completion, snippets, code refactoring, and embedded Git. Users can change the theme, keyboard shortcuts, preferences, and install extensions that add additional functionality.

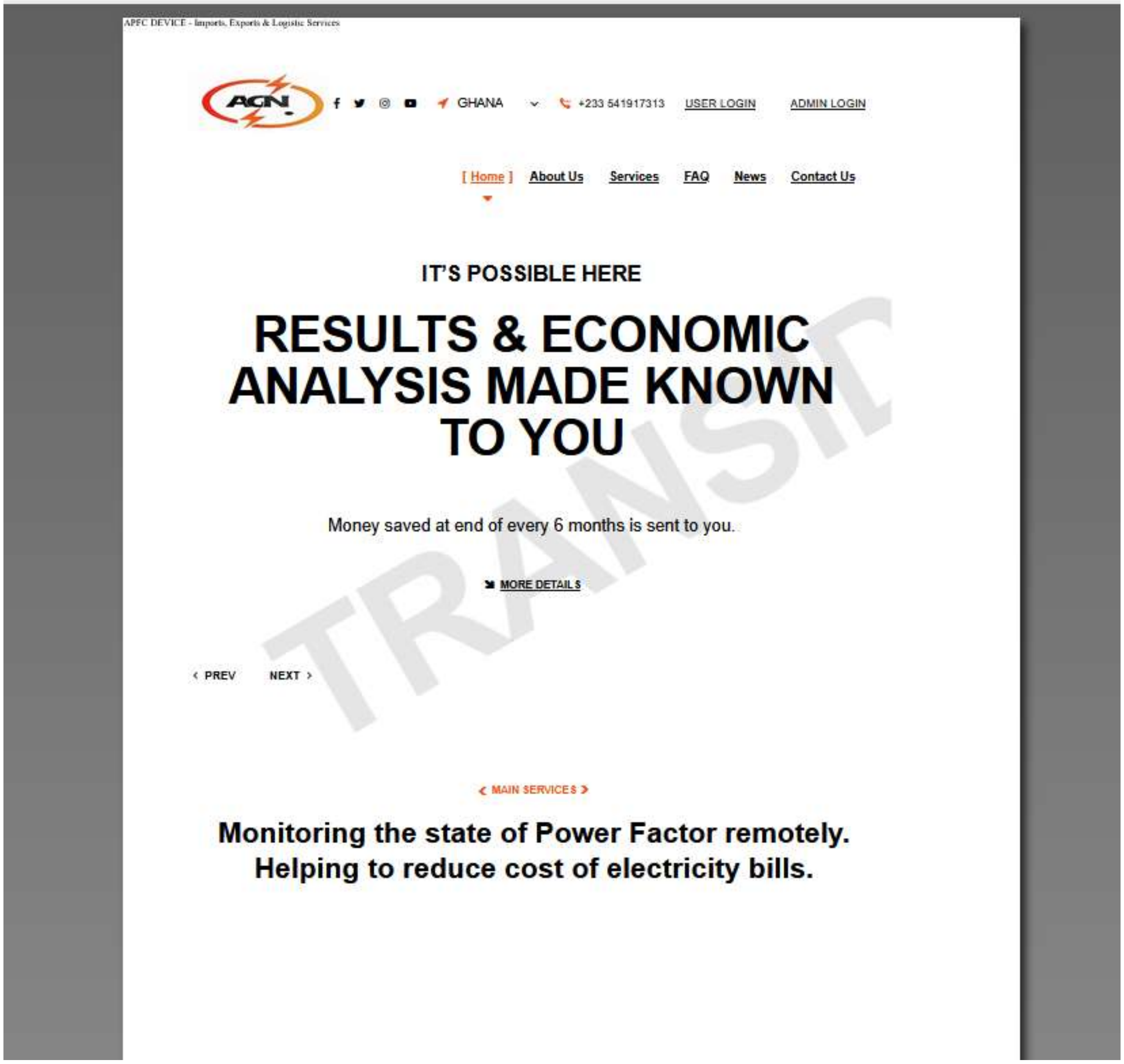

Fig. 3.6.1 Interface of website

3.7 ECONOMIC ANALYSIS

Power factor surcharge = $\frac{0.9 - PF}{0.9} \times$ maximum demand (VA).............eqn10

Table 3.8.1: Economic analysis

Demand (VA)	Cost (GH₵ / VA)
100 – 500	0.06959
500 – 1000	0.05965
1000 – 2000	0.05965

Profit gained = power factor surcharge × cost.............eqn11

The threshold of power factor for industries in Ghana is 0.9. Industries with power factor less than the threshold pay penalty [28]. This is calculated using the power factor surcharge in equation 11 (eqn11) which is then multiplied by the cost in Table 3.8.1 based on the maximum demand (VA) of apparent power within the month.

When the power factor is corrected by the device, the penalty which was associated to the power factor being less than the threshold then becomes the profit 0f the user in those months.

CHAPTER FOUR

TESTING

4.1 INTRODUCTION

This chapter contains the construction of the device, and the load used. It comprises of the specification of the motor used for the testing of results. It also contains the results obtained before and after testing the various parameters.

4.2 SPECIFICATION OF MOTOR USED

Fig. 4.2.2: Specification of inductive motor used

The voltage of the load is obtained based on the source voltage which was 238V for this work and rated current of 2A. With the power of the motor being 0.37kW, the power factor of the motor is expected to be 0.778 from the power factor calculation using equation 1 (eqn1).

4.3 TESTING

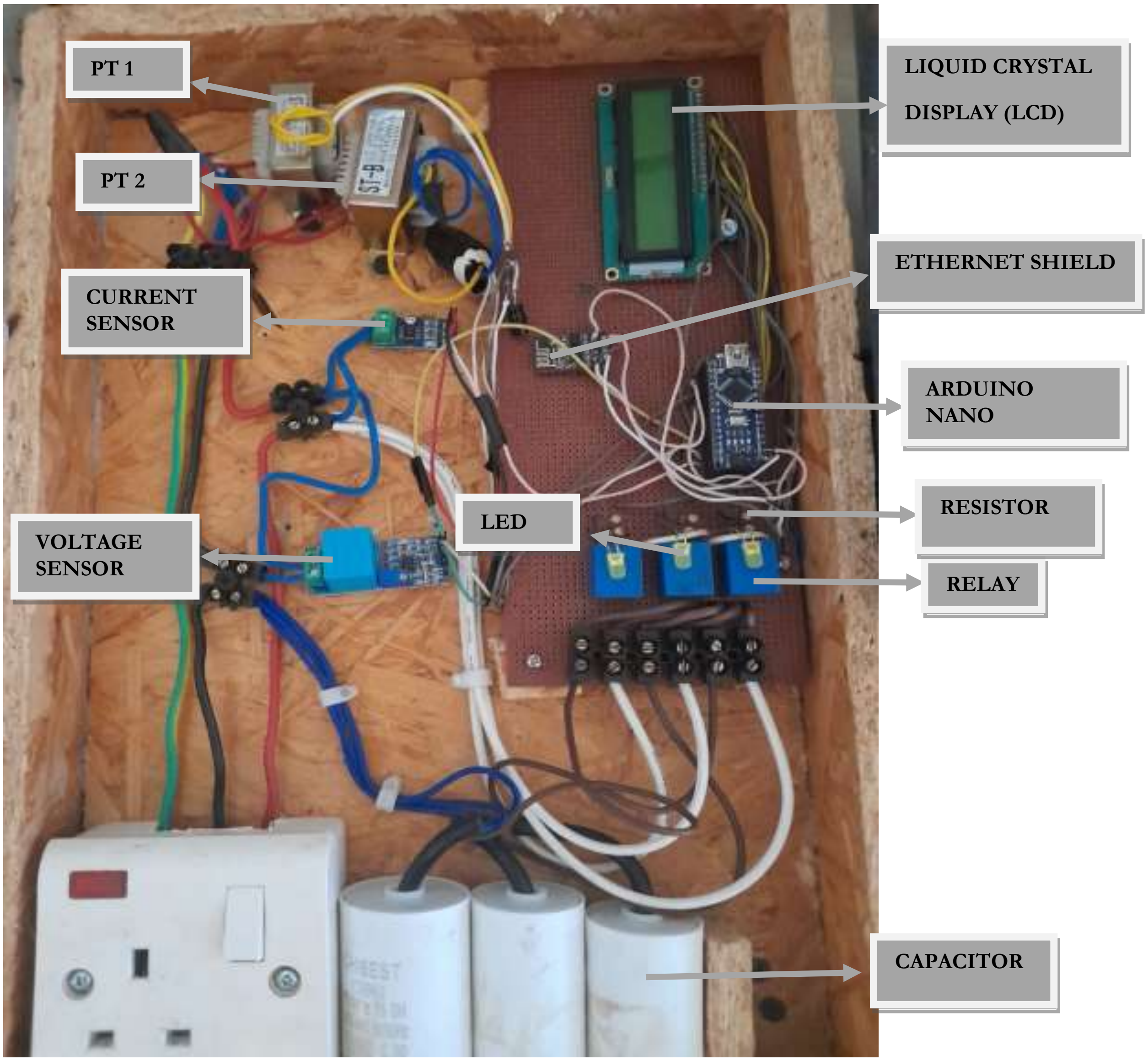

Fig. 4.3.1: Prototype of entire system

Fig 4.3.2: Prototype calculating the pf of the motor

Fig 4.3.3: Results before correction

After the device was tested with the load (Fig. 4.3.2), Fig. 4.3.3 was obtained which had voltage of 237V and current of 2.04A similar to the expected voltage of 238V and current of 2.00A of the motor. The power factor, on the other hand, had a little difference in value due to errors in the system. However, the power factor of 0.729 obtained was closer to the expected power factor of 0.778.

Fig 4.3.4: Prototype calculating the PF after relay 1 on

Fig 4.3.5: Results after correction pf of the motor

Because the power factor was less than the desired power factor (0.95), relay one was switched on (Fig. 4.3.4) based on the calculation of the capacitance value needed to correct the power factor to the desired result. Fig. 4.3.5. shows the results after the injection was done. The capacitance value that was injected into the system was 10µF.

4.4 EXPECTED RESULTS AFTER INJECTION OF CAPACITOR BANK ONE

$$Q = 2\pi f v^2$$
$$Q = 2\pi \times 50 \times 238^2$$
$$Q = 177.95 VAR$$
$$Q = P\tan(\theta_1) - P\tan(\theta_2)$$
$$\text{Tan}(\theta_2) = \tan(\theta_1) - \frac{Q}{P}$$
$$\theta_2 = \tan^{-1}(\tan(\cos^{-1}(0.778)))\text{-}\frac{177.95}{370}$$
$$\theta_2 = 0.27$$
$$\text{Expected power factor (PF) = } \cos(0.27)$$
$$\text{PF = 0.964}$$
$$\text{Expected current (I) = } \frac{P}{PF \times V}$$
$$\text{I} = \frac{370}{0.964 \times 238}$$
$$\text{I} = 161\text{A}$$
$$\text{Power factor surcharge = } \frac{0.9 - 0.778}{0.9} \times (238 \times 2)$$
$$\text{Expected profit = } 64.524 \times 0.06959$$

Expected profit = GH₵ 4.49

Comparing the expected results to the results in Fig. 4.3.4 indicates that the device was able to correct the power factor. However, due the slight errors in components used, the values displayed is slightly different from the results shown in Fig. 4.3.4.

The results in Fig. 4.3.2 and Fig. 4.3.4 show that as power factor is corrected or increases, current decreases.

4.5 RESULTS SHOWN ON THE THINGSPEAK

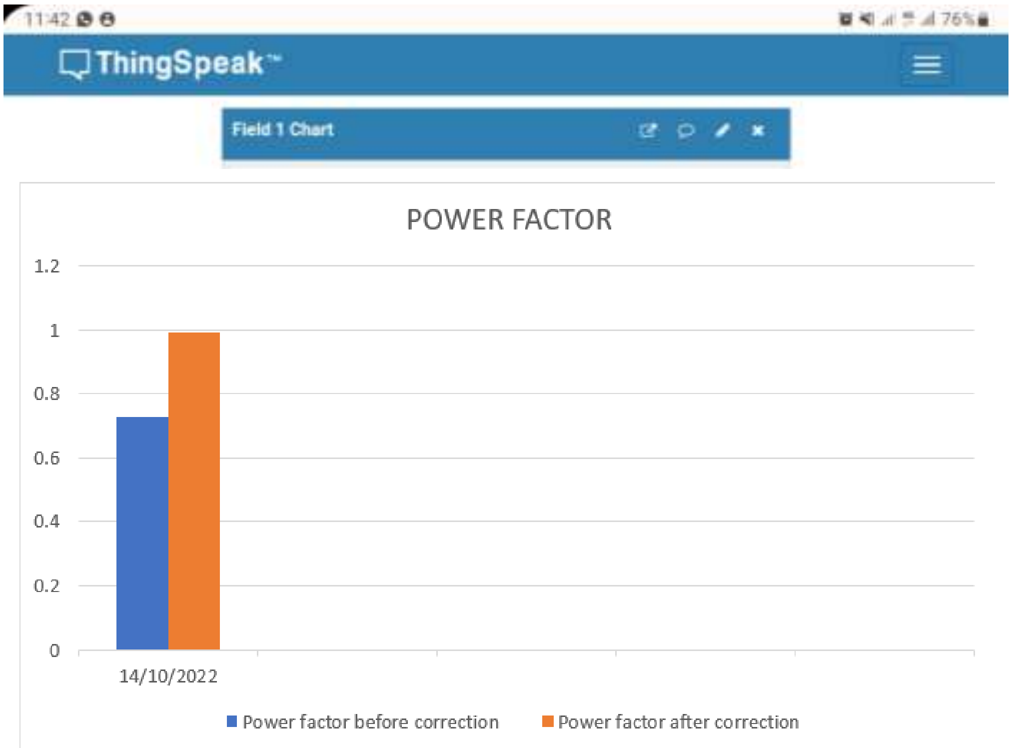

Fig. 4.5.1 Graphical representation of PF before and after correction

The results in Fig. 4.5.1 shows the graphical representation of the power factor before correction (0.729) and after correction (0.992).

Fig. 4.5.2: **Graphical representation of Profit Gained**

The results in Fig. 4.5.2 shows the graphical representation of the profit gained at the month when the same load or a load of the same wattage is used for the entire month. This graph shows that, as power factor is corrected to 0.95 or above, money is being saved (GH₵ 6.39). The profit gained was GH₵ 1.90 higher than the expected profit. This was due to the error in the power factor before correction that was displayed by the LCD. The difference in the power factor amounted to the difference in profit.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The results were obtained by placing an inductive motor with power rating of 0.37kW on the device.

The power factor of the load used was less than 0.95 so one of the relays was switched on (relay one) for the injection of capacitance in capacitor bank one (CB 1) with capacitance of 10μF into the system. This injection brought about the correction of the power factor from 0.729 to 0.992. In the correction of the power factor, there was a reduction of current from 2.04A to 1.69A. The voltage on the hand remained constant. The results obtained before and after correction were all displayed on the LCD screen.

The results were also sent to the user remotely trough the ethernet shield to public webpage which was accessed by private account of the user on the webpage. The profit gained by the user from current the power factor was also sent to the same webpage for assessment.

5.2 RECOMMENDATION

The results obtained using this device has proven to be closer to the expected results. However, errors were seen during testing so the power factor results were not as accurate as expected. This is due to the voltage sensor used which needed an LCD with select button on to clear all fake currents in the system but could not be obtained in Ghana as well as calibration of voltage sensor to give accurate results.

The ethernet shield to transfer information to the local host created was unavailable so different shield was used which works only with internet connection. The shield also could not transfer much information to the user.

All these errors and inconveniences can be improved to make the device more accurate and improve easy access of information by the user remotely.

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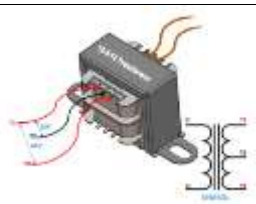
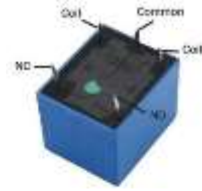
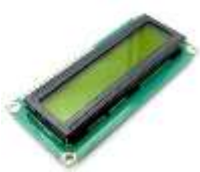
APPENDIX A

HARDWARE COMPONENTS

FIGURE (NAME)	IMAGE	USE(S)	SPECIFICATION
Potential Transformer (PT)		Steps down the voltage to a safe limit value which can be easily measured by the ordinary low voltage instrument	Input Voltage: 220V AC at 50Hz Output Voltage: 12V, 6V or 0
Voltage sensor (ZMPT101B)		It is used to calculate and monitor the amount of voltage in an object. Voltage sensors can determine the AC voltage	Operating Voltage: DC 5V-30V Measure within 250V AC
Current sensor (ACS712)		Measures the current running through a wire by using the magnetic field	Input current: 5A Operating voltage: 5V
Arduino NANO		Used for programming.	Operating voltage: 5 volts Input voltage: 5 to 20 volts

Relay		It used in an automatic control circuit and to control a high-current using a low-current signal	Input Voltage: 0-5V
Capacitor bank		It is used to inject reactive power in the form of capacitance	
Ethernet shield		It is used to transfer data to a website	3.3 input voltage 2.4GHz Wi-Fi
Liquid Crystal Display (LCD)		The LCD in this project is used to display the voltage, current and power factor (pf)	Backlight: LED/5.0V(Y/G) Operating temperature: 0 to 50℃

APPENDIX B

ARDUINO CODE

```
#include <LiquidCrystal.h>

// Phase Angle By Solarduino

// Note Summary

// Note :  Safety is very important when dealing with electricity. We take no responsibilities

while you do it at your own risk.
```

```
// Note :  This Phase Angle Code needs 2 signal waves of the same frequency to work. You can use AC current module and AC Voltage Module.

// Note :  This Code monitors phase difference between 2 waves and also its frequency value.

// Note :  The value shown in Serial Monitor is refreshed every second, can be used for 50Hz and 60Hz.

// Note :  The frequency is measured by counting time and average it for every 50 samples taken (for 50 hz)(1 sample is 1 cycle).

// Note :  The pre-calibration of voltageAnalogOffset & currentAnalogOffset are needed to do it manually.

// Note :  The unit provides reasonable accuracy and may not be comparable with other expensive branded and commercial product.

// Note :  All credit shall be given to Solarduino.

/*/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////*////////////*/

        /* 0- General */

        int decimalPrecision = 2;                   // decimal places for all values shown in LED Display & Serial Monitor

        /* 1 - Phase Angle, Frequency and Power Factor measurement */

        int expectedFrequency = 50;                 // Key in frequency for main grid (50 / 60 hz)
```

int analogInputPin1PA = A0; // The input pin for analogRead1 sensor. Use voltage sensor as primary reference here.

int analogInputPin2PA = A1; // The input pin for analogRead2 sensor. Use current or voltage as secondary reference.

float voltageAnalogOffset =4; // This is to offset analog value for analogInput1

float currentAnalogOffset =-12; // This is to offset analog value for analogInput2

unsigned long startMicrosPA; /* start counting time for Phase Angle and Period (in micro seconds)*/

unsigned long vCurrentMicrosPA; /* current time for analogInput1 (voltage) (in micro seconds). AnalogInput1 is used for reference for phase angle*/

unsigned long iCurrentMicrosPA; /* current time for analogInput2 (current/voltage) (in micro seconds).*/

unsigned long periodMicrosPA; /* current time for record period of wave */

float vAnalogValue =0; /* is the analog value for voltage sensor / analogInput1 and center at 0 value */

float iAnalogValue =0; /* is the analog value for current sensor / analogInput2 and center at 0 value */

float previousValueV =0; /* use to record peak value for voltage sensor*/

float previousValueI =0; /* use to record peak value for current sensro*/

float previousphaseAngleSample=0; /* previous sample reading to replace false value less than 100 micro seconds*/

float phaseAngleSample =0; /* is the time difference between 2 sensor values (in micro seconds) */

float phaseAngleAccumulate =0; /* is the accumulate time difference for accumulate samples*/

float periodSample=0; /* is the time difference for a period of wave for a sample (in micro seconds)*/

float periodSampleAccumulate = 0; /* is the accumulate time difference for accumulate samples */

float phaseDifference =0; /* is the averaged set of time difference of 2 sensors*/

float phaseAngle =0; /* is the phase angle in degree (out of 360)*/

float frequency = 0; /* is the frequency of the voltage sensor wave*/

float voltagePhaseAngle=0; /* is the time recorded from begining to reach peak value for analogInput1 in micro seconds*/

float currentPhaseAngle=0; /* is the time recorded from begining to reach peak value for analogInput2 in micro seconds*/

float averagePeriod =0; /* is the average set of time recorded for a period of wave */

```
int sampleCount = 0;                /* to count how many set of samples */

int a = 3;                          /* use for switching operation*/

float powerFactor;                  /* to calculate power factor */

int value;

int value1;

int pinA = A2;

//int pinB = A1;

int vOUT=0;

int cOUT=0;

int s=0;

//int sensorIn = A1;

int mVperAmp = 185;

double Voltage = 0;

double VRMS = 0;

double AmpsRMS = 0;

float current;

int ledPin  = 13;  //to switch on capacitor 15uF

int ledPin1 = 12; // to switch on capacitor 12uF
```

```
int ledPin2 = 11; // to switch on capacitor 10uF

float P = s * AmpsRMS * powerFactor ; // Power of the load

float C = 0; // Capacitance value needed for correcting pf

float pf = 0.0; // Measured PF

float Q = 0.0;

float dpf = 0.95;

float pi = 22/7;

int f = 50;

float getVPP();

float powerFactorSurcharge;

float cost;

float profitGain;

 int rs = 5;

 int en = 6;

 int d4 = 7;

 int d5 = 8;

 int d6 = 9;

 int d7 = 10
```

```
      LiquidCrystal lcd(rs,en,d4,d5,d6,d7);

      byte Updatevalue;

void setup() {

lcd.begin (16,2);     //set LCD number

  lcd.setCursor (0,0);

  lcd.print ("PF Correction");

  lcd.setCursor (0,1);

  lcd.print ("Loading.");

  delay (1000);

  lcd.setCursor (0,1);

  lcd.print ("Loading..");

  delay (1000);

  lcd.setCursor (0,1);

  lcd.print ("Loading...");

  delay (1000);

  lcd.setCursor (0,1);

  lcd.print ("Loading....");

  delay (1000);
```

```
  lcd.setCursor (0,1);

  lcd.print ("Loading.....");

  delay (1000);

  lcd.setCursor (0,1);

  lcd.print ("Loading......");

  delay (2000);

  lcd.clear ();

  pinMode (ledPin,  OUTPUT);  // relay that switches on capacitor 15uF

  pinMode (ledPin1, OUTPUT); //  relay that switches on capacitor 12uF

  pinMode (ledPin2, OUTPUT); // relay that switches on capacitor  10uF

      /* 0- General */

      Serial.begin(9600)

}

void loop()

{

      /* 1 - Phase Angle, Frequency and Power Factor measurement */

      vAnalogValue = analogRead(analogInputPin1PA)-512 + voltageAnalogOffset;       /*
read analogInput1 with center adjusted*/
```

```
iAnalogValue = analogRead(analogInputPin2PA)-512 + currentAnalogOffset;       /*
read analogInput2 with center adjusted*/


if((vAnalogValue>0) && a == 3)                              /* initial begining stage of
measurement when analogInput1 wave larger than 0 */
{
  a=0;                                          /* allow to change to the next stage */
}
if((vAnalogValue<=0) && a ==0)                              /* when analog value of
analogInput1 smaller or equal than 0*/
{
  startMicrosPA = micros();                          /* start counting time for all*/
  a=1;                                          /* allow to change to the next stage */
}
if((vAnalogValue>0) && a ==1)                               /* when analog value of
analogInput1 larger than 0*/
{
  a = 2;                                        /* allow to change to the next stage */
```

```
         previousValueV = 0;                                /* reset value. This value to be
compared to measure peak value for analogInput1 */

         previousValueI = 0;                                /* reset value. This value to be
compared to measure peak value for analogInput2 */

      }

      if((vAnalogValue > previousValueV ) && a==2)                    /* if current
measured value larger than previous peak value of analogInput1 */

      {

         previousValueV = vAnalogValue ;                          /* record current measure
value replace previous peak value */

         vCurrentMicrosPA = micros();                             /* record current time for
analogInput1 */

      }

      if((iAnalogValue > previousValueI) && a==2)                     /* if current measured
value larger than previous peak value of analogInput2 */

      {

         previousValueI = iAnalogValue ;                          /* record current measure
value replace previous peak value */

         iCurrentMicrosPA = micros();                             /* record current time for
analogInput2 */
```

}

if((vAnalogValue <=0) && a==2) /* when analog value of analogInput1 smaller or equal than 0*/

{

periodMicrosPA = micros(); /* record current time for 1 period */

periodSample = periodMicrosPA - startMicrosPA; /* period wave is the current time minus the starting time (for 1 sample)*/

periodSampleAccumulate = periodSampleAccumulate + periodSample; /* accumulate or add up time for all sample readings of period wave */

voltagePhaseAngle = vCurrentMicrosPA - startMicrosPA; /* time taken for analogInput1 from 0 (down wave) to peak value (up wave)*/

currentPhaseAngle = iCurrentMicrosPA - startMicrosPA; /* time taken for analogInput2 from 0 (down wave) to peak value (up wave)*/

phaseAngleSample = currentPhaseAngle - voltagePhaseAngle; /* time difference between analogInput1 peak value and analogInput2 peak value*/

if(phaseAngleSample>=100) /* if time difference more than 100 micro seconds*/

{

```
    previousphaseAngleSample = phaseAngleSample;            /* replace previous
value using new current value */
    }
    if(phaseAngleSample<100)                                /* if time difference less than
100 micro seconds (might be noise or fake values)*/
    {
    phaseAngleSample = previousphaseAngleSample;            /* take previous
value instead using low value*/
    }
    phaseAngleAccumulate = phaseAngleAccumulate + phaseAngleSample;     /*
accumulate or add up time for all sample readings of time difference */
    sampleCount = sampleCount + 1;                          /* count sample number */
    startMicrosPA = periodMicrosPA;                         /* reset begining time */
    a=1;                                                    /* reset stage mode */
    previousValueV = 0;                                     /* reset peak value for
analogInput1 for next set */
    previousValueI = 0;                                     /* reset peak value for
analogInput2 for next set */
   }
```

if(sampleCount == expectedFrequency) /* if number of total sample recorded equal 50 by default */

{

averagePeriod = periodSampleAccumulate/sampleCount; /* average time for a period of wave from all the sample readings*/

frequency = 1000000 / averagePeriod; /* the calculated frequency value */

phaseDifference = phaseAngleAccumulate / sampleCount; /* average time difference between 2 sensor peak values from all the sample readings */

phaseAngle = ((phaseDifference*360) / averagePeriod); /* the calculated phase angle in degree (out of 360)*/

powerFactor = cos(phaseAngle*0.017453292); /* power factor. Cos is in radian, the formula on the left has converted the degree to rad. */

value = analogRead (pinA); // REading value from port A2

vOUT = (value * 5.0 / 1024.0); // Mapping value obtained to Arduino

s = (vOUT/4.0)*230;

Voltage = getVPP();

VRMS = (Voltage / 2.0) * 0.707;

AmpsRMS = (VRMS * 1000)/mVperAmp;

current = (AmpsRMS - 0.16);

```
Serial.print(current);

Serial.print(" Amps RMS_");

Serial.print (s);

lcd.setCursor (0,0);

lcd.print ("V:" + String(s));lcd.write("   "); lcd.print ("I:" + String(current));

Serial.print("Power Factor :");

Serial.println(powerFactor,decimalPrecision);

 lcd.setCursor (0,1);

 lcd.print ("PF:" + String(powerFactor));

 Serial.print("Power Factor :");

 Serial.println(powerFactor,decimalPrecision);

 }

 sampleCount = 0;                                   /* reset the sample counting
quantity */

 periodSampleAccumulate = 0;                        /* reset the accumulated
time for period wave from all samples */

 phaseAngleAccumulate =0;                           /* reset the accumulated
time for time difference from all samples*

}
```

```
float getVPP()
{
  float result;
  int readValue;
  int maxValue = 0;
  int minValue = 1024;
  uint32_t start_time = millis();
  while((millis()-start_time) < 1000)
  {
    readValue = analogRead(analogInputPin2PA);
    if (readValue > maxValue)
    {
      maxValue = readValue;
    }
    if (readValue < minValue)
    {
      minValue = readValue;
    }
```

```
  }
  result = ((maxValue - minValue) * 5.0) / 1024.0;
  return result;
}
// Profit gain calculation
if (powerFactor < 0.9)
{
  powerFactorSurcharge = ((0.9 - powerFactor) / 0.9) * s * current;
}
if (( s * current) > 1000)
{
  cost = 0.05965;
}
if (( s * current) > 500)
{
  cost = 0.05965;
}
if (( s * current) > 100)
```

```
{
  cost = 0.09959;
}
profGain =  powerFactorSurcharge * cost
if (powerFactor < 0.95)
 // Checking for the corrected pf and switching on the recguired capacitor needed to be
injected
         void  pfcalculation() {
         Q = P*tan(acos(pf)-acos(dpf));
         C =  Q* pow (10,6) / 2*pi*f* sq (s);
    // read the capacitance value (C):
         }
         if (0 < C <= 10)
         {
          digitalWrite(ledPin2,HIGH);
         }
         if (10 < C <= 12)
         {
           digitalWrite(ledPin1,HIGH);
```

```
}
if (12 < C <= 15)
{
 digitalWrite(ledPin,HIGH);
}
if (15 < C <= 22)
{
 digitalWrite(ledPin2,HIGH);
 digitalWrite(ledPin1,HIGH);
}
 if (22 < C <= 25)
 {
  digitalWrite(ledPin2,HIGH);
  digitalWrite(ledPin,HIGH);
 }
 if (25 < C <= 27)
 {
  digitalWrite(ledPin1,HIGH);
```

```
 digitalWrite(ledPin,HIGH);
}
if (27 < C <= 37)
{
  digitalWrite(ledPin2,HIGH);
  digitalWrite(ledPin1,HIGH);
  digitalWrite(ledPin,HIGH);
}
 Updatevalue = 1;
}
```