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**MICROCONTROLLER-BASED AUTOMATIC POWER
FACTOR CORRECTION FOR THREE-PHASE LOADS**

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Master's Thesis

Supervisor

Prof. Dr. Galip CANSEVER

Istanbul, 2022

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Zaid Mokhles Kafi AL-JANABI

Signature



DEDICATION

Dear Mom,

I want to dedicate my master's thesis to you. You have been a constant source of support and encouragement throughout my life, and I am forever grateful for everything you have done for me. Your love and guidance have been a cornerstone of my success, and I cannot thank you enough for all that you have given me. I also want to dedicate this degree to the pure soul of my deceased father. He raised me with love and taught me the values that have shaped who I am today. His memory will always be a source of inspiration for me, and I am grateful for the time we had together. To my brothers and my sister and their families for their unwavering support and friendship. Your presence in my life has been a constant source of strength and joy, and I am so grateful to have you by my side.

To my friends, I want to express my deepest gratitude for your help and support throughout this journey. Your kindness and generosity have meant the world to me, and I am so lucky to have such wonderful people in my life.

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ABSTRACT

MICROCONTROLLER-BASED AUTOMATIC POWER FACTOR CORRECTION FOR THREE-PHASE LOADS

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In electrical distribution systems, power factor (PF) adjustment is a fundamental aspect of power quality. This article describes a low-cost Automatic Power Factor Correction (APFC) system for increasing the PF of both trailing and leading three-phase loads. The PF was calculated using the Arduino UNO microcontroller, and the relays that connect individual capacitor/inductor banks to a load in parallel were activated. As a result, the APFC system generated the appropriate capacitive or inductive reactive power by automatically attaching the capacitor/inductor banks to the load in parallel. On an LCD screen, the APFC system may also monitor and show several electrical characteristics of the load, including voltage level, RMS current, PF, and actual, reactive, and apparent power. The phase angle differences between both the load current and voltage waveforms are determined using two zero crossing detector circuits. The APFC system's measuring capacity was evaluated for resistive, inductive, and capacitive loads of various sizes. When the measurement findings were compared to those of a commercially digital power meter, a measurement inaccuracy was discovered. The APFC

system's PF correction capabilities were tested for both inductive and capacitive loads of various sizes. Experiments reveal that for both trailing and leading loads, the PF climbed to near unity.

Keywords: Power Factor, Capacitor Bank, Power Factor Correction, PIC Microcontroller.



TABLE OF CONTENTS

	<u>Pages</u>
ABSTRACT	viii
LIST OF FIGURES.....	xi
ABBREVIATIONS.....	xiii
LIST OF SYMBOLS	xv
1. INTRODUCTION	1
1.1 OVERVIEW.....	1
1.2 POWER FACTOR	2
1.3 POWER FACTOR CORRECTION.....	2
1.4 THE DRAWBACKS OF A LAGGING POWER FACTOR.....	3
1.5 BENEFITS OF POWER FACTOR CORRECTION	4
1.6 POWER FACTOR IMPROVING STRATEGIES.....	4
1.7 PROBLEM STATEMENT.....	4
1.8 SYSTEMS STABILITY	5
1.9 OBJECTIVE.....	6
1.10 THESIS ORGANIZATION	6
2. LITERATURE REVIEW	8
2.1 DEVELOPMENT OF POWER FACTOR USING ARDUNIO	8
2.2 PLC BASED INTELLIGENT POWER FACTOR CORRECTORS FOR INDUSTRIAL POWER SYSTEMS	9
2.3 DESIGN AND IMPLEMENTATION OF DIGITAL ENERGY METERS WITH POWER FACTOR MEASUREMENT AND LOAD INDICATION FEATURE.....	10
2.5 POWER STANDARD BASED ON A HIGH PRECISION POWER-FACTOR METERING	12

2.6 SMART METER FOR POWER FACTOR ENHANCEMENT IN REAL TIME	13
2.7 RESEARCH GAP	15
3. METHODOLOGY AND TECHNICAL DETAILS.....	16
3.1 RESEARCH DESIGN.....	16
3.2 ALGORITHM	17
3.3 BLOCK DIAGRAM	17
3.4 DESIGN OF DIFFERENT LOADS.....	18
3.4.1 Resistive(R) Load Design.....	19
3.4.2 Plan for A Series R-L Load	19
3.4.3 Constructing an R-L Load in Parallel.....	20
3.5 TECHNICAL SPECIFICATIONS.....	20
3.5.1 Potential Transformer (PT).....	20
3.5.2 Current-Transformer.....	22
3.5.3 Zero Crossing Detector.....	22
3.5.4 Circuit Power Supply	23
3.5.5 Rectifier	24
3.5.6 Filter	24
3.5.7 Voltage-Regulator	25
3.5.8 Liquid-Crystal-Display.....	26
3.5.9 LCD Connections	27
3.6 MICRCONTROLLER	27
3.7 SPDT RELAY MODULE.....	28
3.7.1 Relay-Driver	29
3.8 POWER FACTOR CORRECTIONS.....	30

3.8.1 Static Capacitors	30
3.8.2 Synchronous Condensers.....	30
3.8.3 Phase Advancers.....	31
3.8.4 Shunt Capacitors as Power Factor Controlling.....	31
4. RESULT AND DISCUSSION	33
4.1 THE PROPOSED MODEL	34
4.1.1 Prototype without Inductive Load	34
4.1.2 Prototype with Inductive Load	35
4.2 XOR GATE	37
4.3 COMPARATOR CIRCUIT	37
4.4 THE RIGHT CAPACITOR	38
4.5 MATLAB CIRCUIT DIAGRAM	40
5. CONCLUSION	41
REFERENCES	42

LIST OF FIGURES

	<u>Pages</u>
Figure 1.1: Current triangle [2]	3
Figure 2.1: Power-factor-meter hardware [2].....	8
Figure 2.2: Corrected power-factor value after applying IPFC [4]	9
Figure 2.3: Real time data of power factor [8]	11
Figure 2.4: Hardware setup (Power factor correction single phase) (Own creation)	14
Figure 3.1: Flow chart of PFC	14
Figure 3.2: Block diagram	14
Figure 3.3: Power guard [14].....	14
Figure 3.4: Resistive load [14]	14
Figure 3.5: RL series load [7].....	19
Figure 3.6: RL parallel circuit [7].....	20
Figure 3.7: Step down transformer as potential transformer [18]	21
Figure 3.8: Working of CT (Current transformer) [17]	22
Figure 3.9: LM 339 pinout [20].....	23
Figure 3.10: Rectifier circuit [22].....	24
Figure 3.11: Voltage regulator [23].....	25
Figure 3.12: LCD 1602 [24]	26
Figure 3.13: LCD connection [24]	27
Figure 3.14: Microcontroller pinout [8]	28
Figure 3.15: SPDT relay internal diagram [9].....	29
Figure 3.16: Pinout for the ULN2003 relay driver [21]	30
Figure 3.17: Shunt capacitors [7]	32
Figure 4.1: Schematic diagram.....	34
Figure 4.2: LCD display with PF = 0.9	36
Figure 4.3: LCD display with PF = 0.6	36
Figure 4.4: LCD display with PF = 0.2	36
Figure 4.5: MATLAB representation	40

ABBREVIATIONS

AC	:	Alternating Current
DC	:	Direct Current
CT	:	Current Transformer
VT	:	Voltage Transformer
PT	:	Potential Transformer
NC	:	Normally Close
NO	:	Normally Open
COM	:	Common
LCD	:	Liquid- Crystal Display
LED	:	Light Emitting Diode
SD	:	Secure Digital
PLC	:	Programmable Logic Controller
PF	:	Power Factor
PFC	:	Power Factor Correction
APFC	:	Automatic Power Factor Correction
SVG	:	Static Var Generator
APF	:	Active Power Filter

AMI : Advanced Metering Instrumentation

GUI : Graphical User Interface

TOU : Time-Of Use

ZCD : Zero Cross Detect

IPFC : Interline Power Flow Controller

SPDT : Single-Pole Double-Throw Relay

LIST OF SYMBOLS

μ : Electron Mobility

λ : Wavelength

ω : Angular Frequency



1. INTRODUCTION

Energy is critical in today's technological revolution, and the energy system is becoming more complex by the day. As a result, each unit of generated power must be transmitted over greater distances while consuming less energy. However, as the number of inductive loads increased, as did the variation in load, losses doubled. As a result, it's a good idea to look into the causes of power outages and improve the power system. The system load factor decreases significantly as the use of inductive loads increases, increasing system failures and, as an outcome, power system efficiency. An automated power factor correction device calculates the lag in the arrival of the current point with respect to the source voltage signal through the use of an intrinsic timer to estimate the potential component of a voltage level and line current with extreme accuracy. Controls the amplitude and phase attenuation () here between the current and voltage signals [1]. The CPU then determines the proper offset and activates the required amount of capacitance, and the power factor reaches unity in the capacitor bank. The application can be used in various industries for their stabilization. As a result, the network becomes significantly more stable, increasing the system and apparatus efficiency. As a result, implementing a microcontroller-based system [2] reduces overall costs for both energy consumers and providers.

1.1 OVERVIEW

To increase the efficiency of an electrical system, a reduction of the power factor is necessary. The key factor is quality of the power in all industrial and many more applications [2]. Power factor correction reduces reactive power consumption, due to which losses are significantly reduced while increasing electrical system efficiency. Considering two main things, which are power savings and responsive power management, led to the [3] creation of three-phase capacitor banks for residential and commercial applications. The purpose of this project is improving and upgradation of the operation of single-phase capacitor banks, which is only possible if we develop a control system which is based on microprocessor. In this procedure, the variable charge will allow the control unit to control the capacitor bank's operating steps. For the sample process, the current transformer, mainly known as CT, is used to measure the load current. Mainly it is ensured by the constant capacitor step consumption to control the microprocessor efficiently. It reduces the number of switching operations, as well as improves

power factor correction. At the same time, the choke present inside the compact fluorescent lamp will be mainly used as an inductive load.

1.2 POWER FACTOR

In an alternating current (AC) electrical power system, the power factor, often known as PF, is defined as "the proportion of the real power moving towards the load, to the apparent power present in the circuit". So, the real power of the circuit is its capacity to carry out the work in the relative time the capacity of the circuit to carry out work in a given amount of time is the real power of the circuit. The product of a device's current and voltage gives an indication of its apparent power. The distortion of signal is due to the energy that is stored in the load of the system and the distorted load that is returned towards the source. The distortion of signal is due to the energy that is stored in the load of the system and the distorted load that is returned towards the source. The above-mentioned scenario is because of the wave pattern of the current when it is pulled from the original source. Due to which the real power will be greater than the apparent power. The most effective supply provided towards the supply is mostly due to the power factor value of 1. While the least efficient loading is when the power factor is 0.5 and it will cause higher level of losses in the system. Changing the design of the equipment or spending a lot of money is necessary if a skewed current waveform is causing power factor. Mostly harmonic filters are used to provide a noticeable level of improvement. In order to create a system that is efficient, the power factor needs.

1.3 POWER FACTOR CORRECTION

The strategy known as PFC is used for mitigating the negative effects of electrical loads with power factors (PF) which are less than one. To improve the stability of a system and its effectiveness or the effort of consumers to reduce the cost imposed by an electrical supplier, adjustment to power factor can be made by the electrical transmission service. In circuits with induction motors, capacitive power factor adjustment is used to reduce the inductive element of the power and thus supply losses. The term "Static Power Factor Correction" refers to the use of capacitors linked and are usually regulated by each starter. The total current generated by the motor is equal to the leakage reactance of the current while the current present in coils that are

magnetizing is not dependent on the load which is placed on the motor. In most cases, the magnetizing current will fall somewhere in the range of 20% to 60% of the rated full load current of the motor [3]. The actual work output of the motor is not affected by the magnetizing current. The engine's operation is done by the catalyst. The main effect on power dissipation is caused by the catalyst being in charge of the engine's proper operation. The main effect on the power dissipation of a system is caused by magnetizing power and leakage reactance, but it has no effect on the motor's energy requirement.

The resistive components of motor current are as follows:

- i. Current of charging
- ii. Power outage

The following are the inductive components of motor current:

- i. Reactance to leakage
- ii. Current that attracts.

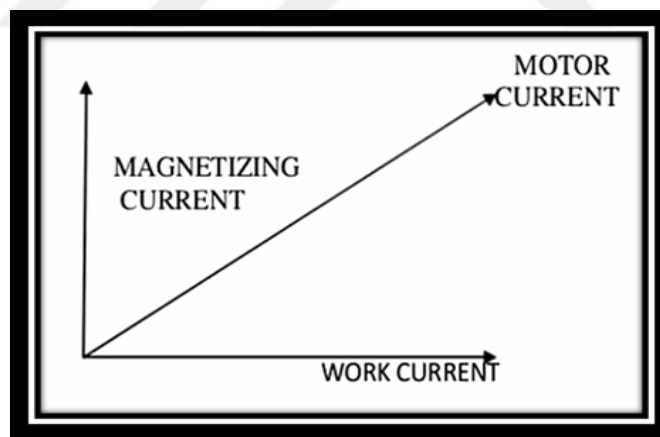


Figure 1.1: Current triangle [2]

1.4 THE DRAWBACKS OF A LAGGING POWER FACTOR

The energy dissipation in a power system is affected by the Power factor, and it has great importance in alternating current circuits [5]. We now understand that for a three-phase alternating current circuit is power is given by

We now understand that the power in a three-phase alternating current [6] circuit is:

$$P = \sqrt{3} V \times I \cos\phi$$

Where the power factor is denoted by P.

We can say that as the power factor in a system is increased, the current flow in the system declines [7]. Conversely, as this factor declines, the net current in the system is increased.

1.5 BENEFITS OF POWER FACTOR CORRECTION

Enhancing power factor has the following advantages:

- a. Stimulate greater efficiency with pf fee.
- b. The demand costs are reduced
- c. Improved load-carrying capacity.
- d. Increased voltage.
- e. The energy system has low losses.

1.6 POWER FACTOR IMPROVING STRATEGIES

The following are several power factor enhancement approaches that may be used depending on whether the load is constant or variable.

- a. Correction of individual power factors
- b. Correction of the group power factor.
- c. Corrections to the central power factor.

The corrections mentioned above can be improved by using following techniques:

- i. Power factor control using a fixed power factor
- ii. Power factor regulation automatically
- iii. Correction for Mixed Power Factors

1.7 PROBLEM STATEMENT

Power factor (PF) is a vital performance measure of voltage profile in alternating current (AC) power systems. A power factor is a number between zero and one. When the power factor level drops, it indicates a poor-quality power supply since a low PF pulls a larger internal power, and

the extreme heat creates damage and/or shortens the equipment's life span. The cosine of angle among voltage and current is defined as the power factor (PF). Because of their inductive nature, most loads have such a low PF. And as a result of the low PF, the network current rises. This PF ought to be as near to unity as feasible in order to decrease the current. Figure 1 shows a power triangle that may be used to do power factor analysis. Because of the low PF, the apparatus will require more ratings, core loss, and conductor size, and may result in more ratings inability to manage the system.

1.8 SYSTEMS STABILITY

When the electrical energy is supplied to the system, a power system's power factor indicates the system's ability to perform productive Work. Low power factor results in significant losses, which are sanctioned by the utility provider. Automated three-phase charging systems have a low power factor due to the use of various electrical equipment that requires more reactive power. Keeping the monthly average power factor close to unity can result in significant savings on utility energy costs. The use of shunt capacitor banks to improve power factor (PFC) is a well-known technique methodology. The capacitor switching method is increasingly being automated to gain the greatest real-time advantage. Because of their dependability and performance. Energy is extremely vital in today's tech revolution, as well as the energy system is becoming increasingly complex with each passing day. As a result, each unit of produced power must be transmitted over greater distances with low power loss. However, as the variety of inductive loads has increased, as has the load variance, the losses have doubled. The reasons for power outages and upgrade the power system. Because of the increased usage of load current, the power factor of load reduces significantly, increasing system losses and reducing power system efficiency. Power factor measures the efficiency with which current is transformed into usable labor output. A load must have a power factor of 1.0 in order to be efficient; otherwise, supply system losses will be significantly higher. A significant phase difference between the two parameters; current and voltage, at the load terminals, along with too many oscillating components or a distorted current waveform, can all contribute to poor power factor. Inadequate load. As an outcome, the system becomes much more stable, and the system's and apparatus's efficiency rise.

As a result, the usage of micro-controller power factor correction [8] leads to lower total costs for both customers and power suppliers. The adjustment of the power factor using capacitor banks minimizes the use of reactive power, resulting in the minimizing of losses while increasing the efficiency of an electrical system. Concerns about energy saving and reactive power regulation have led to the creation of permanent capacitor banks [9] for domestic and industrial usage. The purpose of this project is to develop a microprocessor-based control system which can be used to improve and modernize the operation of single-phase capacitor banks. A central controller will manage the operational phases of the capacitor bank, which can be based on the fluctuating charging current this microprocessor control unit's intelligent regulation ensures consistent capacitor step consumption, reduces the number of operations and improves power factor correction.

1.9 OBJECTIVE

The major objective of the task was to create a rectification team that might monitor the power factor of the mine's electrical framework and enhance it to a target value.

The research was conducted with the following goals in mind:

- i. To conduct an electric survey of the current system in such a three-phase load to investigate configuration settings and load trends, power factor fluctuation, and power conversion facility analysis, if any.
- ii. Create a microcontroller-based correction device to increase the output power [10] of the set to the appropriate value.
- iii. To validate the result, establish the system and monitor various models of load demand and diverse load patterns.
- iv. Conduct an economic study to enhance the power factor

1.10 THESIS ORGANIZATION

This thesis is broken down into five chapters. The first chapter provides an introduction to power factor and the importance of its correction in the system and its impact on the load of the system.

In the second chapter, we take a high-level look at the demerits of the low power factor and variety of studies and experiments which are conducted to improve the power factor by using a control system.

The experimental program, which includes the parameters that were evaluated, the work technique, and the simulation of the system on the MATLAB, is described in Chapter three of the dissertation. The results are discussed as well as the methodology behind the computation of the work in chapter four. The last chapter is called the finale.



2. LITERATURE REVIEW

2.1 DEVELOPMENT OF POWER FACTOR USING ARDUNIO

Power was measured by drawing multiple characteristics from the AC source, including voltage and current. In order to establish the power factor, an Arduino was connected to the readings from a set of voltage and current sensors. The experimental findings of the traditional monitoring calibration. It was proved that the proposed Power-factor-meter worked as intended. To facilitate future monitoring, the measured real numbers were also written to an SD card and transmitted to MATLAB via its GUI. If the smart meter infrastructure is used correctly, it can provide benefits beyond just recoding electricity consumption, such as simplified billing, the identification of power dissipation resulting from possible fraud, the anticipation of blackouts, and the implementation of precise real-time fee structures [5]. Data collected by a digitally based power factor meter is conveniently retained for later use [6, 7]. To process the electrical parameters, a zero-crossing detector is used, whose output is low if the thing that is different is zero [8]. Analog circuits are used throughout the power factor measuring system. In [9], the programming design is used to compute and log power consumption data, as well as five outage events, complete with the outage's onset, duration, and recovery times. [11]

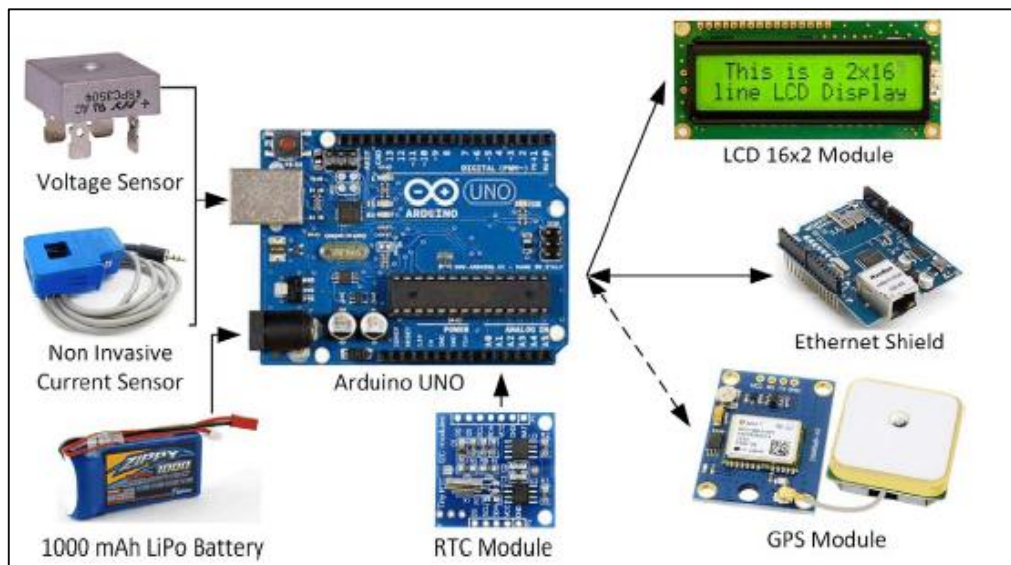


Figure 2.1: Power-factor-meter hardware [2]

2.2 PLC BASED INTELLIGENT POWER FACTOR CORRECTORS FOR INDUSTRIAL POWER SYSTEMS

The purpose of this paper was to detail a method for reducing the penalty for having a low power factor by employing a smart power factor corrector premised on a PLC (Programmable Logic Controller) as a management system, with a focus on the correction of the power used in industrial settings. This is important not only for the proper functioning of the electrical equipment employed in these settings, but also to keep costs down. The power factor value is measured from the supply line with a power meter, and a PLC software is developed to calculate and activate capacitor banks of the appropriate rating to make up for insufficient reactive power, bringing the power factor close to unity.

For each load variation, the value of the capacitors (capacitor bank) needed to compensate for the power factor alteration is calculated. It is the PLC's job to initiate the parallel connection of the power system to the load in order to bring the power factor close to unity. Programming is done independently in the PLC's programming software, which supports the Ladder Diagram software package. Businesses and most of the world's essential infrastructures today couldn't function without automation. Power systems are also a vital part of our society's infrastructure, therefore naturally there has been a surge of interest in the study of automation for purposes such as monitoring and controlling, remote switching, etc. [12]



Figure 2.2: Corrected power-factor value after applying IPFC [4]

2.3 DESIGN AND IMPLEMENTATION OF DIGITAL ENERGY METERS WITH POWER FACTOR MEASUREMENT AND LOAD INDICATION FEATURE

As soon as possible, we need to upgrade from inefficient electromechanical energy meters to more precise digital ones. The popularly used electro mechanical meters have mechanical components, making them vulnerable to temperature and time variations. There are issues with the billing process, beginning with the gathering of meter readings. The major goal is to create an energy meter that can calibrate energy precisely, automatically detect whether the load is ahead or behind, and act as a conduit of communication between the producer and the consumer. The microcontroller figures out the load type based on the power factor measured via XOR logic. By analyzing this data in real time, consumers are better able to manage their energy budgets and understand the nature of the load they are putting on the grid. As a result, manufacturers would have an accurate picture of supply and demand at any given moment.

The vast majority of watt meters are electromechanical, requiring human inspection to verify the accuracy of a household's overall energy consumption. A watt-hour meter, often known as an energy meter, is a device that tracks the amount of electricity a household consumes. Utilities put these devices in every building, home, factory, and office to measure and bill customers for their individual electrical demands. The watt is the primary measure of energy output. The electrical power measuring unit is KW. One kilowatt-hour of use is equal to one unit of electricity used. Instantaneous power is measured by these meters as a product of the current and voltage readings. All of this energy consumption is calculated by integrating this power over a given time frame. The major drawback of the currently installed meters is that we will not have enough information on how many powers are being utilized at any one time accurately, and we will have to manually gather data to charge the consumer. Intelligent meters read and process data and provide feedback to customers as part of this cutting-edge metering system. It keeps track of usage, cuts off power to consumers remotely, and lets them set their own usage caps. The improved functionality of a smart metering system is the result of the utilization of cutting-edge metering infrastructure system technologies. This allows for two-way communication between manufacturers and end users. They can both send and receive data to and from the utilities, including information on energy use, parameter values, alarms, and automatic meter readings as well as instructions for reconnecting and disconnecting service and

updating the meter's software. Less trips to the house are needed to read or take a meter reading for the monthly bills thanks to these innovations. Smart meters also eliminate the possibility of unauthorized power use by making it impossible to tamper with the meter. Smart meters' primary benefit is the potential for real-time data on use at any given time, which would provide critical insights into how load may be managed at different times of day and night [13].

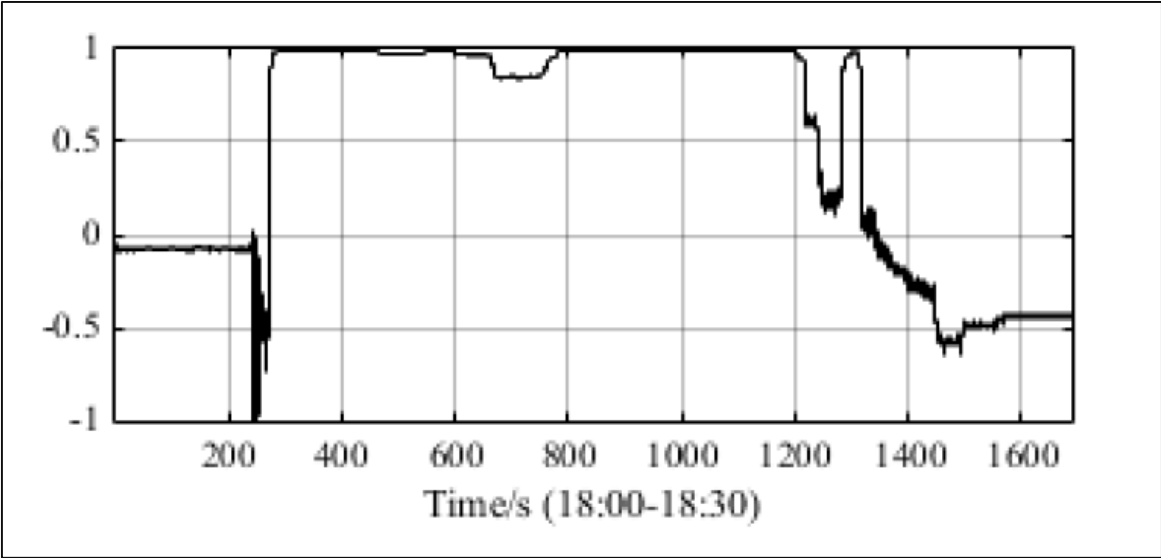


Figure 2.3: Real time data of power factor [8]

2.4 RESEARCH ON ELECTRICAL ENERGY METERING OF DIANSHIGOU TRACTION SUBSTATION

Many negative repercussions on the electricity grid have resulted from the rapid expansion of electrified railways. Issues with electric energy metering are typically brought on by electrification railway loads due to power factor, harmonics, and negative sequence. In this paper, we analyze the power quality at the Dianshigou traction substation and recommend remedial actions based on the statistical findings of our in-field measurements.

As the electrified railway of our county have expanded significantly in recent years, the power quality issues brought on by electricity have caught the eye of the appropriate power departments. Electric trains have three notable technical features: a low power factor, a significant negative sequential power, and a high harmonic content [1-3]. Traction load power factor has decreased due to electric power department's reactive power metering. There are

traction substations that have power factors as low as 0.6 and are penalized millions of yuan annually because of it. As a result, increasing the traction substation's power factor is a pressing concern. The complexity of the power measuring problem is exacerbated by the fact that electric railroads, as a high-voltage and large-capacity user, generate power quality problems such harmonics and negative sequence. To encourage accurate electric energy assessment, it is crucial to identify the sources of power quality disturbance. This article tested the Dianshigou traction converter, collecting a vast amount of real-world measured data, to determine the most accurate method for measuring electric energy. The propulsion power supply system's interference factors, including harmonic negative sequence, were examined by taking the high voltage side's voltage and current data as the object. A combination of high voltage regulation, high harmonic content, and massive negative sequences active power is identified as the primary cause of insufficient electric energy metering. The installation of a static reactionary power generator (SVG) and an active power filter (APF), as well as the use of electric energy metering based on comparable effective power factor, active power metering technique with weighting coefficient, positively active power metering, are all strongly suggested. [14]

2.5 POWER STANDARD BASED ON A HIGH PRECISION POWER-FACTOR METERING

The use of zero crossing detectors is proposed for a high-precision power-factor meter. The impact of input signal distortion is examined, and low pass filtering are proposed to eliminate this potential for inaccuracy. Based on the measurements of voltage, current, and power factor, this system is presented as a new ability standard meter. The power quality (PF) standard system typically consists of a trio of meters (voltmeter, ammeter, wattmeter). The PF is an indirect measure that is generated from these numbers. However, there are also devices that can determine the PF directly by using zero crossing detectors to calculate the phase difference between the current and voltage. Due to their lack of precision, however, they are not accepted as standards. Big mistakes show up even if the supplied waveforms are only slightly distorted [10]. However, in this study, a technique is provided to lessen the impact of harmonic distortion, and accurate findings are achieved. The proposed PF meter can be converted into a power meter by adding a voltmeter and a resistor (for measuring the current). This method flips the

conventional approach to calculating PF from volts, amps, and watts on its head. In the suggested setup, the PF is designated as the primary magnitude, from which the power is extracted [15].

2.6 SMART METER FOR POWER FACTOR ENHANCEMENT IN REAL TIME

The electricity production is rising rapidly due to the expanding human population. Using renewable resources in the power chain is essential because the current electrical grid emits more greenhouse gases (GHG). The existing power systems are struggling to keep up with the rising demand for electricity. The need for consistent electrical power on a worldwide scale is met by smart grids. Providing utilities with a wealth of fresh data that can be used to optimize business operations, Advanced Metering Instrumentation (AMI) technology is a crucial component of the smart grid. Smart meters are able to record electricity consumption in real time, can be read both locally and remotely, and can impose consumption caps or even completely shut off power. In an effort to reduce unnecessary electricity consumption, this study proposes a system to aid both residential and business consumers in detecting instances of inefficient energy consumption. High-quality electricity is delivered to consumers thanks to precise monitoring of voltage, current, and voltage level up to 0.9. As an added bonus, it can detect power quality and send that information to the server (utility) wirelessly via ZigBee.

Smart grid integrates data science and renewable power sources to provide reliable electricity to users. Utilities can better manage the demands placed on regional power grids thanks to the real-time data made available to them via the communication infrastructure. If we are going to make it easier for society to make the change to a low-carbon economy, power systems are a must [11]. By controlling how much energy people consume, it helps cut down on wasteful transmission and distribution. Power quality concerns and power loss can be detected with the use of AMI, a technology [12] used in the smart grid. Using Advanced Metering Architecture with smart meters, power quality concerns and power loss can be identified immediately, allowing system operators to begin troubleshooting immediately. With its two-way communication capabilities, smart meters provide users with up-to-the-moment data on their utility costs and consumption patterns. Customers can then take steps to lower their peak load and, by extension, their electricity consumption. Because it promotes two-way communications

and serves as a gateway between utilities and consumers in managing energy usage, smart meters are a crucial component of AMI that offers amazing benefits if integrated in Smart Grids. As a means of encouraging load shifting away from peak periods, utilities can implement dynamic pricing to reward customers for doing so. In addition, customers can monitor their use and choose the most cost-effective times to run their appliances. Future smart meters will allow end users to immediately log on to acquire the real time data, however in the meanwhile, consumers can access their energy usage statistics through the online using a PC or dumbphone that associates with the utility in off-line mode. Power factor penalties are calculated as a percentage of either the number of kVAR hours used or the number of kVA required, and are thus a standard part of the grid's pricing structure. If the power factor drops below a specified threshold, a fee is typically assessed. When pricing is comparable to the cost of providing the service, it is mutually beneficial for the utilities and the customer. All electrical activity, both active and reactive, is recorded precisely by smart meters. This can be used with TOU tariffs to further incentivize load shifting by consumers. [16]

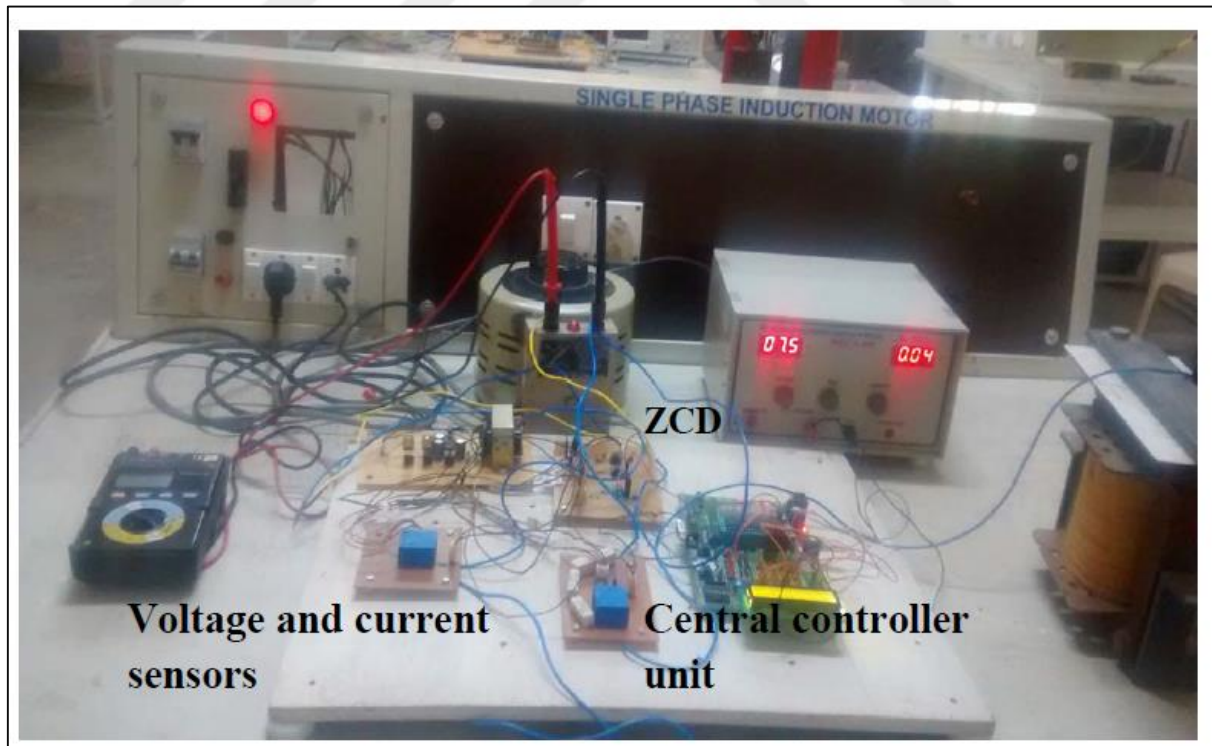


Figure 2.4: Hardware setup (Power factor correction single phase) (Own creation)

2.7 RESEARCH GAP

- a. All the previous researches on power factor improvement worked on the improvement of the power factor manually by using synchronous condensers.
- b. In this research it is suggested that a system will be analyzed automatically throughout the day according to the need of the system.
- c. It is suggested to step by step add the capacitors according to our needs so that the system will be injected according to its capacity and the system will not go on leading which is possible if single large capacitor is used.
- d. If we use single capacitor, it can cause the unnecessary leading of the power which is not needed for the system.
- e. If we inject one large capacitor it gives jerk to the system which disturbs the power quality.
- f. In this research many small capacitors are injected automatically to maintain the quality and stability of the system. And by doing that one can improve power factor according to the system needs without any unnecessary leading of the power factor.
- g. In the past researches, single capacitor is added manually to the system due to which stability and quality of the power couldn't be maintained.
- h. We will be working both on Proteus and MATLAB they have entirely different methodologies and we will implement the results on both software's and on two different environments.
- i. Moreover, we are using capacitive induction to improve power factor.
- j. Our load will be connected and whenever huge inductive load is present, we will present the power factor value if the power factor goes down this preset value our system will automatically inject the capacitor banks into the system so that our power factor will be improved.

3. METHODOLOGY AND TECHNICAL DETAILS

3.1 RESEARCH DESIGN

The 89S52 is the brains of the embedded system used to create the Automatic Voltage Regulation gadget. System voltage and current signals are sampled and used as input, with the phase angle being represented by the time difference between the wave forms' arrivals. The phase angle that results from this discrepancy is then used to determine the power factor. Before deciding how many batteries from the bank need to be switched on, the system's power factor is matched to the target level. Reactive power and phase lag values are conveniently displayed.

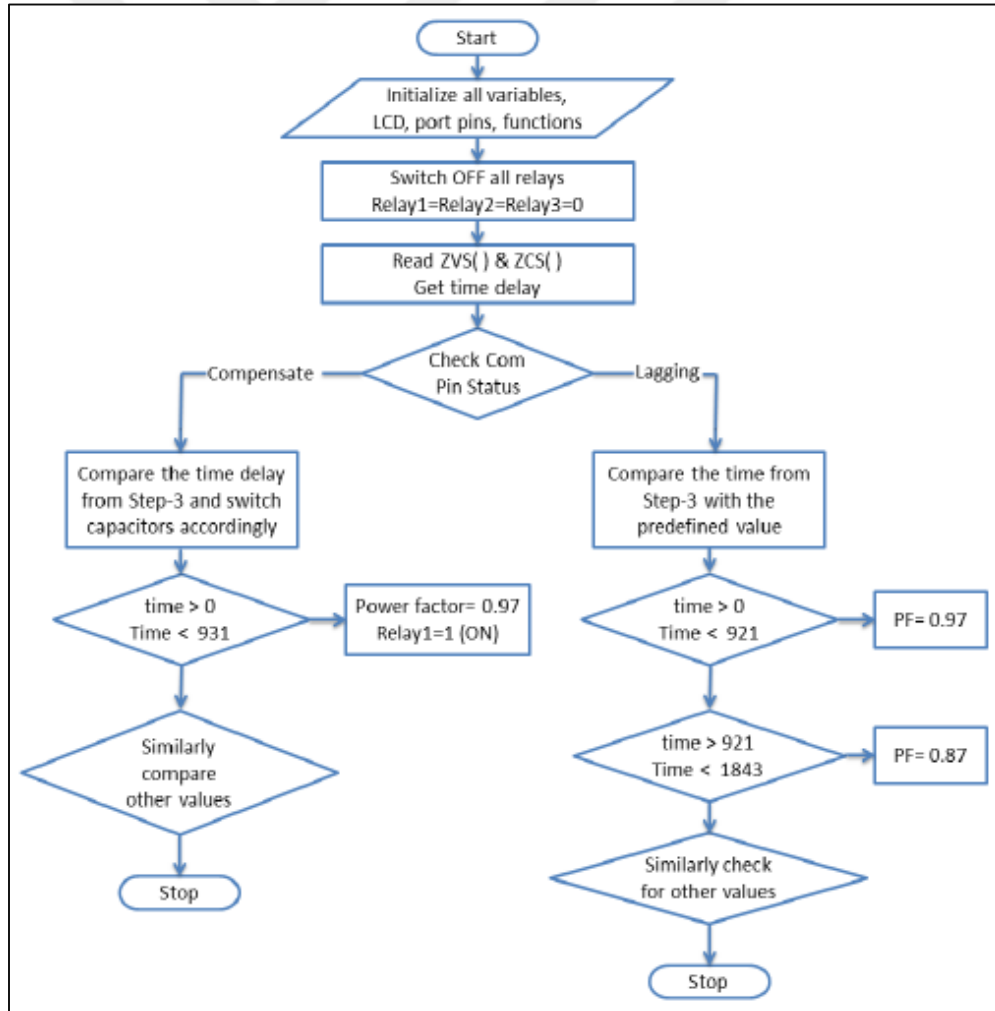


Figure 3.1: Flow chart of PFC

3.2 ALGORITHM

- Input the circuit's voltage and current.
- To determine the power factor and phase lag, proceed to Step 2.
- Determine the amount of reactive power needed by differentiating from the ideal power factor.
- Based on the amount of reactive power supplied, turn on or off the necessary number of capacitances from the capacitor bank.
- Check again the power factor against the desired PF and then return to Step 1.

3.3 BLOCK DIAGRAM

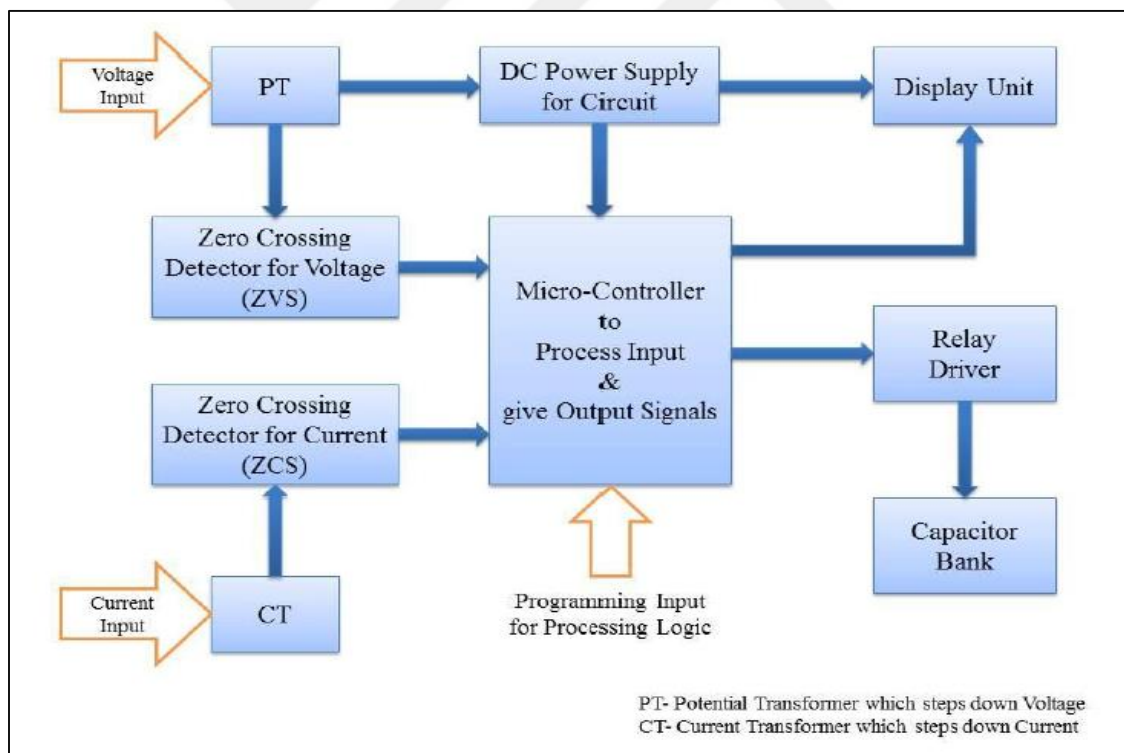


Figure 3.2: Block diagram

Reactive power and energy use are the important metrics to track. Also, keeping an eye on the supply voltage, the load current, and the active power will prove useful. Mecor Power Guard Model PG08 [22] is the instrument utilized for any and all purposes. This item is able to keep

tabs on all of your electrical appliances based on the high microcomputer chips and unique Energy Metering IC, as well as its larger power sensor and LCD. Various home equipment, like the air conditioner, refrigerator, and microwave, can be tracked with its help. This item can be used in a wide variety of settings, including private homes, commercial offices, laboratories, and more



Figure 3.3: Power guard [14]

3.4 DESIGN OF DIFFERENT LOADS

Three distinct kinds of applications are meant to mimic the realistic loads in a normal power system, allowing the device's performance to be tested and monitored. As a result, the loading profile, power consumption, power factor, etc. will be faithfully reproduced. Rourkela Institute of Technology, a Branch of the National Institute of Technology

3.4.1 Resistive(R) Load Design

A 100W incandescent light bulb can be utilized to build a pure resistive load. Below is a diagram of the circuit connection. The resistance of the filament in the light bulb is shown by the resistor R. For this example, let's use 230 volts and 550 ohms for V and R, respectively. If you use Ohm's law, you can calculate the current as

$$I = \frac{230}{550} = 0.41 \text{ mA}$$

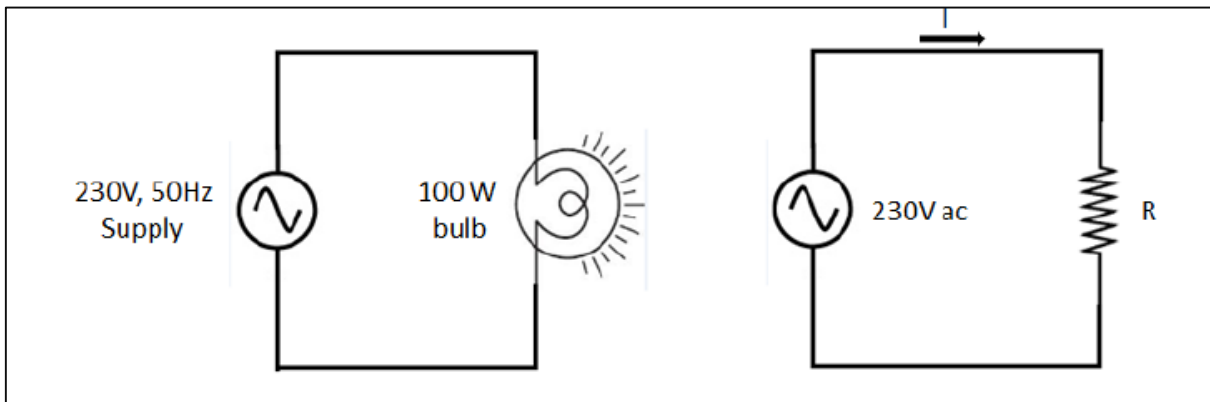


Figure 3.4: Resistive load [14]

3.4.2 Plan for a series R-L load

Tube light chokes can be used to simulate inductive loads. In this configuration, the choke and the bulb act as a series R-L load. What follows is a diagram of the circuit connection. This dip in the choke means that the bulb's operating voltage will be lower than the supply voltage. Circuit impedance is calculated as $Z = R + jXL$ at $I = 3.6.3 \text{ mA}$.

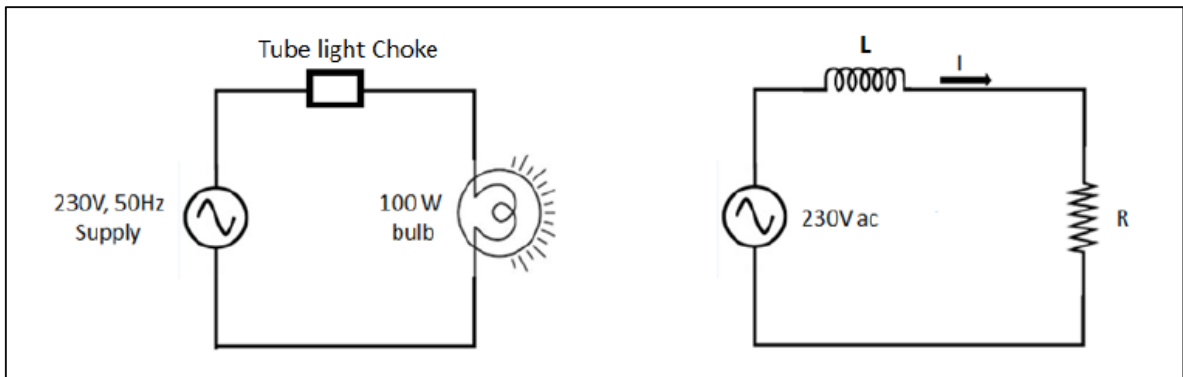


Figure 3.5: RL series IOAD [7]

3.4.3 Constructing an R-L Load in Parallel

When the bulb is connected in parallel with the choke, the two components will act as a parallel R-L load. The bulb's voltage will be identical to that of the power source. Below is a diagram of the circuit connection

The impedance of the circuit will be, $Z = \frac{R \times jXL}{R + jXL}$

Current, $I = \frac{V}{Z}$

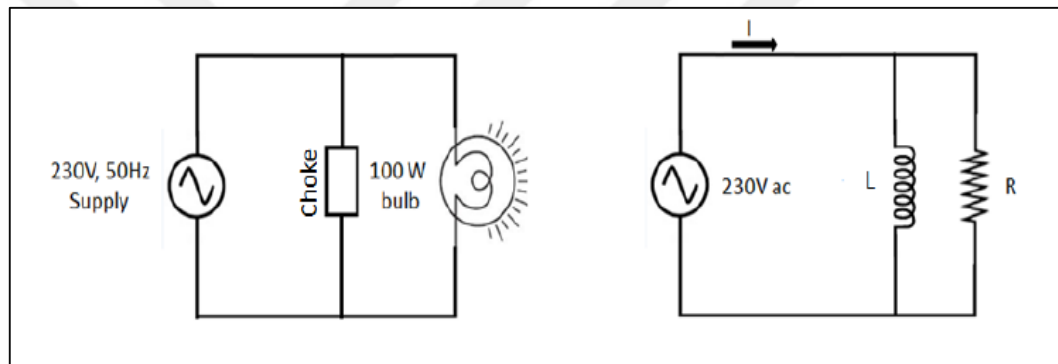


Figure 3.6: RL parallel circuit [7]

3.5 TECHNICAL SPECIFICATIONS

This section provides a comprehensive breakdown of the suggested power factor correction apparatus, outlining its architecture and how each component functions. Each block has a number of parts that must be wired together in a specific method to produce the desired result. Detailed schematics of the circuits used in the final fabrication are included. During production, we took extra precautions to ensure that no accidental path shorts would occur at any points where multiple pathways crossed.

3.5.1 Potential Transformer (PT)

With minimal energy waste, transformers change the voltage of alternating current from one voltage to another. Every substation has a potential transformer (PT) that employs a step-down transformer to lower the greatly elevated voltage to a more manageable low voltage (usually

110 Volts). A PT is employed to convert the 230 V supply voltage to the 12 V that the circuit needs. For any and all monitoring and measuring needs in conjunction with relay functioning, a PT's output is what you need. A Transformer, 230 to 12 Volts [24] Turn ratio, which is the ratio of the number of turns on each coil, is what sets the relative voltages. The high voltage mains connection is linked to the primary (input) coil of a step-down transformer, which has many more turns than the secondary (output) coil, resulting in a lower output voltage.

$$\text{Turn Ratio} = \frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{i_p}{i_s}$$

- i. V_p is the Primary (or input) voltage.
- ii. Voltage at the secondary terminal, or the output are denoted by V_s
- iii. Number of turns in the primary coil, denoted by " N_p ,"
- iv. N_s is the number of turns of the secondary coil
- v. Input (primary) Current = I_p
- vi. I_s = secondary current (or output).



Figure 3.7: Step down transformer as potential transformer [18]

3.5.2 Current-Transformer

A current transformer (CT) is a device used to measure electric currents in a circuit. Current transformers are part of a larger class of transformers called instrument transformers that also includes voltage transformers (VT) and potential transformers (PT). A current transformer is used to lower the current so that it can be easily applied to taking the readings instruments when the original current is too high. In addition, it protects the measuring devices from the potentially lethal voltage present in the monitoring circuit. Metering and preventative relays in the power grid rely heavily on them. Figure below shows How a Current Transformer Is Supposed to Work [26].

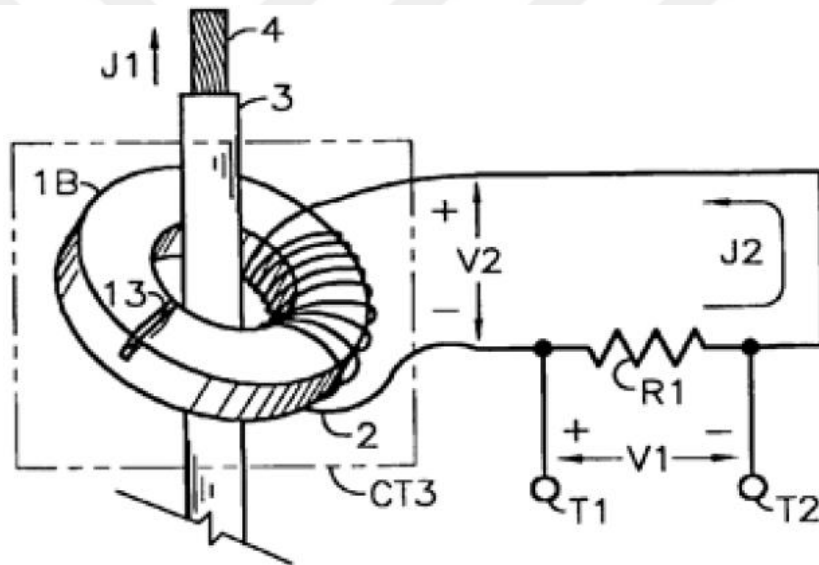


Figure 3.8: Working of CT (Current transformer) [17]

3.5.3 Zero Crossing Detector

The input signal detector transforms sinusoids into squares. Using two detectors, one for each signal, we can determine when each one first arrived, and so determine the phase delay between the currents and voltages. To calculate the phase angle lag, simply compare the two arrival instances and use the angle calibration. The cosine of this phase delay is used to determine the

circuit's power factor. As such, we've decided to use 0 V as our reference voltage. When and in what orientation an input signal goes below zero volts can be seen by observing the resulting voltage waveform. The output voltage will take longer to transition from one saturation pressure to another if the input voltage is a low-frequency signal. Additionally, the output may swing from positive to negative saturation voltage V_{sat} if there is noise between the two input nodes. The LM339 integrated circuit is a comparator that can also detect zero crossings.

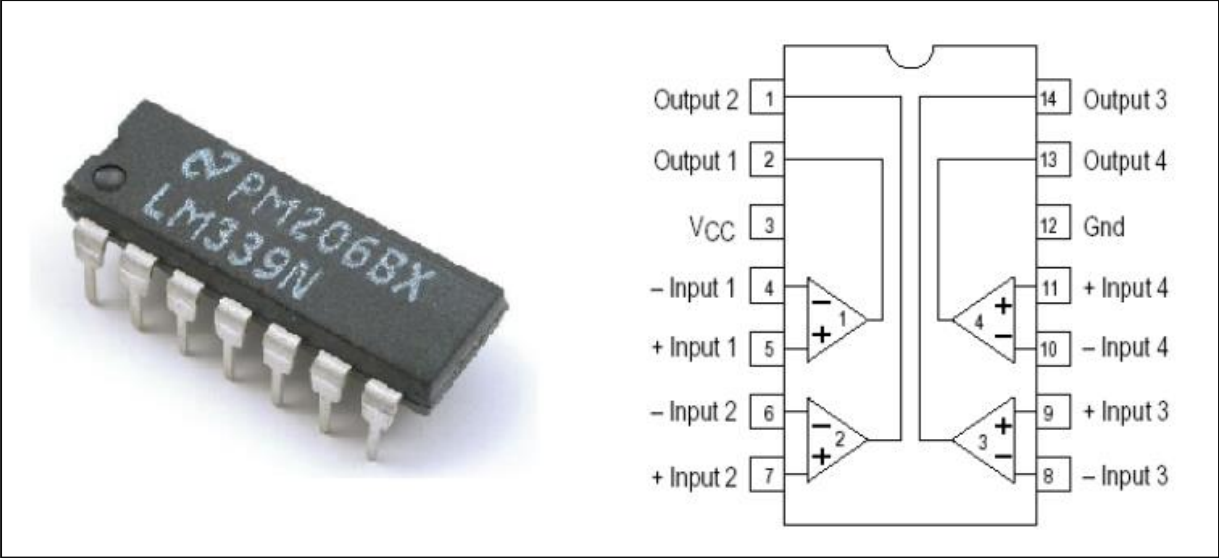


Figure 3.9: LM 339 pinout [20]

3.5.4 Circuit Power Supply

A common operating voltage for the circuitry of embedded systems is between 12- and 5-volts DC. Therefore, a DC-to-AC converter is necessary to transform the available 230-Volt AC current. The first step is to use a transformer to reduce the voltage from 230 V AC to 12 V AC. In this scenario, a second step-down transformer is unnecessary because the output from the potential transformer (PT) can be used directly. The second step is fixing the problem. The 12 V AC is converted to a 12 V DC alternating current using a complete bridge rectifier circuit. In the third stage, a capacitive filter is used to smooth out the pulsing DC, resulting in a standard 12V DC at the output. A consistent supply voltage for the control circuit is generated in the fourth stage with the help of a 12 V and a 5 V voltage regulator.

3.5.5 Rectifier

When performing the rectification process, a rectifier switches the direction to unidirectional direct current (DC) from alternating current (AC). It changes the alternating current into the direct current that causes pulses. Either a half wave or full wave rectifier may be used. Because of its advantages, including as excellent biocompatibility and full wave rectification, a bridge rectifier is typically employed. Only one pair of diodes will conduct in the forward bias half of the cycle, and the other two diodes will deal in the reverse bias half. Rourkela Institute of Technology, a Branch of the National Institute of Technology Page 21 Output and Input of a Full-Bridge Rectifier [29].

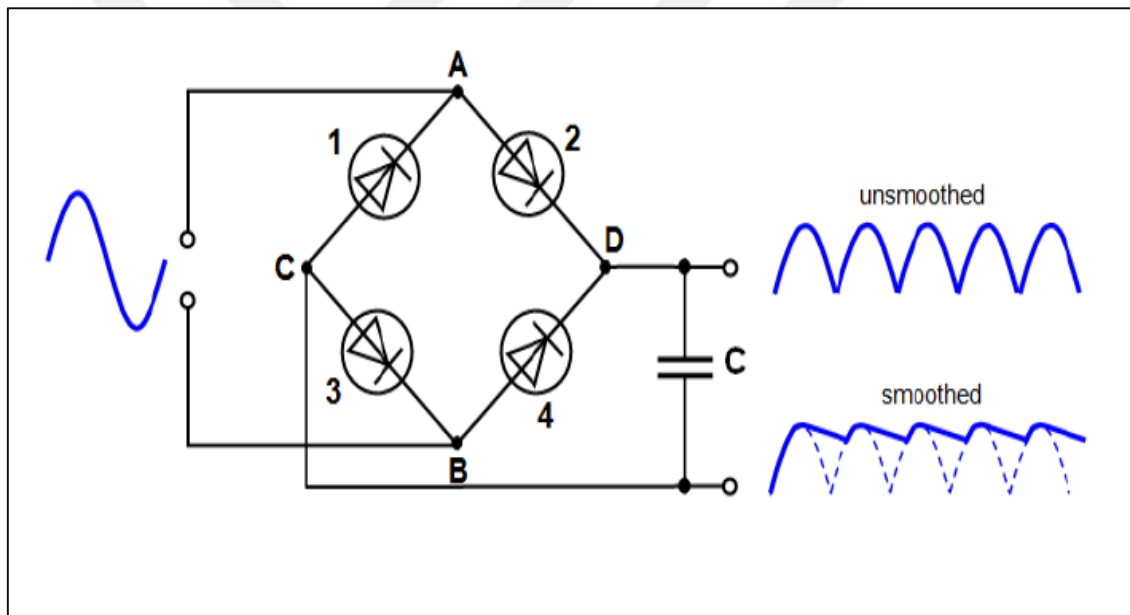


Figure 3.10: Rectifier circuit [22]

3.5.6 Filter

This project makes use of a capacitive filter. When applied to the rectifier's output, it eliminates ripples and provides a more uniform DC current. As long as the electricity voltage and load are held steady, the output from this filter remains unchanged. The most fundamental form of filter seen in electrical systems is the capacitor filter.

3.5.7 Voltage-Regulator

Voltage Stabilizer Multiple preset output voltages and the TO-220/D-PAK container make the LM78XXA or LM78XX series of positive three-terminal regulators suitable for a wide variety of uses. Every type features a cutoff thermal region, a limiter of current, and a protective region known as the safe operating area, making them practically invulnerable. With heat dissipation, output current of 1A can be produced. These devices are typically employed as fixed voltage regulators, but with the addition of some external components, variable voltages and currents can be obtained. The final two numbers, XX, of the part number indicate the output voltage of the LM78XX. LM7805 has a 5 Volt output, while LM7812 has a 12 Volt output. Connecting the LM7805 [30] is depicted in Figure 3.11

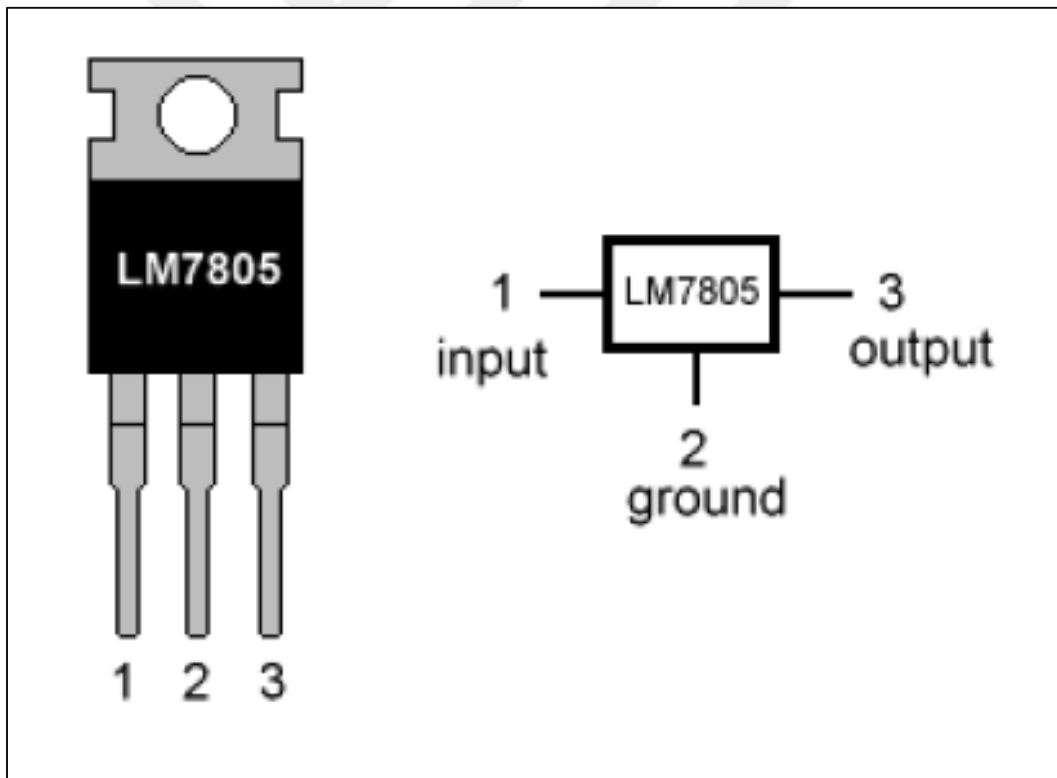


Figure 3.11: Voltage regulator [23]

3.5.8 Liquid-Crystal-Display

The microcontroller in an embedded system receives information from and sends it to the outside world via input and output devices. An LCD display is a common peripheral for microcontrollers. Many people use 16x2 and 20x4 LCDs that are linked to the microcontroller. This translates to 16 characters across 2 lines, 20 across 4 lines, and 40 across 6 lines. In this application, we use a 16x2 LCD, type JHD 162A, to display the voltage profile and the phase lag between the voltage and the current in milliseconds. See Figure 3.12 for an example of a 16x2 LCD screen.



Figure 3.12: LCD 1602 [24]

3.5.9 LCD Connections

A total of 4 or 8 I/O lines are needed to connect to the microcontroller's data bus, and 3 control lines are also required. The LCD can use either a 4-bit or 8-bit data bus, the latter of which can be chosen by the user. The LCD needs a total of 7 data lines to function with a 4 bit data bus (3 control lines plus the 4 lines for the data bus).The LCD needs 11 data lines in order to function with an 8-bit data bus (3 control lines plus the 8 lines for the data bus). Connection Description and Pinout for a 16x2 4-bit LCD Display is shown below.

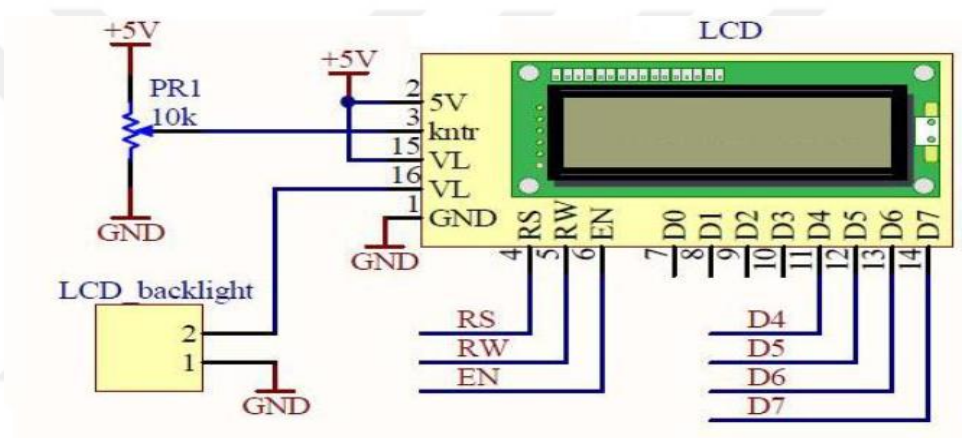


Figure 3.13: LCD connection [24]

3.6 MICRONTROLLER

A microcontroller, at the center of every embedded system, does all the necessary logic processing. It receives data as input, processes it in accordance with the instructions given to it by the programmer, and returns the results as output. It also contains on-chip memory for use in storing intermediate results and other data while processing is underway. The AT89S52 8-bit controller is used as the microcontroller. In-system modifiable flash memory of 8K bytes makes the AT89S52 a low-power, increased CMOS 8-bit microcontroller. The manufacturing process employs Atmel's high-density nonvolatile memory technology, and the device is compatible with the standard instruction set and pin out. In-system reprogramming of the program memory is possible thanks to the on-chip flash, and the memory can also be rewritten using a standard nonvolatile memory programmer. The Atmel AT89S52 is a potent microcontroller that provides

a highly-flexible and cost-effective solution to many embedded control applications by integrating a configurable 8-bit CPU with in-system programmable flash on a monolithic chip. The AT89S52 comes equipped with the following features as standard: It has a full duplex serial interface, an on-chip oscillator and clock circuits, 32 I/O lines, 8K bytes of flash memory, 256 bytes of RAM, a watchdog timer, two data pointers, three 16-bit timer/counters, and a six-vector two-level interrupt architecture. 89S52, Figure below depicts pinout of a Microcontroller

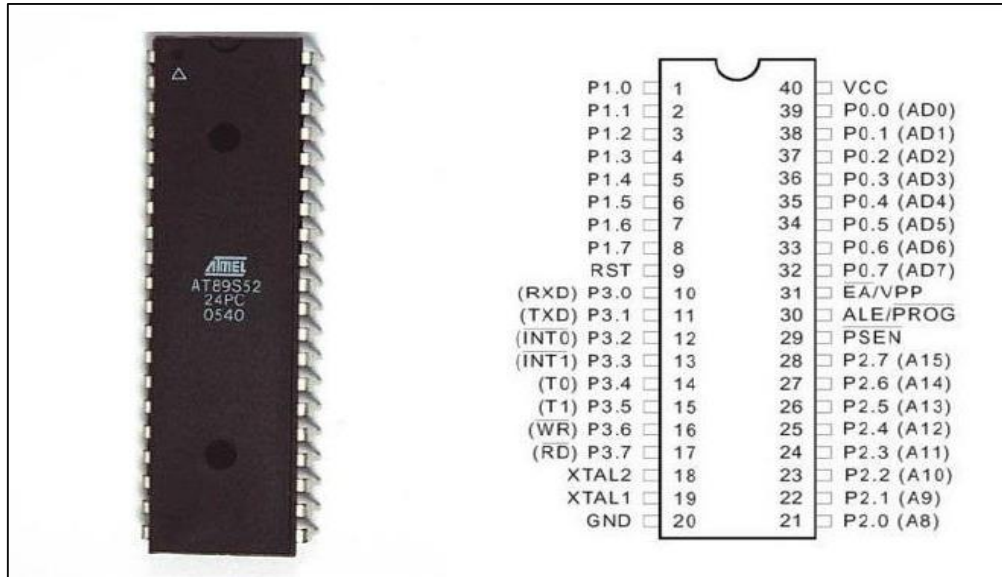


Figure 3.14: Microcontroller pinout [8]

3.7 SPDT RELAY MODULE

A relay driver and relays make up this module. This component regulates the high power circuit from the low power circuit, as the microcontroller output cannot actually control the switching of capacitors. Simply put, a relay is a switch that is powered by electricity. To control several circuits with a single signal or to control a circuit with a low-power signal (with perfect electrical isolation between management and controlled circuits), relays are utilized. The relay's coil generates a magnetic field in response to the current flowing through it, drawing a lever in to flip the switch contacts. Relays typically have COM, NC, and NO marked on the switch terminals. Connect constantly to the "COM" terminal; this is the switch's "moving" component. (When the relay coil is not in use, electrical current flows from this NC (normally closed) terminal to the common (COM) terminal. (When the relay coil is activated, COM is linked to the NO terminal, which is always open. Diagram of the 12 V Relay's Internal Wiring

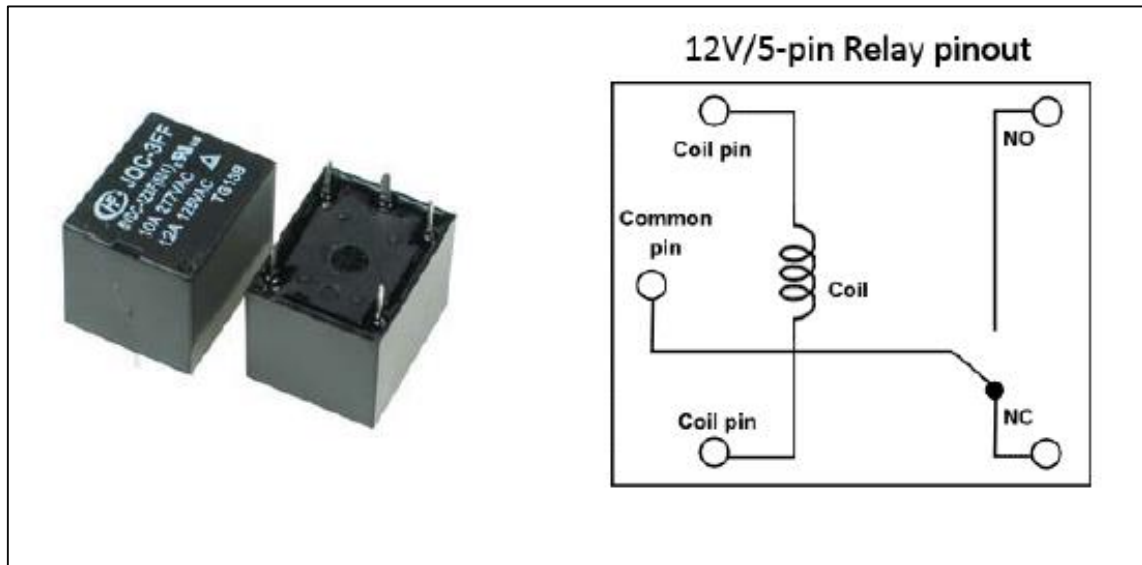


Figure 3.15: SPDT relay internal diagram [9]

3.7.1 Relay-Driver

The relay coil requires more current than the microcontroller's output pin can provide, so a relay driver ULN2003 is employed. The ULN2003 array of Darlington transistors is designed to handle high current and voltage. To put it simply, the ULN2003 is an array of high-current Darlington transistors that can handle extremely high voltages. Consisting of seven NPN Darlington pairs, each with a high-voltage output and a Clamp diode in its common anode, the circuit may switch inductive loads. A single Darlington pair can handle up to 500mA in current at the collector. It is possible to parallel the Darlington pairs to increase their current carrying capacity. Relay producers, hammer drivers, lamp drivers, panel drivers (for LED gas discharge), line drivers, and logic buffers are just a few of the many uses for these devices. It can see the pinout for the ULN2003 relay driver in Figure

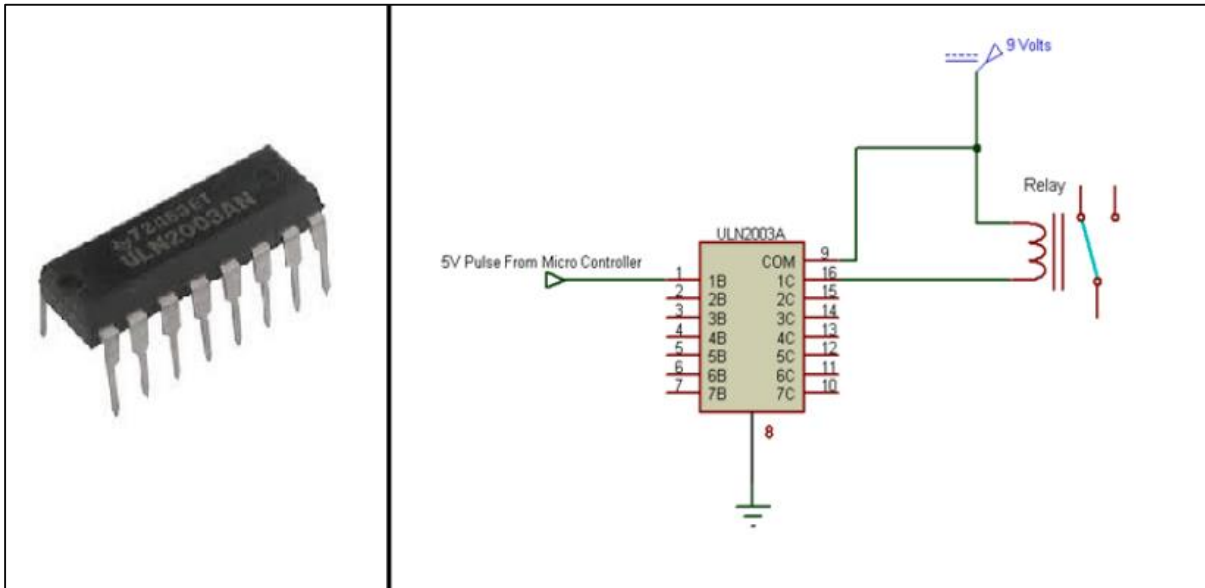


Figure 3.16: pinout for the ULN2003 relay driver [21]

3.8 POWER FACTOR CORRECTIONS

3.8.1 Static Capacitors

Connecting passive components with trailing power factor equipment is a common practice in manufacturers. To cancel out the trailing reactive component of the load current, the static capacitor must either draw a leading current or be charged to a higher potential than the load current. The capacitance can be managed in either a delta or a star configuration for three-phase loads.

3.8.2 Synchronous Condensers

Typically, this approach is employed by major corporations. If a synchronous motor is over-excited when operating at no load, it is referred to as a synchronous condenser. When the motor is overexcited, it becomes a capacitor, draws leading current, and cuts down the reactive component of the system.

3.8.3 Phase Advancers

The power factor of induction motors can be increased with their help since the current used by the stator circuit lags the power factor by 90 degrees. The power factor can be raised by the use of a phase advancer, which does this by supplying exciting ampere turns. Using slip frequency, it generates thrilling ampere turns.

3.8.4 Shunt Capacitors as Power Factor Controlling

A shunt capacitor bank is a device used to enhance the reliability of the power grid and the effectiveness of the power system. Research shows that line losses can be drastically cut if the system voltage is kept constant. Shunt capacitor banks may be placed conveniently and affordably all around the system with little effort. The reactive power demand determines whether or not the bank of shunt capacitors is energized. Capacitor switching can be done either by hand or mechanically with relays. Shunt capacitors substantially change the system resistivity variation with frequency, whether they are installed at the customer location for power factor control or on the distribution system for voltage management. Although capacitors don't generate harmonics on their own, they can be blamed for causing significant harmonic distortion in some situations. The voltage via a feeder gradually shifts due to a passive filter at its end. The ideal condition for the capacitor's percentage voltage rise is for it to be zero when the load is not present and to reach its maximum value when the load is present. However, when using shunt capacitors, the percentage of voltage increase is not significantly affected by the load. The switching of capacitors might also cause transient overvoltage in the customer's facilities. Connecting passive components with trailing power factor equipment is a common practice in manufacturers. To cancel out the trailing reactive component of the load current, the static capacitor must either draw a leading current or be charged to a higher potential than the load

current. The capacitance can be managed in either a delta or a star configuration for three-phase loads.



Figure 3.17: Shunt capacitors [7]

4. RESULT AND DISCUSSION

The project's target is to achieve a nearby unity value of the power factor and to upgrade the efficiency and operating performance of capacitor banks. As much as the power factor is close to unity, the more the system's efficiency and the less the power losses and consumption. The power factor's formula is shown below; ratio of real power to apparent power.

$$= \frac{KW}{KVA}$$

Or

$$P = VI\cos\theta \rightarrow \cos\theta \text{ is the power factor}$$

Apparent power is needed to process, activate, or run equipment in a given time interval; the real power is the present or actual load on the system. Power correction helps reduce power consumption, which further helps increase the system's efficiency or the network. Power correction is a process in which we use capacitors to create a leading current to compensate for the lagging current. Voltage and current are analog signals at the initial stage, whereas a microcontroller is a digital device. To convert the two parameters, voltage and current, comparator circuits are used, which converts the sine wave to a square wave, which is a digital form of a signal and the right input for the microcontroller. The Comparator circuit compares the two inputs and produces an output of either 1 or 0. Moreover, one of the important applications of the comparator is zero crossing. In zero crossing, the difference of time parameter for both the voltage and current is measured as it crosses the zero marking or gets a slight surge in either a positive or negative region from the origin. If the time difference is more, the power factor is less, and efficiency is low. However, if the voltage and current time difference are low, the power factor will be close to unity. In ideal cases, if there is no time difference, the power factor will be unity, resulting in the most efficient system.

A proper algorithm is made to work a capacitor automatically by connecting it to the system with the help of a relay. The microcontroller is used to deduce when the switching occurs and give commands to the relay to add an additional capacitor when the inductive load increases.

Consequently, bringing the power factor close to unity, increasing the network's efficiency and reducing electricity bills. The output is displayed on the LCD that mentions not only the power factor but also the other parameters like V, A, PF, AP, and VPF.

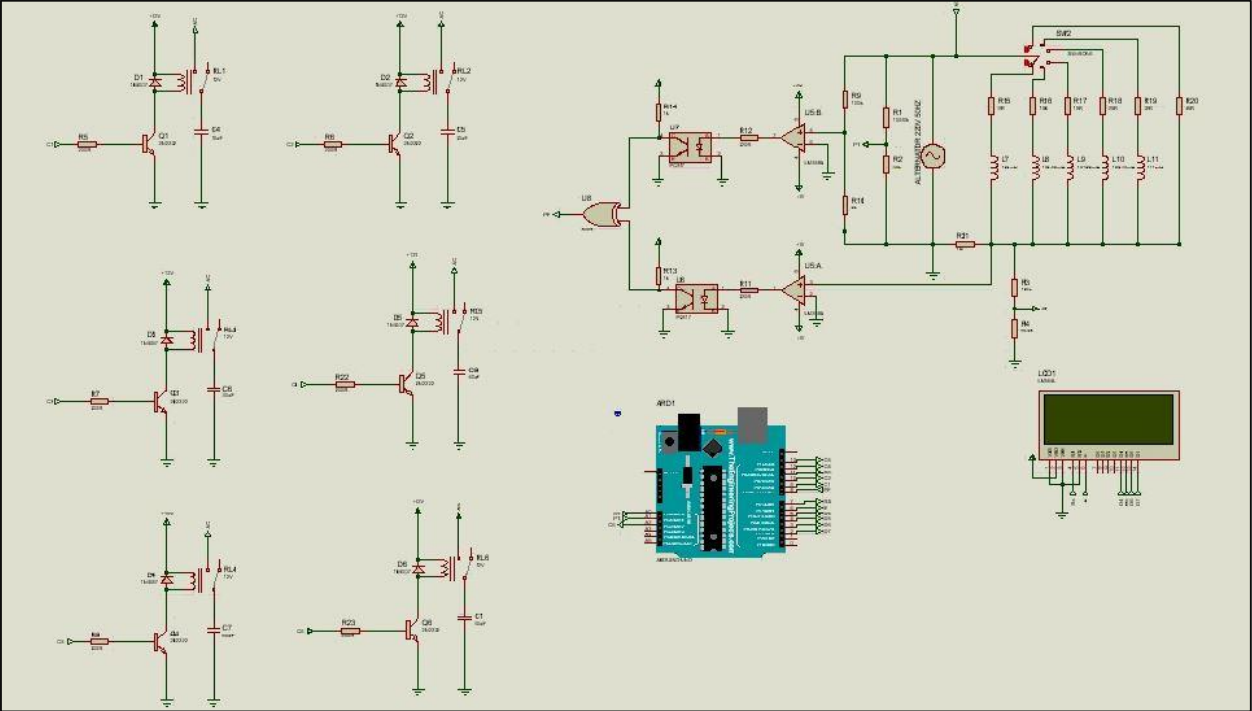


Figure 4.1: Schematic diagram

4.1 THE PROPOSED MODEL

4.1.1 Prototype without Inductive Load

A circuit without an inductive load produces a unity power factor for the ideal case. It is because in ideal cases, the losses, KVAR, load current magnitude, and other factors are not considered, which contributes to a unity pf. A power factor equal to one means that the voltage and current, the two parameters, are in phase with each other and have low oscillating content. On the other hand, pf of zero means that voltage and current parameters are 90 degrees out of phase. In most circuits, the power factor is not equal to 1 because there is always some interference and impedance in the power lines. In pure resistive circuits, the power factor is zero because there is a zero phase angle between current and voltage; otherwise, it is not possible to get a power factor equal to 1.

In this project, a prototype is built without the inductive load, giving an output of a unity pf. The purpose of the prototype was to compare it with a realistic situation in which an induction motor is connected to the circuit. Inductive loads like lightning ballasts, furnaces, and PT are not used in the circuit. Thus, no switching is required by the relays to add capacitors to the circuit when no inductive load is applied.

4.1.2 Prototype with Inductive Load

For a circuit with an inductive load, the losses, current magnitude calculations, and other parameters are considered, which prevents the system from achieving unity. Other factors include high harmonics, distortion, discrete or discontinuity in the waveform, or increased phase difference between voltage and current. The system load factor decreases as the inductive load increases, thus increasing system failures. Connecting the motor to the circuit increases the inductive load, decreasing the power factor, making the microcontroller power or push more relays, resulting in more shunt capacitors connected with the circuit. Relays are electrical switches that open and close based on the signal they receive from outside sources. The number of capacitors in a circuit depends upon the load on a specific system. These parameters and conditions must be fulfilled while dealing with the power factor improvement and compensating product. In simpler words, a prototype with inductive load initially gives a lagging power factor that can be fixed by the proper working of Automatic Power Factor Correction (APFC). It gives an improved power factor close to 1 or precisely 0.98 max.

In this project, the prototype focuses on adding shunt capacitors to the circuit in parallel combination. The rating of the capacitor is covered later in this section since our project focuses on optimization and cost-efficiency; thus, the right components must be used for higher general efficiency. The APFC corrects the power factor; the automation uses a microcontroller which takes input from the comparator circuit and commands the relays for switching. The increased load for the project proposed six power factor outcomes:

$$pf = 0.9 \mid pf = 0.6 \mid pf = 0.5 \mid pf = 0.4 \mid pf = 0.3 \mid pf = 0.2.$$

The outcome showed that as the load is increased, the number of capacitors used in the circuit increase, and the power factor is decreased. In our results, $pf = 0.9$ is the most efficient and $pf = 0.2$ is the least efficient of all the experiments conducted.

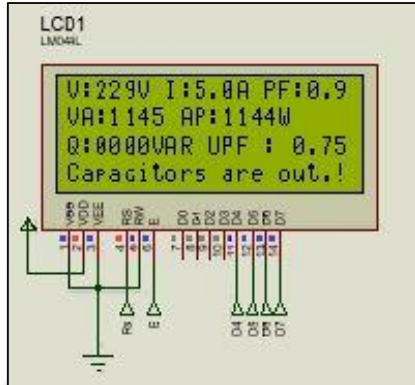


Figure 4.2: LCD display with PF = 0.9

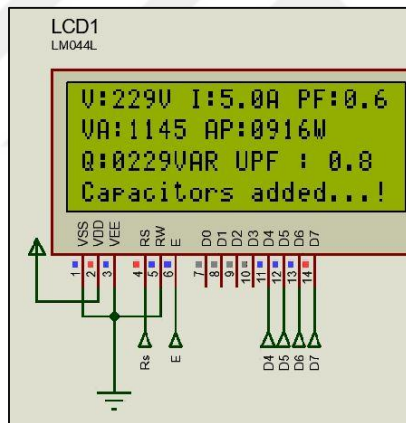


Figure 4.3: LCD display with PF = 0.6

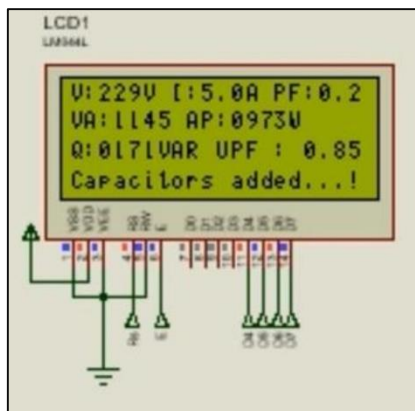


Figure 4.4: LCD display with PF = 0.2

4.2 XOR GATE

XOR is an abbreviation of Exclusively-OR gate. To perform logical operations on multiple binary inputs and produce a single binary output, logic gates are utilized. Simply put, the electronic circuits of a digital system are known as logic gates. XOR is not a basic gate since it is the combination of four universal NAND gates. The truth table of XOR with two inputs shows that when both inputs are low, the output is low or zero. On the other hand, if both the inputs are high or one, the output will still remain at zero. To achieve a high or one output, the input "A" and "B" must be different, i.e. either one of them is low or high at a given time.

Two input "A" and "B" "Exclusive-OR" gate is a modulo two adders since it provides the result of two binary numbers addition, which results in a more complex design than other basic logic gates. **The XOR's Boolean Expression is shown below:**

$$Q = (A \oplus B)$$

The main objective is to develop an energy meter that can correctly calibrate energy, determine if the load is automatically ahead of course or behind schedule, and serve as a communication link between the consumer and the producer. From the power factor obtained by XOR logic, the microcontroller determines the type of load. The power factor of the XOR is measured by monitoring the ON time. If it is below 0.98, the capacitor and relay switches will be operated in parallel by the microcontroller to achieve a power factor near 1.

4.3 COMPARATOR CIRCUIT

It is a circuit that compares two inputs given to a circuit and gives an output either as 1 or 0. The comparator compares the measured value with a reference value; usually, it is 0.98 pf. The high output shows that the voltage is on the positive side, and the low output indicates that the voltage is on the opposing side. Through it, get to know which is the larger one. Comparator circuits help to detect zero crossing. Sine waves have two zero crossings. One is at 180 degrees, and the other is at 360 degrees. Zero crossing is a way to compare two parameters as they cross the origin or horizontal axis with a slight positive or negative surge. The time difference between voltage and current with reference to zero crossing is inversely proportional to the power factor.

In other words, greater the time difference computed by the comparator circuit, the lower the power factor will be observed. The relation is shown below:

$$\text{Time Difference} \propto \frac{1}{\text{Power Factor}} \rightarrow \text{Inversely Proportional Relation}$$

Moreover, the comparator circuit converts the waveform from analog (Sine wave) to a digital signal (Square wave), the desired input of the microcontroller used in the project for power factor correction. The output of the Arduino is output which helps in the operating of relays for adding shunt capacitors to the circuit.

4.4 THE RIGHT CAPACITOR

Choosing the right capacitor is vital, since a single overrated capacitor can induce jerks in the system leading to inefficiency; whereas, smaller rated capacitor can't be effective enough to correct the power factor to load ratio. Therefore, choosing the right capacitor is essential. In our prototype, we computed the ratings as below to find the suitable capacitor that can handle the load and improve the pf greatly.

$$\text{Inductive Load} = P$$

$$\text{Initial and Final Power Factor} = \cos\theta_1 \text{ and } \cos\theta_2, \text{ respectively.}$$

Initially, we'll compute the KVAR of the capacitor and later will convert it into Farads. The entire process is shown below:

$$I_c = \frac{V}{X_c}$$

$$\text{Capacitive Reactance} \rightarrow X_c = \frac{1}{2\pi fC}$$

Substituting the above two equations give:

$$I_c = V2fC$$

Kilovolt-Ampere Reactive Formula:

$$kVAR = P (Tan\theta_1 - Tan\theta_2)$$

$$kVAR = \frac{(V \times I_c)}{1000}$$

In form of farad (F), the equation becomes:

$$Capacitance = \frac{[\frac{V \times I_c}{1000}]}{2\pi fV^2} \text{ in microfarad}$$

4.5 MATLAB CIRCUIT DIAGRAM

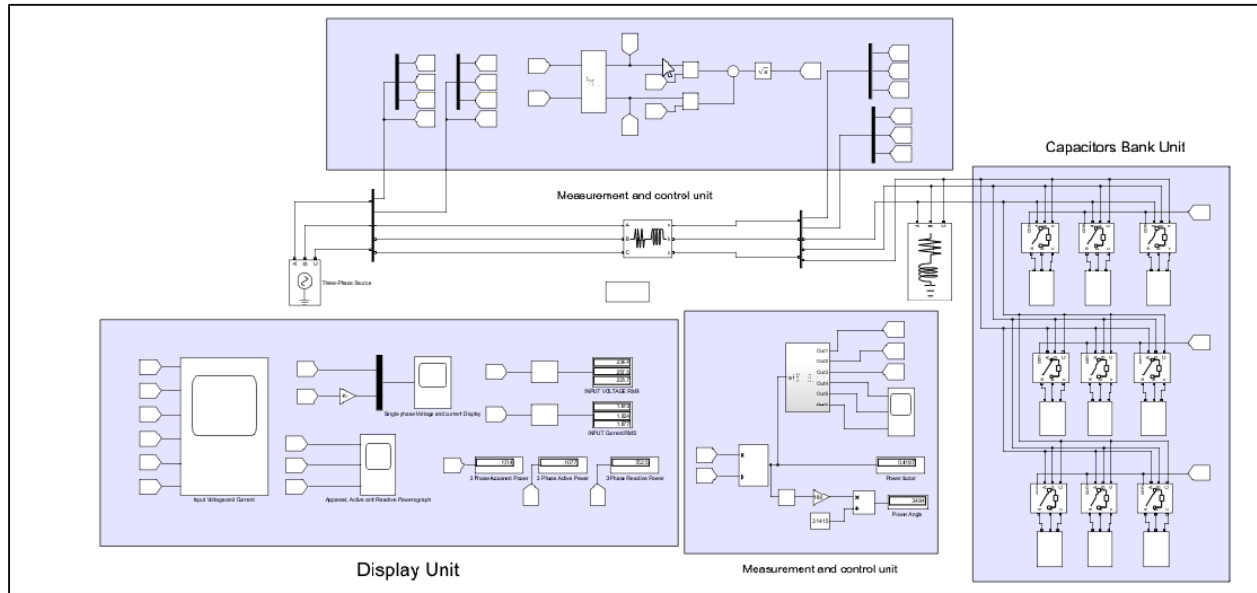


Figure 4.5: MATLAB representation

5. CONCLUSION

The distribution and supply chain of electricity is severely affected in many parts of the world. Researchers all around the globe are trying to come across ways to reduce transmission losses and make distribution efficient. Increasing population result in increasing load, longer distances, greater consumption, and increased current magnitude through the lines. All these factors contribute to lowering the power factor, which is the real-to-apparent power ratio. Power factor is an essential parameter for commercial usage and optimized electricity consumption; therefore, till today, researchers are trying to reach closer to the ideal condition to meet the demand and supply of the growing world.

In this project, "Microcontroller-based automatic power factor correction for three-phase loads," the load is increased multiple times, and the power factor is computed. Automatic power factor detection and correction is a way to improve and increase the power factor and bring it close to 1 or precisely 0.98. The input signals are converted to square waveform by passing them through the comparator circuit. The comparator circuit performs zero crossing detection technique. Zero detection indicates if the time difference is greater between voltage and current, which helps decide the microcontroller to compute the power factor. The phase difference variation between the parameters is inversely proportional to the power factor.

To verify the performance, Automatic Power Factor Correction (APFC) was used, and the circuit was added with an inductive load. It means that an inductive motor or other inductive load were added to compare the prototype with the idealistic condition, where the power factor is unity and zero inductive load is present. With the increase in the inductive load, the power factor decreases. To increase the power factor, the microcontroller drives the relay, which switches to connect the shunt capacitors parallel in the circuits. The number of parallel capacitors depends upon the load attached to the circuit. These shunt capacitors help in increasing the power factor of the system. A liquid crystal device (LCD) is an electronic display device used to display the power factor value and other significant parameters.

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