

**AUTOMATIC POWER FACTOR CORRECTION SYSTEM.**

**BY**

**OSES-OYEDOH DIVINE OSELUMHEN-ENG2002319**

**DEPARTMENT OF ELECTRICAL AND ELECTRONICS**

**ENGINEERING**

**FACULTY OF ENGINEERING**

**UNIVERSITY OF BENIN**

**OCTOBER, 2025**

**AUTOMATIC POWER FACTOR CORRECTION SYSTEM.**

**BY**

**OSES-OYEDOH DIVINE OSELUMHEN-ENG2002319**

**A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND  
ELECTRONICS ENGINEERING IN PARTIAL FULFILMENT OF THE  
REQUIREMENT  
FOR THE AWARD OF BACHELOR OF ENGINEERING (BENG),  
UNIVERSITY OF BENIN, BENIN CITY.**

**SUPERVISOR: Engr. Prof. S.O. Onohaebi**

**OCTOBER, 2025.**

## **CERTIFICATION**

This is to certify that the project titled “Automatic Power Factor Correction System” submitted in partial fulfillment of the requirements for the award of a Bachelor of Engineering from the department of Electrical and Electronics Engineering was performed by **OSIS-OYEDOH DIVINE OSELUMHEN** has been read and approved for meeting part of the requirements and regulation governing the award of Bachelors of Engineering degree in the University of Benin, Benin City, Edo state, Nigeria.

---

**ENGR. PROF. S. O. ONOHAEBI**  
**Project Supervisor**

---

**DATE**

**ENGR. DR. O. S. OMOROGIUWA**  
**(HEAD OF DEPARTMENT)**

---

**DATE**

## **DEDICATION**

I dedicate this work to my family, friends, and mentors, whose unwavering support, patience, and encouragement have been instrumental in our journey.

## ACKNOWLEDGEMENT

I extend our deepest gratitude to God Almighty for granting me the strength and perseverance to complete my journey at the University of Benin in pursuit of a Bachelor's degree in Electrical and Electronic Engineering. Through His grace, I successfully navigated this project despite the challenges posed by the condensed academic calendar and other obstacles.

Our sincere appreciation goes to my project supervisor, Prof. S.O. Onohaebi whose patience, guidance, and unwavering support were invaluable throughout this process.

I would like to express special thanks to my parents for their constant encouragement and unwavering support throughout my academic journey.

I am also immensely grateful to my friends, Tega, Chioma, Oghosa, Osezele, the 'EEE Boys' and other group members who stood by me and provided assistance whenever I needed it, a special mention being Jesse, their kindness and support helped us overcome numerous challenges.

My appreciation goes out to my uncles, Engr. Dr. Martins Oyedoh and Pharm. Dr. David Osadolor, for without them, this would not have been possible.

A special mention goes to my late grandmother, Lady B.L.N. Osadolor, for her unwaivering support throughout my journey. It is a shame she could not see the end of it.

Lastly, a heartfelt appreciation goes to every member of the Electrical and Electronic Engineering graduating class of 2024/2025. The journey was far from easy, but together, we made it to the finish line.

Congratulations to us all!

## ABSTRACT

Efficient power utilization is a key concern in modern electrical systems, especially in industries where large inductive loads cause a reduction in power factor and overall system efficiency. In this part of the world, power factor correction has been accomplished through manually operated capacitor banks; however, manual systems are not flexible enough to react dynamically to changing load conditions. Therefore, this project focuses on the design and simulation of an Automatic Power Factor Correction (APFC) system using the Proteus software environment, aimed at improving the power factor of electrical systems operating under varying load conditions.

The project was done by deploying an Arduino Uno microcontroller-based control logic, supported by zero-crossing detectors to convert voltage and current waveforms into square signals for accurate phase difference and power factor calculation. The experimental setup was designed and simulated using Proteus 8 Professional software. The Proteus simulation replicates the real-time operation of the APFC system, enabling precise observation of voltage and current waveforms, zero-cross detection, and automatic capacitor switching. A resistive load and an inductive load were modelled to test the system's capability to measure and correct the power factor dynamically.

Simulation results showed a significant improvement in power factor after correction, confirming the effectiveness of the control strategy. Base load of 30mH; 60mH; 30mH and 60mH; 30mH and 90mH; 60mH and 120mH; 30mH, 60mH, 120mH and 90mH; had power factors of 0.87; 0.84; 0.78; 0.60; 0.58

respectively, but recorded tremendously improved power factors of 1.00; 0.91; 0.98; 0.95; 0.98 respectively after correction. As load increases, the system automatically activates additional capacitors to offset the rise in reactive power demand, thereby enhancing voltage stability, reducing energy losses, and improving overall power efficiency.

.

CERTIFICATION .....	i
DEDICATION.....	iv
ACKNOWLEDGEMENT.....	v
ABSTRACT.....	vi
CHAPTER ONE .....	1
INTRODUCTION .....	1
1.1 Background of the Study.....	1
1.2 Problem Statement .....	2
1.3 Aim of the Project .....	3
1.4 Objectives of the Project .....	3
1.5 Relevance of Project.....	3
1.6 Research Method.....	4
CHAPTER TWO .....	5
2.1.1 Power Factor .....	5
2.1.2 Methods of Power Factor Correction.....	6
2.2 Components And Their Descriptions.....	8
2.2.1.1 Capacitor .....	8
2.2.1.2 Capacitor Bank.....	9
2.2.1.3 Capacitor Switching.....	9
2.2.2 Relay or Contactor .....	11
2.2.3 Current Transformer (CT).....	11

2.2.4 Voltage Divider Circuit.....	12
2.2.5 Zero-Cross Detection Circuit.....	13
2.2.6 LCD (Liquid Crystal Display) .....	13
2.2.7 Diodes .....	14
2.2.8 Resistors.....	15
2.2.9 Optocouplers.....	15
2.2.10 Transistors.....	16
2.2.11 Power Supply Unit (PSU).....	16
2.2.12 Proteus Design Suite.....	17
2.3 Factors Affecting Power Factor.....	17
2.4 Previous Studies on Automatic Power Factor Correction Systems.....	18
2.5 Application of Power Factor Correction.....	21
2.6 Impact of Poor Power Factor Correction.....	23
CHAPTER THREE .....	28
METHODOLOGY .....	<b>Error! Bookmark not defined.</b>
3.1 Experimental Setup.....	28
3.2 Instrumentation and Measurement Techniques .....	29
3.2.1 Testing Protocol for Different Load Conditions.....	37
CHAPTER FOUR.....	51
RESULTS AND DISCUSSION .....	51
4.1 Data Analysis.....	51

4.2 Discussion of Findings.....	53
4.3 Implications of Results .....	62
CHAPTER FIVE CONCLUSION AND RECOMMENDATIONS .....	65
5.1 Conclusions.....	65
5.2 Recommendations.....	66
REFERENCES .....	68
APPENDIX.....	72

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background of the Study

For modern electrical power systems to operate at their best and be cost-effective, energy efficiency and power quality are essential components (Ghosh and Ledwich, 2002). The power factor, a crucial metric that measures how efficiently electrical power is being used, has a major impact on both. Power factor is a number between 0 and 1 that is defined as the ratio of real power (kW) to apparent power (kVA). Low power factor is a sign of inefficiency that leads to increased demand charges, higher losses in the electrical system, and overloading of transformers and generators, among other equipment (Kothari and Nagrath, 2011).

Inductive loads, like motors, transformers, and fluorescent lights, are common in commercial and industrial settings and draw reactive power (kVAR), resulting in a lagging power factor. Historically, power factor correction has been accomplished through manually operated capacitor banks; however, manual systems are not flexible enough to react dynamically to changing load conditions (Gupta, 2012).

The development of Automatic Power Factor Correction (APFC) systems, which employ microcontrollers or programmable logic controllers (PLCs) to continuously monitor the power factor and automatically switch capacitor banks in and out of the circuit as needed, has been made possible by these limitations (Ghosh and Ledwich, 2002). The APFC system has become an essential part of modern power distribution networks, helping to achieve energy efficiency, lower operating costs, and extend the lifespan of electrical equipment. It also improves power factor, reduces energy losses,

improves voltage regulation, and minimizes utility company penalties for low power factor (Ghosh and Ledwich, 2002).

## **1.2 Problem Statement**

Low power factor is a common and persistent problem in electrical systems, particularly those that involve machinery and inductive loads such as motors, pumps, welding machines, and air compressors (Kothari and Nagrath, 2011). Inductive machines naturally draw reactive power, which is required to maintain magnetic fields but does no useful work. This leads to a lagging power factor, which is frequently much lower than the optimal value of 1.0 (Gupta, 2012).

Numerous technical and financial issues arise when the power factor is decreased:

Firstly, When the power factor is low, more apparent power is needed to provide the same amount of real power (kW). Higher capital and operating costs result from the need for larger capacity equipment (transformers, cables, switchgear) (Ghosh and Ledwich, 2002).

Again, A low power factor puts more current into the system, which raises  $I^2R$  losses (copper losses) in transformers and cables. This lowers system efficiency and can lead to overheating (Kothari and Nagrath, 2011).

Greater voltage drops brought on by excessive reactive power flow result in inadequate voltage regulation and may have an impact on the lifespan and functionality of delicate equipment (Gupta, 2012).

Because low power factor strains the grid, electricity companies frequently impose penalties on commercial and industrial customers. These reactive energy charges may result in higher electricity bills for users (Ghosh and Ledwich, 2002).

The electricity distribution network's effective capacity is decreased, allowing for the support of fewer loads without modifications, which results in inefficiency and increased expenses (Ghosh and Ledwich, 2002)

### **1.3 Aim of the Project**

The aim of this research is to design and develop an Automatic Power Factor Correction (APFC) system that can monitor and improve the power factor of an electrical system by automatically switching capacitor banks based on load conditions.

### **1.4 Objectives of the Project**

- i.** Conduct a comprehensive literature review on power factor correction methods, capacitor switching techniques, and their relevance in improving energy efficiency in electrical systems.
- ii.** Design and simulate an automated power factor correction system using Proteus to evaluate its performance under various load conditions.
- iii.** Implement a microcontroller-based control system capable of detecting lagging power factor conditions and automatically switching appropriate capacitor banks for correction.
- iv.** To collect and analyze data on power factor, voltage, current, and reactive power before and after correction to assess system effectiveness.

### **1.5 Relevance of Project**

The analysis of the APFC system holds several key relevance points:

- **Energy Efficiency:** With increasing energy consumption globally, improving power factor can significantly reduce the energy consumed by industrial and commercial setups, which contributes to both cost savings and energy conservation.

- **Regulatory Compliance:** Many utilities impose penalties for low power factors. Therefore, ensuring the proper functioning of an APFC system helps businesses avoid such penalties.
- **Economic Benefits:** Businesses can avoid paying higher electricity charges due to poor power factor, leading to reduced operational costs.
- **Sustainability:** By enhancing the efficiency of power use, an APFC system supports sustainable energy practices, reducing the carbon footprint of the organization.

## **1.6 Research Method**

Proteus Design Suite is used as a simulation tool in the research and development of Automatic Power Factor Correction (APFC) systems. It allows for the modeling of electrical circuits and the integration of microcontrollers to test control logic for switching capacitor banks. With Proteus, researchers can simulate power factor behavior under varying loads, making it easier to identify and correct design issues before hardware implementation. This reduces development time and cost while improving system accuracy and reliability.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Introduction to Electrical Power

Electrical power refers to the rate at which electrical energy is transferred or consumed in an electrical circuit. It is a measure of how much energy is used per unit of time and is typically measured in watts (W) (Kothari and Nagrath, 2011).

$$P = VI \cos \theta \dots\dots\dots (2.1)$$

##### 2.1.1 Power Factor

The efficiency with which electrical power is used in a system is indicated by its power factor. It is defined as the ratio of real power, or the power that really does useful work, measured in kilowatts (kW) (Gupta, 2012) to apparent power, or the overall power supplied to the circuit, measured in kilovolt-amperes (kVA).

$$\text{Power Factor} = \frac{\text{Real Power (kW)}}{\text{Apparent Power (kVA)}} \dots\dots\dots (2.2)$$

- i. **Real Power (kW)** refers to the portion of electrical power that is actually used by devices to perform meaningful work, such as turning a motor or lighting a bulb (Kothari and Nagrath, 2011).
- ii. **Apparent Power (kVA)** is the total power supplied to the circuit. It is the combination of both real and reactive power, calculated as the product of voltage and current, regardless of phase angle (Gupta, 2012).
- iii. **Reactive Power (kVAR)** represents the power that oscillates between the source and reactive components (like inductors and capacitors). Although it doesn't perform any useful work, it is essential for maintaining the magnetic and electric fields required by inductive or capacitive equipment (Wildi, 2006).

The **power factor** is expressed as a value between 0 and 1. A power factor of 1.0, also known as **unity power factor**, signifies optimal efficiency—where all the electrical power drawn from the supply is effectively converted into useful work. On the other hand, a lower power factor (typically below 0.9) signals poor utilization of electrical power, as a considerable amount is consumed by non-productive reactive components, leading to wasted energy and reduced system performance (Gupta, 2012; Wildi, 2006).

### 2.1.2 Methods of Power Factor Correction

Power factor correction (PFC) can be achieved in several ways, depending on the specific needs of the system.

- I. **Capacitor Banks** are the most common method. Capacitors provide reactive power to the system, helping to balance the inductive reactive power caused by inductive loads. By supplying leading reactive power, they offset the lagging reactive power from devices like motors, improving the overall power factor (Gupta, 2012).
  - **Static Capacitors** provide a fixed amount of reactive power.
  - **Automatic Capacitor Banks** use relays or contactors to switch capacitor units in or out based on real-time power factor measurements (Wildi, 2006).
- II. **Synchronous Condensers** are unloaded synchronous motors that generate reactive power and are typically used in high-power industrial systems where larger adjustments are needed (Kothari and Nagrath, 2011).
- III. **Phase Advancers** are applied in large induction motor systems to advance the current's phase angle, thus reducing reactive power demand (Gupta, 2012).

- IV. **Active Power Factor Correction (APFC)** involves using power electronic components like IGBTs, MOSFETs, or controlled rectifiers to shape the input current waveform and bring it in phase with the voltage. This method is widely used in sensitive electronic systems such as computers and LED lighting (Wildi, 2006).
- V. **Improved Load Management** is a preventive strategy that aims to reduce unnecessary reactive power consumption by using energy-efficient equipment and maintaining balanced and consistent load profiles (Kothari and Nagrath, 2011). More widely used devices are Flexible AC Transmission Systems (FACTS) devices. Flexible AC Transmission Systems (FACTS) are power-electronic-based devices designed to enhance the controllability, stability, and power transfer capability of AC systems through dynamic control of voltage, impedance, and phase angle (Hingorani and Gyugyi, 2000).

In the context of Automatic Power Factor Correction (APFC), FACTS devices serve as advanced reactive power compensators, automatically adjusting the system's reactive power in real time to maintain the power factor near unity. Unlike conventional switched capacitor banks, which operate in discrete steps, FACTS devices provide continuous and fast compensation, making them particularly effective in systems with rapidly changing or unbalanced loads (Wang et al., 2021; Psillakis and Alexandridis, 2020).

The most relevant FACTS devices for APFC are shunt-connected types, such as the Static VAR Compensator (SVC) and the Static Synchronous Compensator (STATCOM). An SVC uses thyristor-controlled reactors and thyristor-switched

capacitors to supply or absorb reactive power, making it suitable for voltage regulation and large-scale reactive power compensation in industrial plants and transmission substations (Psillakis and Alexandridis, 2020). STATCOM, based on voltage-source converter (VSC) technology, offers faster and more precise var control, with the ability to maintain full reactive current even during voltage sags, making it ideal for dynamic loads such as electric arc furnaces and crane systems (Chang and Liao, 2017; Rafi et al., 2022). Hybrid APFC systems combine a STATCOM with switched capacitor banks, supplying steady-state vars from the capacitors while using the STATCOM for transient or unbalanced load compensation (Rafi et al., 2022).

While FACTS devices offer superior speed, precision, and performance over conventional APFC methods, they also have notable drawbacks. These include high capital cost, complex control requirements, and the need for skilled operation and maintenance (Tariq et al., 2022).

## **2.2 Components And Their Descriptions**

### **2.2.1.1 Capacitor**

A capacitor is a passive electrical device with two terminals that stores energy in the form of an electrostatic field. Its ability to resist rapid voltage fluctuations and exchange reactive power makes it particularly effective for use in alternating current (AC) systems. Because of these characteristics, capacitors play a vital role in compensating for reactive power in systems heavily loaded with inductive elements (Wildi, 2006).

Inductive components such as electric motors, transformers, and fluorescent lamps typically cause the current to lag behind the voltage, resulting in a reduced or lagging power factor. By introducing a leading current into the system, capacitors provide the necessary reactive power to counteract the inductive effects, thus helping to correct and improve the overall power factor (Kothari and Nagrath, 2011).

### **2.2.1.2 Capacitor Bank**

A capacitor bank is an arrangement of multiple capacitors connected either in parallel or series-parallel configurations to collectively supply reactive power to an electrical system. In AC circuits with inductive loads (like motors, fans, compressors), the current lags behind the voltage, resulting in a lagging power factor. Capacitors, by nature, produce a leading current, which counteracts the lagging reactive power produced by inductive components (Kothari and Nagrath, 2011).

In the APFC system, the capacitor bank is divided into stages (typically 2–4 banks). Each stage can be independently switched in or out of the system by relays. This staged design allows fine-grained control of the total capacitance added to the system, helping to dynamically correct the power factor depending on the varying inductive load conditions. When the power factor drops below a set threshold (e.g., 0.9), the Arduino activates one or more capacitor banks to compensate and bring the power factor closer to unity (Gupta, 2012).

### **2.2.1.3 Capacitor Switching**

Effective power factor correction depends heavily on how capacitors are introduced into or removed from the electrical system. Improper switching can lead to problems

such as voltage spikes, equipment stress, or harmonic distortion. To address these challenges, several capacitor switching strategies are employed:

### **Electromechanical Switching (Using Contactors)**

This method utilizes contactors—mechanical relays activated by electrical signals—to control the connection of capacitor banks.

- v. **Operation:** The contactor physically closes or opens a circuit in response to a control signal (Wildi, 2006).

### **Static Switching (Using SCRs or Thyristors)**

This technique replaces mechanical contactors with semiconductor devices such as Silicon Controlled Rectifiers (SCRs), which allow for faster, more precise control.

- vi. **Operation:** Capacitor banks are engaged at specific points in the AC cycle—typically at zero current—to minimize electrical disturbance (Ghosh and Ledwich, 2002).

### **Hybrid Switching**

This method merges both electromechanical and static approaches to leverage their respective strengths.

- vii. **Operation:** SCRs are used to initiate the connection—suppressing inrush currents—while contactors maintain the connection thereafter (Kothari and Nagrath, 2011).

### **Intelligent Control (Microcontroller or PLC-Based)**

This advanced method involves the use of a microcontroller (e.g., Arduino) or a programmable logic controller (PLC) to manage the switching process.

- viii. **Operation:** The controller constantly monitors parameters like voltage, current, and phase angle, then computes the power factor in real time to determine how many capacitor stages should be engaged or disengaged (Monk, 2013).

### 2.2.2 Relay or Contactor

A **relay** is an electromechanical switch that allows low-voltage control of a high-voltage circuit. It consists of a coil that, when energized, creates a magnetic field to close or open a set of electrical contacts. In this project, the relay is controlled by the Arduino Uno's digital output pins, which toggle the state of the relay to connect or disconnect the capacitor banks (Wildi, 2006).

The purpose of relays in the APFC system is to:

- ix. Isolate the low-voltage control circuit (Arduino) from the high-voltage capacitor bank circuit.
- x. Switch capacitor banks on or off based on the real-time calculated power factor.
- xi. Automate the correction process with no manual intervention.

For industrial applications, **contactors** are used instead of relays because they are designed to handle larger currents and voltages and are more durable under frequent switching (Gupta, 2012).

### 2.2.3 Current Transformer (CT)

A Current Transformer (CT) is a device used to safely monitor high AC currents by producing a scaled-down replica of the current waveform. It operates on the principle of electromagnetic induction and is typically toroidal (doughnut-shaped), with the

current-carrying conductor passing through its center (Wildi, 2006).

In this APFC system, the CT serves two critical functions:

1. **Current Measurement:** It outputs a low-voltage AC signal proportional to the line current, which is safe to interface with the Arduino after signal conditioning.
2. **Phase Angle Calculation:** The current waveform is compared to the voltage waveform to measure the phase difference (delay angle). This delay is used to calculate the power factor using trigonometric or timing methods (Gupta, 2012). The CT is essential for detecting load changes, which affect power factor, thus triggering capacitor bank adjustment (Kothari and Nagrath, 2011).

#### 2.2.4 Voltage Divider Circuit

The Voltage Divider is a passive linear circuit made from two or more resistors arranged in series. It is used to reduce a high input voltage to a lower output voltage proportionally, based on the ratio of the resistors (Malvino and Bates, 2016).

In this APFC system:

- The voltage divider is connected to the AC voltage line through a protective circuit (diode, optocoupler, or transformer).
- It scales down the mains AC voltage to a voltage level within the 0–5V range required by the Arduino's analog input pins.
- The scaled-down voltage signal is used for zero-crossing detection and to ensure synchronization with the current waveform for accurate power factor computation (Horowitz and Hill, 2015).

**Safety Note:** Since AC mains are involved, proper isolation and protection must be used (e.g., using a transformer or opto-isolator) to prevent damage to the Arduino and ensure user safety.

### **2.2.5 Zero-Cross Detection Circuit**

The Zero-Cross Detection Circuit identifies the precise moment when the AC voltage or current waveform crosses the zero-voltage point (0V). This moment is used as a timing reference to measure the phase difference between the voltage and current waveforms, which is a direct indicator of the power factor (Wildi, 2006). Here's how it works in the APFC system:

- The circuit usually uses optocouplers (e.g., PC817 or H11AA1) or comparators (like LM358) to detect zero crossing.
- When the AC waveform transitions from positive to negative (or vice versa), the output signal changes state.
- The Arduino uses interrupts to capture the exact time at which these crossings occur for both voltage and current.
- By calculating the time delay between the zero-cross points of voltage and current, the Arduino determines the phase angle ( $\Phi$ ), and hence the power factor (Gupta, 2012).

### **2.2.6 LCD (Liquid Crystal Display)**

An LCD (Liquid Crystal Display) is a flat-panel display technology commonly used to provide visual feedback in electronic systems. In this APFC system, the 16x2 LCD display (with I2C communication) is used to display real-time information, such as:

- Voltage across the load.
- Current flowing through the system.
- Power factor value.
- Relay status, indicating whether a capacitor bank is connected or disconnected (Monk, 2013).

I2C communication reduces the number of required pins on the Arduino. The LCD display communicates with the Arduino via the I2C protocol, using just two data pins (SDA and SCL) for communication, which is especially useful in systems with limited GPIO pins.

### **2.2.7 Diodes**

A diode is a semiconductor device that allows current to flow in only one direction (forward direction) and blocks it in the reverse direction. In the APFC system, diodes are typically used for:

- **Rectification:** In case the system needs to convert AC voltage to DC, diodes are used in a rectifier circuit (for example, a bridge rectifier).
- **Protection:** Diodes can protect sensitive components like the Arduino from voltage spikes by being placed across the input voltage or relay circuits (commonly referred to as fly back diodes) (Malvino and Bates, 2016).

For instance, in your relay circuits, flyback diodes (like 1N4007) are placed in parallel with the relay coils to protect the circuit from voltage spikes caused by the inductive load when the relay switches off (Horowitz and Hill, 2015).

### 2.2.8 Resistors

A resistor is a passive electrical component that resists the flow of current. It is used in this experiment for several purposes:

- I. **Current Limiting:** In voltage divider circuits, resistors limit the current flowing through components to ensure safe operation.
- II. **Signal Conditioning:** Resistors help in shaping signals, such as those from current transformers (CTs), by providing necessary load or biasing for active components like transistors or operational amplifiers.
- III. **Pull-Up/Pull-Down Resistors:** These resistors are used to ensure that inputs to the Arduino are either pulled up to a high voltage or pulled down to ground, preventing floating input values (Horowitz and Hill, 2015).

Resistors are also essential in the design of the zero-cross detection and voltage divider circuits.

### 2.2.9 Optocouplers

An optocoupler (also known as an optoisolator) is an electronic component that transfers electrical signals between two isolated circuits by using light. In the APFC system, optocouplers are critical for isolation between the high-voltage AC components and the low-voltage control circuit (Arduino) (Wildi, 2006).

For example:

- I. **Zero-Cross Detection:** Optocouplers isolate the AC voltage sensing line from the microcontroller while still transmitting signal changes for zero-crossing detection.
- II. **Relay Control:** Optocouplers provide electrical isolation to protect the Arduino and other low-voltage components from high-voltage spikes (Malvino and Bates, 2016).

### 2.2.10 Transistors

A transistor is a semiconductor device that can amplify or switch electronic signals. In the APFC system, transistors are typically used as switching elements for controlling relays or other high-power components.

- I. **Switching Relays:** Transistors (e.g., 2N2222) allow the Arduino to energize relay coils by acting as switches.
- II. **Signal Amplification:** Transistors can also amplify low-voltage signals from sensors (e.g., CTs) to readable levels for microcontrollers (Horowitz and Hill, 2015).

### 2.2.11 Power Supply Unit (PSU)

The Power Supply Unit (PSU) is responsible for providing stable and regulated DC power to the microcontroller (Arduino) and other components.

- I. **AC to DC Conversion:** Converts 230V AC to usable DC voltage (usually 5V/9V) for the system.
- II. **Voltage Regulation:** Ensures a consistent voltage level regardless of input fluctuation using voltage regulators like 7805 (Malvino and Bates, 2016).

### 2.2.12 Proteus Design Suite

Proteus Design Suite is a simulation and PCB design software used for testing circuit designs virtually.

- I. **Simulation:** Enables simulation of the APFC system before real-world implementation.
- II. **Microcontroller Programming:** Supports Arduino code integration in the simulation environment.
- III. **Component Behavior:** Models and tests behavior of real components under varying conditions (Ibrahim, 2012).

### 2.3 Factors Affecting Power Factor

Power factor is the ratio of real power (kW) to apparent power (kVA) in an electrical system (Kothari and Nagrath, 2011).

Key influencing factors include:

- a) Load Type:
  - *Inductive Loads* like motors and transformers cause current to lag, increasing reactive power and lowering PF.
  - *Capacitive Loads* cause current to lead, which can help correct PF.

- b) **Harmonics:** Non-linear loads introduce waveform distortion, increasing kVA without increasing useful work (Ghosh and Ledwich, 2002).
- c) **Load Variation:** Light and full load conditions affect how much real vs. apparent power is used.
- d) **Voltage Fluctuations:** Low voltage can reduce motor efficiency; high voltage may cause energy waste.
- e) **Age of Equipment:** Aging equipment becomes less efficient, increasing losses and degrading power factor (Gupta, 2012).

#### 2.4 Previous Studies on Automatic Power Factor Correction Systems

There have been various studies and implementations of automatic power factor correction systems. Some notable studies include:

**Talha Akhtar (2023)** designed a microcontroller-based APFC system using the AT89C51 controller. The project reads the phase difference between line voltage and line current using zero-crossing detectors, calculates the power factor, and actuates capacitor banks accordingly through relay drivers. The microcontroller manages user interface elements such as LCD displays and error indication via buzzers. The system also integrates software-based delay algorithms to fine-tune the phase angle measurement, enabling more precise compensation.

Akhtar's system offers a structured modular design, including components like power supply units, zero-crossing detectors, and capacitor bank switching. His use of an 8051 microcontroller, although widely supported, may limit computational efficiency and flexibility when compared to more modern platforms like the Arduino or STM32 series.

Additionally, the reliance on fixed and switched capacitor banks may restrict dynamic adaptability under rapidly varying load conditions.

**MATEC Conference Paper (2018)** presented an APFC system using a combination of microcontroller logic and switched capacitor banks with relay-based control. Their work emphasized low-cost implementation, targeting small-scale commercial or residential applications. The system relies on delay measurement between voltage and current waveforms to compute phase difference and hence power factor.

This design, while effective for steady-state load correction, lacks advanced features such as real-time harmonic detection or dynamic load prediction. It is more appropriate for environments with predictable, moderately varying inductive loads.

**CORE.ac.uk Report (2015)** approached APFC from a broader theoretical and practical perspective. The system employed sensors to measure voltage and current in real-time, calculating the power factor using phase angle estimation and switching capacitors via microcontrollers. The focus was on enhancing stability, reducing energy bills, and eliminating penalties from utility companies due to lagging power factor.

While the report illustrates foundational concepts well, it lacks in-depth hardware design details or novel algorithmic strategies. The project appears to favor reliability and ease of maintenance over computational innovation, making it suitable for educational or small industrial environments.

**Shinde et al. (2024)** developed a hardware-based Automatic Power Factor Correction (APFC) system utilizing an Arduino microcontroller. The system measures the phase difference between voltage and current using zero-crossing detectors, calculates the power factor, and engages capacitor banks through electromagnetic relays to correct

lagging power factor. Voltage and current inputs are taken from potential and current transformers, scaled appropriately for safe microcontroller input, and processed in real-time.

Their setup includes a modular power supply system, sensing units, relay-based capacitor switching, and an assumed user interface (such as LEDs or an LCD). The design was fully constructed and tested with live inductive loads, demonstrating an improvement in power factor from 0.76 to 0.97. This confirms the system's effectiveness in practical applications and its suitability for residential or industrial use. However, the use of electromechanical relays may introduce wear over time and slower switching speeds compared to solid-state alternatives.

**The IJEAIS (2020)** project focused on the simulation of an Arduino-based APFC system. The model uses current and voltage sensors along with zero-crossing detectors to measure the phase angle between input waveforms. The Arduino logic interprets these values to compute the power factor and then triggers simulated relays to connect or disconnect capacitor banks in a virtual environment.

This design was not physically constructed but was tested in simulation using likely platforms such as Proteus. The system improved power factor from 0.66 to approximately 0.92 in the simulated tests, demonstrating proof of concept. While the simulation allowed for rapid iteration and controlled testing, it lacks validation under real-world electrical conditions, including noise, load variation, and relay behavior.

There are three main microcontrollers that were used in these previous studies, namely: AT89C51, an 8051 microcontroller, then a PIC16PF877A, and an Arduino Uno. Each have their different specifications, advantages and disadvantages.

The **Talha Akhtar (2023)** and **CORE.ac.uk Report (2015)** models, use of an 8051 microcontroller, although widely supported, may limit computational efficiency and flexibility when compared to more modern platforms like the Arduino or STM32 series.

**MATEC Conference Paper (2018)** utilized the PIC16F877A, which has the limitation for applications like **real-time phase angle detection**, rapid interrupt handling, or fast switching in APFC, higher performance can improve accuracy and response time.

**Shinde et al. (2024)** and **The IJEAIS (2020)** made use of Arduino which offers faster response times and finer compensation granularity.

For modern APFC systems—especially with real-time, multi-stage capacitor banks, or remote monitoring—the **PIC16F877A is outdated**. A more developer-friendly, scalable, and precise alternative would be **Arduino Uno (ATmega328P)** for prototyping.

Hence for this project, the Arduino will be used for simulation purposes because of the ease in application in proteus and the programming software is also very user friendly.

## **2.5 Application of Power Factor Correction**

**Power factor correction** is used in various industries and applications to improve energy efficiency and reduce costs:

### **I. Industrial**

### **Plants:**

Power factor correction is crucial in large industrial plants where the demand

for inductive power is high. Poor power factor in these environments can result in large electricity bills, penalties from utilities, and inefficient use of electrical energy. Capacitor banks or synchronous motors are often used for correction (Rashid, 2014; Islam, 2019).

**II. Commercial Buildings:**

Office buildings, malls, and commercial facilities use power factor correction systems to improve the power factor and reduce electrical demand charges. Capacitors or APFC systems are commonly implemented to minimize penalties from power companies and reduce electricity consumption (Arrillaga and Watson, 2003; IEEE, 2010).

**III. Data Centers and IT Equipment:**

Data centers, which house many computers and servers, benefit from power factor correction to maintain efficient power usage. The large number of inductive loads (like fans and cooling systems) in data centers necessitate proper power factor correction to prevent energy waste (McDonald, 2017; U.S. Department of Energy, 2021).

**IV. Electric Vehicles (EV) Charging Stations:**

With the rise in electric vehicle charging stations, power factor correction is becoming increasingly important to ensure the efficient operation of the charging infrastructure. These stations often use inductive loads, which can benefit from APFC systems (Emadi, 2014; Ehsani, Gao, and Gay, 2018).

**V. Renewable Energy Systems:**

In renewable energy systems (solar, wind), power factor correction can help stabilize the voltage and improve the overall efficiency of the system. Some solar inverters incorporate active power factor correction to ensure that the

system operates at a high power factor (Kroposki et al., 2015; Kjaer, Pedersen, and Blaabjerg, 2005).

## **2.6 Impact of Poor Power Factor Correction**

A poor power factor can have significant negative effects on both the electrical system and the overall efficiency of power usage. These impacts can result in increased energy costs, equipment damage, and inefficient power distribution. Below are the key consequences of poor power factor correction:

### **Increased Energy Costs**

- i. **Higher Bills:** Utility companies typically charge businesses and industries more if the power factor is low. A poor power factor increases the total apparent power (kVA) drawn from the grid, even though a large portion of it is reactive and does not perform useful work. This results in higher electricity costs, as utilities may impose penalties for low power factor values (Kothari and Nagrath, 2011).
- ii. **Penalty Charges:** Many utility companies impose penalty charges when the power factor drops below a certain threshold (usually 0.9 or 0.95). These penalties are charged to encourage customers to maintain a high power factor, as a low power factor causes inefficient use of the electrical network (Gupta, 2012).

### **Increased Power Losses**

- i. **Transmission Losses:** In electrical transmission lines, the current flow is directly proportional to the power loss. When the power factor is low, the system needs to supply more apparent power to meet the same load demand, which increases the current flowing through the transmission lines. This higher current leads to higher losses due to the resistance of the transmission lines, resulting in energy wastage (Wildi, 2006).
- ii. **Inefficient Use of Equipment:** Increased current also means that more energy is lost in the form of heat in electrical components, such as transformers, cables, and circuit breakers. This causes overall system inefficiency (Kothari and Nagrath, 2011).

### **Overloaded Equipment**

- i. **Overheating of Equipment:** Low power factor results in higher current, which can lead to the overheating of electrical equipment such as transformers and motors. Overloaded equipment is prone to failures and may need more frequent maintenance (Wildi, 2006).
- ii. **Reduced Equipment Life:** Prolonged operation under a low power factor condition stresses electrical equipment, shortening its lifespan. Overheating and high currents cause additional wear and tear, which can lead to costly repairs or replacements (Gupta, 2012).

### **Reduced Capacity of the System**

- i. **Less Load Handling:** A system with a low power factor consumes more apparent power to supply the same real power, reducing the system's capacity to handle additional loads. This means that the electrical infrastructure (e.g.,

transformers, distribution panels) is underutilized, and the capacity for future expansion is limited (Kothari and Nagrath, 2011).

- ii. **Increased Demand on Electrical Infrastructure:** Since low power factor increases current flow, electrical equipment needs to be rated for higher capacities. This results in an inefficient use of resources and limits the ability to efficiently utilize the full capacity of the system (Wildi, 2006).

### **Voltage Drop and Instability**

- i. **Voltage Instability:** A poor power factor, particularly when the current is high due to inductive loads, can cause voltage instability in the electrical distribution network. This can lead to flickering lights, poor performance of sensitive electronic equipment, and the risk of voltage sags (Kothari and Nagrath, 2011).
- ii. **Overvoltage or Undervoltage Conditions:** When the power factor is poor, electrical systems may experience frequent voltage fluctuations. This can damage sensitive equipment like computers, communication devices, and other electronics that rely on stable voltage levels (Ghosh and Ledwich, 2002).

### **Harmonics and Distortion in Power Quality**

- i. **Introduction of Harmonics:** Certain types of non-linear loads, like rectifiers, inverters, and electronic devices, can introduce harmonics into the electrical system. These harmonics further degrade the power factor, causing more distortion and potential damage to electrical equipment (Ghosh and Ledwich, 2002).

- ii. **Power Quality Issues:** Poor power factor may also contribute to a reduction in overall power quality. Distorted current waveforms can affect sensitive devices and lead to malfunctioning or even permanent damage (Gupta, 2012).

### **Difficulty in System Monitoring and Control**

- i. **Complex System Monitoring:** Low power factor complicates system monitoring and control, as it becomes harder to distinguish between real and apparent power. This reduces the accuracy of the system's performance monitoring, making it difficult to detect faults or inefficient operation (Kothari and Nagrath, 2011).
- ii. **Increased Need for Power Factor Correction Equipment:** Without proper power factor correction, facilities may need to invest in more equipment to manage and regulate energy usage, increasing the overall operational costs (Wildi, 2006).

### **Environmental Impact**

- i. **Increased Carbon Footprint:** When the electrical system is inefficient due to low power factor, more power is drawn from the grid to meet the same demand. This leads to increased fuel consumption in power plants, particularly those reliant on fossil fuels, and results in higher carbon emissions (Gupta, 2012).
- ii. **Wasted Resources:** Poor power factor correction leads to inefficient use of electrical resources, which can also mean that more natural resources are

consumed to generate power, leading to an overall waste of energy (Kothari and Nagrath, 2011).

## CHAPTER THREE

### METHODOLOGY

#### DESIGN OF THE AUTOMATIC POWER FACTOR CORRECTION SYSTEM

This project makes use of simulation in Proteus to design and develop an Automatic Power Factor Correction (APFC) system that can monitor and improve the power factor of an electrical system by automatically switching capacitor banks based on load conditions.

Inductors are used to imitate and inductive machine or system that draws reactive power. The simulation involves the use of capacitors connected in parallel, to improve the power factor of a system that consists of inductive loads. Various combination of capacitor values are applied to the inductive system, once the overall power factor of the drops below a preset value, the simulation keeps running until the power factor is improved.

The use of Proteus for modelling and simulation of this system allows for full testing a possible practical implementation of the improvement system.

#### 3.1 Experimental Setup

The experimental setup for the Automatic Power Factor Correction (APFC) system was designed and simulated using **Proteus 8 Professional** instead of MATLAB. The system comprises a single-phase AC supply, voltage sensor (ZMPT101B), current sensor (ACS712), Arduino Uno microcontroller, relay driver circuit, capacitor bank, and load arrangements. The Proteus simulation replicates the real-time operation of the APFC system, enabling precise observation of voltage and current waveforms, zero-cross detection, and automatic capacitor switching. A resistive load and an inductive load were modelled to test the system's capability to measure and correct the power factor dynamically. The Arduino is programmed to calculate the phase angle between

voltage and current, compute the power factor, and activate the appropriate relay to connect capacitors when the PF drops below a set threshold of 0.95. An LCD module is interfaced with the Arduino to display real-time PF values and correction status.

### **3.2 Instrumentation and Measurement Techniques**

For the experimental setup of the Automatic Power Factor Correction (APFC) project using **Proteus simulation**, the fundamental instrumentation and measurement techniques involved the use of a personal computer (PC) with Proteus 8 Professional software, along with the virtual instruments and simulation models. The above instruments were utilized as follows:

#### **PC**

The HP Pavilion laptop, equipped with 8GB RAM, 1TB HDD, and a 2.4 GHz processor speed, was used as the primary interface for running the Proteus simulation. It provided the necessary computational resources to execute real-time reactive power compensation models and simulate the behavior of the APFC system under different load conditions. The 8GB RAM ensured smooth operation even with multiple sensor models and display modules running simultaneously. The large storage capacity allowed for saving project files, simulation recordings, and result logs. Its reliable performance and portability made it a practical choice for simulation-based academic research.

#### **3.2.1 Proteus Software**

Proteus 8 Professional software was used to design, model, and run the APFC circuit. The simulation incorporated the AC power supply, voltage sensor (ZMPT101B), current sensor (ACS712), Arduino Uno microcontroller, relay driver module, capacitor bank, and load models. Proteus' interactive simulation environment allowed real-time monitoring of voltage, current, phase angle, and power factor, as well as

step-by-step capacitor switching. The use of an Arduino program within the simulation enabled dynamic PF monitoring and control logic testing.

### **3.2.2 Voltage Measurement**

Within the Proteus simulation, virtual voltage probes were placed at key points in the circuit across the load and supply terminals—to measure RMS voltage values. These measurements were displayed on the simulated LCD module and were also available on the Proteus virtual oscilloscope for waveform analysis.

### **3.2.3 Current Measurement**

Current sensors (modelled as ACS712 modules) were integrated into the circuit to measure the current drawn by the load. These measurements were fed into the Arduino for real-time PF calculation. The virtual ammeters in Proteus were also used to confirm current readings for validation purposes.

### **3.2.4 Power and Power Factor Measurement**

The Arduino code calculated real power using instantaneous voltage and current samples, while the phase difference between voltage and current waveforms was used to determine the power factor. The Proteus virtual power meter and oscilloscope were used to verify these results.

### **3.2.5 Reactive Power Measurement**

Reactive power was calculated in the Arduino program based on the measured power factor and apparent power values. This allowed the system to determine the exact reactive power demand and decide on the appropriate capacitor bank switching sequence.

### **3.2.6 Control System Monitoring**

The APFC control system was implemented within the Arduino program and simulated in Proteus. It continuously monitored the voltage, current, and PF values,

and activated the relay driver to connect or disconnect capacitors based on the preset PF threshold.

### **3.2.7 Microcontroller Utilized**

The microcontroller utilized in this simulation is the Arduino Uno. It was chosen because it is developer-friendly and offers faster response times and finer compensation granularity than the other available options.

The other components utilized are as follows:

**3.2.8 OP-AMP:** Receives the waveforms of the voltage and current signals. There is a time delay as it is an inductive load, i.e. voltage lags the current by  $\Delta t$ . Two (2) op-amps are to be used, in the comparator mode, which converts sinusoidal waveforms into square waveforms. This is known as the Zero Detection Circuit.

**3.2.9 Current/Voltage Transformer:** Feeds the waveform gotten from the source into the OP-AMPS

**3.2.10 X-OR Gate:** Receives square waveform from the OP-AMP to give to give a single waveform with the  $\Delta t$ . Which helps the Arduino calculate the power factor in real time.

**3.2.11 Relay/Transistor Mechanism:** Controls the capacitor banks with the help of the Arduino. When +5v is provided in a pin of the Arduino, the transistor connected with that pin energizes a relay, which connects a capacitor with the circuit.

**3.2.12 Capacitor Bank:** Capacitors connected with to the circuit in parallel. The two values for the capacitors chosen are,  $33\mu\text{F}$  and  $47\mu\text{F}$ . Three  $33\mu\text{F}$  capacitors are used and four  $47\mu\text{F}$  capacitors are used to achieve bank values of  $47\mu\text{F}$ ,  $80\mu\text{F}$  and  $160\mu\text{F}$ . Relays are used to switch between the capacitor values required to improve the power factor of the load selected.

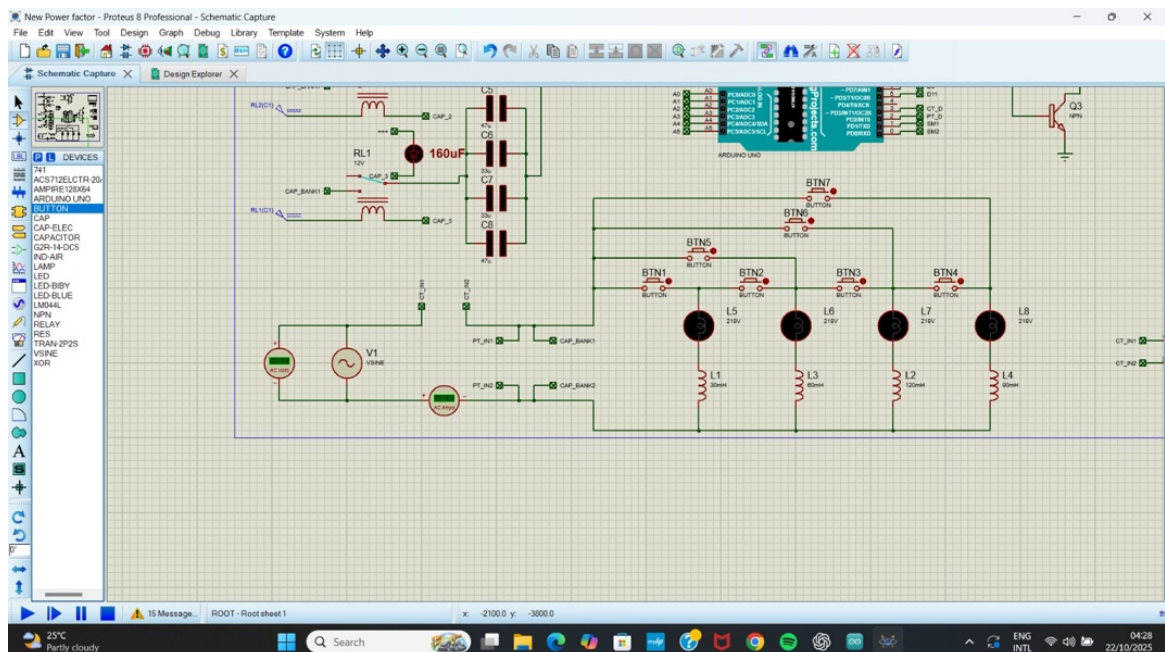
**3.2.13 Inductive System:** Used as the Inductive Load that requires the power factor correction. The values of the inductors are as follows: 30mH, 60mH, 90mH, 120mH, and the buttons are used to switch between their values and combine some too.

**Buttons:** The switches are used to adjust the values of the inductive loads

### 3.3 Circuit Operation:

The operation of the entire circuit is as follows:

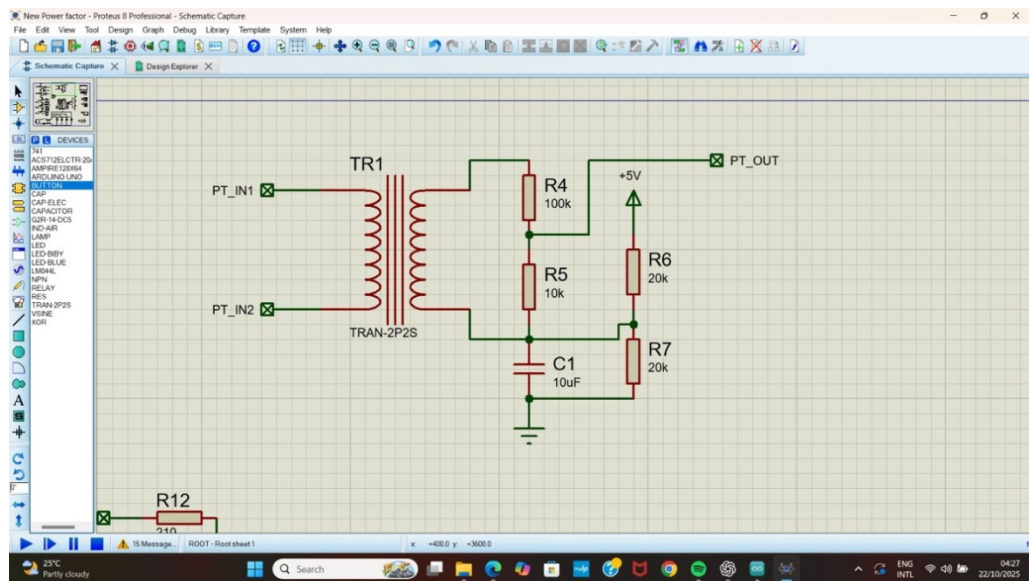
**3.3.1 Power Supply:** Power is originally supplied to the circuit by the power source, and voltage and current measuring element (voltmeter and ammeter). The voltmeter is connected in parallel and the ammeter is connected in series. The voltage and current signals lead or lag according to the type of load connected, in this case, it is inductors acting as the load, which causes a lag of current behind voltage



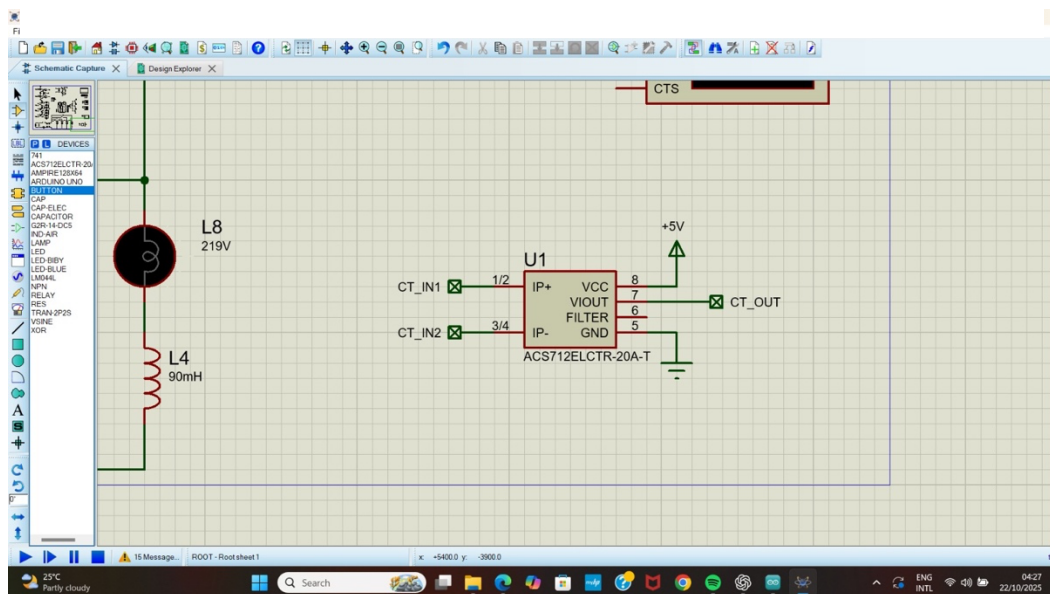
**Figure 3.1: Power Supply Circuit**

**3.3.2 Input Sensing:** The voltage and current signals are taken to the Step-down voltage transformer and the current transformer respectively. The Step down

transformers, reduce the voltage and current values significantly and takes the signal to both the Arduino and the Op-Amp circuit.

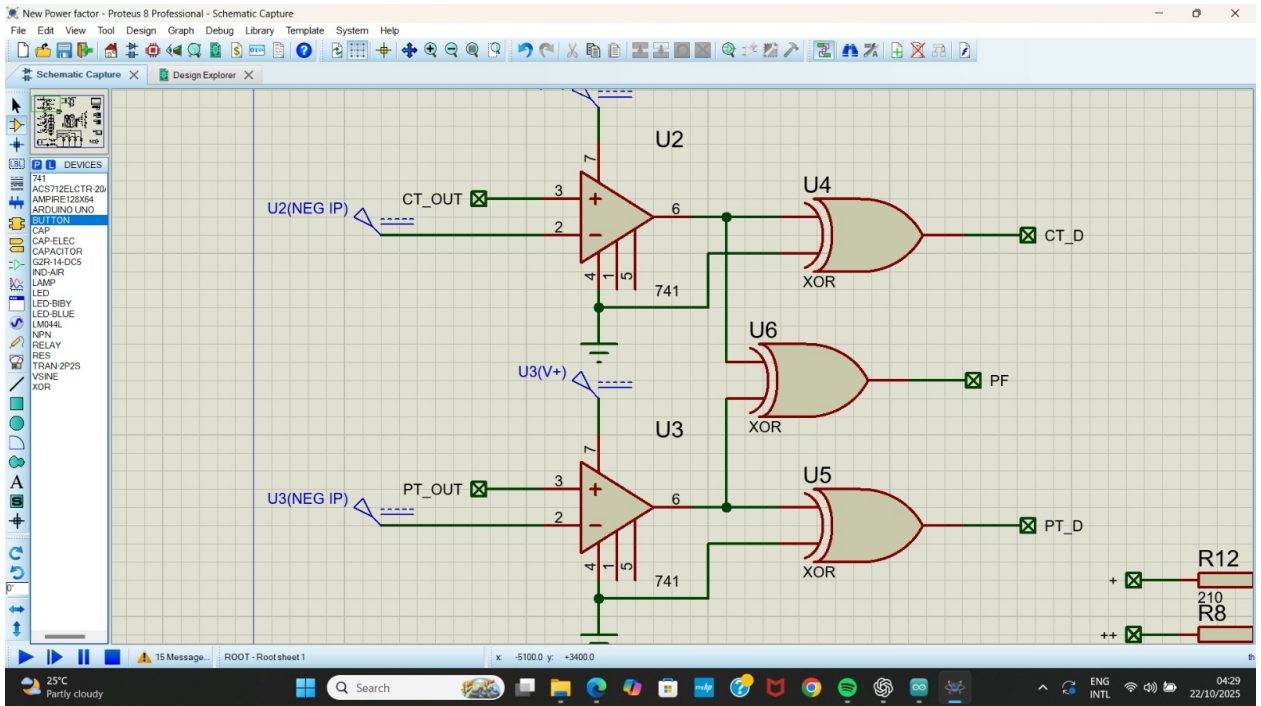


**Figure 3.2: Input Sensing Circuit**



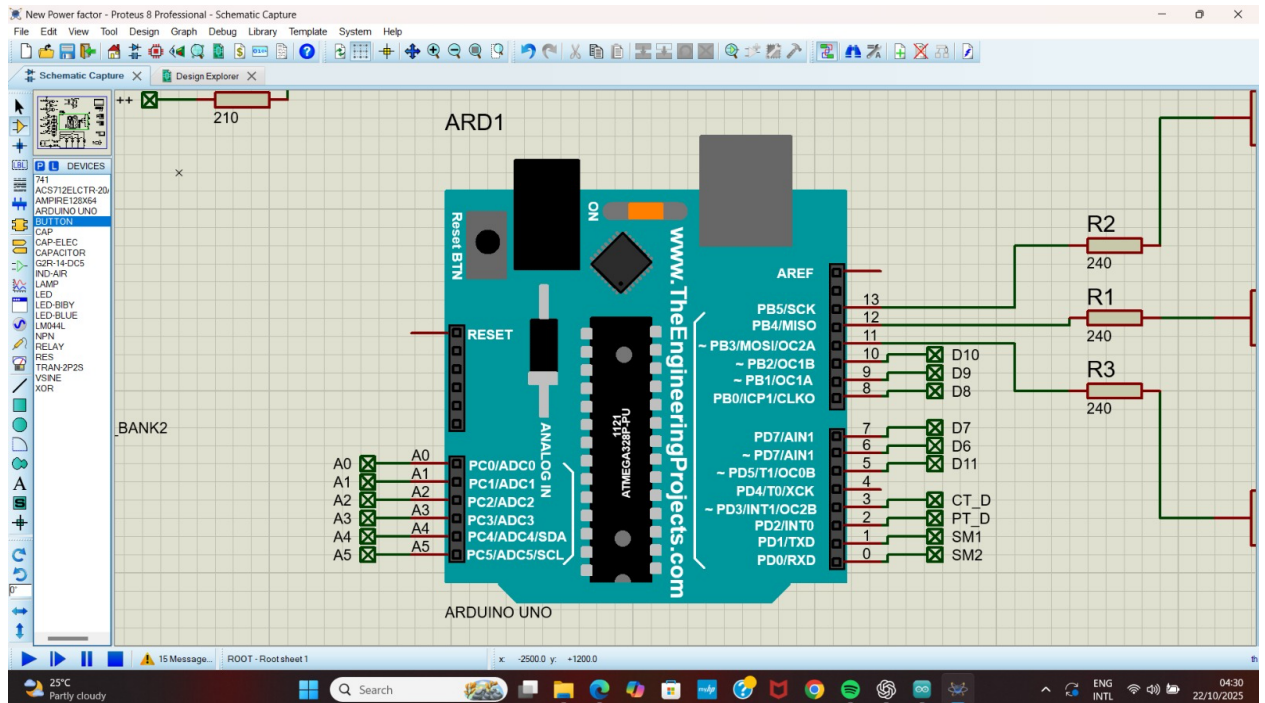
**Figure 3.3: Input Sensing IC**

**Phase Detection:** The signal from the transformer circuits are in sine waveform and there is a need to convert it to square waveform, using the op-amps in comparator mode. The XOR gate measures the phase difference.



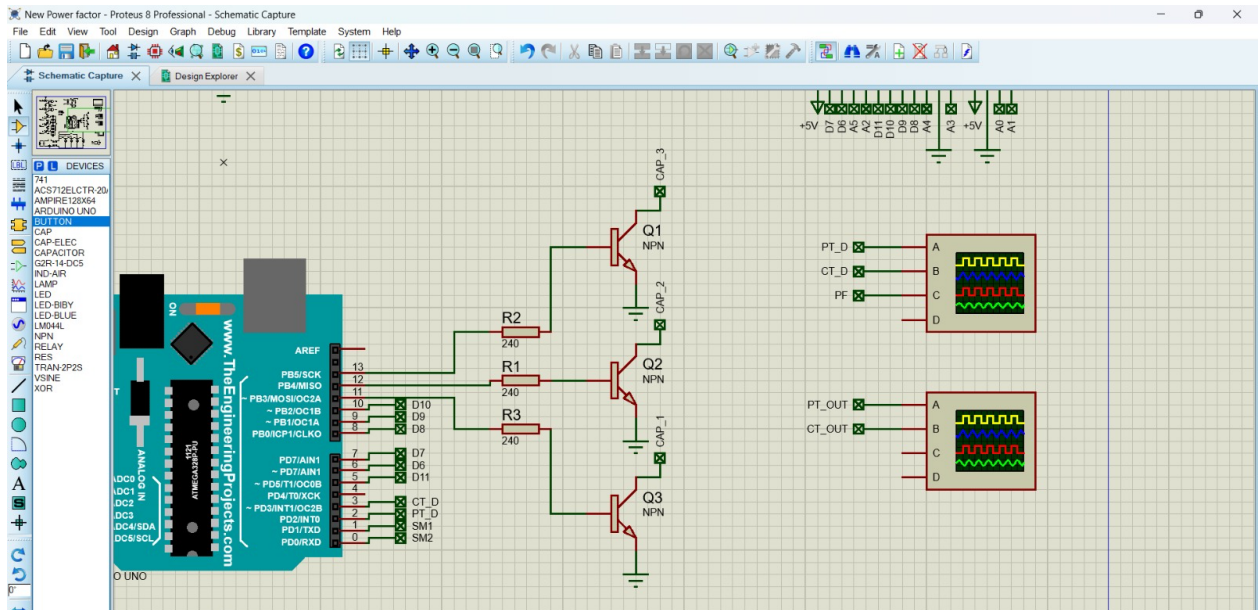
**Figure 3.4: Input Separator**

power factor and triggers the correction process if the calculated power factor is less than 0.9. The Arduino sends the signal to the capacitor bank via transistors.



**Figure 3.5: Programed Arduino**

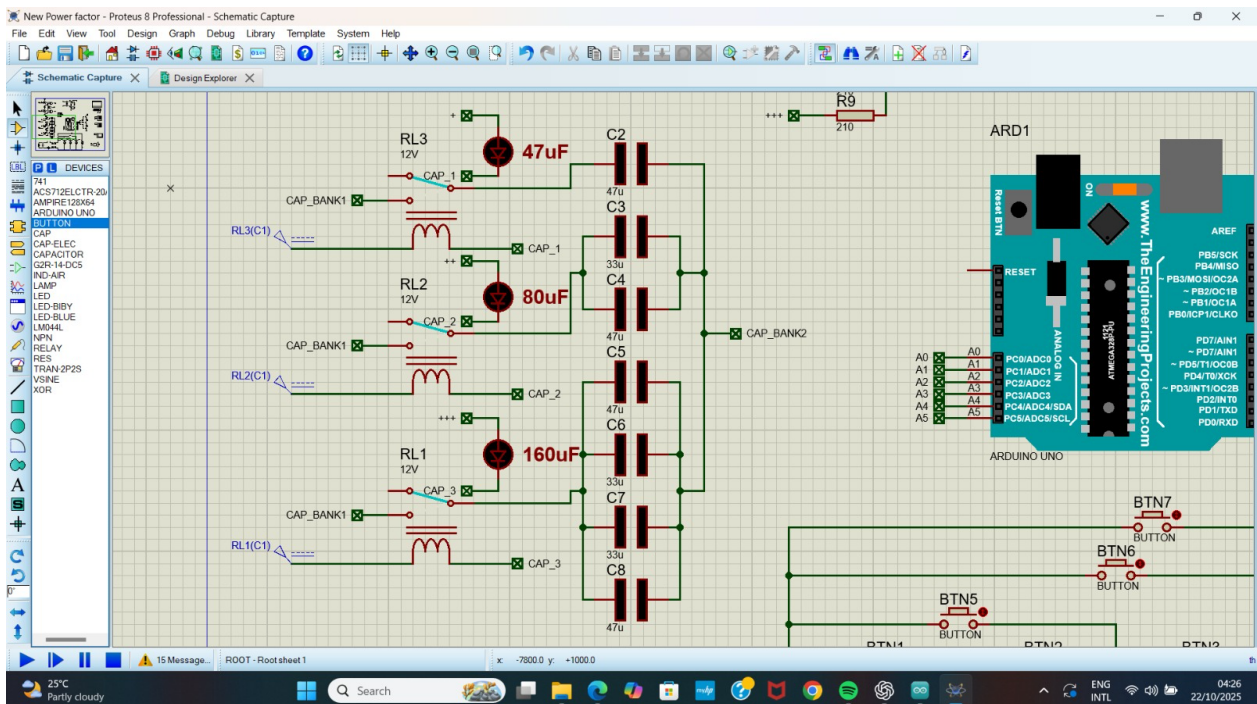
**Correction:** Selected capacitors are switched into the circuit to improve Power Factor.



**Figure 3.6: Display Configuration**

**Display:** LCD and virtual terminal show updated Power Factor and capacitor status.

While the oscilloscope shows the sine waveform and the square waveform of the current and voltage signals.



**Figure 3.7:**

The circuit is shown in figure 3.1 below

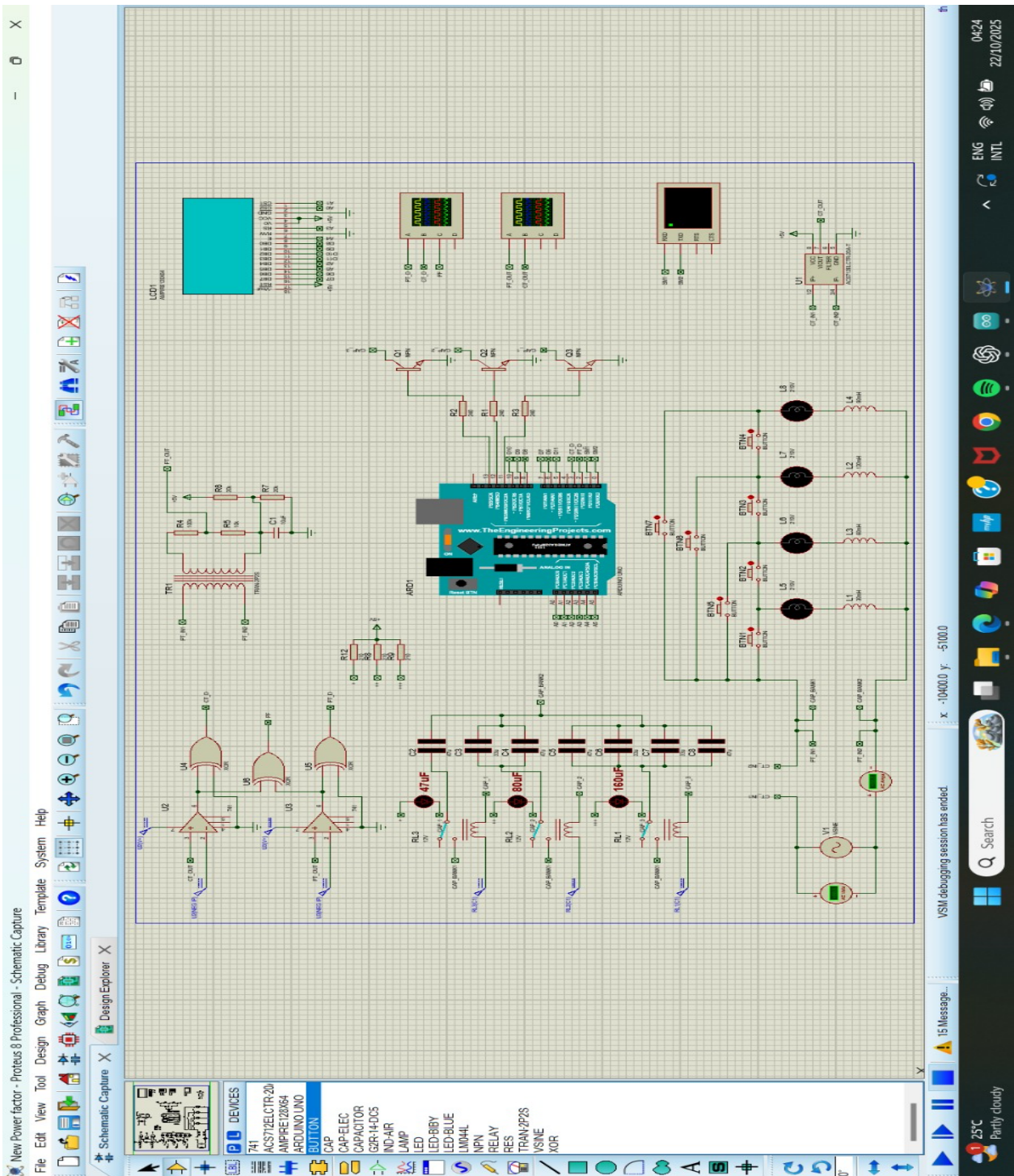
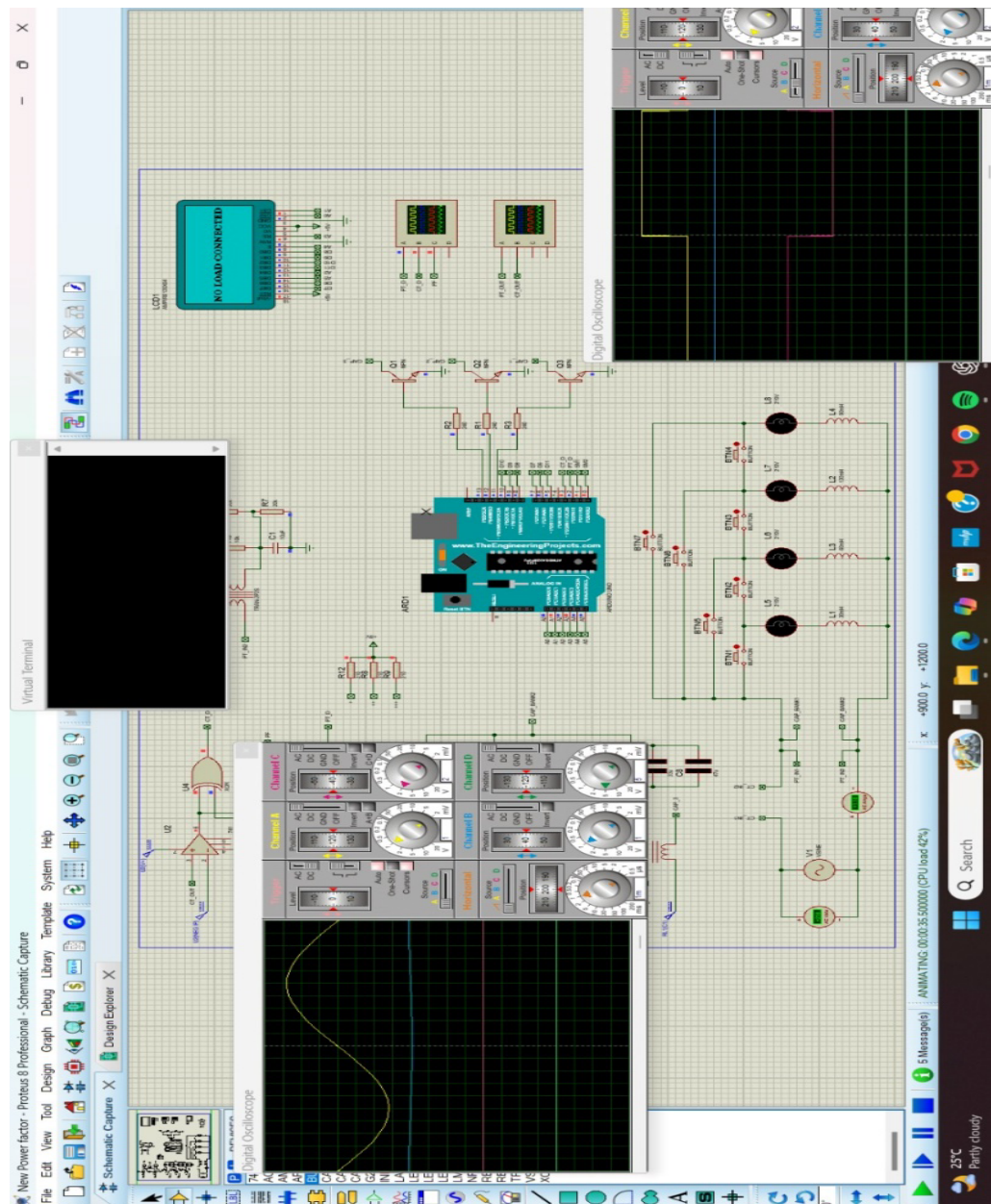


Figure 3.8: Overall Circuit

### 3.2.1 Testing Protocol for Different Load Conditions

The simulation analysis for the various load conditions are provided in the figures below. The Loads were varied to see how the capacitance changed according to load demand.

**For No-Load:**



**Figure 3.9: No Load Configuration**

The data above shows the Proteus simulation for a no-load condition. As there is no load, there is no need for any correction as there is no power delivered to begin with.

Table 3.1: Capacitor Banks triggered at No-Load

S/N	Capacitor Bank	Load
1	–	–

For 30mH Load:

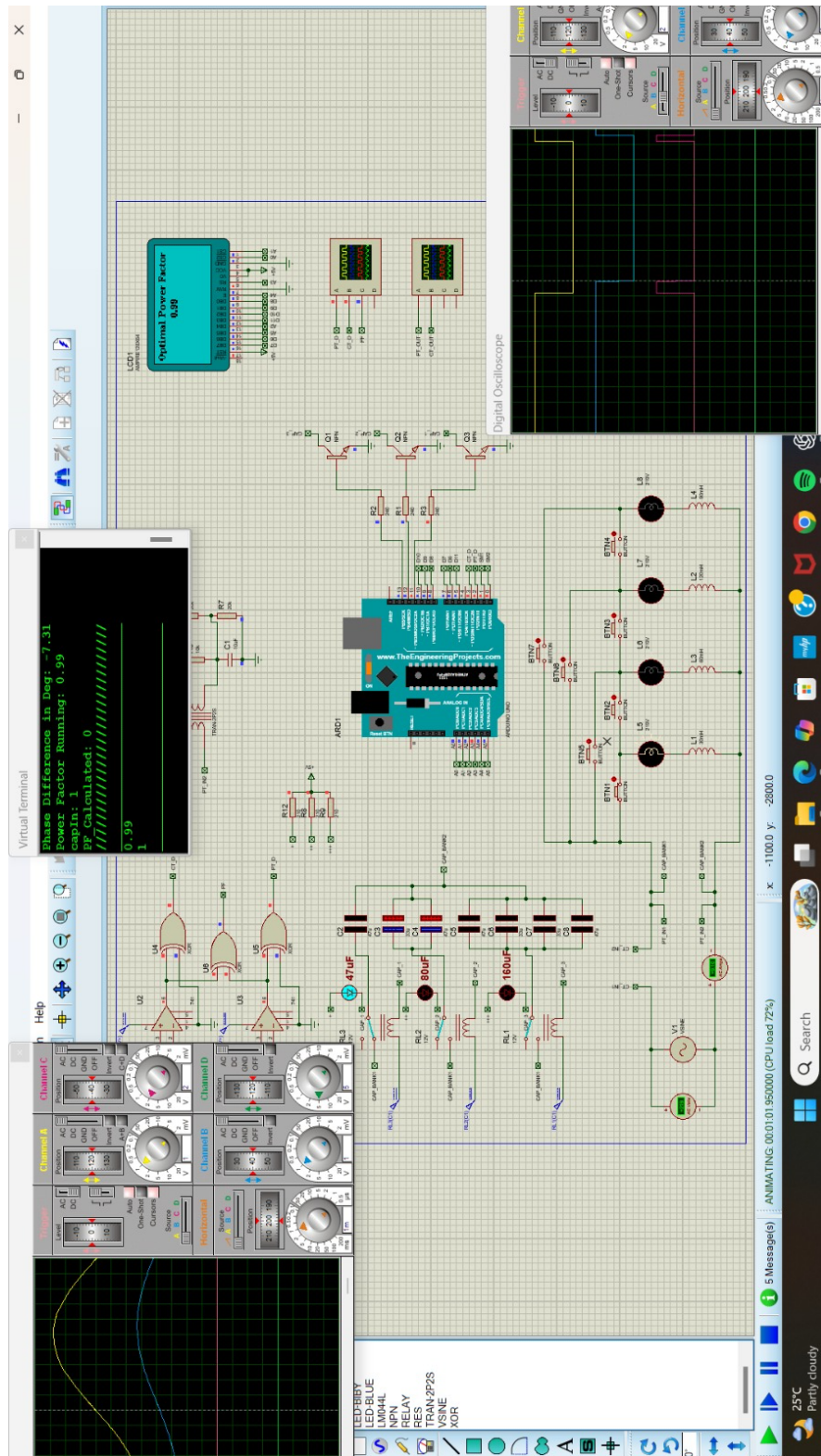


Figure 10: 30mH Configuration

The data above shows the Proteus simulation for a load of 30mH. Power factor was immediately adjusted to 0.99 using just the 47 $\mu$ F capacitor.

Table 3.2: Capacitor Banks triggered at 30mH

S/N	Capacitor Bank	Load
1	47 $\mu$ F	30mH

For 60mH:

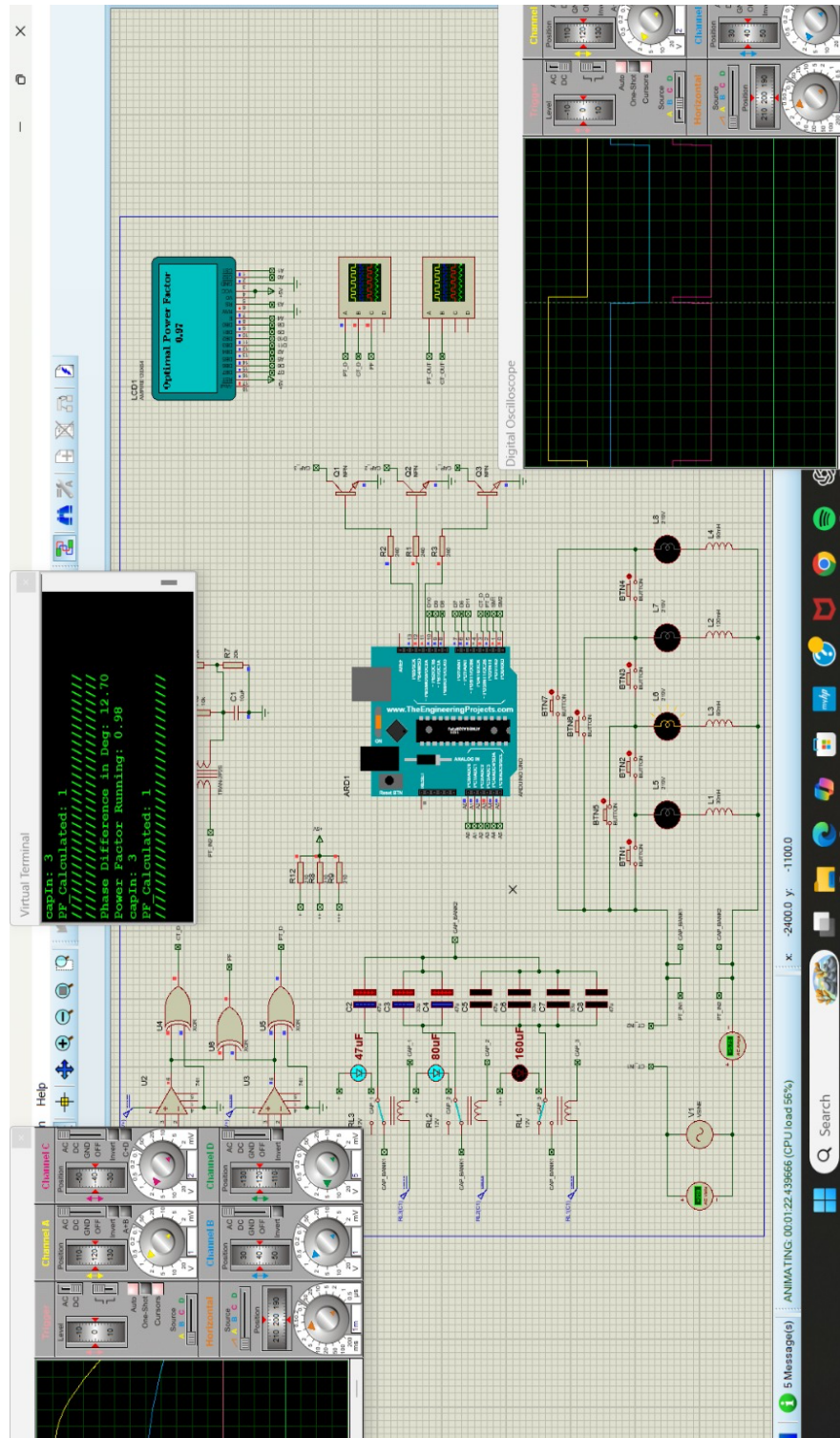


Figure 3.11: 60mH Configuration

The data above shows the Proteus simulation for a load of 60mH. Power factor was immediately adjusted to 0.98 using just the 47 $\mu$ F and 80 $\mu$ F.

Table 3.3: Capacitor Banks triggered 60mH

<b>S/N</b>	<b>Capacitor Bank</b>	<b>Load</b>
1	47 $\mu$ F and 80 $\mu$ F	60mH

For 30mH and 60mH

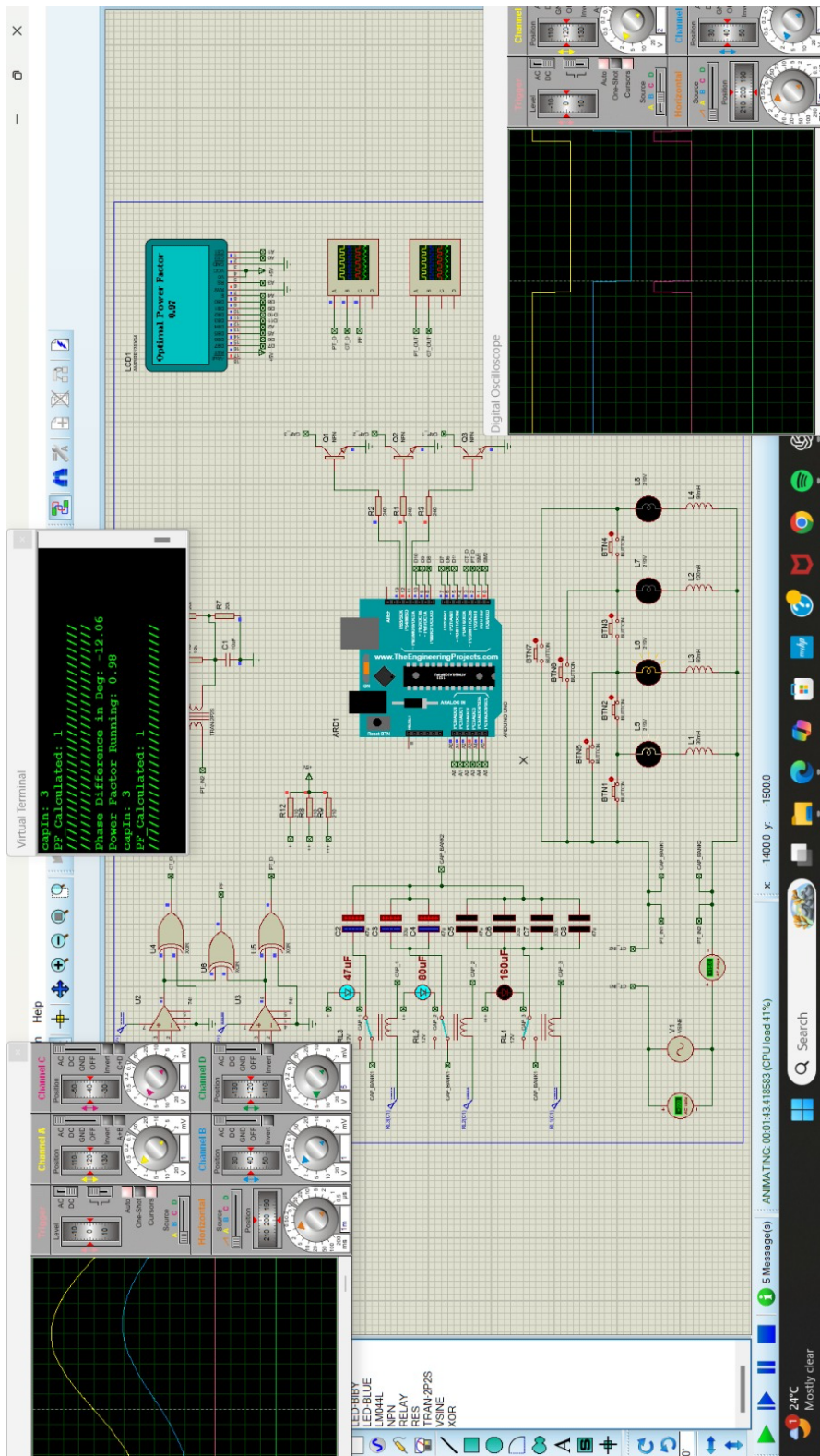


Figure 3.12: 30mH & 60mH Configuration

Data above shows the Proteus simulation for a load of 30mH and 60mH. Power factor was immediately adjusted to 0.98 using just the 47 $\mu$ F and 80 $\mu$ F. Table 3.4: Capacitor Banks triggered 30mH and 60mH

<b>S/N</b>	<b>Capacitor Bank</b>	<b>Load</b>
1	47 $\mu$ F and 80 $\mu$ F	30mH and 60mH

For 30mH and 90mH

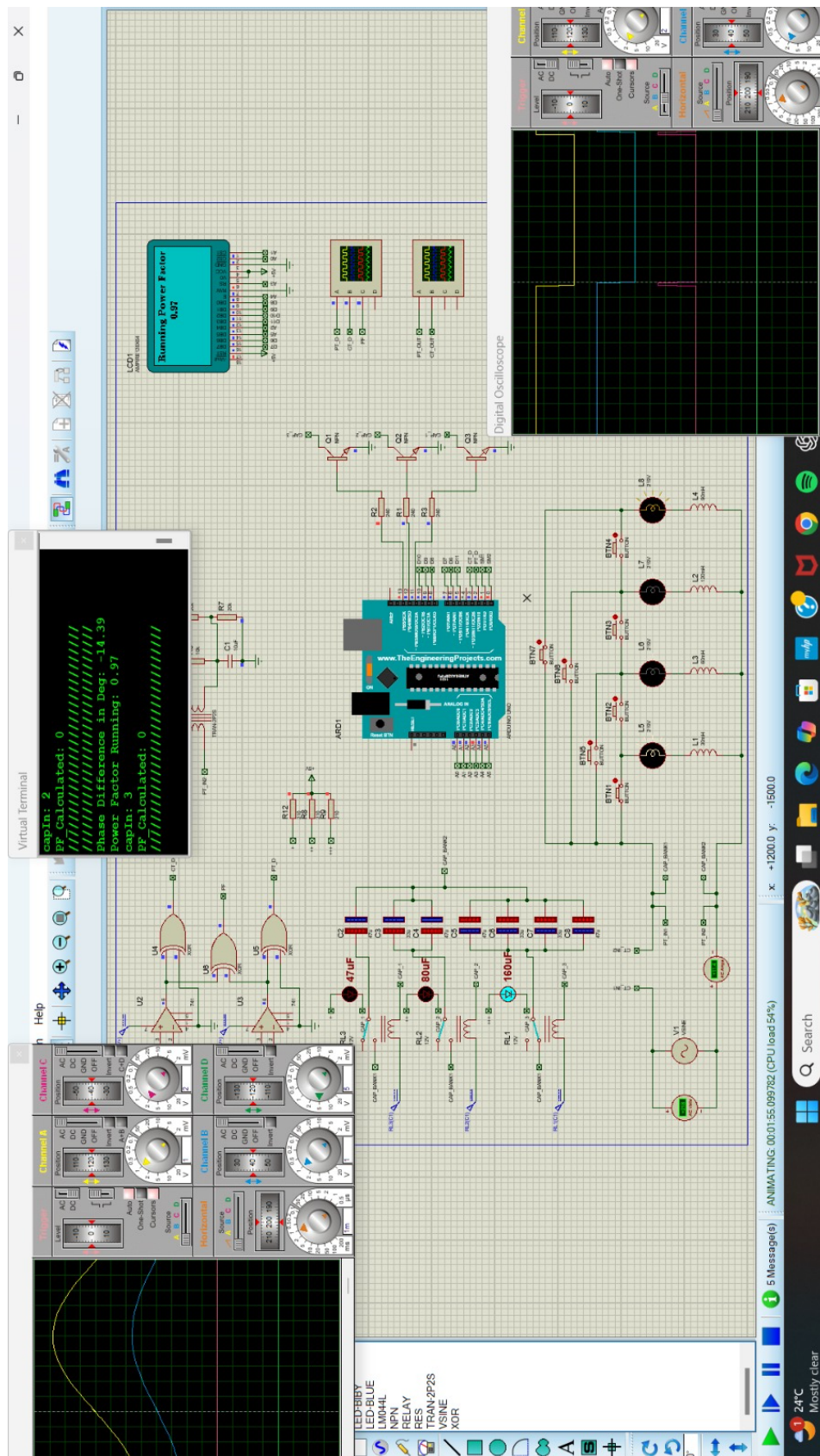


Figure 3.13: 30mH & 90mH Configuration

The data above shows the Proteus simulation for a load of 30mH and 90mH. Power factor was immediately adjusted to 0.97 using the 47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F capacitor banks.

Table 3.5: Capacitor Banks triggered 30mH and 90mH

<b>S/N</b>	<b>Capacitor Bank</b>	<b>Load</b>
1	47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F	30mH and 90mH

For 60mH and 120mH:

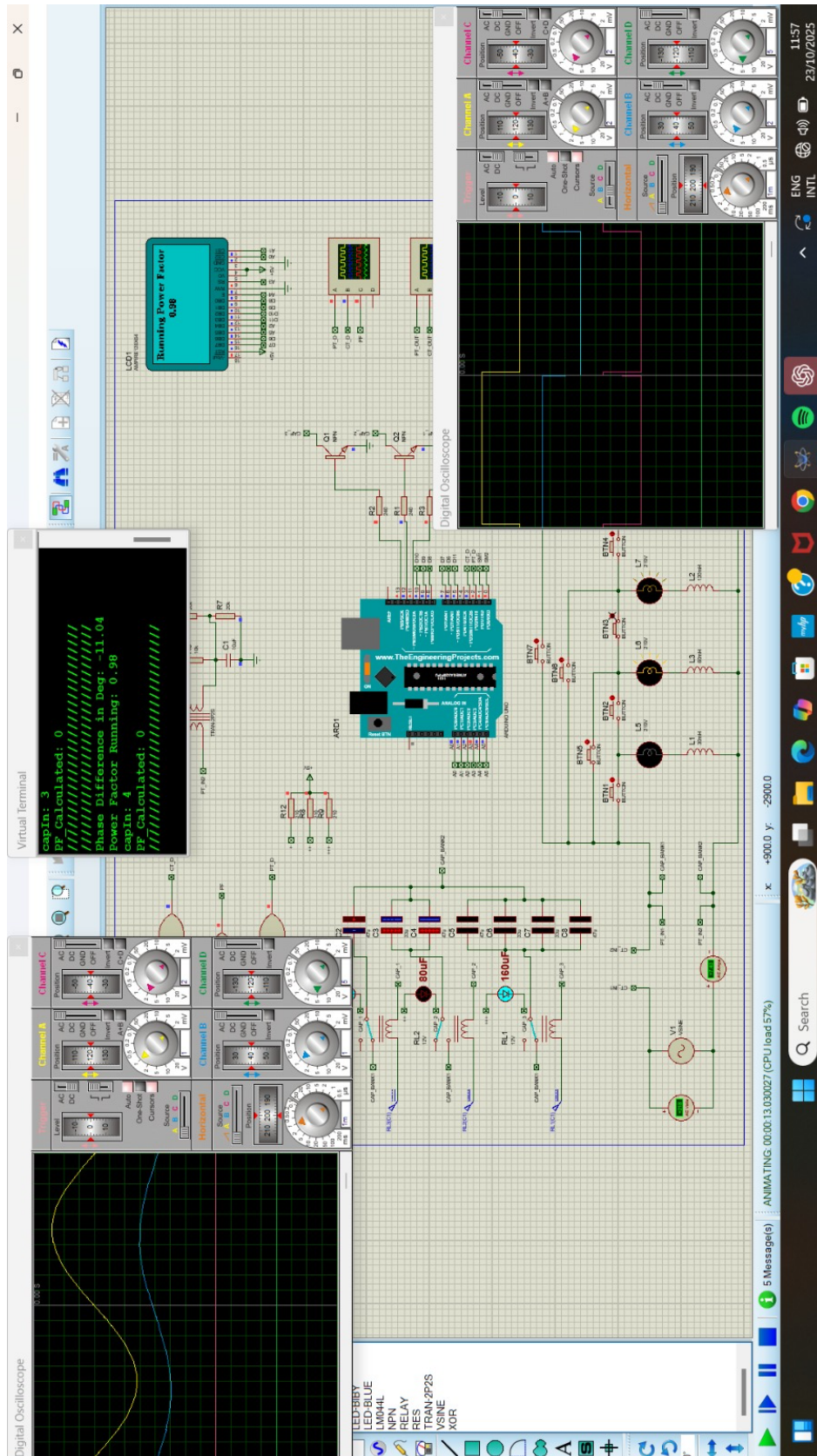


Figure 3.14: 60mH & 120mH Configuration

The data above shows the Proteus simulation for a load of 60mH and 120mH. Power factor was immediately adjusted to 0.98 using just the 80 $\mu$ F.

Table 3.6: Capacitor Banks triggered 30mH, 60mH, 120mH and 90mH

S/N	Capacitor Bank	Load
1	80 $\mu$ F	60mH and 120mH

For 30mH, 60mH, 120mH and 90mH:

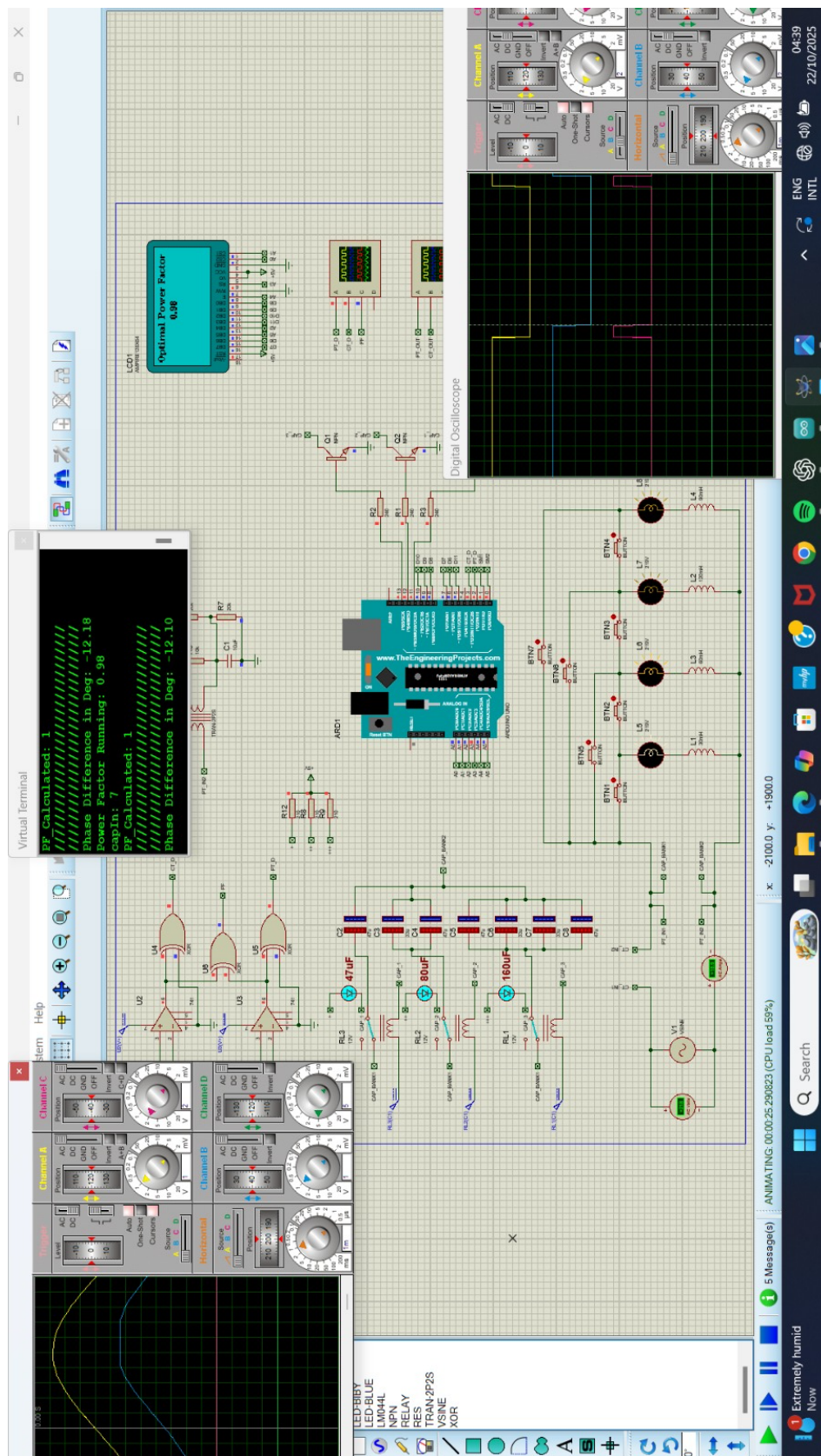


Figure 3.15: 30mH, 60mH, 120mH & 90mH Configuration

The data above shows the Proteus simulation for a load of 30mH, 60mH, 120mH and 90mH. Power factor was immediately adjusted to 0.98 using just the 47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F.

Table 3.6: Capacitor Banks triggered 30mH, 60mH, 120mH and 90mH

S/N	Capacitor Bank	Load
1	47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F	30mH, 60mH, 120mH and 90mH

The Arduino Codes are as presented in **Appendix**.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

This section presents a detailed analysis of the Proteus simulation results for the automatic power factor correction (APFC) system, examining how it performs under different load conditions and capacitor values. The discussion highlights how the system responds to these variations and evaluates the effectiveness of the capacitor bank switching mechanism in improving power factor and maintaining stable operation. It also considers what the results mean for real-world applications, showing how the APFC system can enhance efficiency, reliability, and overall power quality in industrial settings. Finally, the findings offer useful insights that can guide future design improvements and research in power factor correction systems.

#### 4.1 Data Analysis

Table 4.1: Capacitor banks Used to Correct Corresponding Loads

S/N	Capacitor Bank	Inductive Load
1	–	–
2	47 $\mu$ F	30mH,
3	47 $\mu$ F and 80 $\mu$ F	60mH,
4	47 $\mu$ F and 80 $\mu$ F	30mH and 60mH
5	47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F	30mHand 90mH
6	47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F	60mH, 120mH

7	47 $\mu$ F, 80 $\mu$ F and 160 $\mu$ F	30mH, 60mH, 120mH and 90mH
---	--	----------------------------

The results in Table 4.1 clearly illustrate how the Automatic Power Factor Correction (APFC) system responds to varying load conditions in the Proteus simulation. As the load increases, the system automatically switches on additional capacitor banks to balance out the extra reactive power drawn by the inductive components. This behavior shows that the APFC system is accurately detecting changes in power factor and providing the right amount of capacitive compensation to keep the system stable.

This trend supports a well-known principle of power factor correction — that heavier loads create stronger inductive effects, which require more reactive power compensation to maintain a power factor close to unity. In this simulation, the APFC controller performs effectively by engaging capacitor banks step by step as the load grows. The results also demonstrate that the control logic and relay sequencing in Proteus are functioning properly, maintaining a steady balance between active and reactive power.

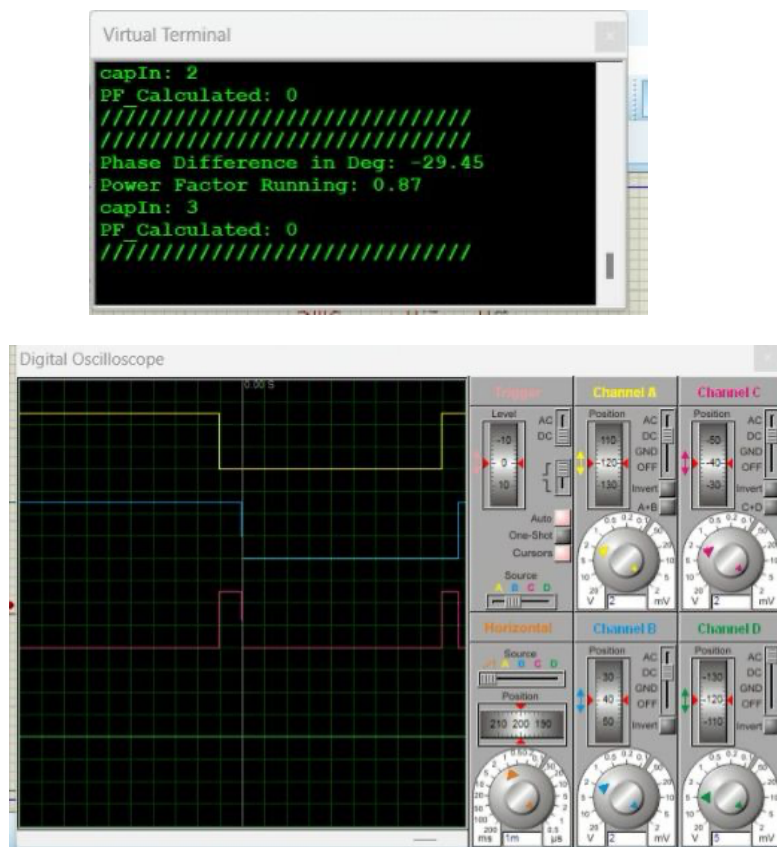
Beyond confirming correct system operation, these results highlight the APFC system's adaptive nature, an important quality for real-world power networks where load demand constantly changes. By automatically adjusting the number of active capacitor banks, the system not only improves power factor but also helps to reduce power losses, enhance voltage stability, and improve overall efficiency. This validates the practical relevance of automatic power factor correction — it reduces the need for manual adjustments and ensures reliable performance under different operating conditions.

In conclusion, the results confirm that the APFC system simulated in Proteus performs exactly as designed. Its ability to intelligently adjust capacitor bank engagement in response to load variations demonstrates a responsive, efficient, and reliable design that can be effectively implemented in both industrial and commercial settings to achieve stable and efficient energy use.

#### 4.2 Analysis of Power factor and Square Waveforms:

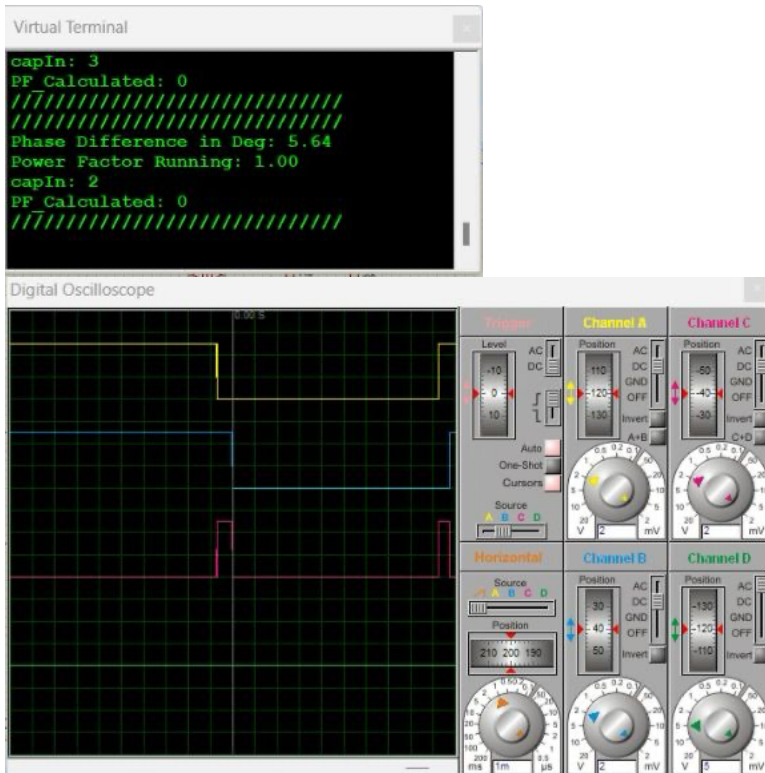
**For 30mH:**

Before Correction:



**Figure 4.1: 30mH Load Before Correction**

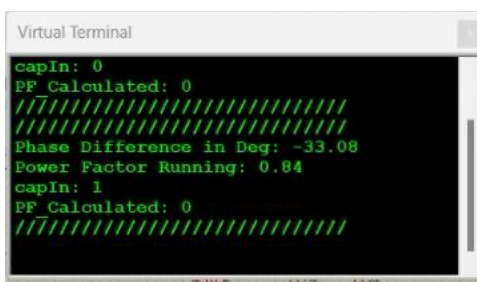
After Correction:

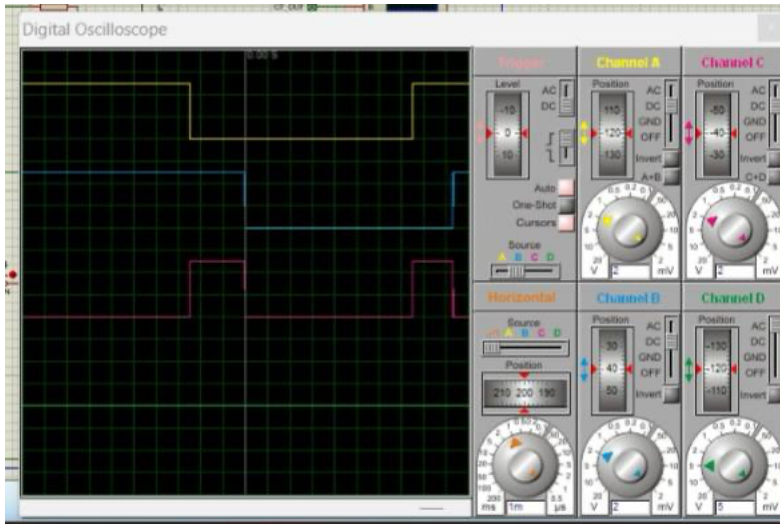


**Figure 4.2: 30mH Load After Correction**

**For 60mH:**

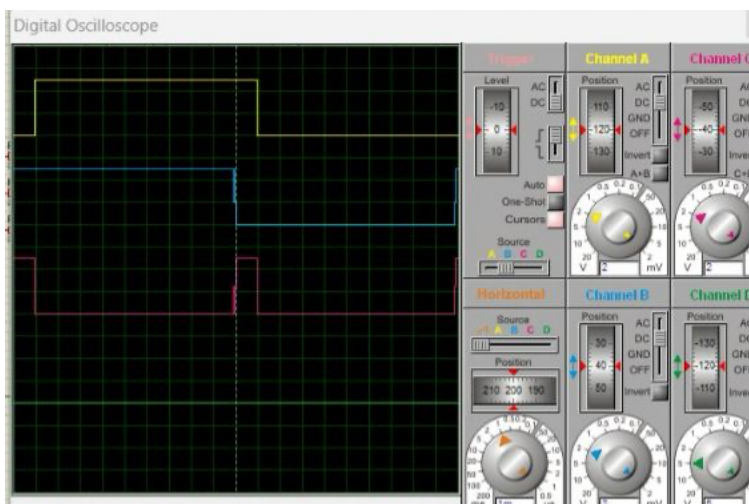
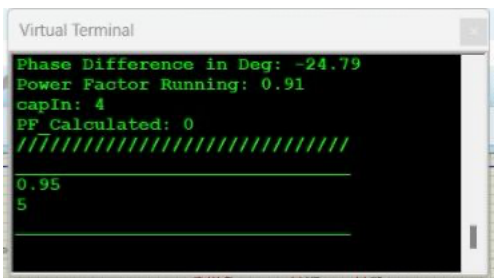
Before Correction:





**Figure 4.3: 60mH Load Before Correction**

After Correction:



**Figure 4.4: 60mH Load After Correction**

**For 30mH and 60mH:**

Before Correction:

```
Virtual Terminal
capIn: 3
PF Calculated: 0
////////////////////
Phase Difference in Deg: -38.66
Power Factor Running: 0.78
capIn: 2
PF Calculated: 0
////////////////////
```

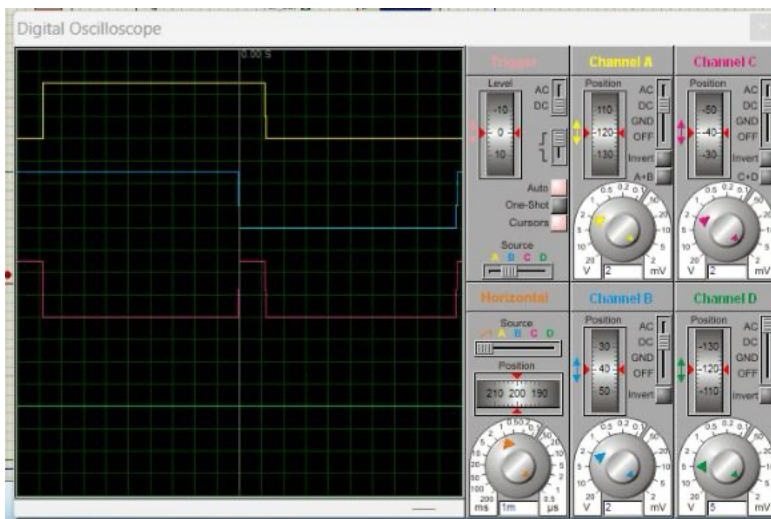
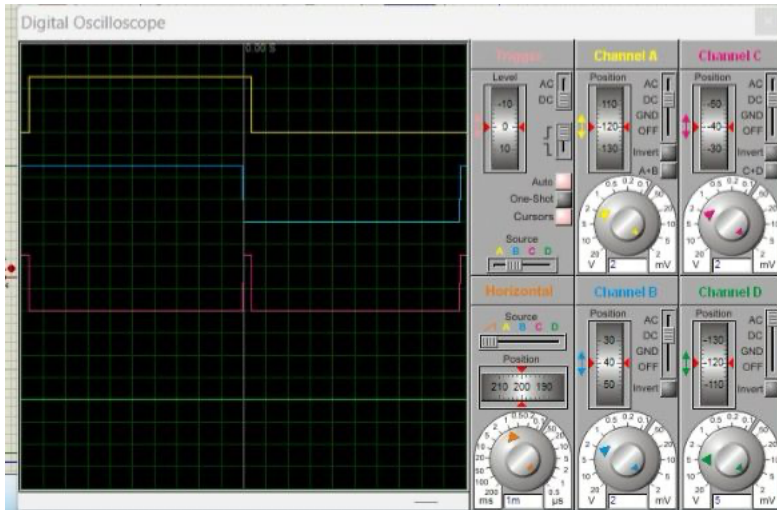


Figure 4.5: 30mH & 60mH Load Before Correction

After Correction:

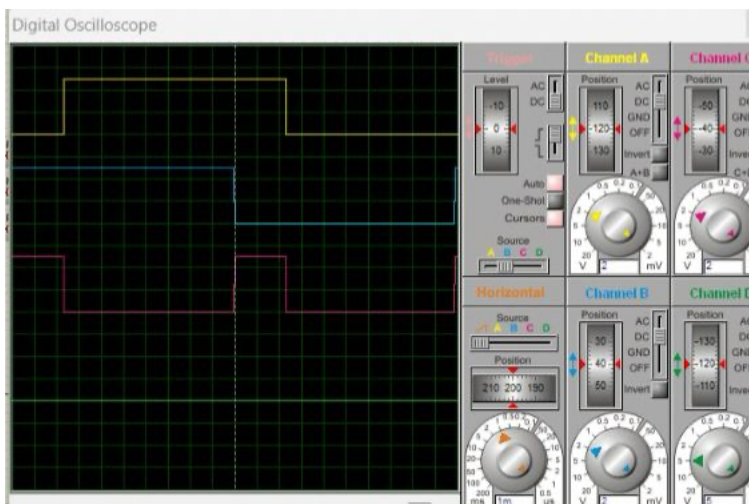
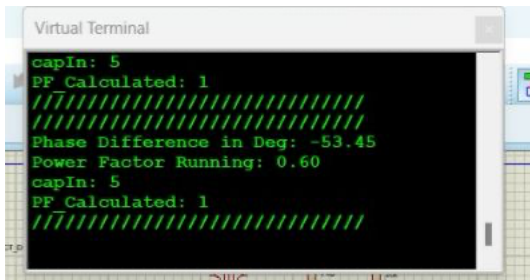
```
Virtual Terminal
capIn: 5
PF Calculated: 1
////////////////////
Phase Difference in Deg: 11.39
Power Factor Running: 0.98
capIn: 5
PF Calculated: 1
////////////////////
```



**Figure 4.6: 30mH & 60mH Load After Correction**

**For 30mH and 90mH:**

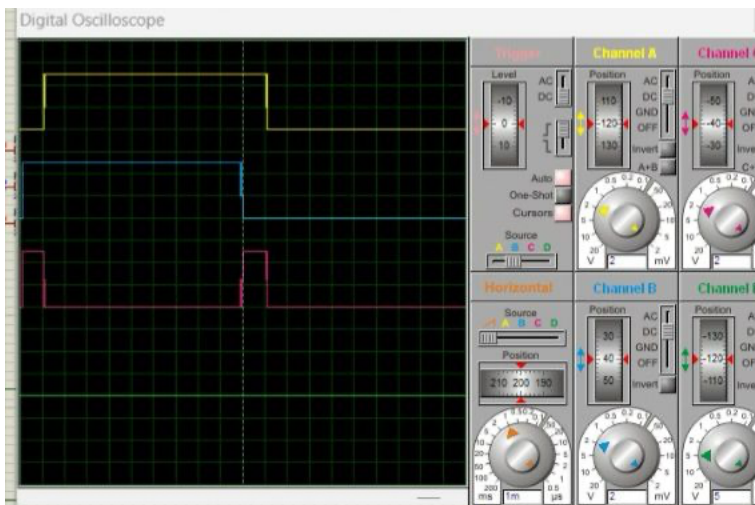
Before Correction



**Figure 4.7: 30mH & .90mH Load Before Correction**

After Correction

```
Virtual Terminal
capIn: 5
PF Calculated: 1
////////////////////////////////////
Phase Difference in Deg: 17.76
Power Factor Running: 0.95
capIn: 5
PF Calculated: 1
////////////////////////////////////
```

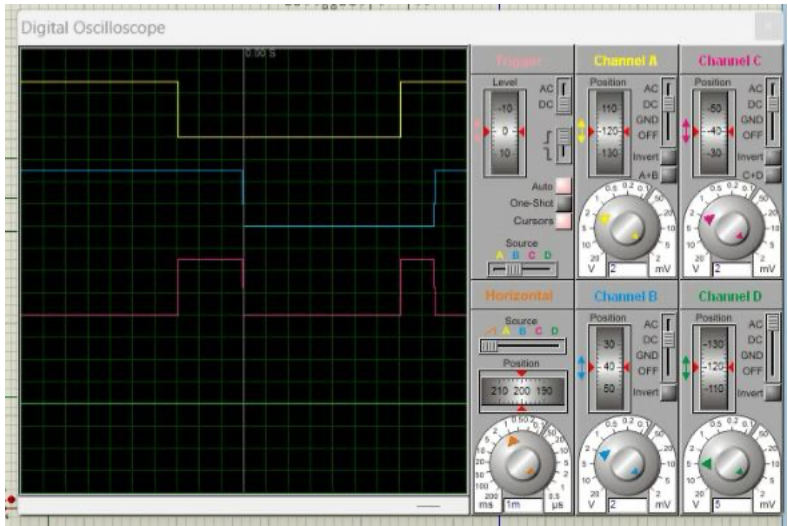


**Figure 4.8: 30mH & 90mH Load After Correction**

**For 30mH, 60mH, 120mH and 90mH:**

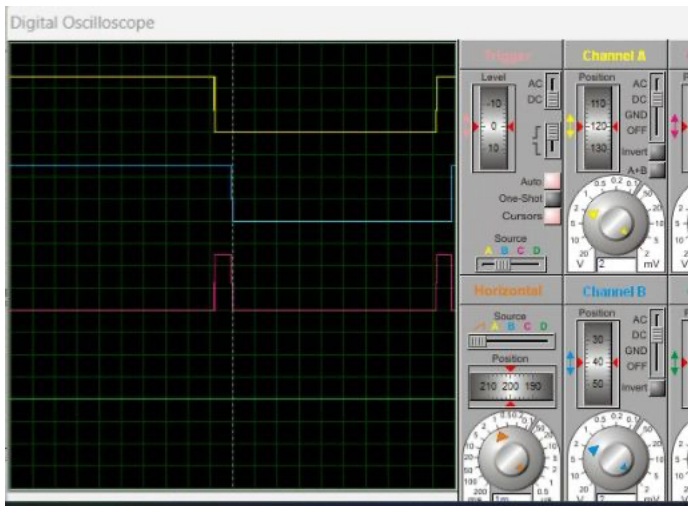
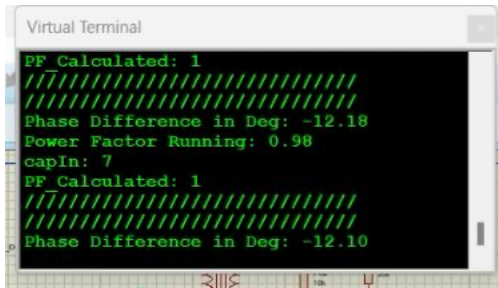
Before Correction

```
Virtual Terminal
capIn: 2
PF Calculated: 0
////////////////////////////////////
Phase Difference in Deg: -54.65
Power Factor Running: 0.58
capIn: 1
PF Calculated: 0
////////////////////////////////////
```



**Figure 4.9: 30mH, 90mH, 60mH &120mH Load Before Correction**

After Correction:



**Figure 4.10: 30mH, 90mH, 60mH &120mH Load After Correction**

Table 4.2 Power factor before correction and Power Factor after Correction

Load	Power Factor B/4 Correction	Power Factor After Correction
30mH	0.87	1.00
60mH	0.84	0.91
30mH and 60mH	0.78	0.98
30mH and 90mH	0.60	0.95
30mH, 60mH, 120mH and 90mH	0.58	0.98

In the Proteus simulation, square waveforms were used to determine the phase difference between the voltage and current signals, which is essential for calculating the power factor. The sinusoidal voltage and current waveforms were first passed through zero-crossing detector circuits that converted them into corresponding square waves. These square waves made it easier to measure the time delay between the voltage and current signals. The time difference ( $\Delta t$ ) between the two square waves represents the phase angle ( $\phi$ ), from which the power factor was calculated using the relationship  $PF = \cos(\phi)$ .

By observing the shift between the voltage and current square waves, the system could accurately detect whether the load was inductive or capacitive and determine how far the power factor deviated from unity. This information was then processed by the microcontroller to decide when to switch capacitor banks for correction. The use of square waveforms thus simplified the detection and computation of the phase difference, enabling reliable and automatic power factor correction in the system.

The values in the Table 4.2 showing the power factor before and after correction further support the earlier observations. It can be seen that as the load increases, the power factor before correction gradually decreases. This confirms that larger loads introduce more inductive effects into the system, resulting in a greater reactive power demand and a lower overall power factor. However, after correction, the APFC system successfully improves the power factor by switching on additional capacitor banks to offset the increased reactive component. This consistent pattern demonstrates that the system not only detects the drop in power factor caused by higher loads but also compensates for it effectively, thereby validating the responsiveness and accuracy of the APFC control mechanism in maintaining optimal operating conditions.

#### **4.2 Discussion of Findings**

The results presented in Table 4.1 provide a clear understanding of how the Automatic Power Factor Correction (APFC) system responds to varying load conditions in the Proteus simulation. As the load increases, there is a noticeable decrease in the system's power factor before correction, indicating a higher reactive power demand caused by the inductive nature of the load. This trend reflects the natural behavior of inductive circuits, where increasing load size results in a greater phase difference between voltage and current, thereby lowering the power factor.

However, after correction, the results show a significant improvement in the power factor across all load levels. The APFC system responds dynamically by switching on additional capacitor banks as the load increases, compensating for the reactive power drawn by the inductive components. This confirms that the system is functioning effectively, with its control mechanism accurately detecting changes in the power factor and providing the necessary capacitive compensation to maintain stable operation.

The observed behavior demonstrates the efficiency of the APFC design in managing fluctuating load conditions. The microcontroller-based control logic in the Proteus simulation automatically engages the appropriate number of capacitor banks in a stepwise manner as load increases, thereby improving the overall system power factor. This adaptive action not only ensures that the power factor remains close to unity but also minimizes power losses, improves voltage stability, and enhances the efficiency of the power supply system.

In some instances, slight variations were observed in the corrected power factor values across different load levels. These fluctuations may be attributed to the switching intervals of the capacitor banks or the response delay within the control circuit. Nonetheless, the general trend remains consistent — higher loads require more capacitive compensation, and the APFC system successfully achieves this balance.

Overall, the results confirm that the APFC system simulated in Proteus performs as intended. Its ability to detect poor power factor conditions and respond automatically through relay-controlled capacitor switching highlights its reliability and suitability for real-world industrial and commercial applications. By maintaining an improved power factor under varying load conditions, the system ensures efficient energy utilization and contributes to overall system stability.

### **4.3 Implications of Results**

The findings from the analysis of the APFC system's performance under varying load conditions and capacitor values reveal several important implications for practical application and future development:

#### **4.3.1 Power Factor Behavior:**

The decrease in power factor before correction as load increases confirms that inductive loads draw more reactive power, thereby lowering the system's efficiency. This reinforces the need for automatic power factor correction systems to maintain a high power factor in dynamic load environments.

#### **4.3.2 Effectiveness of the APFC System:**

The post-correction results demonstrate that the APFC system significantly improves power factor by automatically engaging the necessary capacitor banks. This validates the system's ability to provide real-time compensation and maintain near-unity power factor levels.

#### **4.3.3 Capacitor Bank Performance:**

The analysis highlights that higher load conditions require more capacitor banks to be switched into the circuit. This direct relationship between load magnitude and capacitive compensation demonstrates the reliability of the control logic and relay sequencing implemented in the Proteus simulation.

#### **4.3.4 System Stability and Efficiency:**

By maintaining a high-power factor, the APFC system reduces transmission losses, prevents voltage drops, and enhances the overall stability of the electrical system. This ensures more efficient energy usage and prolongs the lifespan of electrical equipment connected to the supply.

#### **4.3.5 Importance of Proper Capacitor Sizing:**

The results emphasize the importance of selecting appropriate capacitor ratings to

ensure effective compensation. Undersized capacitors may fail to correct the power factor adequately, while oversized capacitors can cause overcompensation, leading to a leading power factor.

#### **4.3.6 Practical and Industrial Relevance:**

The system's adaptive nature makes it highly suitable for industrial and commercial environments where load variations occur frequently. It minimizes the need for manual adjustments and ensures continuous and efficient power management.

#### **4.3.7 Future Development:**

These findings provide valuable insights for future research and development of APFC systems. Further improvements could involve integrating microcontrollers with more advanced sensing techniques, such as real-time digital signal processing (DSP) or IoT-based monitoring, to enhance accuracy and responsiveness.

In conclusion, the results underscore the effectiveness of the Automatic Power Factor Correction system in maintaining optimal power factor levels under varying load conditions. The system's automatic and adaptive response highlights its potential as a cost-effective solution for improving energy efficiency, reducing power losses, and enhancing the stability of electrical networks in practical applications.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusions

This project on the design and simulation of an Automatic Power Factor Correction (APFC) system in Proteus emphasizes the vital importance of power factor improvement in ensuring the efficient, stable, and reliable operation of electrical power systems under varying load conditions. The study demonstrated that as the load increases, the system's power factor naturally decreases due to the inductive characteristics of most electrical loads.

The results clearly show that the APFC system effectively corrects poor power factor by automatically switching capacitor banks in and out of the circuit, depending on the reactive power demand. This dynamic adjustment helps maintain a power factor close to unity, thereby improving overall system efficiency, reducing transmission losses, and stabilizing voltage levels.

The findings also reveal the system's capability to adapt to fluctuating loads without manual intervention, highlighting the effectiveness of the microcontroller-based control logic used in the design. By accurately detecting phase differences between voltage and current through square waveform processing, the system calculates the power factor and responds in real time to compensate for inductive effects.

Furthermore, the project underscores the importance of proper capacitor sizing and stage control, as inappropriate selection can lead to under compensation or overcompensation, both of which affect performance and system stability. Overall, the simulation results validate that an automatic power factor correction system is a practical and cost-effective solution for maintaining power quality, enhancing

equipment lifespan, and improving energy efficiency in both industrial and commercial applications.

The insights gained from this research can guide future developments aimed at integrating more intelligent control algorithms, such as IoT-based or digital signal processing techniques, to further improve responsiveness, monitoring, and energy optimization in APFC systems.

## **5.2 Recommendations**

Based on the findings and outcomes of this APFC system project, the following recommendations are made to improve design, performance, and practical implementation:

**i. Adopt Automatic Power Factor Correction Systems:**

Industries and facilities with variable inductive loads should implement APFC systems to automatically maintain an optimal power factor and reduce energy losses.

**ii. Ensure Proper Capacitor Sizing:**

The selection of capacitor bank ratings should be based on accurate load analysis to prevent undercorrection or overcorrection, ensuring balanced compensation and system stability.

**iii. Incorporate Real-Time Monitoring:**

Power factor and load monitoring units should be integrated to continuously track system performance and provide real-time feedback on compensation levels.

**iv. Use Microcontroller-Based Control:**

Microcontrollers or programmable controllers should be used to handle automatic

switching of capacitor banks efficiently, allowing for precise and timely response to load variations.

**v. Regular Maintenance and Calibration:**

Periodic inspection of capacitors, relays, and control circuits is essential to maintain reliable operation and prevent faults that could affect system performance.

**vi. Operator Training and Awareness:**

Personnel responsible for operating and maintaining APFC systems should be properly trained on the principles of power factor correction, system control, and troubleshooting procedures.

**vii. Further Research and Development:**

Future work should focus on incorporating advanced features such as remote monitoring via IoT, artificial intelligence for predictive control, and integration with energy management systems to enhance overall efficiency and automation.

## REFERENCES

1. Akhtar, E. T. (2023). *Automatic power factor correction* [Working paper]. SSRN.  
<https://www.google.com/search?q=https://doi.org/10.2139/ssrn.4376134>
2. Arrillaga, J., and Watson, N. R. (2003). *Power system quality assessment*. Wiley.
3. Bataresh, I., and Emadi, A. (2014). A review of power factor correction techniques for electric vehicle battery chargers. In *2014 IEEE Transportation Electrification Conference and Expo (ITEC)* (pp. 1-6). IEEE.  
<https://www.google.com/search?q=https://doi.org/10.1109/ITEC.2014.6861793>
4. Chang, W.-N., and Liao, C.-H. (2017). Design and implementation of a STATCOM based on a multilevel FHB converter with delta-connected configuration for unbalanced load compensation. *Energies*, 10(7), 921.  
<https://doi.org/10.3390/en10070921>
5. Cochran, J., Denholm, P., Speer, B., and Miller, M. (2015). *Grid integration and the carrying capacity of the U.S. grid to incorporate variable renewable energy* (Technical Report No. NREL/TP-6A20-62607). National Renewable Energy Laboratory (NREL). <https://doi.org/10.2172/1215010>
6. del Puerto-Flores, D., Scherpen, J. M., and Ortega, R. (2010, July). On linear power factor compensation, power equalization and cyclo-dissipativity of nonlinear loads. In *2010 IEEE International Symposium on Industrial Electronics* (pp. 2993-2998). IEEE.
7. Ehsani, M., Gao, Y., Longo, S., and Ebrahimi, K. (2018). *Modern electric, hybrid electric, and fuel cell vehicles* (3rd ed.). CRC press.

8. Ghosh, A., and Ledwich, G. (2002). *Power quality enhancement using custom power devices*. Kluwer Academic Publishers.
9. Grady, W. M., and Gilleskie, R. J. (2010). A study of power factor in commercial buildings. In *2010 IEEE Power and Energy Society General Meeting* (pp. 1-5). IEEE.  
<https://www.google.com/search?q=https://doi.org/10.1109/PES.2010.5589926>
10. Gupta, J. B. (2012). *Basic electrical and electronics engineering*. S. K. Kataria and Sons.
11. Hingorani, N. G., and Gyugyi, L. (2000). *Understanding FACTS: Concepts and technology of flexible AC transmission systems*. Wiley-IEEE Press.
12. Horowitz, P., and Hill, W. (2015). *The art of electronics* (3rd ed.). Cambridge University Press.
13. Ibrahim, D. (2012). *Introduction to Proteus Design Suite: A practical guide for beginners*. Newnes.
14. Islam, M. R. (2019). Power factor correction in industrial plants using synchronous motors. *International Journal of Engineering and Advanced Technology (IJEAT)*, 8(5C), 112-116.
15. Kjaer, S. B., Pedersen, J. K., and Blaabjerg, F. (2005). A review of single-phase grid-connected inverters for photovoltaic modules. *IEEE Transactions on Industry Applications*, 41(5), 1292-1306.  
<https://doi.org/10.1109/TIA.2005.853371>
16. Kothari, D. P., and Nagrath, I. J. (2011). *Modern power system analysis* (4th ed.). McGraw-Hill Education.
17. Malvino, A., and Bates, D. J. (2016). *Electronic principles* (8th ed.). McGraw-Hill Education.

18. Monk, S. (2013). *Hacking electronics: An illustrated DIY guide for makers and hobbyists*. McGraw-Hill Education TAB.
19. Psillakis, H. E., and Alexandridis, A. T. (2020). Coordinated excitation and static var compensator control with delayed feedback measurements in SGIB power systems. *Energies*, 13(9), 2181.  
<https://www.google.com/search?q=https://doi.org/10.3390/en13092181>
20. Rafi, K. M., Prasad, P. V. N., and Vithal, J. V. R. (2022). Coordinated control of DSTATCOM with switchable capacitor bank in a secondary radial distribution system for power factor improvement. *Journal of Electrical Systems and Information Technology*, 9(4).  
<https://www.google.com/search?q=https://doi.org/10.1186/s43067-022-00044-3>
21. Rashid, M. H. (2014). *Power electronics: Circuits, devices, and applications* (4th ed.). Pearson Education.
22. Rija, B. M., Hussain, M. K., and Vural, A. M. (2020). Microcontroller-based automatic power factor correction for single-phase lagging and leading loads. *Engineering, Technology and Applied Science Research*, 10(6), 6515–6520.
23. Routray, S. S. (2015). *Microcontroller-based automatic power factor correction in mines* [Master's thesis, CORE Repository]. <https://core.ac.uk>
24. Shinde, A. A., Patil, P. S., Pawar, S. B., and Kulkarni, A. S. (2024). Hardware Implementation of Automatic Power Factor Correction using Zero Crossing Detector and Electromagnetic Relays. In *2024 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE)* (pp. 1-6). IEEE.

<https://www.google.com/search?q=https://doi.org/10.1109/IITCEE61303.2024.10543634>

25. Tariq, M., Al-Turki, Y. A., and Hannan, M. A. (2022). A cost-effective power factor correction technique for nonlinear loads using FACTS devices. *Ain Shams Engineering Journal*, 13(4), 101688. <https://doi.org/10.1016/j.asej.2021.101688>
26. U.S. Department of Energy. (2021). *Data center power factor and energy efficiency*. (Technical Report No. DOE/GO-102121-5678). National Renewable Energy Laboratory (NREL).
27. Wang, Y., Chen, Z., Zhang, H., and Wu, L. (2021). A review on FACTS devices: Drawbacks, challenges and potential opportunities. *IEEE Access*, 9, 78450-78468. <https://www.google.com/search?q=https://doi.org/10.1109/ACCESS.2021.3083310>
28. Wildi, T. (2006). *Electrical machines, drives, and power systems* (6th ed.). Pearson Prentice Hall.
29. Xu, S., and McDonald, B. A. (2017). *U.S. Patent Application No. 15/204,631*.
30. Zaidi, M. N., and Ali, A. (2018). Power factor improvement using automatic power factor compensation (APFC) device for medical industries in Malaysia. *MATEC Web of conferences*, 150, 01004. <https://doi.org/10.1051/mateconf/201815001004>

## APPENDIX

### Arduino Code

```
*/  
  
#include <Arduino.h>  
  
#include <U8g2lib.h>  
  
#ifndef U8X8_HAVE_HW_SPI  
#include <SPI.h>  
#endif  
  
#ifndef U8X8_HAVE_HW_I2C  
#include <Wire.h>  
#endif  
  
#define PT_D 2 //Interrupt Pin for PT Signal  
#define CT_D 3 //Interrupt Pin for CT Signal  
  
#define CAP_BANK1 11 //Pin for Including/Excluding Capacitor 1  
#define CAP_BANK2 12 //Pin for Including/Excluding Capacitor 2  
#define CAP_BANK3 13 //Pin for Including/Excluding Capacitor 3  
  
volatile unsigned long pulseInTime_PT = 0; //Variable to store time in uS of  
PT Signal  
  
volatile unsigned long pulseInTime_CT = 0; //Variable to store time in uS of  
CT Signal
```

```

volatile bool    waveRecorded_PT = false;    //Variable to determine whether PT
signal has been recorded or not

volatile bool    waveRecorded_CT = false;    //Variable to determine whether CT
signal has been recorded or not

float           timeDifferenceAv = 0;        //Variable for storing Average time
difference b/w PT and CT Signals

int            divider = 0;                //Variable is being used to take mean value of time
difference b/w PT and CT signals

const float freq = 50.0;                  //System/Grid Frequency in Hz (either 50 or 60).

float    thetaDeg = 0;                    //Phase between Voltage and Current in Degrees

float    thetaRad = 0;                    //Phase between Voltage and Current in Radians

float    runningPF = 1;

int    capIn = 0;                        //Variable to store current number of Capacitors included
in the system

int    CAP_IN[8] = {};                    //Array to store 8 feasible number of capacitors-
combinations

float    POWER_FACTOR[8] = {};            //Array to store 8 respective power-factors

int    index = 0;                        //For Indexing

float    optimalPF = 0;                    //Most optimal POWER FACTOR resulted for the load

bool    PF_Calculated = false;            //Variable to find whether Optimal PF is being
calculated for the load

```

```

U8G2_KS0108_128X64_F u8g2(U8G2_R0, 8, 9, 10, 5, 16, 19, 6, 7, /*enable=*/ 18,
/*dc=*/ 17, /*cs0=*/ 14, /*cs1=*/ 15, /*cs2=*/ U8X8_PIN_NONE, /* reset=*/
U8X8_PIN_NONE); // Set R/W to low!

```

```

/////////////////////////////////////////////////////////////////

```

```

/////////////////////////////////////////////////////////////////ISR FOR RECORDING THE TIME, THE PT SIGNAL
ARRIVED/////////////////////////////////////////////////////////////////

```

```

void potentialTransformer()          ///////////////////////////////////////////////////////////////////
{
    //Once the Signal-time for potential transformer is
    recorded
    pulseInTime_PT = micros();        //The interrupt to PT_D pin is detached and
    this event is indicated
    detachInterrupt(digitalPinToInterrupt(PT_D)); //by waveRecorded_PT variable as
    being TRUE
    waveRecorded_PT = true;           //-----SAME FOR CURRENT
    TRANSFORMER-----//
}
    ///////////////////////////////////////////////////////////////////

```

```

/////////////////////////////////////////////////////////////////ISR FOR RECORDING THE TIME, THE CT SIGNAL
ARRIVED/////////////////////////////////////////////////////////////////

```

```

void currentTransformer()
{
    pulseInTime_CT = micros();
    detachInterrupt(digitalPinToInterrupt(CT_D));
    waveRecorded_CT = true;
}

```

```

}

void optimalPowerFactor(int, float);    //Function for Finding Optimal Power Factor
and Related Number of Capacitors

void pfCorrection();                    //Function for Changing Capacitance in the System
Depending on Whether Current is leading or Lagging

void setup() {

    Serial.begin(115200);

    pinMode(PT_D, INPUT);                //Define PT_D Pin as input
    pinMode(CT_D, INPUT);                //Define CT_D Pin as input

    pinMode(CAP_BANK1, OUTPUT);         //
    pinMode(CAP_BANK2, OUTPUT);         //Define CAP_BANK1 as output
    pinMode(CAP_BANK3, OUTPUT);         //

    digitalWrite(CAP_BANK1, LOW);       //Initially no capacitor is included in the
system
    digitalWrite(CAP_BANK2, LOW);       //
    digitalWrite(CAP_BANK3, LOW);       //These Pins or connected to relays as in
Circuit Diagram

```

```

attachInterrupt(digitalPinToInterrupt(PT_D),    potentialTransformer,    RISING);
//Attach Interrupts to PT_D pin

attachInterrupt(digitalPinToInterrupt(CT_D),    currentTransformer,    RISING);
//Attach Interrupts to CT_D pin

pinMode(9, OUTPUT);

digitalWrite(9, 0); // default output in I2C mode for the SSD1306 test shield: set the
i2c adr to 0

u8g2.begin();

}

void loop() {

if(waveRecorded_PT == true andand waveRecorded_CT == true )
////////////////////////////////////

{ // Once time for both PT_D and
CT_D is recorded, these
    waveRecorded_PT = false; //statements will execute.
Initially setting both waveRecorded_CT
    waveRecorded_CT = false; //and waveRecorded_PT
as false. Then measuring the time difference
//b/t PT_D and CT_D signals. The
inner if statement ensures that both

```

```

    long timeDifference = pulseInTime_PT - pulseInTime_CT;          //PT_D and
CT_D corresponds to the same wave. Time difference is

```

```

//averaged over 10 signals recorded

```

accurately.

```

    if( timeDifference > -5000 andand timeDifference < 5000 )      //
    {
        //
        timeDifferenceAv = timeDifferenceAv + timeDifference;      //
        divider++;
        //
    }
    //
    attachInterrupt(digitalPinToInterrupt(PT_D), potentialTransformer, RISING); //
    attachInterrupt(digitalPinToInterrupt(CT_D), currentTransformer, RISING); //
}
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

```

```

if(divider > 9 )
//This statement will execute
once 10 accurate time difference are recorded

```

```

{
    timeDifferenceAv = timeDifferenceAv / divider; //Take Mean Value of pulse
durations

```

```

    timeDifferenceAv = timeDifferenceAv / 1000000.00; //Convert microseconds into
seconds

```

```

Serial.println("////////////////////////////////////");

thetaDeg = timeDifferenceAv * freq * 360.0;    //Calculate angle in degrees

Serial.print("Phase Difference in Deg: ");
Serial.println(thetaDeg);

thetaRad = thetaDeg * 0.0174533 ;           //Calculate angle in radians

runningPF = cos(thetaRad);

Serial.print("Power Factor Running: ");
Serial.println(runningPF);

Serial.print("capIn: ");
Serial.println(capIn);

Serial.print("PF_Calculated: ");
Serial.println(PF_Calculated);

Serial.println("////////////////////////////////////");

    timeDifferenceAv = 0;

divider = 0;

    if( (runningPF < optimalPF * 0.975 || runningPF > optimalPF * 1.025) andand
PF_Calculated == true ) // This statment checks whether the system is running at
Optimal PF

        PF_Calculated = false;                //If power
factor does not match the optimal PF the variable PF_Calculated

```

//is assigned a FALSE

value, meaning that new Optimal PF needs be calculated

```
if(PF_Calculated == false)
{
    detachInterrupt(digitalPinToInterrupt(PT_D));
    detachInterrupt(digitalPinToInterrupt(CT_D));
    optimalPowerFactor(capIn, runningPF);
}
}
}
```

////////////////////////////////////

//////POWER FACTOR ////

```
void optimalPowerFactor(int cap_In, float PF)
{
    CAP_IN[index] = cap_In;
    POWER_FACTOR[index++] = PF;
    if(index > 7)
    {
        index = 0;
        int INDEX = 0;
        PF_Calculated = true;
        for(int i = 0; i < 8; i++)
        {
            if( POWER_FACTOR[0] < POWER_FACTOR[i] )
```

```

    {
        POWER_FACTOR[0] = POWER_FACTOR[i];

        INDEX = i;
    }
}

optimalPF = POWER_FACTOR[0];

capIn = CAP_IN[INDEX];

pfCorrection();

Serial.println("_____");

Serial.println(optimalPF);

Serial.println(capIn);

Serial.println("_____");

////////////////////////////////////////////////////////////////

u8g2.clearBuffer();          // clear the internal memory

u8g2.setFont(u8g2_font_ncenB08_tr); // choose a suitable font

u8g2.setCursor(2,10);        // set cursor position

u8g2.print("Optimal Power Factor");

u8g2.setCursor(50,25);

u8g2.print(optimalPF);        // write power factor to the internal memory

u8g2.sendBuffer();

////////////////////////////////////////////////////////////////

attachInterrupt(digitalPinToInterrupt(PT_D), potentialTransformer, RISING);

attachInterrupt(digitalPinToInterrupt(CT_D), currentTransformer, RISING);

} else

```

```

{
    if( thetaDeg < 0 )
        capIn++;
    else if(thetaDeg > 0)
        capIn--;

    if( capIn < 0 )
        capIn = 0;
    else if( capIn > 7)
        capIn = 7;

    ///////////////////////////////////////////////////////////////////

    u8g2.clearBuffer();          // clear the internal memory
    u8g2.setFont(u8g2_font_ncenB08_tr); // choose a suitable font
    u8g2.setCursor(2,10);       // set cursor position

        u8g2.print("Running Power Factor");

    u8g2.setCursor(50,25);

    u8g2.print(runningPF);      // write power factor to the internal memory
    u8g2.sendBuffer();

    ///////////////////////////////////////////////////////////////////

        pfCorrection();
    }
}

void pfCorrection()
{
    switch(capIn)

```

```
{  
case 0:  
    digitalWrite(CAP_BANK1, LOW);  
    digitalWrite(CAP_BANK2, LOW);  
    digitalWrite(CAP_BANK3, LOW);  
    break;  
case 1:  
    digitalWrite(CAP_BANK1, HIGH);  
    digitalWrite(CAP_BANK2, LOW);  
    digitalWrite(CAP_BANK3, LOW);  
    break;  
case 2:  
    digitalWrite(CAP_BANK1, LOW);  
    digitalWrite(CAP_BANK2, HIGH);  
    digitalWrite(CAP_BANK3, LOW);  
    break;  
case 3:  
    digitalWrite(CAP_BANK1, HIGH);  
    digitalWrite(CAP_BANK2, HIGH);  
    digitalWrite(CAP_BANK3, LOW);  
    break;  
case 4:  
    digitalWrite(CAP_BANK1, LOW);  
    digitalWrite(CAP_BANK2, LOW);  
    digitalWrite(CAP_BANK3, HIGH);
```

```
    break;

case 5:

    digitalWrite(CAP_BANK1, HIGH);

    digitalWrite(CAP_BANK2, LOW);

    digitalWrite(CAP_BANK3, HIGH);

    break;

case 6:

    digitalWrite(CAP_BANK1, LOW);

    digitalWrite(CAP_BANK2, HIGH);

    digitalWrite(CAP_BANK3, HIGH);

    break;

case 7:

    digitalWrite(CAP_BANK1, HIGH);

    digitalWrite(CAP_BANK2, HIGH);

    digitalWrite(CAP_BANK3, HIGH);

    break;

default:

    break;

}

attachInterrupt(digitalPinToInterrupt(PT_D), potentialTransformer, RISING);

attachInterrupt(digitalPinToInterrupt(CT_D), currentTransformer, RISING);

}
```