RAMAIAH
Institute of Technology

Department of Electrical &
Electronics Engineering

A Project Report on

Design And Development Of Inclined Plane Test Setup

Submitted in partial fulfillment of the requirements for the award of the degree of

Bachelor of Engineering in Electrical and Electronics Engineering

By

Nanditha S	**1MS20EE029**
Shilpa H B	**1MS20EE049**
Shivam Anand	**1MS20EE050**
Tharun BG	**1MS21EE404**

Under the guidance of

DR. RAMAKRISHNA MURTHY K
Assistant Professor,
EEE Dept., MSRIT

M S RAMAIAH INSTITUTE OF TECHNOLOGY

(Autonomous Institute, Affiliated To VTU)
Bengaluru – 560054

May 2024

RAMAIAH
Institute of Technology

Department of Electrical & Electronics Engineering

CERTIFICATE

Certified that the project work entitled **"Design And Development Of Inclined Plane Test Setup"** is carried out by **Nanditha S -** USN **1MS20EE029**, **Shilpa H B -** USN **1MS20EE049, Shivam Anand -** USN **1MS20EE050** and **Tharun BG** - USN **1MS21EE404**, bonafide students of **M S Ramaiah Institute Of Technology, Bengaluru** in partial fulfillment for the award of **Bachelor of Engineering in Electrical and Electronics Engineering** of Visvesvaraya Technological University, Belagavi during the year **2023 - 24**. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the department library. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said degree.

Project Guide	**Head of the Department**
Dr. RAMAKRISHNA MURTHY K	**Dr. PRADIPKUMAR DIXIT**

External Examiners

Name of Examiners: **Signature with Date**

1.

2.

RAMAIAH
Institute of Technology

Department of Electrical & Electronics Engineering

DECLARATION

We, hereby, declare that the entire work embodied in this project report has been carried out by us at M S Ramaiah Institute of Technology, Bengaluru, under the supervision of **Dr. Ramakrishna Murthy K.** This report has not been submitted in part or full for the award of any diploma or degree of this or any other University.

Nanditha S	**1MS20EE029**
Shilpa H B	**1MS20EE049**
Shivam Anand	**1MS20EE050**
Tharun BG	**1MS21EE404**

ACKNOWLEDGEMENT

We are pleased to present this project report upon its successful completion. This project would not have been possible without the guidance, assistance, and suggestions of many individuals. We would like to express our deep sense of gratitude to each and every person who has contributed to making this project a success.

First and foremost, we express our deep sense of gratitude and indebtedness to our guide Dr. Ramakrishna Murthy K, Assistant Professor, Department of Electrical and Electronics Engineering, MSRIT, Bangalore, for his valuable guidance, continuous assistance and in the critical appraisal of the thesis.

We also express our sincere gratitude to Dr. Pradipkumar Dixit, Professor and Head, Department of Electrical and Electronics Engineering, MSRIT, for his encouragement and support throughout the project.

It is with great pleasure we extend our gratitude and thanks to Dr. N.V.R. Naidu, Principal, MSRIT, Bangalore, for providing the facilities required for the completion of this project work.

We thank the Board of Management of MSRIT for providing us with the opportunities to learn, grow and progress as students and as engineers.

We are thankful to Dr. R Subha, Project coordinator, Department of Electrical and Electronics Engineering, MSRIT, for her encouragement in successfully completing this project work.

We express our sincere thanks to the Department of Electrical and Electronics Engineering, MS Ramaiah Institute of Technology for the Project Funding.

Special thanks are due to all the staff members of Department of Electrical and Electronics Engineering, MS Ramaiah Institute of Technology for their help and cooperation.

Finally, We feel short of words to express our heartfelt thanks to all our family members and friends and all those who have directly or indirectly helped us during our course.

1MS20EE029 Nanditha S

1MS20EE049 Shilpa H B

1MS20EE050 Shivam Anand

1MS21EE404 Tharun BG

ABSTRACT

The performance of polymeric insulators are superior over traditional ceramic and glass insulators, but they degrade when subjected to environmental and electrical stresses. This degradation leads to increase in leakage current on the insulator’s surface, arcing, dry band formation and eventually a flashover. To evaluate the tracking and erosion performance of the polymeric materials, Inclined Plane Test setup is used. The test setup mimics the degradation of polymeric insulating material due to electrical and environmental stresses. In the present work, an efficient and automated Inclined plane test setup has been developed. The work includes design and development of an indigenous leakage current data acquisition system, potential divider and a control panel. The setup has been tested for its intended functionality. This test setup helps in ensuring a safe and reliable operation of power systems by accelerating widespread adoption of superior polymeric insulators in transmission lines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

1.1 BACKGROUND

Insulators are essential components in electrical systems, used to prevent unwanted flow of current and to support and separate electrical conductors. The main types of insulators include ceramic, glass, and polymeric insulators. Ceramic and glass insulators have been traditionally used due to their good electrical and mechanical properties. However, polymeric insulators, made primarily from materials like silicone rubber and ethylene propylene diene monomer (EPDM), have gained popularity and are often considered superior. This superiority stems from their lightweight nature, high resistance to vandalism, excellent hydrophobic properties, and better performance in polluted environments. Additionally, polymeric insulators are less prone to breakage, easier to handle and install, and have a longer service life under various environmental conditions, making them a preferred choice in modern electrical applications. The two major constituent materials of polymeric insulators are silicone rubber, which offers excellent weather resistance and hydrophobicity, and EPDM, Ethylene Propylene Diene Monomer which provides superior flexibility and durability. The different parts of the polymeric insulators are shown in Fig. 1.1. whose individual functions are given below

1. Core (Rod): The core is typically made of a strong, insulating material such as fiberglass-reinforced resin. This rod provides the mechanical strength necessary to support electrical conductors and withstand mechanical stresses like wind and ice loading.
2. Housing (Sheath): The housing is the outer layer of the insulator, usually made from silicone rubber or EPDM (ethylene propylene diene monomer). This sheath protects the core from environmental factors such as moisture, pollution, and UV radiation, and provides the hydrophobic surface that helps prevent contamination build-up and surface currents.
3. Weather Sheds (Sheds): The sheds are the umbrella-like extensions on the housing that increase the creepage distance, which is the path along the insulator surface between conductors. They enhance the insulator's ability to resist electrical leakage and flashover, especially in polluted environments.
4. End Fittings: These are the metal parts attached to both ends of the core rod, used to connect the insulator to the electrical hardware and conductors. The end fittings must be securely bonded to the core to ensure mechanical stability and effective load transfer. Common materials for end fittings include galvanized steel and aluminum.
5. Seals: Seals are placed between the end fittings and the housing to prevent moisture ingress, which could degrade the insulator's performance. High-quality seals are crucial for maintaining the insulator's integrity and prolonging its service life.

Each of these parts works together to provide the necessary electrical insulation and mechanical support in a compact, durable, and efficient design, making polymeric insulators suitable for a wide range of applications in modern power systems.

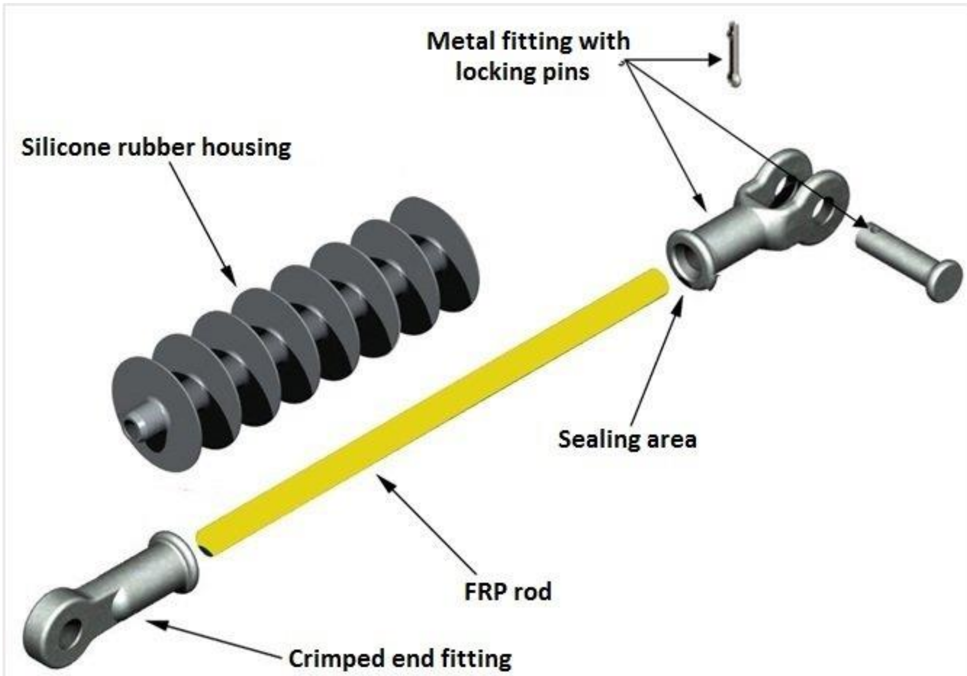


Fig. 1.1 Different parts of polymeric insulators

As polymer insulators embrace outdoor environments, they inevitably encounter the ravages of time and the relentless onslaught of natural forces. Aging and degradation of the housing material emerges as a formidable adversary, wherein factors such as UV radiation, temperature fluctuations, humidity, and mechanical stresses conspire to diminish the performance of these insulators. Such degradation can culminate in cracks, erosion, and even the loss of their coveted insulating properties. Herein lies the significance of hydrophobicity , a trait that empowers polymer insulators to repel water, thwarting the intrusion of moisture, pollutants, and contaminants that can sabotage their integrity. Amidst these challenges, the inclined plane testing setup emerges as a beacon of scientific rigor.

This setup simulates real-world conditions wherein water cascades down the insulator's surface. This setup is used to test the polymeric insulator. By subjecting polymer insulators to controlled water flow, engineers gain invaluable insights into their hydrophobic behavior and tracking resistance. Through careful observation, it becomes apparent whether the polymer's surface repels water, fostering droplets that adroitly evade surface wetting. This setup is used to determine whether an polymeric material is suitable to be used as an insulator.

1.2 LITERATURE SURVEY

This comprehensive literature review scrutinizes the evolving landscape of electrical insulation technology, focusing on the prominent use of silicon rubber composites (SiR) and their application in outdoor high-voltage scenarios spanning over five decades. Despite SiR's widespread adoption, the intricate dynamics of its long-term performance under DC voltage, particularly concerning vulnerability to tracking and erosion degradation, remain inadequately explored. The absence of an international standard for DC inclined plane tests has led to the adaptation of AC procedures, introducing complexities and making comparisons challenging. Polarity effects, parameter selection inconsistencies, and the qualitative presentation of results further complicate the evaluation of SiR insulators. The study's findings include the suggestion that, with a 0.3 ml/min pollutant flow rate, 3.5 kV AC and DC inclined plane tests give relatively similar qualitative results, although DC degradation is quantitatively more severe. However, above 3.5 kV DC, the results become erratic and unsuitable as a repeatable standardized procedure. The text also proposes that if the IEC-60587 standard is to apply to DC, the leakage current limit of 60 mA should be the sole failure criterion[1]. To determine the optimal composition of polymeric insulators for extended life expectancy, various tests simulating outdoor conditions were conducted. One such test involved applying a controlled voltage while continuously supplying a contaminant solution to the insulator's surface. This simulation creates conditions similar to those leading to electrical discharges and degradation in real-world scenarios. These tests prove instrumental in categorizing insulating materials based on their capacity to endure voltage stress and contaminants, offering valuable insights into their behavior under specific circumstances [2]. Moreover, the study delved into the impact of different pollution patterns on insulator performance. Simulation involved applying mixtures of water and salt with varying conductivity to mimic pollution. This study tested three pollution configurations: near the high-voltage electrode, near the ground electrode, and in the middle of the insulator. Varying widths of polluted layers were utilized. By analyzing leakage current waveforms and applied voltage data, the study aimed to understand how the insulator performed under polluted conditions. The study also employed techniques such as Fast Fourier Transform (FFT) and Discrete Wavelet Transform (DWT) for frequency analysis of leakage current signals, focusing on frequency characteristics [3]. One challenge faced by outdoor insulators is their exposure to wet and contaminated conditions, leading to moisture condensation and the formation of a continuous wet film over time. This film allows leakage current to flow through it, impacting performance. Traditional methods for monitoring leakage currents were found to be inadequate for real-life scenarios. An alternative method was employed, utilizing harmonic components of leakage current for evaluation and monitoring. However, this method lacked the ability to accurately capture the underlying characteristics of discharge sequences during the flashover process. To address this limitation, a recurrent plot technique was introduced to monitor and investigate the non-linear characteristics of leakage current [4]. For the leakage current model the real time data acquisition is necessary and this particular research paper presents an inexpensive, open-source USB data acquisition device built with an Arduino Uno and 16-bit ADC. This device offers a cost-effective alternative to commercial USB data acquisition devices, providing a solution for laboratories requiring multiple setups [5]. The paper presents a detailed investigation of a resistive voltage divider for DC voltage measurement up to 10 kV or 20 kV. Key features include 20 high-voltage resistors, a 100 kΩ output resistor, and circular electrodes forming parallel capacitors to minimize corona currents and leakage resistance. The calibration process involves verifying resistor voltage dependence, facilitating easy recalibration for prolonged usage. The divider is designed for versatility, capable of measuring AC and impulse voltages with frequency independence ensured through compensatory capacity and automatic correction methods. The paper underscores the structural components, such as MACOR insulation rods and thin-film resistors, while acknowledging the need for a more comprehensive literature review within the complete paper to contextualize the study within existing research on high-voltage dividers and calibration techniques [8].

1.3 SUMMARY OF LITERATURE SURVEY

- Testing polymeric insulators under simulated outdoor conditions reveals insights into their durability and performance.
- Controlled voltage application with contaminant exposure mimics real-world stresses, aiding in material categorization.

- Such tests are crucial for identifying insulators' ability to withstand voltage stress and contaminants, guiding material selection for longevity.
- Investigating diverse pollution patterns' impact on insulator performance reveals crucial insights.
- Advanced techniques like FFT and DWT aid in analyzing leakage current signals, highlighting frequency characteristics for deeper insights.
- Traditional leakage current monitoring methods prove insufficient, prompting the use of harmonic components for evaluation.
- Introduction of recurrent plot technique enhances monitoring by capturing non-linear characteristics during the flashover process.
- Real-time data acquisition is crucial for accurate leakage current modeling.
- Detailed investigation of a resistive voltage divider for precise DC voltage measurement up to 10 kV or 20 kV.

1.4 MARKET SURVEY

As per the market survey that has been conducted where several questions have been asked to the industries. The project has been built to cater to their requirements. There have been totally 9 responses and the data obtained from the market survey done is shown below.

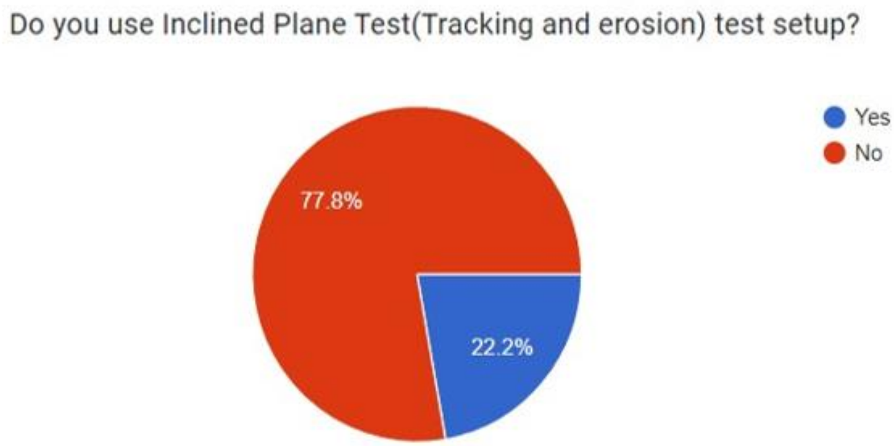


Fig. 1.2 Percent of responders currently using incline plane test setup

1.) Based on the data as seen in Fig.1.2, only 22.2% of users currently utilize the fully automated Inclined Plane Test Setup. This indicates a significant demand for this advanced test setup within the industry. Its adoption can greatly benefit various government and private sector organizations by providing more efficient and accurate testing capabilities.

Fig. 1.3 Percent of responders planning to buy one

2.) As per the above data given in Fig. 1.3, 62.5% of the responders are interested in buying the test setup.

3.) A few questions were asked about the requirements and facilities needed by the customers so that a test setup catering to all these requirements can be built. Fig. 1.4 shows the analysis obtained from the industries.

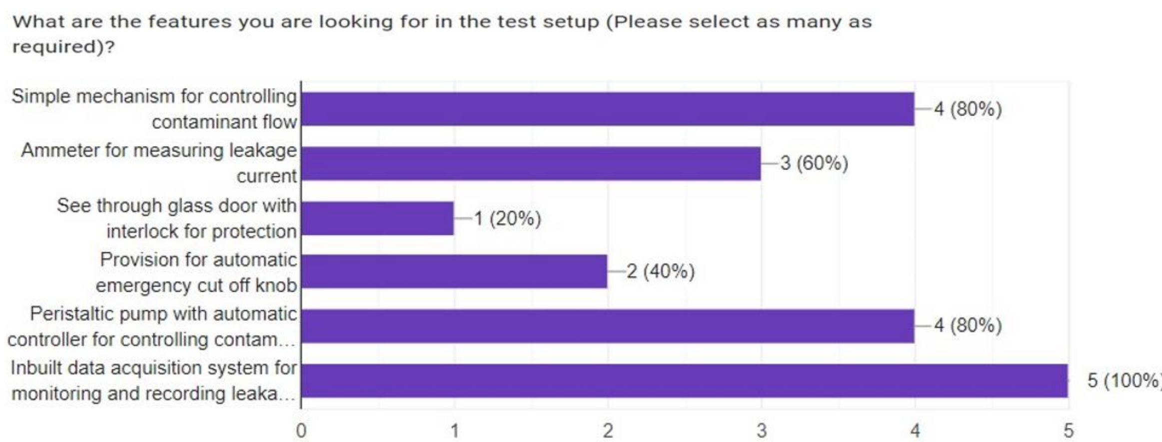


Fig.1.4 Requirements of responders

1.5 PROBLEM STATEMENT

The project work aims to design and develop a reliable, safe, cost effective and automized inclined plane test setup for performing tracking and erosion test on polymeric insulator housing materials.

1.6 OBJECTIVES

The main objectives of the project are given below

- To design and develop a cost-effective Inclined plane test setup for assessing tracking and erosion performance of polymeric insulating specimens
- To test the IPT setup for its intended functionality.

1.7 ORGANIZATION OF CHAPTERS

CHAPTER 1 sets the stage by delving into the project's foundation: its background, literature review, market analysis, and the precise problem it aims to address. Furthermore, it delineates the objectives and the expansive scope of the project.

CHAPTER 2 then navigates into the conceptual underpinnings of the project, offering a comprehensive exploration of the circuit's functionality. Later this chapter describes the indigenous design of the panel developed, the components used in the panel and the specifications of the developed testing panel.

CHAPTER 3 gives the in-depth methodology behind the working of the key components of the panel which are the leakage current measuring ammeter with data acquisition system, potential divider and the saline flow control method. It also talks about the difficulties faced with peristaltic pumps and the alternative method adopted. A brief overview of the control wiring is also explained here.

CHAPTER 4 talks about the panel testing done and the results obtained after testing.

CHAPTER 5 concludes the entire project work done and discusses the future scope.

Chapter 2

SYSTEM WORKING AND ARCHITECTURE

In this chapter the working of the panel circuit, testing procedure, criteria for determining test results , the specifications of the panel developed, CAD design and components used are discussed in detail in the following sections of this chapter.

2.1 CIRCUIT EXPLANATION

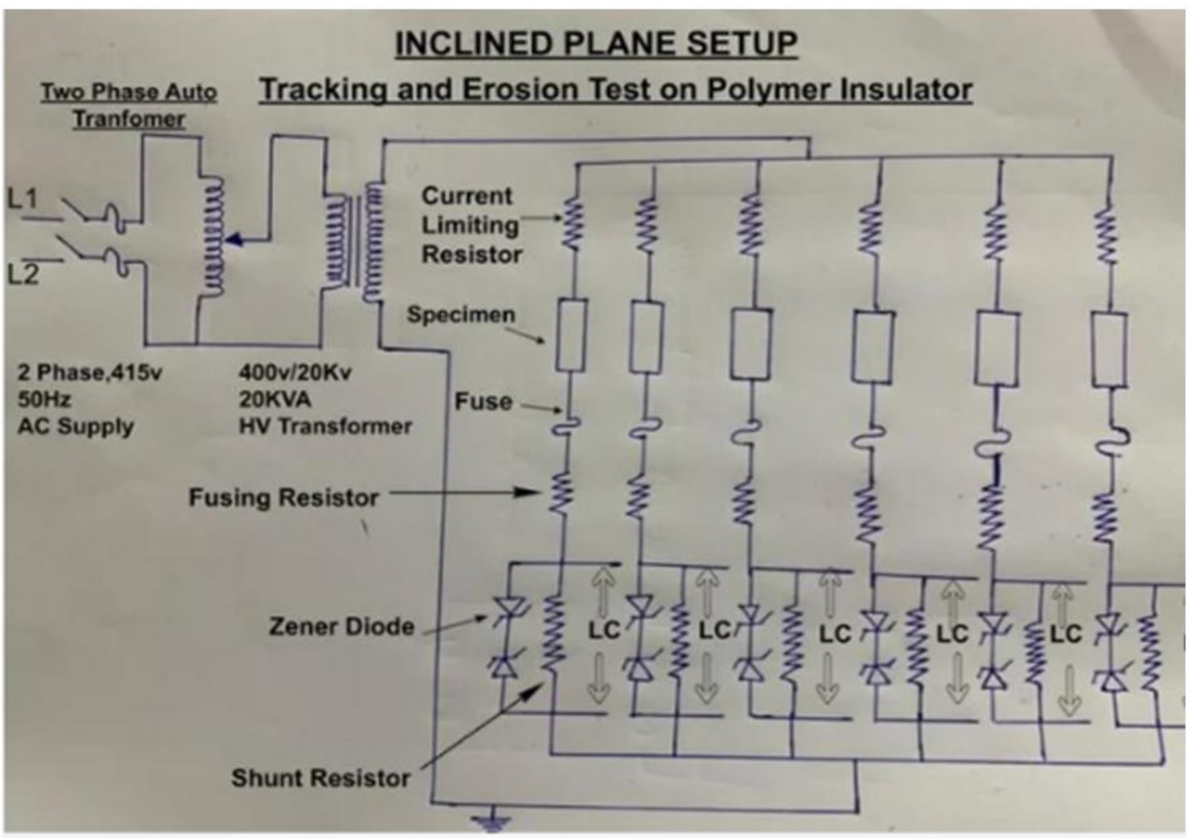


Fig. 2.1 Circuit diagram

The basic circuit used for the testing process is shown in Fig. 2.1. The specifications of the components used are described in the following points.

- Current Limiting Resistor - Non-Inductive Ballast Resistor, 33k ohms, 200 watts
- Shunt Resistor - 100 milliohms
- Fuse - 60 mA
- Fusing Resistor - 330 ohm, ½ watt
- LC - Leakage Current

2.1.1 Components and their functions

1. Two Phase Auto Transformer:

- This device is used to vary the two-phase, 415V input AC supply to the voltage required for the test.
- L1 and L2 are the input lines from the 2-phase, 415V, 50Hz AC supply.

2. HV Transformer:

- The high-voltage transformer steps up the 415V output from the auto transformer to 20kV.
- It has a 20kVA rating, which indicates the power capacity of the transformer.

3. Current Limiting Resistor:

- A non-inductive ballast resistor with a resistance of 33 k ohms and a power rating of 200 watts.

- Its function is to limit the current flowing through the circuit to prevent damage to the specimen and other components.

4. Specimen:

- This is the polymer insulator being tested for tracking and erosion.
- It is placed in the circuit to be exposed to high voltage and monitored for its performance under stress.

5. Fuse:

- Rated at 60mA, it provides overcurrent protection.
- If the current exceeds this value, the fuse will blow, breaking the circuit to protect other components.

6. Fusing Resistor:

- A resistor with a value of 330 ohms and a power rating of 1/2 watt.
- It acts as a protective component that will fuse under excessive current, thereby providing additional protection.

7. Zener Diode:

- Used for voltage regulation and protection.
- It ensures that the voltage across the leakage current measurement setup does not exceed 2.7V.

8. Shunt Resistor:

- A low-value resistor with a resistance of 100 milliohms.
- It is used to measure the leakage current (LC) by producing a voltage drop proportional to the current passing through it.

9. Leakage Current (LC):

- The leakage current is the current that flows through the specimen (polymer insulator) under test conditions.
- Each LC path includes a Zener diode to protect against overvoltage

2.1.2 Circuit Operation

1. Power Input:

- The system receives a 2-phase, 415V, 50Hz AC supply.
- This input is fed into the auto transformer, which is used to vary the input voltage to 400V and then further stepped up to 20kV by the HV transformer.

2. Current Limiting and Testing:

- The high voltage is passed through a current limiting resistor to control the current flowing through the specimen.
- The specimen is subjected to this high voltage to simulate real-life conditions that can cause tracking and erosion.

3. Protection Mechanisms:

- The fuse and fusing resistor provide overcurrent protection, ensuring the safety of the components in the event of excessive current flow.
- Zener diodes in the leakage current measurement circuit prevent overvoltage damage.

4. Leakage Current Measurement:

- The shunt resistor is used to measure the leakage current by producing a small voltage drop proportional to the current.
- Multiple measurement points (LC paths) allow for monitoring the leakage current at different positions or under different conditions.

2.2 TESTING PROCEDURE

The testing procedure of the polymeric insulating samples are performed in accordance with the IEC 60587 (International Electrotechnical Commission) and ASTM D2303 (American Society for Testing and Materials) which are discussed in the following subsections

2.2.1 Specimen preparation

The specimens shall be washed with a suitable solvent (e.g. isopropyl alcohol) to remove leftovers such as fat from handling. After that the specimens shall be rinsed with distilled water.

2.2.2 Test Setup

The test setup used for conducting the inclined plane test is described below

1. Power Supply : A 60-Hz power supply with an output voltage stabilized to 61 % which can be varied from 1 to at least 7.5 kV with a rated current of no less than 0.1 A for every test station to be used.
2. Electrodes : Stainless steel top and bottom electrodes. A pad of filter paper is cut to fit under the top electrode and used to smooth out the flow of the contaminant solution.
3. Contaminant: Unless otherwise specified 0.1 % ± 0.002 % by mass of NH4Cl (ammonium chloride) analytical quality, and 0.02 % ± 0.002 % by mass of iso octylphenoxypolyethoxyethanol (a non-ionic wetting agent) in distilled or deionized water are used. This contaminant shall have a resistivity of 3.95 Ωm ± 0.05 Ωm at 23 °C ± 1 °C and shall be not more than four weeks old. Its resistivity shall be checked before each series of tests. The rate of application of contaminant shall be within +/- 10% of 0.075, 0.15, 0.3, 0.6, 0.9 ml/min.
4. Ventilation: The test chamber shall be equipped with a ventilation to allow an exhaust of steam and gaseous decomposition products. The ventilation of the test chamber should be moderate and constant to avoid permanent condensation of water. Direct airflow across the test specimens shall be avoided.

2.2.3 Testing process

1. Preparation for the test: Unless otherwise specified, the test shall be carried out at an ambient temperature of 23 °C ± 2 °C on sets of at least five specimens for each material. Mount the specimen, with the flat test surface on the underside, at an angle of 45° ± 2° from the horizontal as shown in Fig. 2.2 with the electrodes 50 mm ± 0.5 mm apart. The test for a further 5 specimens can be achieved either

simultaneously or respectively. Start introducing the contaminant into the filter-paper pad by inserting a needle halfway through the filter paper. Allow the contaminant to wet the paper thoroughly. Adjust the contaminant flow and calibrate to give a flow rate as specified in the previous subsection. Observe the flow for at least 10 min and ensure that the contaminant flows steadily down the face of the test specimen between the electrodes. For a specimen that has never been subjected to voltages and contaminant (that is, new specimen), start the contaminant injection into the filter paper, allowing the fresh contaminant to wet the filter paper thoroughly and replace the old liquid in the tubes and syringes and to flow as a steady stream (not intermittent bursts) across the test specimen face between electrodes. The contaminant shall flow from the quill hole of the top electrode and not from the sides or the top of the filter-paper. Adjust the specimens so that the contaminant runs down as nearly as possible the centerline of the specimen.

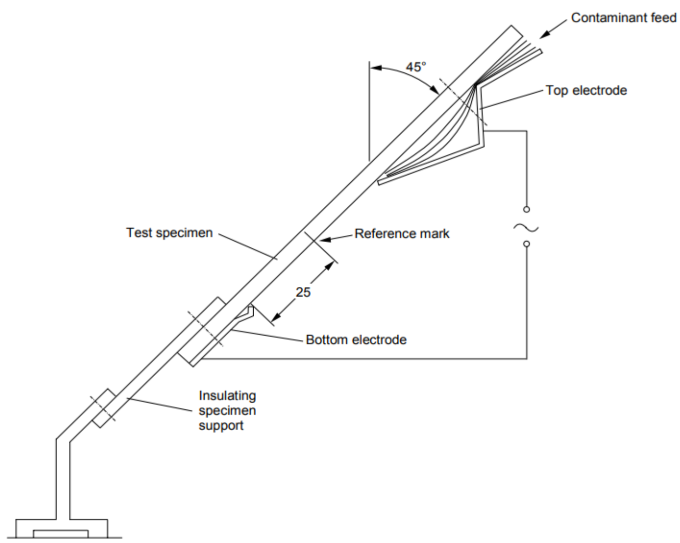


Fig. 2.2 Specimen placement (taken from international standard IEC 60587)

2. Voltage application: There are two methods for inclined plane test setup, one under the influence of constant tracking voltage and the other under the influence of stepped tracking voltage. In this project only constant tracking voltage approach has been used. With the contaminant flowing uniformly at the specified rate, switch on and raise the voltage to one of the preferred test voltages, 2.5 kV, 3.5 kV or 4.5 kV, which should be reached within a maximum of 10 s, and start the timing device. The voltage shall be maintained constant for 6 h. If the test has to be repeated at a higher or lower voltage, a further set of five specimens shall be tested for each selected preferred voltage. Effective scintillation, small yellow to white (perhaps with some parts blue) arcs, is expected to appear predominantly just above the teeth of the lower electrode within at most a very few minutes after application of the voltage. These discharges are expected to occur in essentially a continuous fashion, although they sometimes “dance” from one tooth to another before finally settling down to cause a small, bright “hot spot” which will start “chewing” on the specimen surface and which will ultimately lead to tracking failure. Effective scintillation is critical and if not obtained, then the electrical circuit, the contaminant flow characteristics, and the contaminant conductivity must be carefully checked and adjusted to create the condition for effective scintillation.

2.3 CRITERIA FOR DETERMINING TEST RESULTS

The specimen under test is deemed to have passed successfully if, throughout the entirety of the 6-hour testing period, it satisfies the following criterias:

- Tracking should not be more than 50% of the gap distance between the electrodes.

- There should be no through hole in the specimen due to tracking.
- Leakage current should not be more than 60 mA for more than 2 seconds.
- The specimen should not ignite.

2.4 PRECAUTIONS TO BE TAKEN

The following precautions are to be taken during inclined plane test:

- Steady scintillation between successive injections should be obtained.
- Loss of any contaminant, such as by squirting outside of filter paper should not occur.
- Whether the contaminant stream down the test specimen face is steady instead of in spurt.
- Air bubble leaks into the syringes which would change the contaminant feed rate should be prevented
- Stuck syringe pistons.

2.5 SYSTEM ARCHITECTURE

This section talks in detail about the CAD model designed, components used in the panel and the specifications according to which the panel is developed

2.5.1 CAD diagram

The CAD Design is drawn on Auto CAD student version software. The CAD model consists of Front view, right view, left view, rear view, cross sectional right side view and back view with door open which are shown in Fig. 2.3, 2.4 and 2.5. All the dimensions for the design are given in millimeters. The overall dimensions of the panel are

- Height of the Panel - 6 feet
- Breadth of the Panel - 5 feet
- Thickness of the Panel - 2 feet

The detailed description of the dimensions and components present in each view are given below

1. Left View: The detailed description of the dimensions and components present in the left cross section of the panel are shown in Fig. 2.3. The entire structure stands at a height of 1920 mm and a width of 609.6 mm. Key components include an exhaust fan, measuring 150 mm x 150 mm, located on the left side to remove fumes generated during testing. In the top left corner, there is a stand with dimensions of 150 mm x 150 mm x 120 mm, designed to hold the water tank containing saline water. The panel is equipped with a tower light system to indicate the status of the system: pressing the emergency switch activates a red light and triggers an alarm, while pressing the start button illuminates a green light, signaling that the panel is operational.

2. Front View: The detailed description of the dimensions and components present in the front cross section of the panel are shown in Fig. 2.3. The entire structure stands at a height of 1920 mm and a width of 1623.99 mm. The front view is divided into four sections, each 380.75 mm wide, except the last section which is 381.73 mm. The front view illustrates the placement and dimensions of various components, including indicator light for operational status feedback, an emergency switch for immediate power shutdown, an on/off switch for primary power control , and a leakage current measuring ammeter (indicated as A) with dimensions of 96 x 96 mm. Additionally, it shows a voltmeter

(indicated as V and F) with the same dimensions. Other features visible in the front view are the acrylic sheet door, handles, name plate, and danger plate, clearly marking their locations and sizes.

3. Right View: The detailed description of the dimensions and components present in the right cross section of the panel are shown in Fig. 2.3. The right view has the same dimensions and components as the left view, in addition it also includes HV and LV bushings for connecting high-voltage and low-voltage circuits.

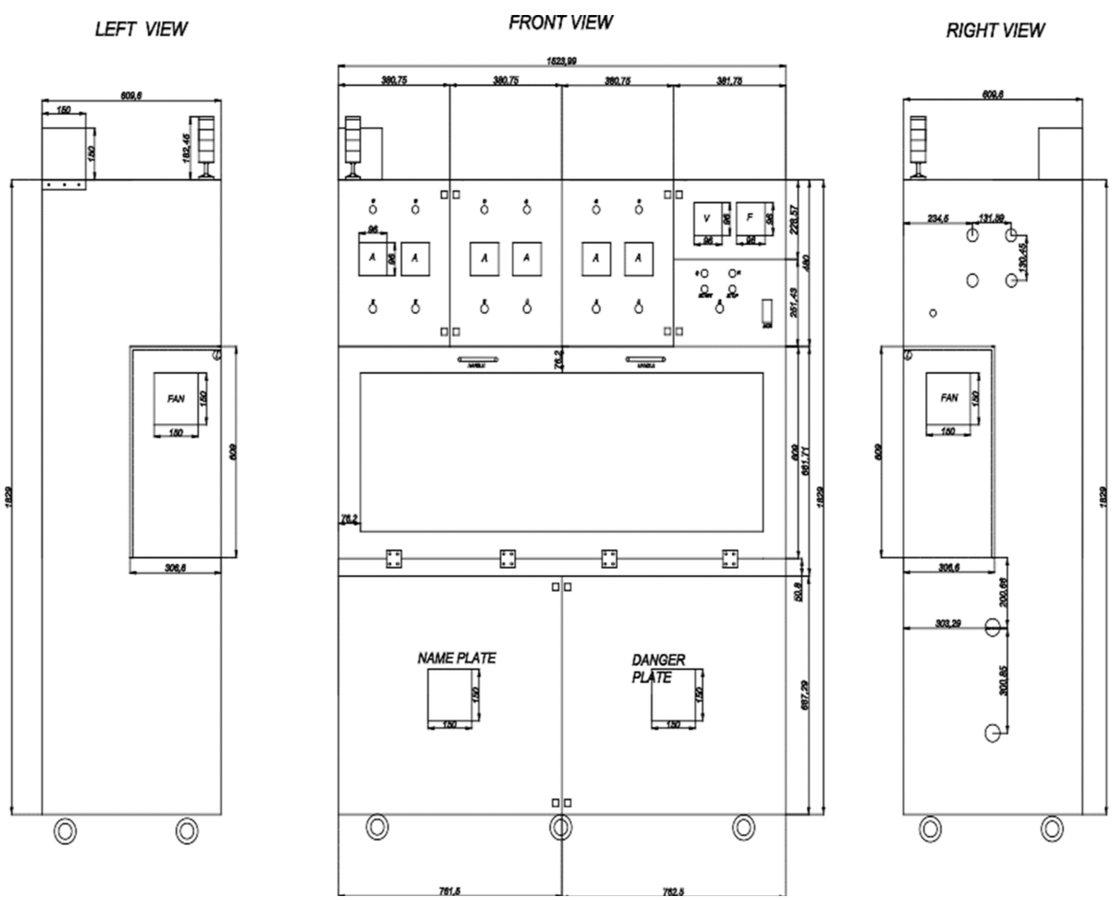


Fig. 2.3 CAD diagram showing front, left and right view

4. Back view with door open: Fig. 2.4 provides a detailed description of the dimensions and components visible in the back view with the door open. This view illustrates how connections are made from the 33k ohms bus bar through various sections of the panel, which function like a bus bar. The layout and design of these sections facilitate the efficient distribution of electrical connections throughout the panel, highlighting the organized and accessible arrangement of components.

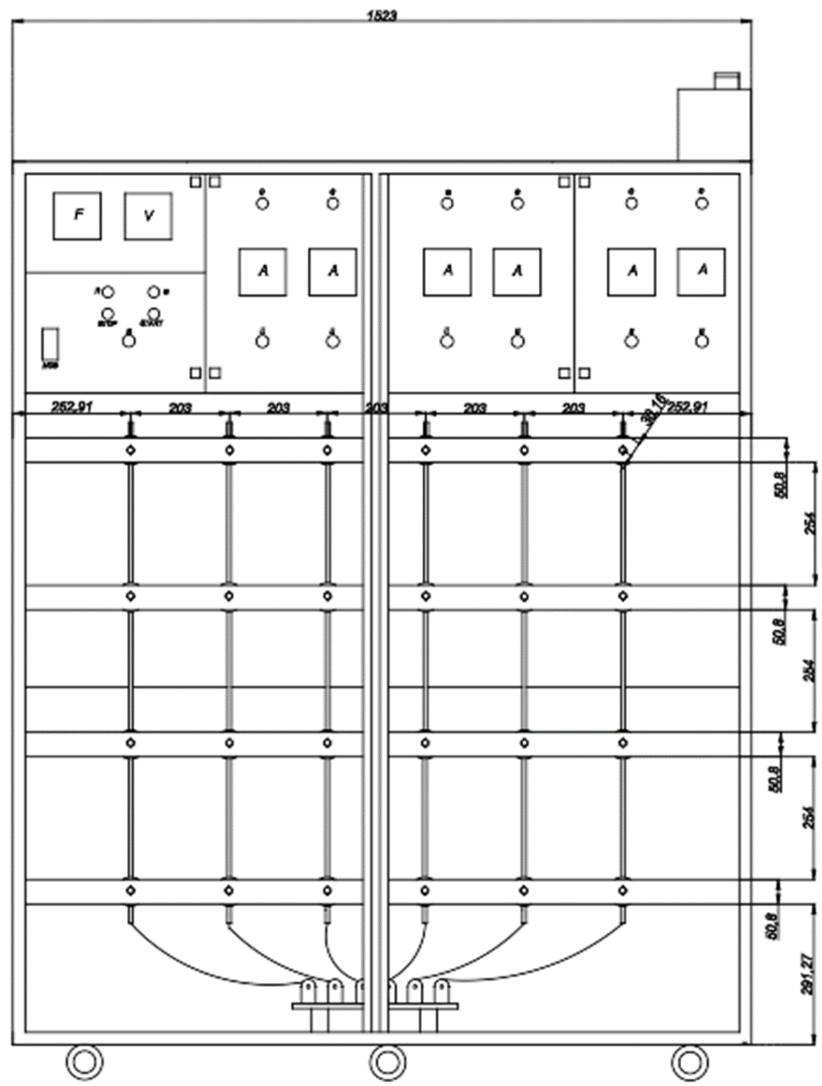


Fig. 2.4 CAD diagram showing back view with door open

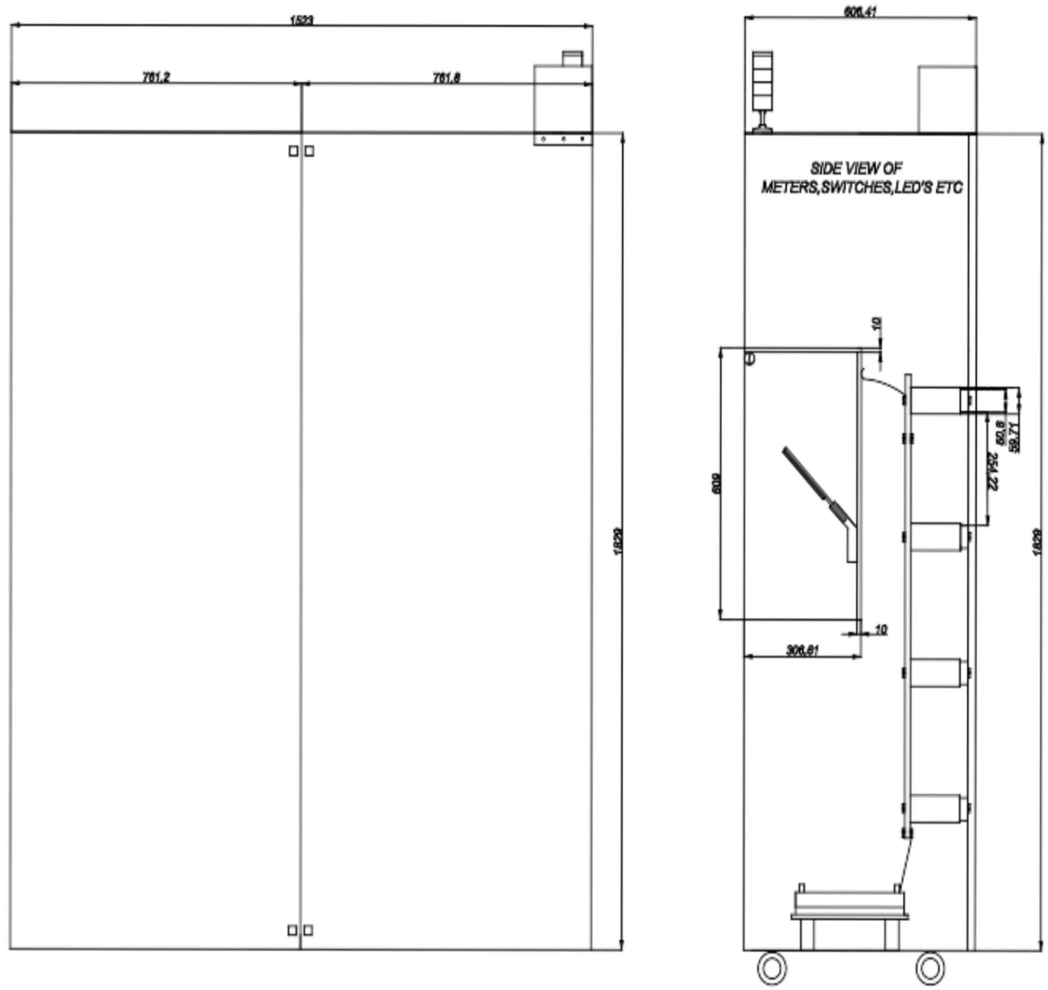


Fig. 2.5 CAD diagram showing rear and right cross sectional views

5. Cross-Sectional Right-Side View: Fig. 2.5 provides a detailed description of the dimensions and components in the right cross-sectional view of the panel. This view also illustrates the position where the specimen is placed and the angle it makes with respect to the FRP sheet. The precise layout ensures accurate positioning and alignment, which is crucial for the effectiveness and reliability of the test setup.

6. Rear view: Fig. 2.5 illustrates the rear view of the panel, detailing the dimensions of the doors located at the back. This view provides a comprehensive understanding of the panel's design and access points, ensuring that the layout and size of the rear doors are clearly described for maintenance and operational purposes.

2.5.2 Panel components

The Components used in the panel are described in this section

1. SSR : A solid state relay (SSR) is an electronic switching device that switches on or off when an external voltage (AC or DC) is applied across its control terminals.SSR’s provide complete electrical isolation between their input and output contacts with its output acting like a conventional electrical switch in that it has very high, almost infinite resistance when nonconducting (open), and a very low resistance when conducting (closed). Solid state relays can be designed to switch both AC or DC currents by using an SCR, TRIAC, or switching transistor output instead of the usual mechanical normally-open (NO) contacts. Solid state relays have no such limitations.Thus the main advantages solid state relays have over conventional electro-mechanical relays is that they have no moving parts to wear out, and therefore no contact bounce issues, are able to switch both “ON” and “OFF” much faster. Table 2.1 shows the specifications of SSR used. The SSR used in the panel is FOtek SSR - 75A 380 VAC / 32 VDC as shown Fig.2.6 .

Fig. 2.6 Solid state relay FOtek

Table 2.1 Specifications of SSR

PARAMETERS	VALUES/ RANGE
Operating voltage (Output)	24V - 380V AC
Control voltage (Input)	3V - 32V DC
Rated Current	75 A
Response time	up to 10ms
Operating temperature	-30°C to 80°C
Dimensions	63 X 45 X 23 mm

2. Single Pole MCB: A Single Pole Miniature Circuit Breaker (SP MCB) is a critical component in electrical panels used to protect circuits from overcurrent conditions. An SP MCB is designed to interrupt the flow of current in a single-phase electrical circuit in the event of an overload or short circuit. This protection is essential for preventing electrical fires and damage to equipment. In the panel designed, the SP MCBs are utilized to manage and protect individual circuit branches, ensuring that faults can be isolated without affecting the entire system. Fig. 2.7 shows the SP MCB used in the panel.

Fig. 2.7 SP MCB used in the panel

The specifications of the SP MCBs used in the panel are:

- Rated Voltage: 230V AC
- Rated Current: Typically ranges from 6A to 63A, depending on the circuit requirements

- Breaking Capacity: 6kA to 10kA, suitable for residential and light commercial applications
- Tripping Characteristics: Type B, which trips at 3-5 times the rated current, ideal for circuits with low inrush currents, such as lighting and general outlets.

SP MCBs provide robust protection against overcurrent conditions, which significantly reduces the risk of electrical fires. They ensure continuous operation by isolating only the affected circuit in the event of a fault, thereby maintaining the overall functionality of the electrical system. Faulty circuits can be easily identified and serviced without disrupting other parts of the electrical system, which facilitates ease of maintenance. Additionally, the compact design of SP MCBs allows for efficient use of space within the panel, enabling a neat and organized layout.

3. Bushings: In panel boards, bushings serve essential roles in ensuring the safety, reliability, and organization of the electrical distribution system. These components, typically constructed from insulating materials like rubber or plastic, provide insulation and protection for electrical conductors as they pass through the panel board enclosure. By creating smooth interfaces at the openings in the enclosure, bushings prevent damage to the wires' insulation, minimizing the risk of electrical faults, short circuits, or fires. Moreover, bushings aid in organizing the wiring by offering designated channels for routing, ensuring neatness and accessibility for maintenance purposes. They also play a crucial role in environmental protection by sealing the enclosure's openings against dust,

moisture, and other contaminants, thus safeguarding the integrity of the electrical connections. Additionally, bushings contribute to the stability of the panel board system by dampening vibrations, particularly in industrial environments, where excessive movement could jeopardize wire connections. Overall, bushings in panel boards are integral components that enhance safety, reliability, and efficiency in electrical distribution systems. Here porcelain bushings are used as shown in Fig. 2.8. The general specifications of the bushings used are given in Table 2.2.

Fig. 2.8 Porcelain Bushings

Table 2.2 Specifications of bushings

Parameters	Materials/ Values/ Range
Material	Porcelain
Rated Voltage	11kV
Voltage Range	11-33kV
Model Number/ Name	RC INDIA

1. HV Bushings:

- HV bushings are designed for high voltage applications, typically ranging from thousands to hundreds of thousands of volts.
- They provide insulation between high voltage conductors and grounded components or equipment, preventing electrical arcing and ensuring safe containment of high voltage currents.
- HV bushings are constructed from high-quality insulating materials such as porcelain, epoxy resin, or silicone rubber, capable of withstanding high electrical stresses without breaking down.
- These bushings come in various designs, including solid type, capacitance graded type, or oil-filled type, tailored to specific applications and requirements.
- They are mounted on the walls or enclosures of electrical equipment and are rated for specific voltage levels, ensuring safe and reliable operation in high voltage electrical systems.

2. LV Bushings:

- LV bushings, on the other hand, are designed for low voltage applications, typically ranging from a few hundred volts to a few thousand volts.
- Similar to HV bushings, LV bushings provide insulation between low voltage conductors and grounded components or equipment, preventing electrical arcing and ensuring safe containment of low voltage currents.
- LV bushings are also made from materials such as porcelain, epoxy resin, or silicone rubber, offering good electrical insulation properties suitable for lower electrical stresses present in low voltage applications.
- They come in various designs, including solid type, capacitance graded type, or oil-filled type, depending on specific application requirements.
- LV bushings are mounted on the walls or enclosures of electrical equipment and are rated for specific voltage levels, ensuring safe and reliable operation in low-voltage electrical systems.

4. Leakage current measuring and data acquisition ammeter: Leakage current refers to the current that flows on the surface of the insulator under applied voltage. It is important to measure leakage current as it acts as one of the criterias in determining whether a specimen passes or fails the test. Due to the non-sinusoidal nature of the current waveform, a true RMS method is adopted for measurement of leakage current. The detailed methodology behind the working of leakage current measuring and data acquisition ammeter is explained in the future sections. Fig. 2.9 shows the ammeter designed and developed. This ammeter has an operating voltage of 12V and a range of 0-60mA.

Fig. 2.9 The leakage current measuring and data acquisition ammeter

5. Digital voltmeter: Root Mean Square (RMS) voltmeters are essential instruments in electrical engineering and instrumentation for measuring the effective voltage of alternating current (AC) signals. They are preferred for their ability to provide an accurate representation of AC voltage levels, which is crucial in various applications. Unlike peak or average voltage measurements, RMS voltmeters calculate the effective voltage of an AC signal, equivalent to the DC voltage that would produce the same amount of power dissipation in a resistive load. This consistency across waveforms, regardless of shape or distortion, makes RMS measurements reliable and compatible with power calculations. Moreover, RMS voltage has become the standard method for expressing AC voltage levels in the industry, ensuring conformity and facilitating communication between devices and

systems. Modern digital voltmeters often include RMS measurement capabilities, making it easy for technicians and engineers to obtain accurate AC voltage readings without complex calculations. Besides, RMS measurements play a vital role in assessing safety hazards associated with electrical systems, allowing for the implementation of appropriate safety measures. Overall, RMS voltmeters are indispensable tools for accurately measuring AC voltage signals in a wide range of applications, from power distribution systems to electronic devices, contributing to efficient testing, troubleshooting, and safety practices in electrical engineering.The digital voltmeter used is shown in Fig. 2.10. Table 2.3 shows the specifications of the digital voltmeter used.

Fig. 2.10 Digital voltmeter

Table 2.3 Specifications of digital voltmeter

Parameters	Values/ Range/Type
Display	7 segment LED display
Digits	4
Rated input voltage	11 to 300V(L-N), 19 to 519V(L-L)
Electrical connection	3ϕ- 4 wire, 3ϕ - 3 wire, 1ϕ- 2 wire
Accuracy	+/- 0.5% of full scale
Auxiliary supply	40V to 300V AC/DC
PT Primary settings	1-999kV(Programmable to any value)
PT Secondary settings	100-500(Programmable to any value)
Mounting	Panel mount
Dimensions	96 x 96 mm

6. Potential divider: A potential divider, also known as a voltage divider, is a fundamental circuit component used to split a voltage into smaller, proportional parts. In this project, a potential divider with a 1000:1 ratio, meaning that for every 1000 units of input voltage, the circuit produces 1 unit of output voltage, is designed as shown in Fig. 2.11. This design choice offers precise control over voltage levels,

crucial for various applications where maintaining specific voltage thresholds is essential. By implementing this divider, the project operates with accuracy and efficiency, meeting the stringent requirements of design objectives while facilitating optimal performance across a range of operating conditions. The detailed design and fabrication of the potential divider used in the test setup is described in the future sections

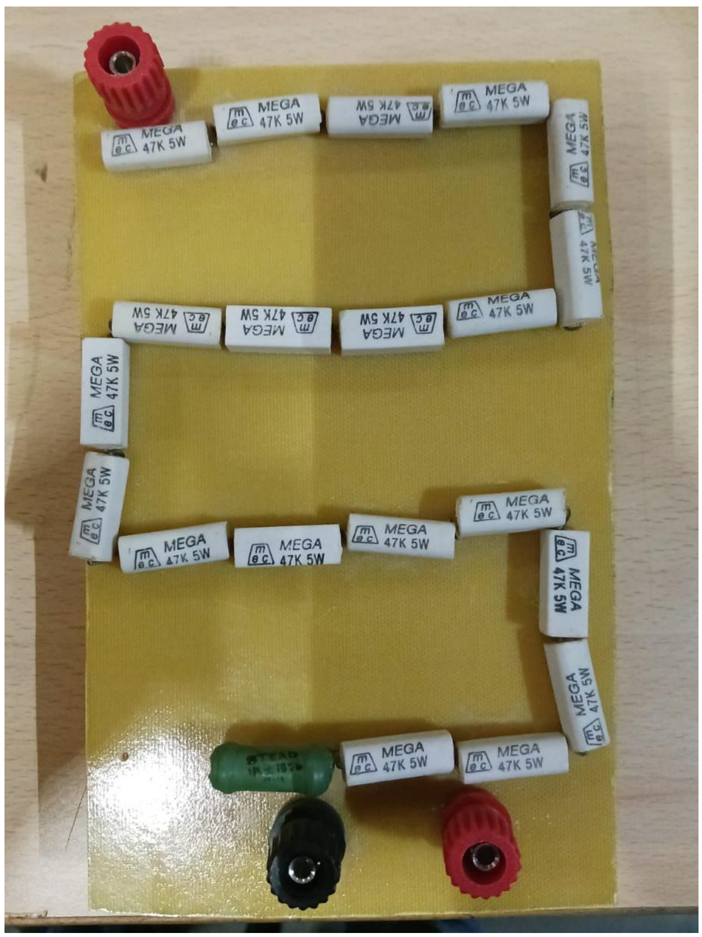


Fig. 2.11 Potential divider

7. Tower light : Tower lights are essential visual signaling devices utilized across diverse industrial, commercial, and construction environments. Mounted on tall

structures like poles or towers for maximum visibility, these lights offer immediate and clear indication of equipment status, process conditions, safety hazards, and emergency situations. Equipped with multiple colored lights, such as red, yellow, green, and blue, tower lights can be illuminated individually or in combinations to represent various states or conditions. In industrial settings, they play a critical role in enhancing safety and awareness by alerting workers to potential hazards, equipment malfunctions, or process abnormalities. Tower lights also aid in process monitoring, logistics operations, and emergency signaling, facilitating efficient operations, streamlined workflows, and organized responses to critical situations. With options for customization and integration into existing control systems, tower lights provide flexibility to suit specific application requirements, contributing to enhanced workplace safety, reduced downtime, and improved operational efficiency. The tower light used in the test setup and its specifications are shown in Fig. 2.12 and Table 2.4 respectively.

Fig. 2.12 Tower light

Table 2.4 Specifications of tower light

Parameters	Values/ Ranges/ Type
Brand	greatselec
Bulb type	LED
LED Color	Red, Green
Number of bulbs	1
Number of functions	3
Wattage	24W
Voltage requirement	24V DC

8. Push buttons; A push button is a small, sealed mechanism that completes an electric circuit when you press on it as shown in Fig. 2.13. When it's on, a small metal spring inside makes contact with two wires, allowing electricity to flow. When it's off, the spring retracts, contact is interrupted and current won't flow. The specifications of the push buttons used are given in Table 2.5.

Fig. 2.13: Push buttons

Table 2.5 Specifications of push buttons

Parameters	Range/Value/Type
Rated thermal circuit	10A
Rated insulation voltage for all push buttons and selector switches excluding luminous switches and lamp holders	AC 500V, 50Hz DC 250V
For illuminated switches and lamp holders	AC 250V, 50Hz DC 250V
Rated operational voltage for contact blocks	AC 500V, 50Hz, DC 220 V
Electrical ratings	AC 15 = 4A, 415V AC DC 13=0.5A, 110V DC with an time constant of 300ms

9. Contactor: A contactor is an electrical device primarily used to control a high-power circuit with a lower-power signal. It consists of a coil that, when energized, generates a magnetic field, attracting a movable core to close the contacts. These contacts, typically made of conductive materials like copper, connect or disconnect the power supply to the load. Contactors are often employed in applications where the power requirement exceeds the capacity of conventional switches or relays,

such as in industrial machinery, HVAC systems, and large motors. Contactors serve several crucial purposes in electrical systems. Firstly, they provide a reliable and durable method for switching high-current circuits, ensuring efficient operation and minimizing the risk of overheating or damage. Secondly, they enable remote or automatic control of electrical equipment, allowing for safer and more convenient operation in various industrial and commercial settings.

Fig. 2.14 shows the contactor used in the panel and Table 2.6 talks about its specifications

Fig. 2.14 Contactor

Table 2.6 Specifications of contactor

Parameters	Range/Value/Type
Series	AF09
Number of poles	3
Coil voltage	100-250V AC
Contact current rating	7A
Contact voltage rating	690V
Normal state configuration	NO(Auxiallar), 3NO(Main)
Number of auxiliary contacts	1
Power rating	5.5kW
Terminal type	Screw

2.5.3 Panel specifications

The specifications of the inclined plane test setup panel developed are given in Table 2.7

Table 2.7 Specifications of panel

Parameters	Values/ Materials
Input Supply	2 phase, 415 V AC, 50Hz
Stations	6
Electrode System	Stainless Steel Material
Potential Divider	1000:1
Size of Specimen	(150 x 50)mm
Flow Control	0.075 - 0.9 ml/min
Emergency Trip	6 Individual Stations
Test Voltage	0 - 7500 V AC
Ammeter	0 - 60 mA
Panel Dimensions	(6 x 5 x 2) ft.

Chapter 3

METHODOLOGY AND IMPLEMENTATION

During the course of this project the leakage current measuring with data acquisition system (Ammeter) and potential divider have been uniquely designed. The methodology of their designing and working has been described in detail in the current chapter

3.1 LEAKAGE CURRENT MEASURING AND DATA ACQUISITION SYSTEM

Leakage current in this setup refers to the current that flows along the surface of the insulating material under the applied voltage which eventually leads to the formation of tracks on the surface of the insulator. It is seen that the leakage current waveform is not purely sinusoidal in nature, Hence conventional method of computing true RMS current cannot be used as shown in (Eq. 3.1)

$$I_{rms} = I_{max} / \sqrt{2} \qquad \text{(Eq, 3.1)}$$

Where Irms is the RMS current and Imax is the maximum current.

For this reason the true RMS approach of computing leakage current has been adopted. The true RMS method computes the leakage current by taking the square of the instantaneous values of current, computing their mean and taking their root which is depicted in (Eq. 3.2)

$$V_{\mathrm{RMS}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V_i^2} \qquad \text{(Eq. 3.2)}$$

Where VRMS is the root mean square value. N is the total number of samples taken over a period. Vi is the amplitude of the waveform at the ith sample.

3.1.1 Hardware Implementation

The circuit design, implementation and testing will be discussed in detail in the current subsection.

3.1.1.1 Design and Calculation

The leakage current circuit using operational amplifiers (741 and OP07) , Resistors, capacitors and LF398 sample and hold IC was designed. The Leakage current circuit consists of seven parts:

1. Shunt resistor : The input voltage is measured through the shunt resistor method. By measuring the voltage appearing across the resistor the current flowing through it can be calculated. Two zener diodes are connected back to back across the shunt resistor as a protection scheme as shown in Fig. 3.1

   Calculations:

   consider Vin = 6mV , R (shunt resistor) = 0.1 ohms

   Using (Eq. 3.3) the current flowing through the specimen can be calculated.

   $$I = Vin/R \quad \text{(Eq. 3.3)}$$

   Where I is the current flowing through the specimen, V is the voltage appearing across the shunt resistor and R is the shunt resistor value.

I = 6mV/0.1

I = 60mA

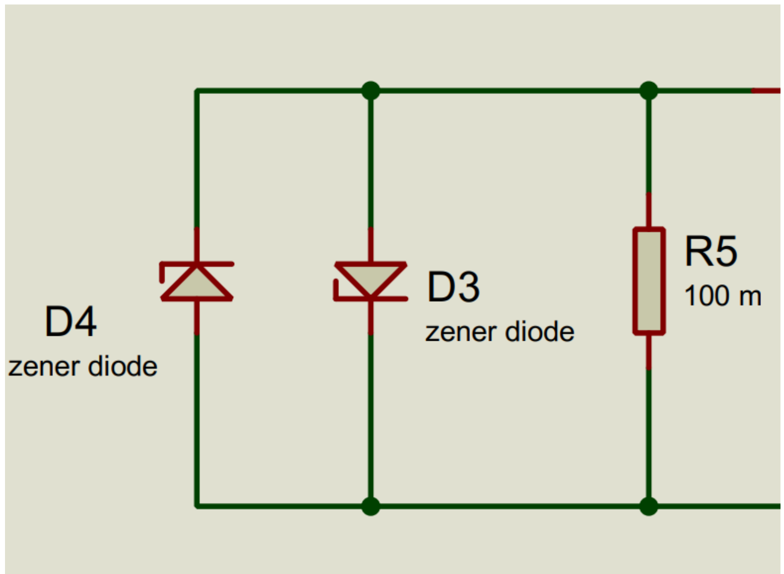


Fig. 3.1 Shunt resistor connections

2. Sense Amplifier: The input voltage is amplified and using a feedback capacitor the harmonics are removed. In this circuit the harmonics till 10th harmonics have been filtered as 3rd, 5th, 7th and 10th harmonics are the most prominent harmonics . Here 0P07 is used as it has low input offset voltage. The circuit is shown in Fig. 3.2.

Calculations

Consider Vin = 6mV, R2 = R4 = 360kΩ, R1 = R3 = 1kΩ , f1=500Hz

The amplified output voltage is calculated using (Eq. 3.4)

$$Vout = (R2/R1)*Vin \qquad \text{(Eq. 3.4)}$$

Vout = (360k/1k)*6mV

Vout = 2.16V

The value of the feedback capacitor is calculated using (Eq. 3.5)

$$CF= 1/(2\pi*f1*R2) \qquad \text{(Eq. 3.5)}$$

Where, CF = feedback capacitor

CF = 1/(2π*500*360k)

CF = 884.194pF

The standard capacitor value used is CF = 820pF.

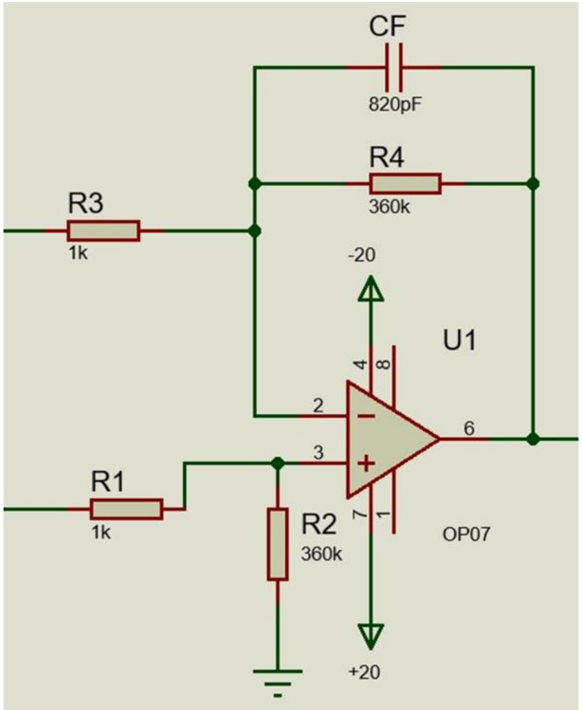


Fig. 3.2 Sense amplification circuit

3. Full wave rectifier: It is used to rectify the input voltage as negative voltage cannot be fed to the microcontroller . The circuit diagram is shown in Fig. 3.3

Calculations:

Consider Vin = 2.16 V, R11 = R12 = 4.3k ohms , I1 = 500uA

R8=V1/I1 = 4.3k Ω

(R9 + R10) = 2R1 = 8.6k Ω= (8.2k + 390) Ω

Hence R9 = 8.2kΩ , R10 = 390Ω

R15 = R1||R2 = 2.869kΩ = (2.7k + 150) Ω

R13 = (Vout/Vin)*R5 = 4.3k Ω

R14 = R4||R5||R6 = 1.5k Ω

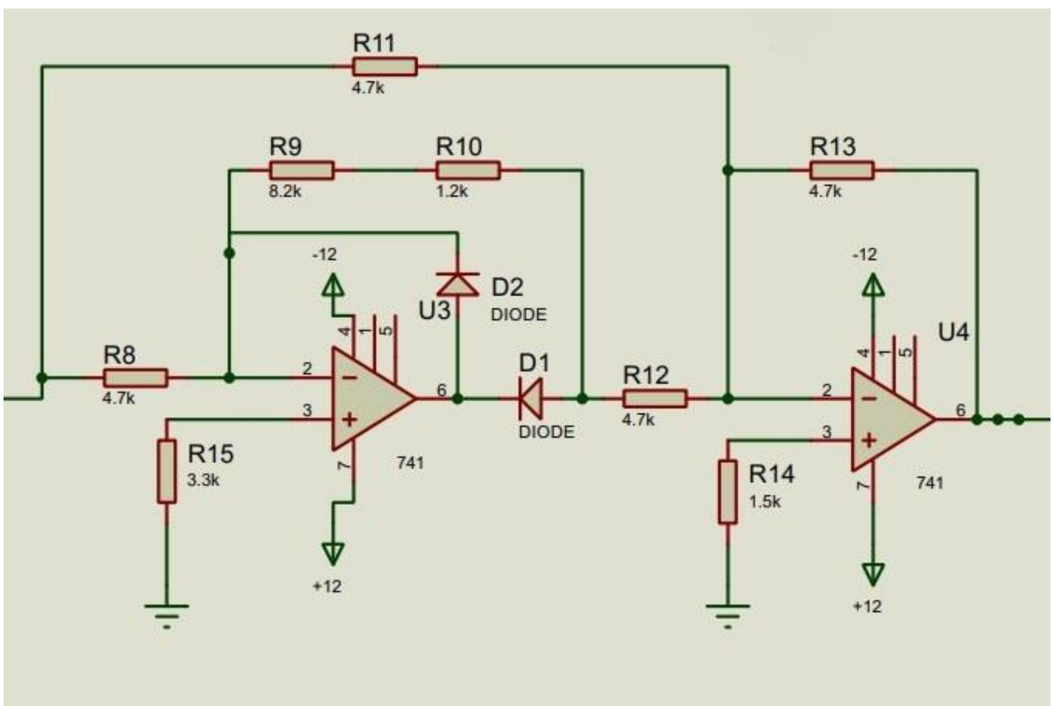


Fig. 3.3 Full wave rectifier

4. Sample and hold:Two LF398N sample and hold ICs are interconnected to achieve flat top sampling. This preference for flat top sampling is justified through examination of Fig. 3.4 and Fig. 3.5. In Fig. 3.4, the output from a single LF398N IC resembles a stepped sine wave, making it challenging for the microcontroller to accurately capture values due to the waveform's sloped nature. Conversely, by coupling two LF398N ICs in tandem, Fig. 3.5 demonstrates flat top sampling, where constant values are present and can be easily captured by the microcontroller.

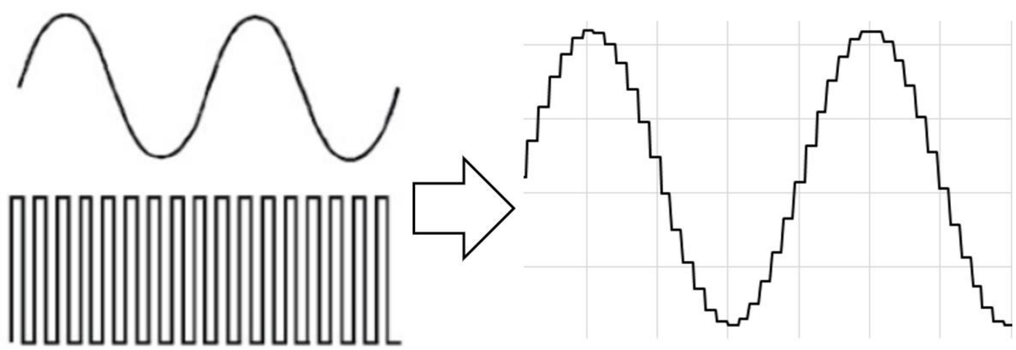


Fig. 3.4 Stepped sine wave

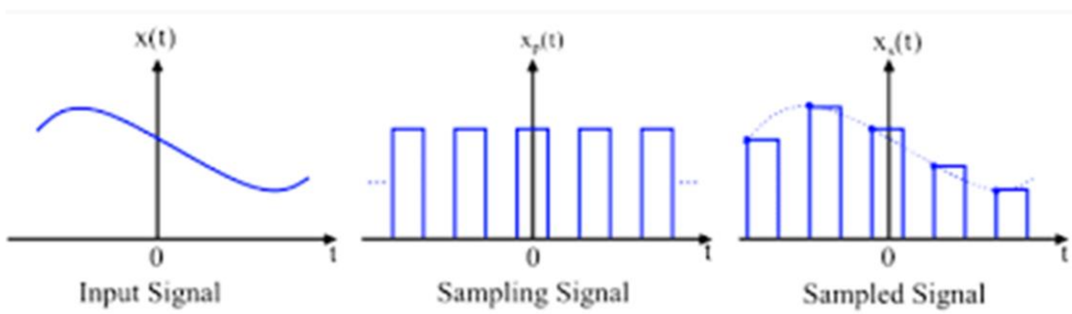


Fig. 3.5 Flat topped sampling

Here we are employing the standard flat top sampling circuit diagram (Fig. 3.6), the required 5V pulses are supplied through the timer circuit.

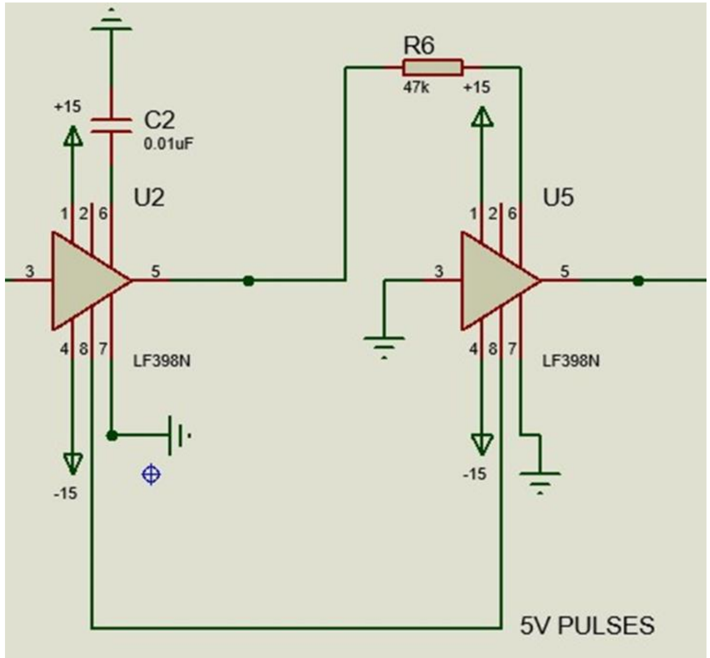


Fig. 3.6 Flat top sampling circuit diagram

5. Zero Crossing Detector: The detection of the input waveform's zero crossing point is facilitated by a Zero Crossing circuit, depicted in Fig. 3.7. This circuit employs two zero crossing circuits, one inverting and the other non-inverting. Together, they serve to signal the commencement and conclusion of each half cycle of the waveform.It is also seen that zener diodes are connected back to back across the output which ensure that the voltage level of zero crossing output is within the safe limits to be fed to ESP32. Here the zener diodes are of voltage rating of 2.7V. Further an diode is connected in series to ensure only the positive cycle is fed to ESP32.

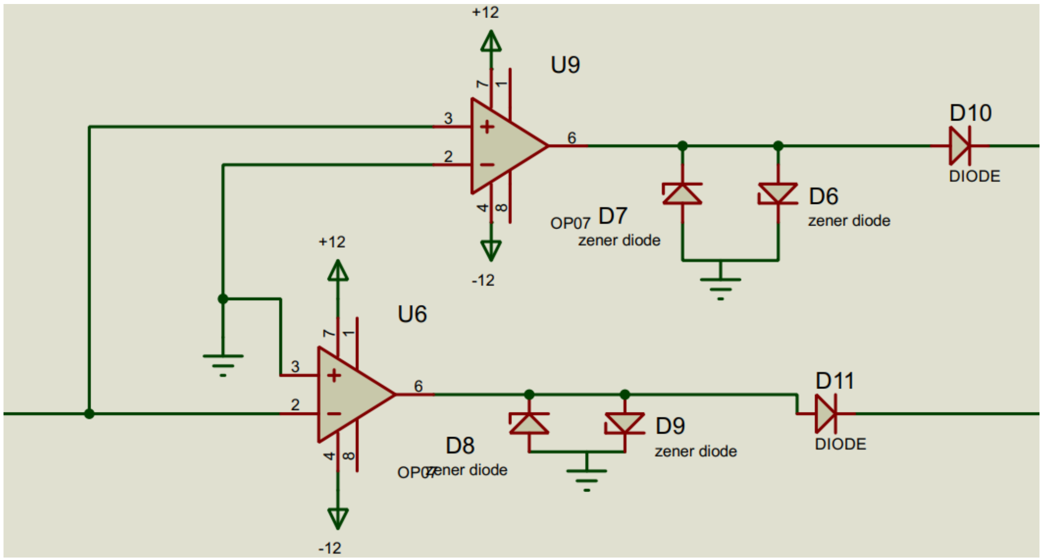


Fig. 3.7 Zero crossing circuit

6. Timer Circuit: The timer circuit is used to generate pulses of frequency 1kHz which are fed to the LF398N IC's. The timer circuit is shown in Fig. 3.8.

Calculations:

T = 1/f = 1/ 1kHz = 1ms

T1 = T2 = 0.5ms

The Time high (T1) is the amount of time during which the pulse stays high (5V) in the output wave. This can be calculated using (Eq. 3.6)

$$\text{High time (T1)} = 0.693 \times (R1+R2) \times C1 \qquad \text{(Eq. 3.6)}$$

The Time low (T2) is the amount of time during which the pulse stays low(0V) in the output wave. It can be calculated using (Eq. 3.7)

$$\text{Time low (T2)} = 0.693 \times R2 \times C1 \qquad \text{(Eq. 3.7)}$$

$0.5ms = 0.693 \times R2 \times 0.01uF$

$R2 = 330\ \Omega$

$R1 = 330\ \Omega$

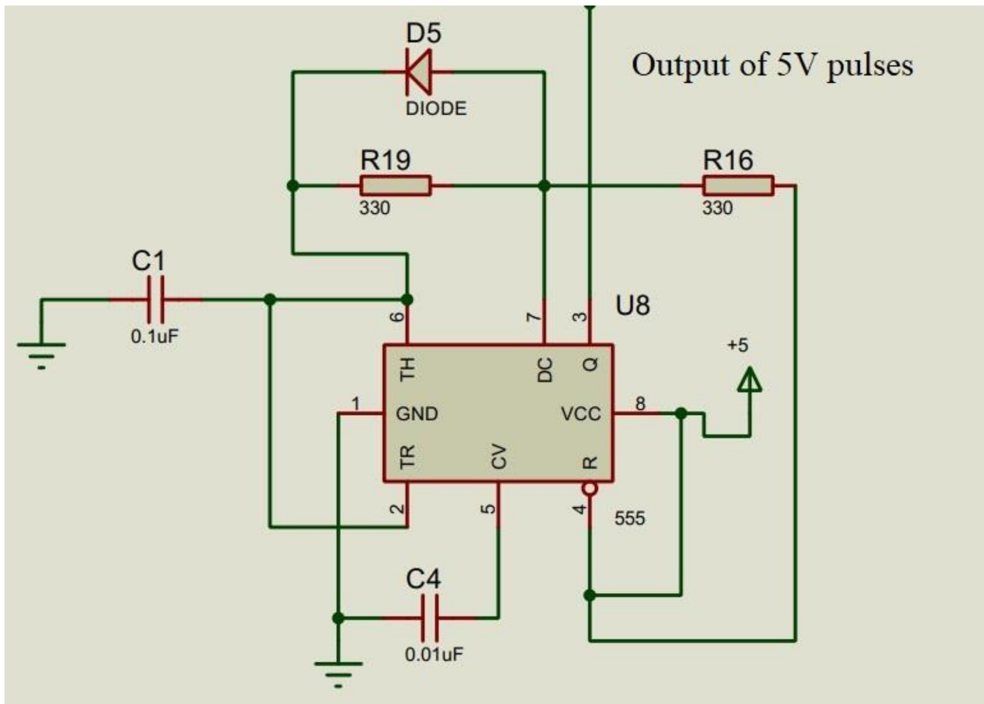


Fig. 3.8 Timer circuit

The frequency is chosen based on nyquist criteria which states that for a continuous-time signal to be accurately represented by its discrete-time samples, the sampling frequency must be at least twice the highest frequency component present in the signal.

Here Highest frequency component = fmax = 50Hz,

hence the Sampling frequency = fs = 2*fmax = 2*50 = 100 Hz

Sampling rate = Sampling frequency * Time period of signal = 100 * 20* 10^-3

= 2 samples/cycle

Hence the minimum number of samples per cycle are 2. For better accuracy we are considering 20 samples per cycle which leads to a sampling frequency of 1kHz (fs)

The minimum duration an signal should be present to be captured by ESP32 is given by

Tmin = 2/fs

Tmin = 2/1kHz

Tmin = 2ms

Hence sampling frequency of 1kHz or Time period of 1ms with 50% duty cycle is sufficient for accurate computation of leakage current.

7. Microcontroller: The microcontroller used here is ESP32. The ESP32 receives the voltage samples from sample and hold circuit (1) and point of zero crossing from zero crossing circuit (2) as inputs as shown in Fig. 3.9 and computes the leakage current using true RMS method as discussed in the previous sections.

ESP32 has 12 bit ADC and an maximum input voltage of 3.3V, hence

Hence minimum measurable value = 3.3 / 2^12

= 3.3 / 4096

= 805.644 uV

Hence an 12 bit ADC is sufficiently accurate for out computation and no external ADC is required.

The results are displayed on an LCD display. To make the LCD connections simpler an I2C module is also used.

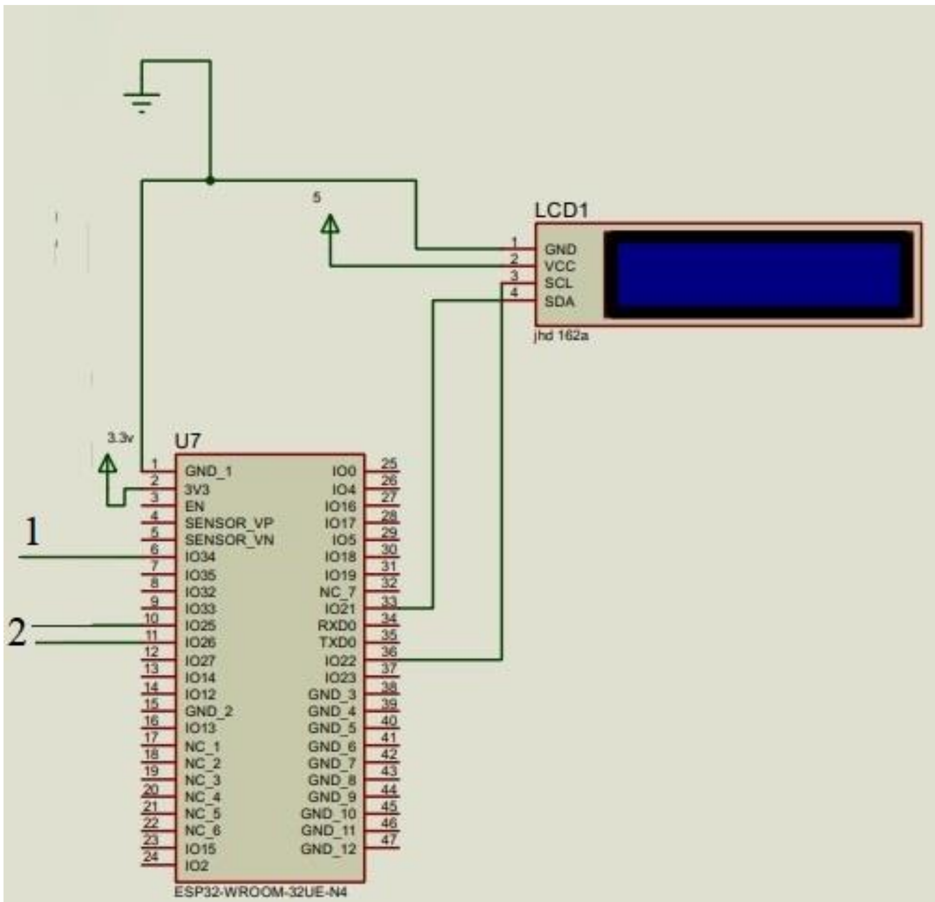


Fig. 3.9 Microcontroller and lcd display

3.1.1.2 Components used

The components used in design and development of leakage current and data acquisition systems are given in the current subsection. Table 3.1 shows the list of resistors used. Table

3.2 shows the capacitors used. The power rating of resistors used are chosen according to the formula given by (Eq. 3.8)

$$P = (I^2)*R \qquad \text{(Eq. 3.8)}$$

Where P is the power rating of the resistor to be used, I is the current flowing through the resistor and R is the resistance value. Since the current flowing through the resistor is in milli-ampere, 0.25W resistors are chosen based on availability. All the resistors used are of SMD type.

Table 3.1 Specifications of resistors used in design of ammeter

Resistance value (Ω)	Power rating (W)	Tolerance
100 mΩ	3 W	+/- 1%
360kΩ	0.25 W	+/- 5%
1kΩ	0.25W	+/- 5%
8.2kΩ	0.25W	+/- 5%
1.2kΩ	0.25W	+/- 5%
4.7kΩ	0.25W	+/- 5%
1.5kΩ	0.25W	+/- 5%
3.3kΩ	0.25 W	+/- 5%
330Ω	0.25 W	+/- 5%

180kΩ	0.25 W	+/- 5%
47kΩ	0.25 W	+/- 5%

Since the maximum voltage that can be present across any component is within the range of 6mV - 5V, the capacitors of voltage rating greater than 5V are chosen . The capacitors of required capacitance and voltage rating based on availability are chosen. All the capacitors used are of SMD type.

Table 3.2 Specifications of capacitors used in design of ammeter

Capacitance Value	Voltage (V)
820 pF	50 V
0.1 uF	50 V
0.01 uF	50V

The specifications of the IC’s used are discussed in the table below

1. op07A: The specifications of op07 used are given in Table 3.3.

Table 3.3 Specifications of op07

Parameters	Values/ Range

Input offset voltage Vos	25µV
CMRR	110dB
Input Voltage range	3 to 18V
Mounting type	SMD

2. LM741: The specifications of LM741 used is given in Table 3.4

Table 3.4 Specifications of LM741

Parameters	Values / Range
Supply voltage (Max)	+/- 22 V
Supply voltage (Recommended)	+/- 15 V
Operating temperature	-55 to 125 C
Power dissipation	500mW
Mounting type	Through hole

3. LF398N : The specifications of LF398N used is given in Table 3.5

Table 3.5 Specifications of LF398N

Parameters	Values/ Range
Supply voltage (Max)	+/- 18 V
Supply voltage (Recommended)	+/- 15 V
Operating temperature	0 to 70 C
Power dissipation	500mW
Mounting type	SMD

4. 555 Timer: The specifications of 555 timer used is given in Table 3.6

Table 3.6 Specifications of 555 Timer

Parameters	Values/ Range
Output current (maximum)	
Supply current (VCC = +5 V)	3 to 6 mA
Maximum Power dissipation	600 mW
Power consumption (minimum operating)	30 mW

Operating temperature	0 to 70 °C
Mounting type	SMD

There are two types of diodes used in the design and development of leakage current measuring ammeter whose specifications are given below

1. RS1M: The specifications of RS1M diode used is given in Table 3.7

Table 3.7 Specifications of RS1M diode

Parameters	Values / Range
Repetitive peak reverse voltage	1000V
Forward voltage	1.3V
Reverse Current	5uA
Mounting type	SMD

2. Zener diode : The zener diode used has an voltage rating of 2.7V and is of through hole type

A microcontroller is used to collect all the instantaneous voltage values, compute them and display the results. The microcontroller used is ESP32 Dev-kit. The specifications of ESP32 are given in Table 3.8

Table 3.8 Specifications of ESP32

Parameters	Values / Range
Clock Frequency	80 - 240 MHz
Operating Voltage	3.3 V
ADC	12 bits
Flash Memory	16MB

The results are displayed on a 16x2 LCD module coupled with an I2C pin whose specifications are given in the Table 3.9 below.

Table 3.9 Specifications of LCD display

Parameters	Value/ Range
Operating voltage	4.7V - 5.3V
Operating current	1mA
Number of Characters	16 characters x 2 lines

3.1.1.3 Simulation

The Circuit was designed and simulated on Proteus Professional 8. The simulation circuit is shown in Fig. 3.10 and the results are discussed subsequently.

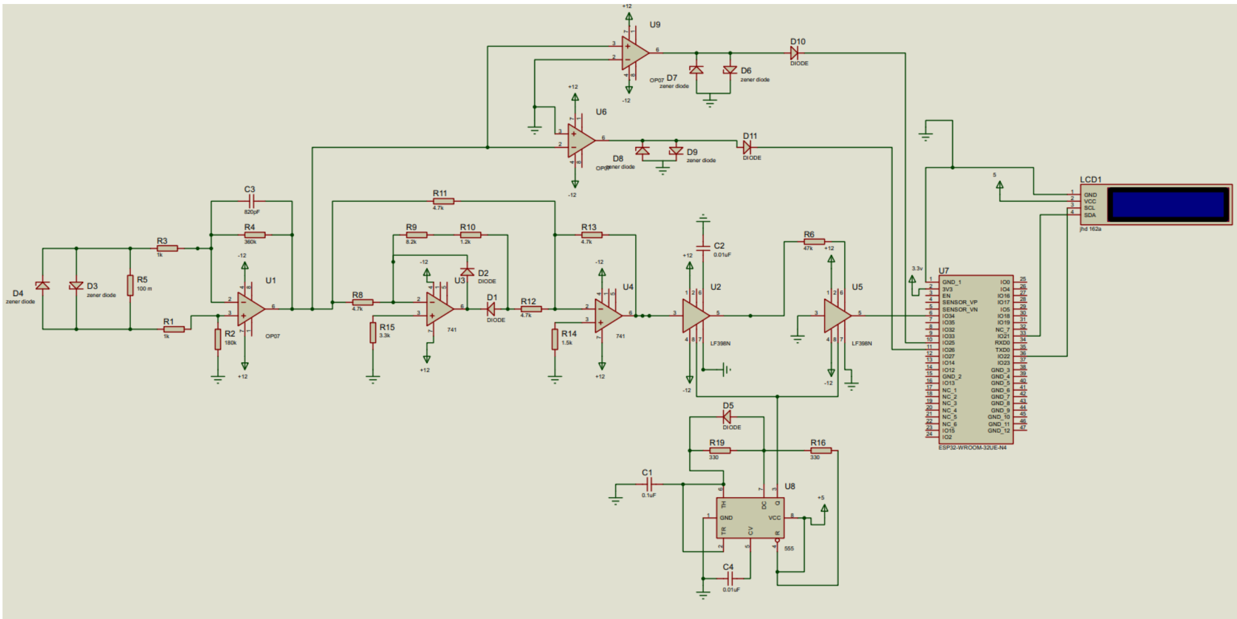


Fig. 3.10 Simulation circuit diagram

3.1.1.4 Simulation results

The results obtained from the simulation are as follows. From Fig. 3.11 , waveform 1 is the input waveform given, waveform 2 indicates the amplified waveform, waveform 3 shows the rectified output obtained after rectification, waveform 4 shows the sampled waveform after passing through one LF398N IC

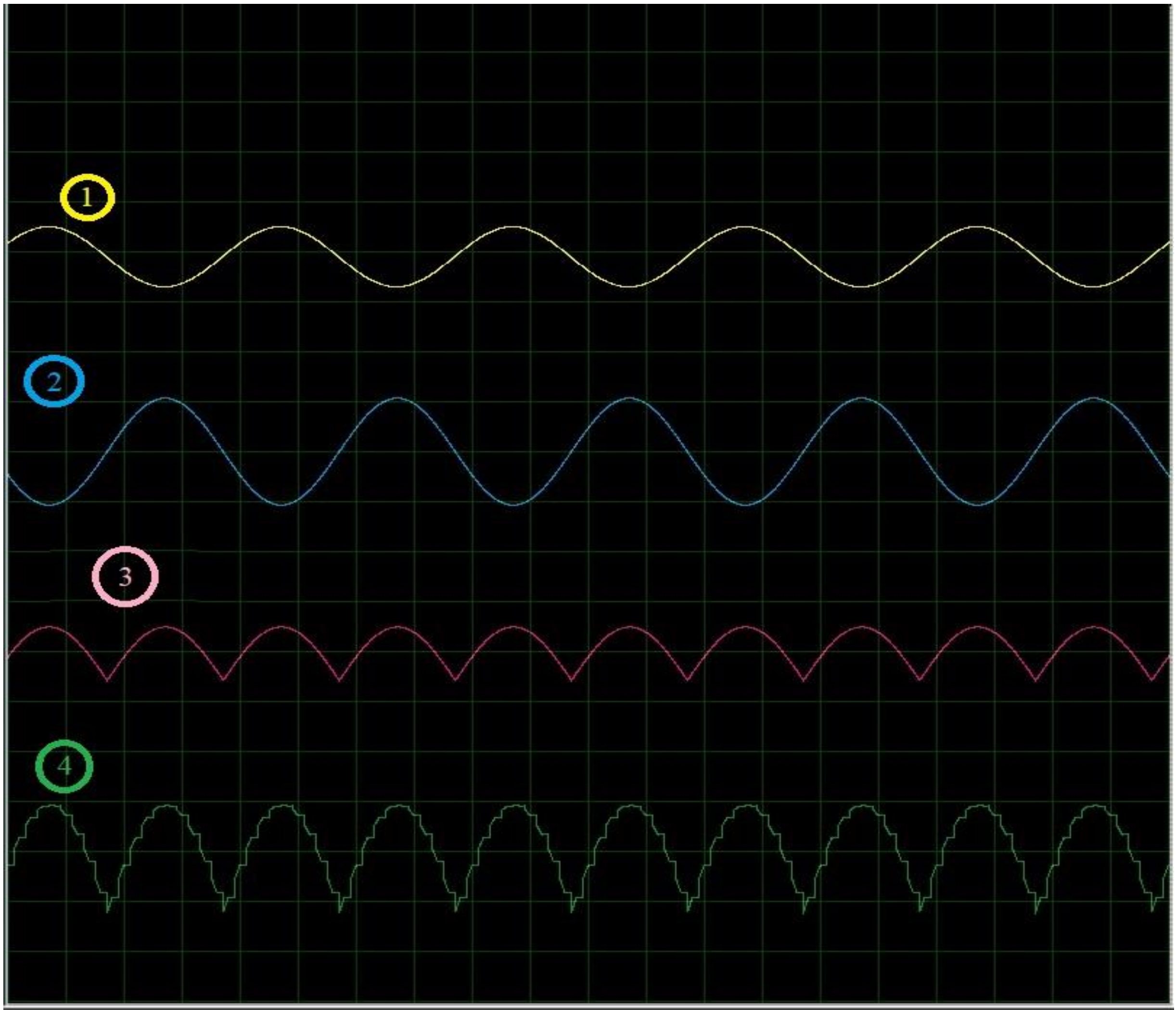


Fig. 3.11 Simulation results 1 of ammeter

In Fig. 3.12. waveform 5 shows the zero crossing output, waveform 6 shows the flat top sampled waveform and waveform 7 shows the timer circuit’s output pulses that are fed to sample and hold circuit.

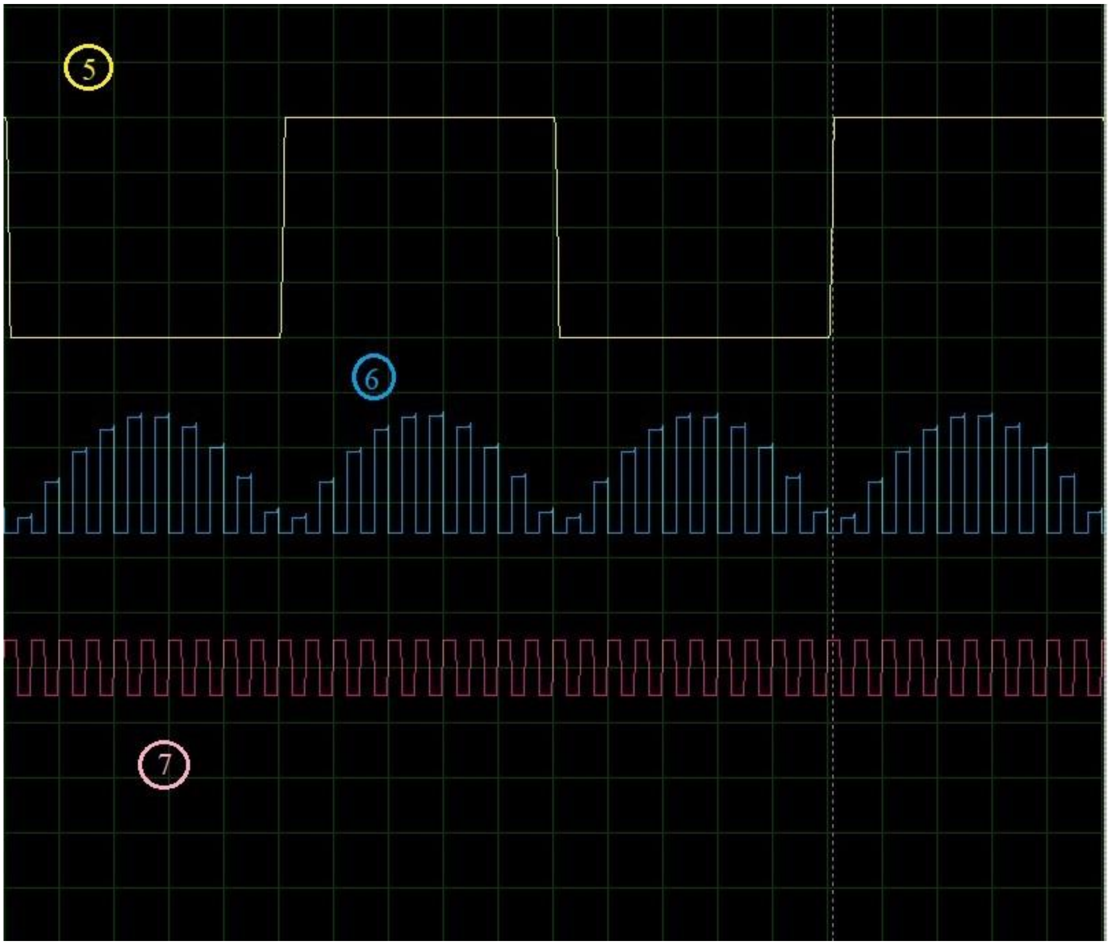


Fig. 3.12 Simulation results 2 of ammeter

3.1.1.5 Hardware verification

The circuit was rigged up on a springboard and the following waveforms were obtained.

Fig. 3.13, 3.14, 3.15, 3.16, and 3.17 show the hardware circuit outputs obtained .

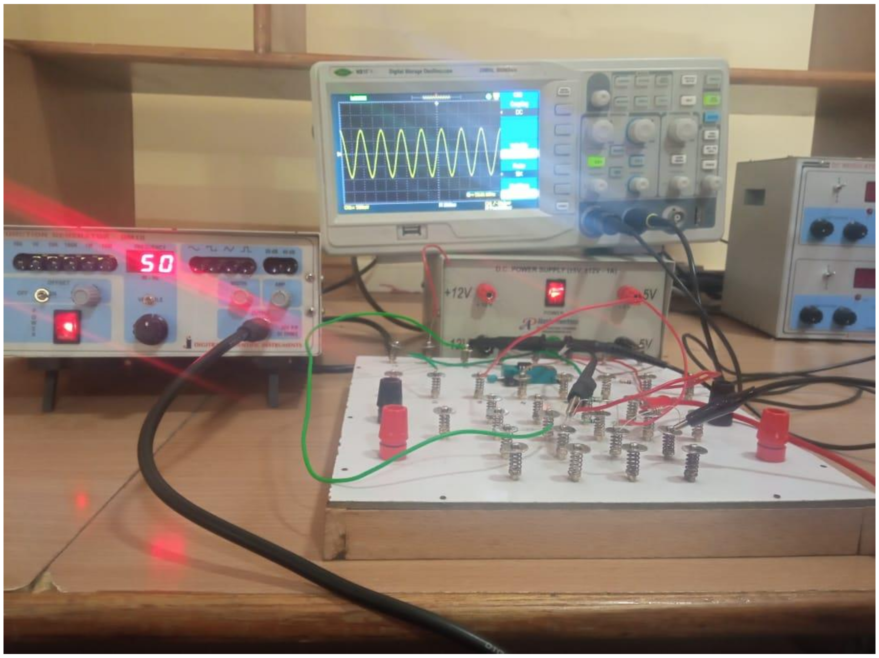


Fig. 3.13 Sense amplifier circuit output

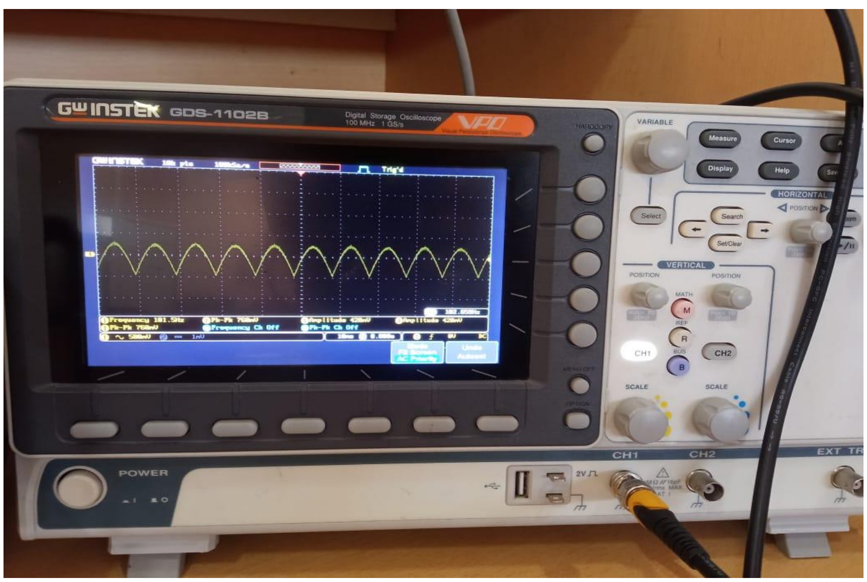


Fig. 3.14 Full wave rectifier circuit output

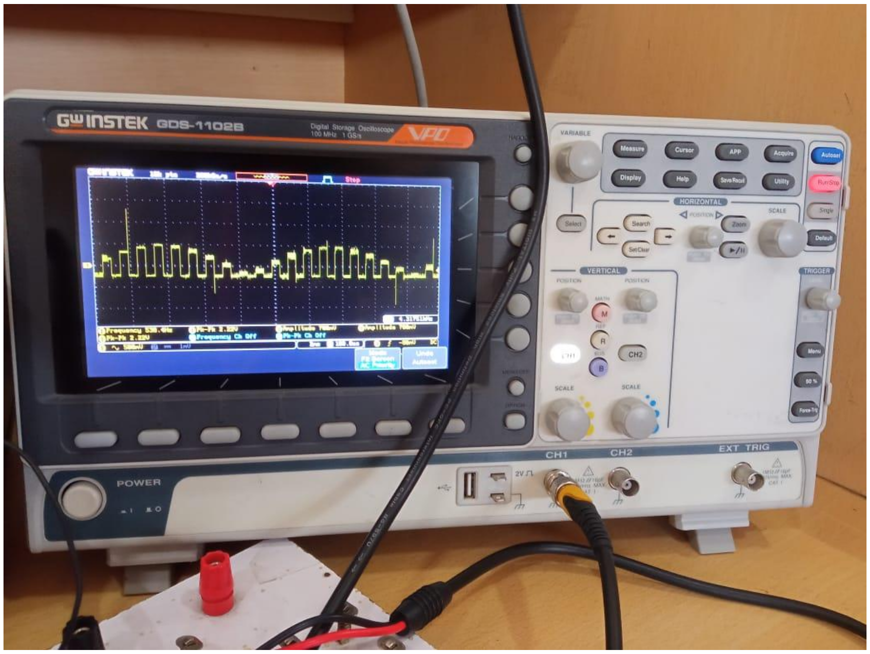


Fig. 3.15 Same and hold circuit output

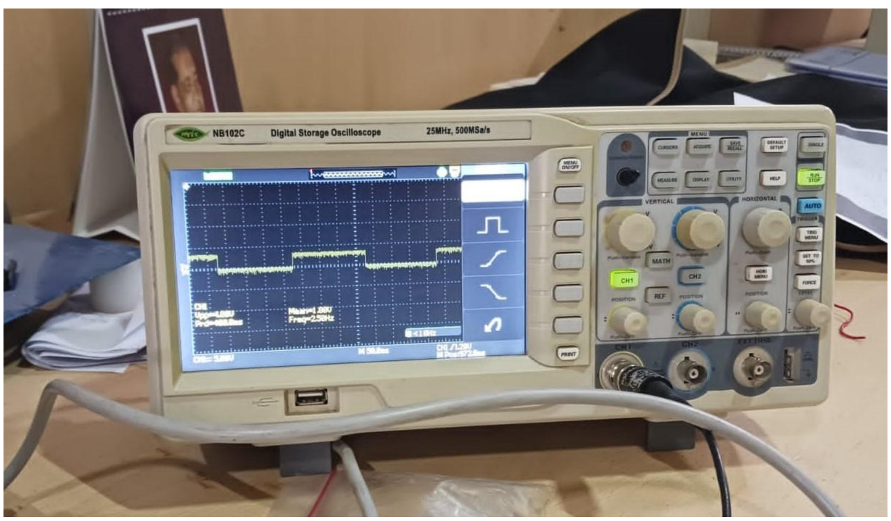


Fig. 3.16 Zero crossing detector circuit output

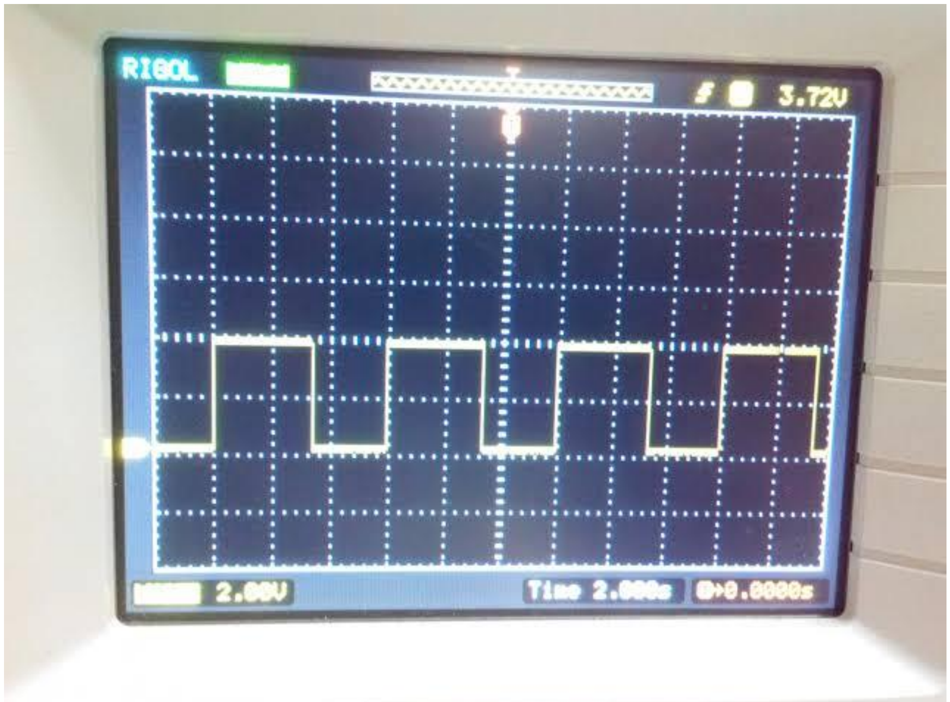


Fig. 3.17 555 timer circuit output

It is seen that the waveforms obtained from the hardware circuit agree with the waveforms obtained in the simulation.

3.1.1.6 PCB design

The PCB was designed using Proteus professional 8 Software. The PCB circuit and the gerber file are shown in Fig. 3.18 and Fig. 3.19 respectively. The designing process is explained in detail in the following points.

- To design a PCB firstly the circuit diagram and the components used are listed.
- From the inbuilt library of proteus the components are selected and placed in the working area and connected as shown in Fig. 3.18
- To design PCB in proteus there is an ARES designing tool that exists which is used to design the PCB.

- Then the working area is defined and the circuit is constructed in the working area.
- After placing all the components, their dimensions are adjusted according the the components used .
- After all the components are placed with satisfaction manual routing is done between the different components as specified in the circuit diagram. The gerbes view of the designed pcb is shown in Fig. 3.19

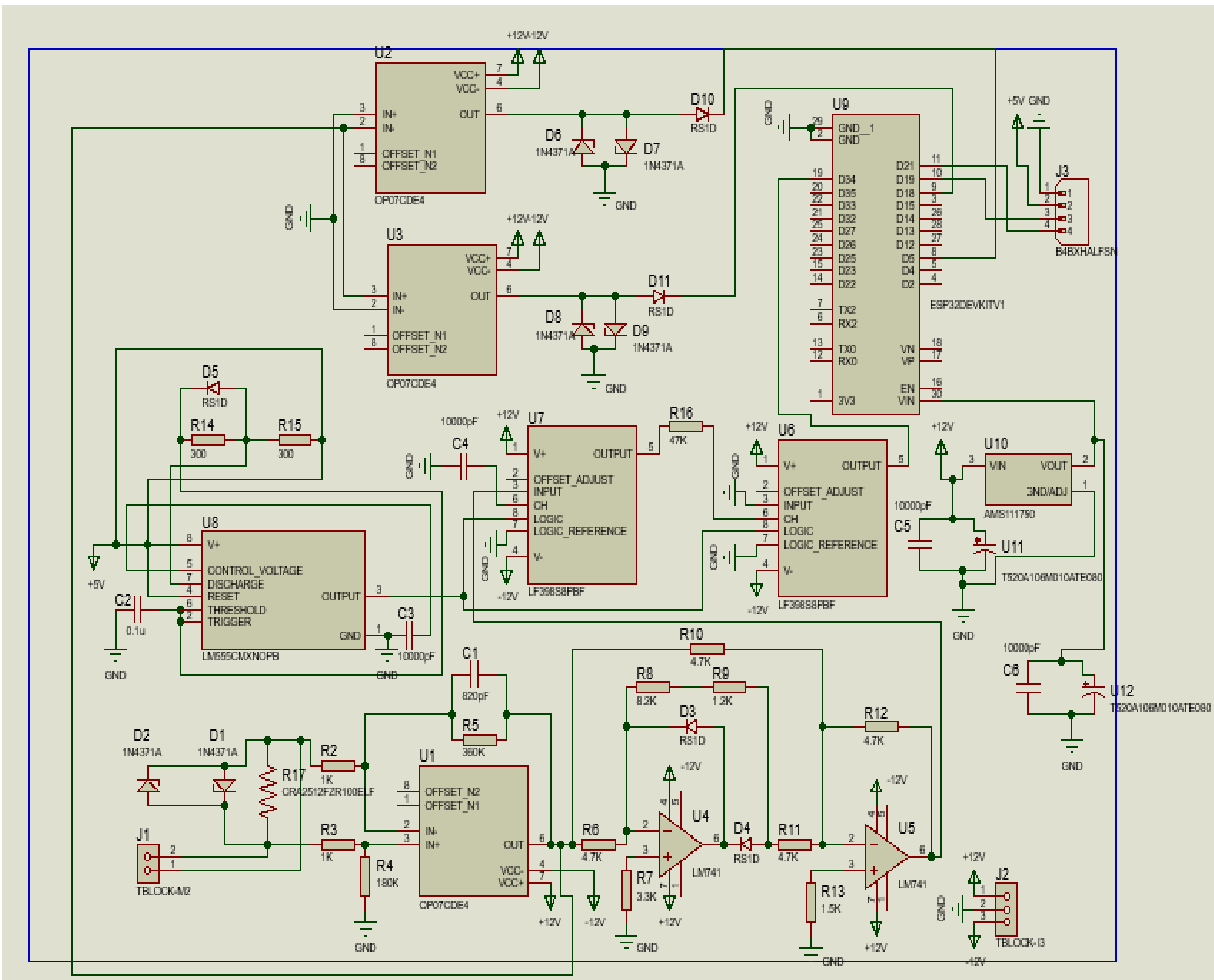


Fig. 3.18 PCB circuit diagram

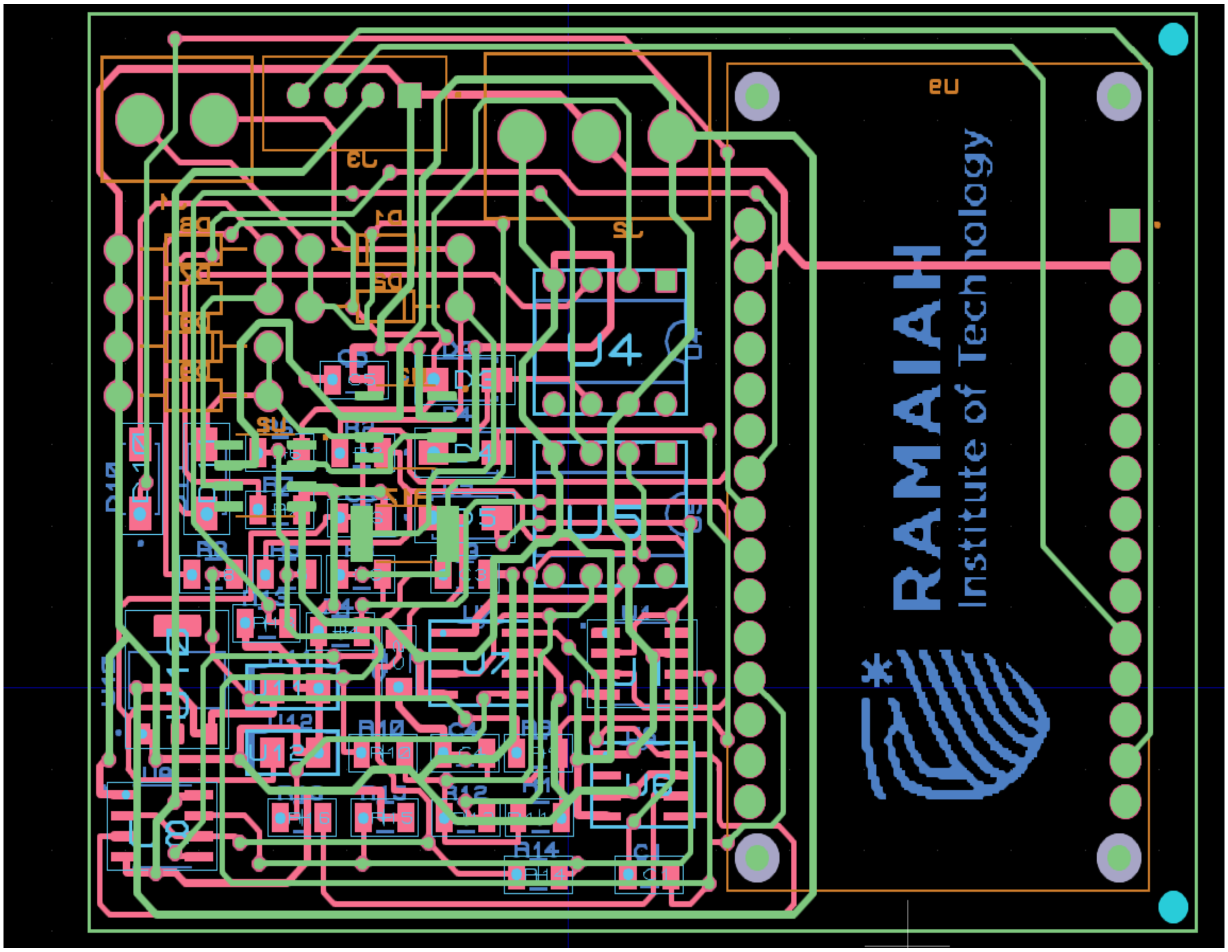


Fig. 3.19 PCB gerber view.

After the PCB is designed, the design is checked using the various DRC's (Design Rule Check). Design Rule Checking (DRC) in Proteus is a critical process which ensures whether the PCB layout designed adheres to a set of predefined rules and constraints. These checks help identify potential manufacturing and functional issues early in the design phase, thus preventing costly errors. The different types of DRC's used are given below:

- Electrical rule check: This check is used to make sure that there are no electrical errors in the PCB design. It checks for

  Unconnected Pins: Identifies pins on components that are not connected to any nets.

Short Circuits: Detects nodes that are accidentally connected together, creating a short circuit.

Power Net Warnings: Checks for power nets without proper connections to power sources.

Incorrect Connections: Ensures that pins with different electrical functions (e.g., input to output) are not incorrectly connected.

- Schematic Design Rule Check: This check is used to make sure that schematic adheres to certain design rules that prevent logical and functional errors. It checks for

  Pin Types: Ensures that pins are used according to their designated types (e.g., input, output, power).

  Net Names: Checks for consistent and appropriate net naming.

  Component Values: Verifies that all components have defined values and part numbers.

- Layout Design Rule Check: Ensures that the PCB layout adheres to manufacturing and design constraints. It check for

  Trace Width: Verifies that all traces meet the minimum and maximum width requirements specified.

  Clearance: Ensures adequate spacing between different nets, pads, and traces to prevent short circuits and signal interference.

Via Sizes: Checks that vias conform to the minimum and maximum diameter rules.

Copper to Edge: Ensures that copper traces are not too close to the edge of the PCB, which could cause manufacturing issues.

Component Placement: Verifies that components are placed correctly, with appropriate clearances from each other and the PCB edges.

3.1.1.7 PCB fabrication

A two layer PCB was fabricated with dimensions of 75 X 75 mm as shown in Fig. 3.20 and Fig, 3.21

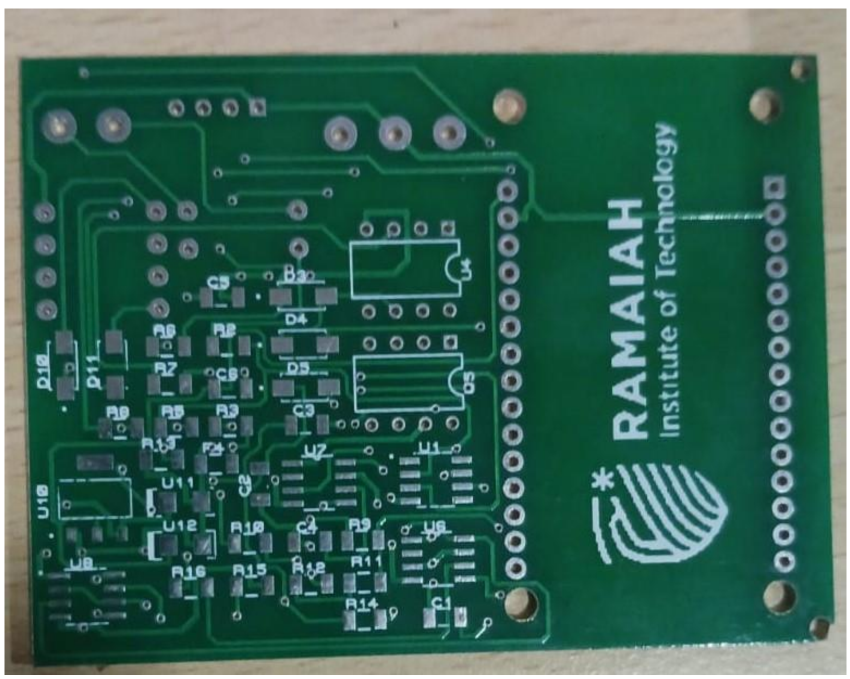


Fig. 3.20 Top side of fabricated two layer PCB

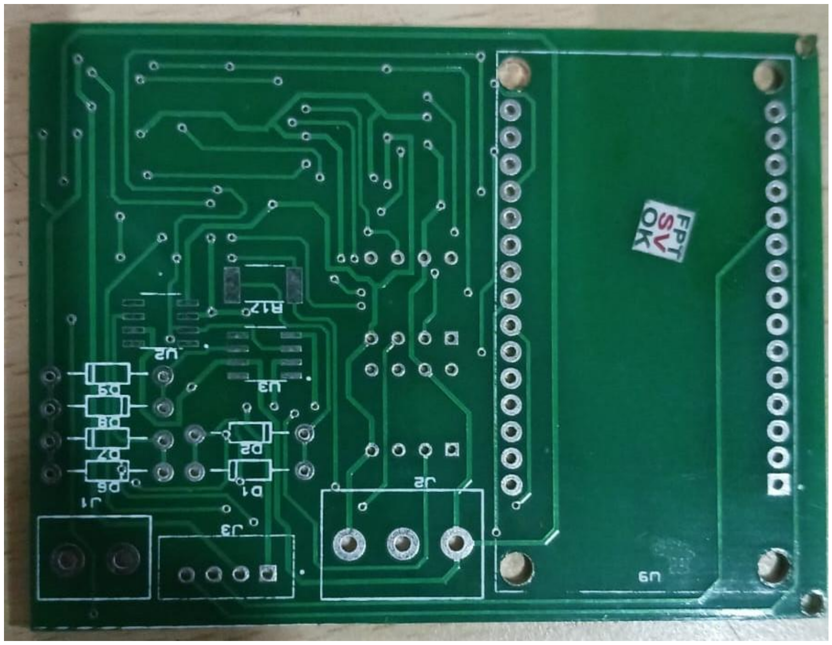


Fig. 3.21 Bottom side of fabricated two layer PCB

The soldered PCB circuit is shown below in Fig. 3.22 and Fig. 3.23

Fig. 3.22 Soldered top layer of fabricated PCB

Fig. 3.23 Soldered bottom layer of fabricated PCB

3.1.2 Software implementation

The purpose of this project is to develop a data acquisition system using an ESP32 microcontroller. The system measures leakage current using two zero-crossing detectors, and sample and hold values to process the data and show it on LCD and sends the results to a Google Sheets document over WiFi. This report details the software implementation, including the setup, data acquisition, processing, and communication components.

System Overview is given below

1. The data acquisition system comprises the following key components:
2. ESP32 Microcontroller: Central processing unit for reading sensor data, processing, and communication.
3. Zero-Crossing Detectors: Sensors to detect the zero-crossing points of AC signals.
4. LCD Display: For displaying real-time current readings.
5. WiFi Module: Built-in ESP32 WiFi capabilities to send data to a remote server.

6. Google Sheets Integration: To log data remotely for further analysis..

3.1.2.1 Software used

The Software used for the development of this code is VS Code which is an IDE that helps to give the environment for different programming languages as well as ESP32 programming using PlatformIO.

3.1.2.2 Work flow of code

The workflow of working code is shown in Fig. 3.24

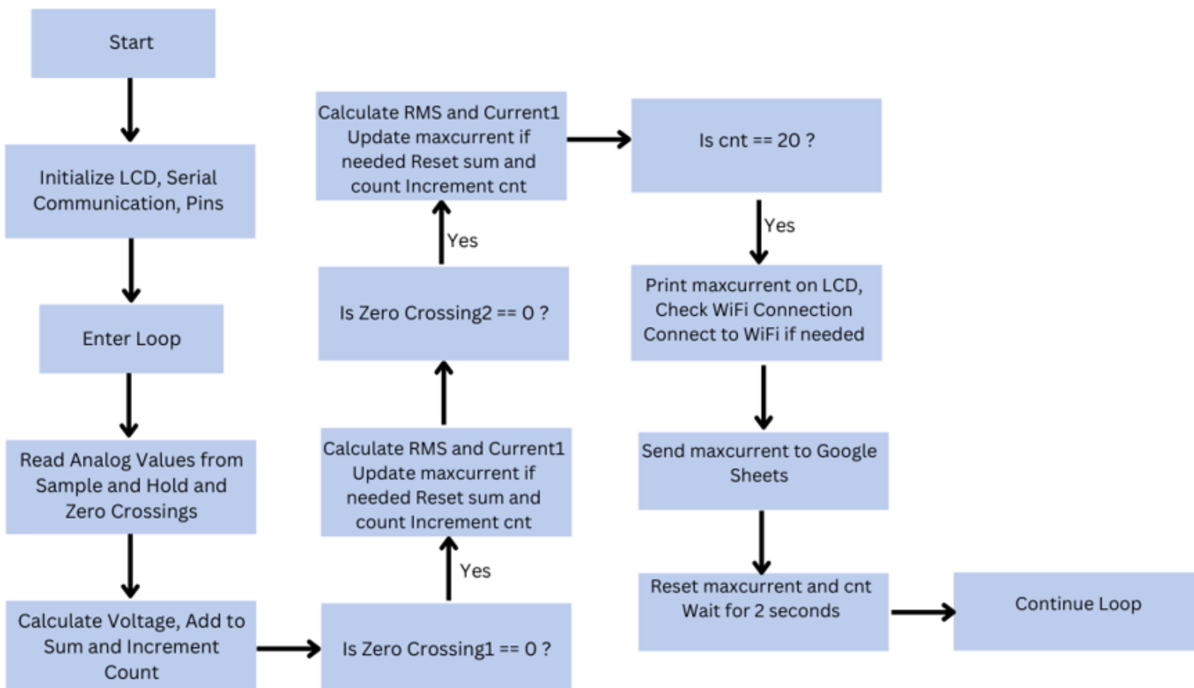


Fig. 3.24 Work flow of code

3.1.2.3 Database used

Database used for collecting the data of leakage current is Google Sheet. Google Sheets is a web-based spreadsheet application that is part of Google's free, web-based Google Docs Editors suite. It allows users to create, edit, and collaborate on spreadsheets online in real-time. Key features include functions for data analysis, chart creation, and pivot tables, as well as integration with other Google services like Google Drive and Google Forms. Google Sheets also supports collaboration, enabling multiple users to work on a document simultaneously, with changes being saved automatically. It is accessible from any device with internet access, making it a versatile tool for both personal and professional use.

Google Sheets supports a maximum of 10 million cells per spreadsheet. The limits on rows and columns are dynamically adjusted based on the number of cells, but commonly, a sheet can have up to 18,278 columns or up to 1,048,576 rows within the overall cell limit.

3.2 POTENTIAL DIVIDER

A potential divider, also known as a voltage divider, is a fundamental circuit component used to split a voltage into smaller, proportional parts. In this project, here designed a potential divider with a 1000:1 ratio, meaning that for every 1000 units of input voltage, the circuit produces 1 unit of output voltage. This design choice offers precise control over voltage levels, crucial for various applications where maintaining specific voltage thresholds is essential. By implementing this divider, the project operates with accuracy and efficiency, meeting the stringent requirements of design objectives while facilitating optimal performance across a range of operating conditions.

3.2.1 Design and Calculation

In this section the design of the developed potential divider is explained in detail. The resistance potential divider designed for simulating a 10 kV AC system comprises 20 parallel-connected resistors with a resistance of 47k ohms each. Additionally, a 1k-ohm output resistor is incorporated into the configuration to enhance the accuracy and stability of the voltage division process. This divider structure is intended for precise measurement and simulation of 10 kV AC scenarios, providing an effective and controlled means for voltage scaling and analysis.

R1= 940kV

Vout = 10 V

Vin = 10kV

The resistance value of the low voltage arm is calculated using (Eq. 3.10)

$$R2= (Vout /(Vin -Vout)) *R1 \qquad \text{(Eq. 3.10)}$$

where R2 is the resistance of low voltage arm and R1 is the resistance of high voltage arm

R2= 10/ (10k-10) *940k= 940 ohm ~ 1k ohm

R1 = 47k ohm of 20 resistors connected in series.

3.2.2 Components

The components used in design and development will be discussed in detail. The specifications of resistors used is given in Table 3.10. The potential divider is designed for an ratio of 1000:1 on a bakelite sheet. The dimensions of the bakelite sheet are:

Thickness = 2mm

Height = 20 cm

Width = 12 cm

Table 3.10 Specifications of resistors used in design of potential divider

Resistance value	Power rating	Tolerance
47kV	5 Watt	5%
1kV	5 Watt	5%

3.2.3 Simulation

The Circuit was designed and simulated on Pspice software. The simulation circuit is shown in Fig. 3.25 and the results are discussed subsequently.

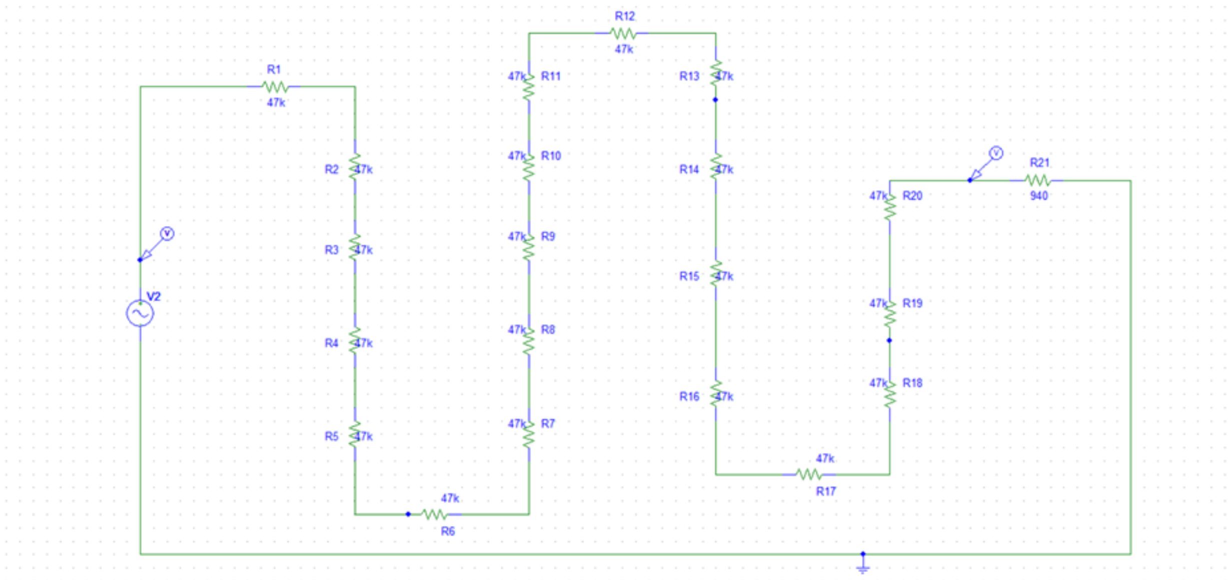


Fig. 3.25 Simulation diagram of 1000:1 potential divider

The diagram illustrates the simulated circuitry of the 1000:1 potential divider, showcasing its voltage dividing capabilities. This component plays a crucial role in this project, offering precise control over voltage levels essential for optimal performance. Through meticulous design and simulation, can ensure accuracy and efficiency in project's operation, meeting the stringent requirements of objectives.

3.2.4 Simulation results

Comparing the input and output waveforms as seen in Fig. 3.26 provides insight into the performance of the 1000:1 potential divider, demonstrating its effectiveness in dividing voltage levels while maintaining stability. The upper waveform illustrates the stable and accurately divided output voltage, while the lower waveform showcases the input voltage signal supplied to the potential divider.

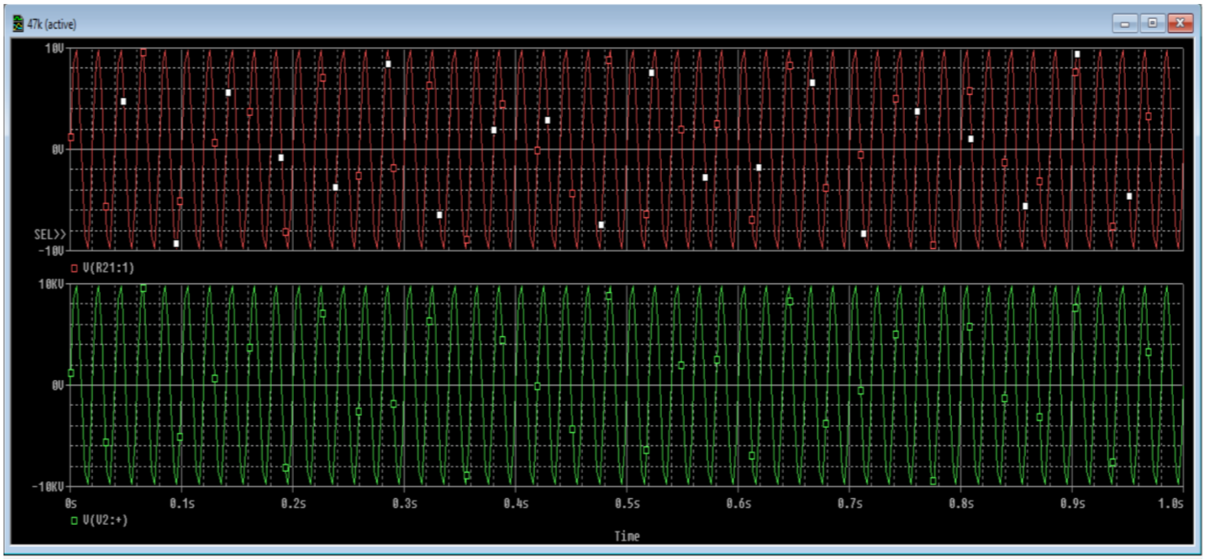


Fig. 3.26 Simulation results of potential divider

3.2.5 Fabrication

The circuit was fabricated on a bakelite sheet as shown in Fig. 3.27 and the following results were obtained.

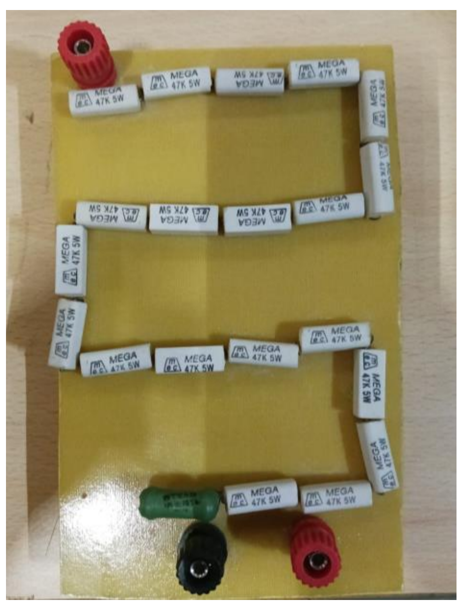


Fig. 3.27 Potential divider fabricated

3.3 PERISTALTIC PUMP

The project developed a six-channel peristaltic pump, which offers variable flow rates influenced by tubing size, roller speed, and compression force. This horizontal, free-standing pump features six all-metal rollers on a central shaft, similar to commercial designs. It includes a main pump body, three lid variants, and a central shaft, along with an assembly jig for the rollers. All components are designed to be 3D-printed and assembled with minimal tools, emphasizing open-source accessibility.

3.3.1 Design and components

Materials used are given below:

1. Base - The main structure of the pump.
2. Lid (1.3 mm) - One variant of the lid used in the design.
3. Shaft - Central shaft for mounting the rollers.
4. Rollers - Six all-metal rollers for the peristaltic mechanism.
5. Ball Bearings (16x8x5 mm) - Two bearings to support smooth rotation.
6. Countersunk M4 x 12 mm Bolts - Six bolts for securing components.
7. M4 Nuts - Six nuts for fastening the M4 bolts.
8. Stepper Motor - Motor to drive the pump mechanism.
9. Flexible Beam Coupling - Coupling to connect the motor to the shaft.
10. Countersunk M3 x 8 mm Bolts - Four bolts for additional assembly requirements.

The design and development of this six-channel peristaltic pump were guided by a reference paper, Alexander Jonsson, Arianna Toppi, Martin Dufva "The FAST Pump, a low-cost, easy to fabricate, SLA-3D-printed peristaltic pump for multi-channel systems in any lab" DTU Health Tech, Technical University of Denmark, Kgs Lyngby, Denmark which provided the basis for the 3D-printed components and overall assembly process as shown in Fig. 3.28. Emphasizing open-source accessibility, the parts can be easily printed and assembled using a minimal variety of tools.

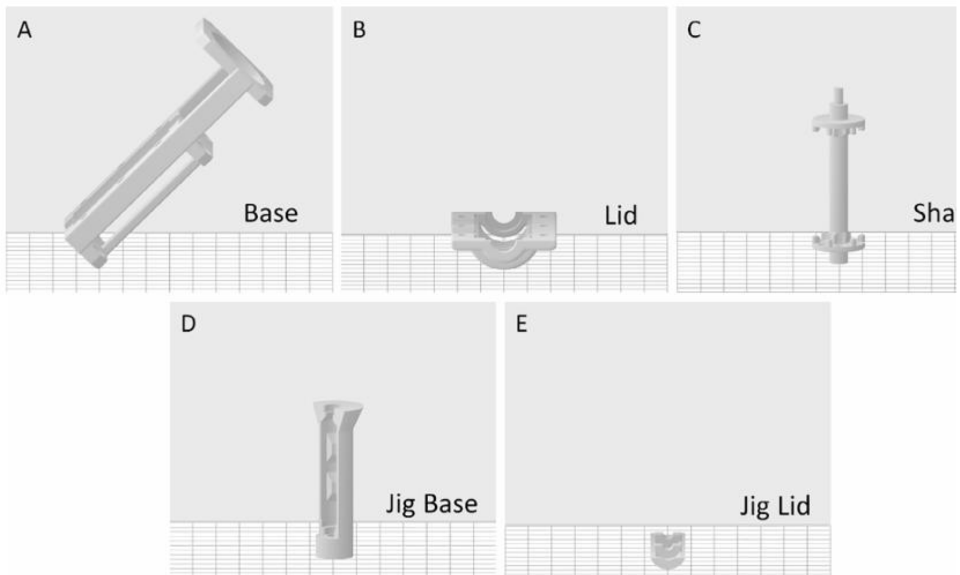


Fig. 3.28 3D printing diagram (taken from Alexander Jonsson, Arianna Toppi, Martin Dufva "The FAST Pump, a low-cost, easy to fabricate, SLA-3D-printed peristaltic pump for multi-channel systems in any lab" DTU Health Tech, Technical University of Denmark, Kgs Lyngby, Denmark)

The components used and their specifications are given in detail below

1. Stepper motor : The stepper motor used and its specifications are shown in Fig. 3.29 and Table 3.11 respectively.

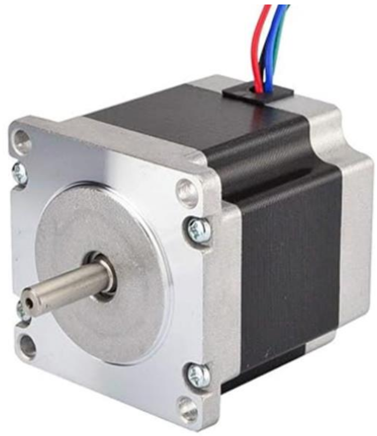


Fig. 3.29 Stepper Motor

Table 3.11 Specifications of stepper motor used

Parameters	Value
Rated voltage	12V DC
Current	1.2 A
Step angle	1.8 deg
Steps per revolution	200
Torque	4.2 Kg-cm

2. Motor driver: The micro stepping motor driver used with its specifications are shown in Fig. 3.30 and Table 3.12 respectively

Fig. 3.30 TB6600 Motor Driver

Table 3.12 Specifications of motor driver used

Parameters	Value
Operating voltage	9-40V DC
Input Current	0-5 A
Clock frequency	200kHz
Output current	0.5-4 A
Maximum power	160W

3. Microcontroller : The microcontroller used is an Arduino Uno whose figure and specifications are shown in Fig. 3.31 and Table 3.13 respectively

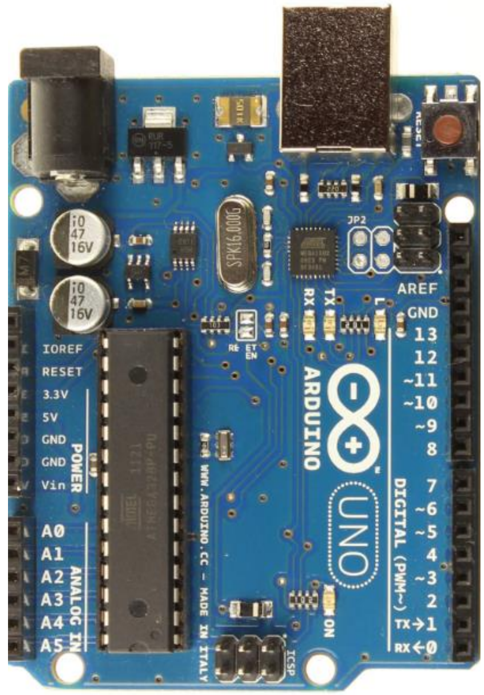


Fig.3.31 Arduino UNO

Table 3.13 Specifications of microcontroller used

Parameters	Value
Operating voltage	5V DC
Input Current	1A
Clock frequency	16MHz
Output current	40-5-mA

3.3.2 Flow Calculations

In the analysis of the peristaltic pump, meticulously calculated the flow control parameters to ensure precise fluid delivery. By determining the volumetric flow rate based on the tube diameter and the rotational speed of the pump and achieved an accurate control of the fluid output, essential for our application's requirements.

Conducted detailed calculations to ascertain the minutes per revolution of the peristaltic pump. By correlating the motor's rotational speed with the pump's mechanical design and establishing a reliable metric for the pump's operational efficiency.

Calculation as follows

Flow Rate from ml/min to ml/sec :

Flow rate in ml/sec=(0.075ml/min) / 60

= 0.00125ml/sec

Each steps=1.8 degree, total 200 steps/ revolution

The step/sec is calculated using (Eq. 3.11)

step/sec = flow rate(ml/sec) / (step/rev*step angle /360) (Eq. 3.11)

step/sec = (0.00125) / ((200*1.8)/360)

= 0.00125 step/sec

The RPM is calculated using (Eq. 3.12)

RPM = (Flow rate*60)/(Pi*ID*Rollers) (Eq. 3.12)

where ID is inner diameter of the silicon tube and rollers is the number of rollers used

RPM = (0.075 *60)/(pi*2*6)

= 0.119 rpm

3.3.3 Circuit diagram

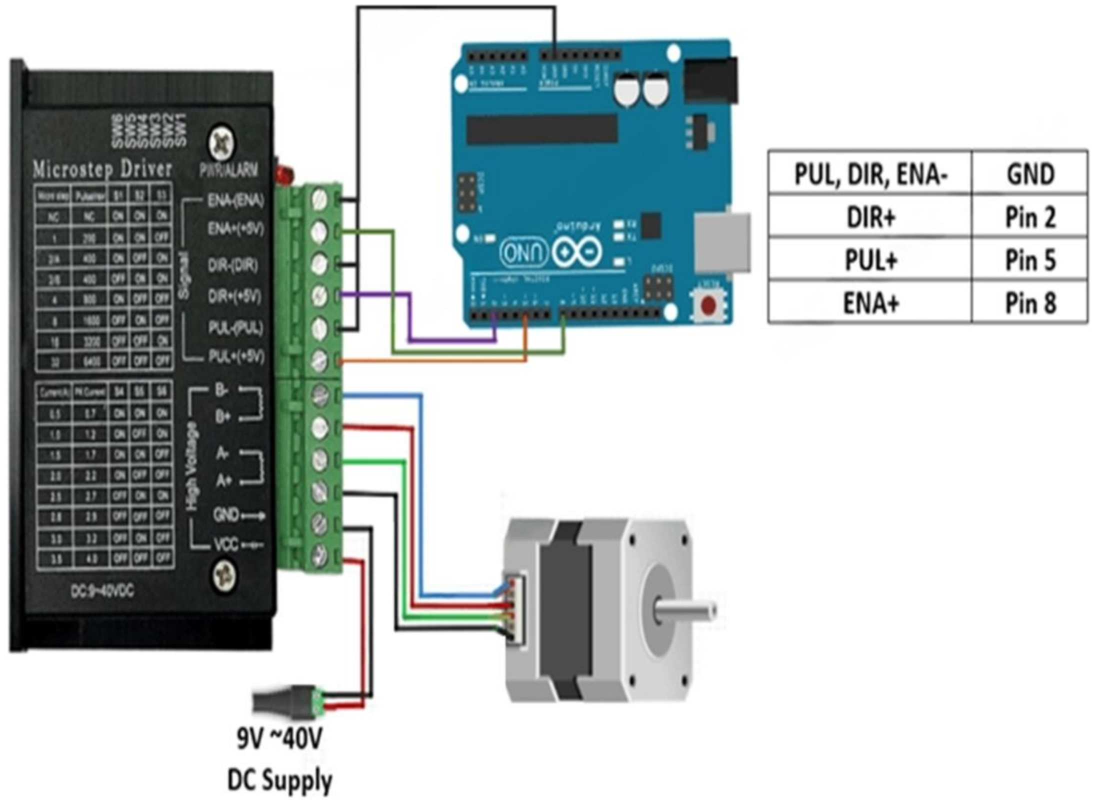


Fig. 3.32 Circuit Diagram of Peristaltic Pump

Fig. 3.32 shows the circuit diagram used.The peristaltic pump circuit utilizes an Arduino to control the operation. The Arduino is programmed to send precise commands to the stepper motor, which is driven by a TB6600 stepper motor driver. This setup allows for accurate control of the pump’s flow rate by adjusting the motor speed and direction, ensuring reliable and consistent performance of the pump.

3.3.4 Work flow of code

The work flow of code is shown in Fig. 3.33.

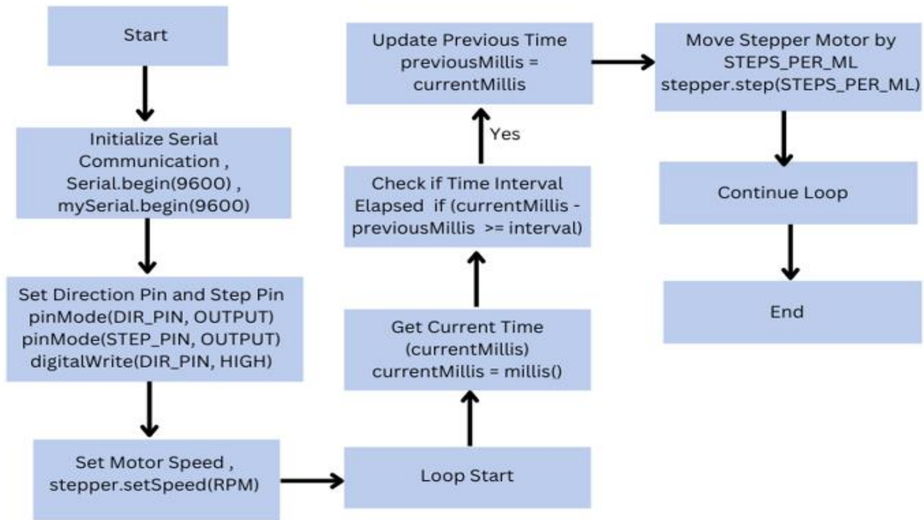


Fig. 3.33 Flow Chart of Code

3.3.5 Difficulties faced

Fig. 3.34 shows the setup that was built and tested in lab

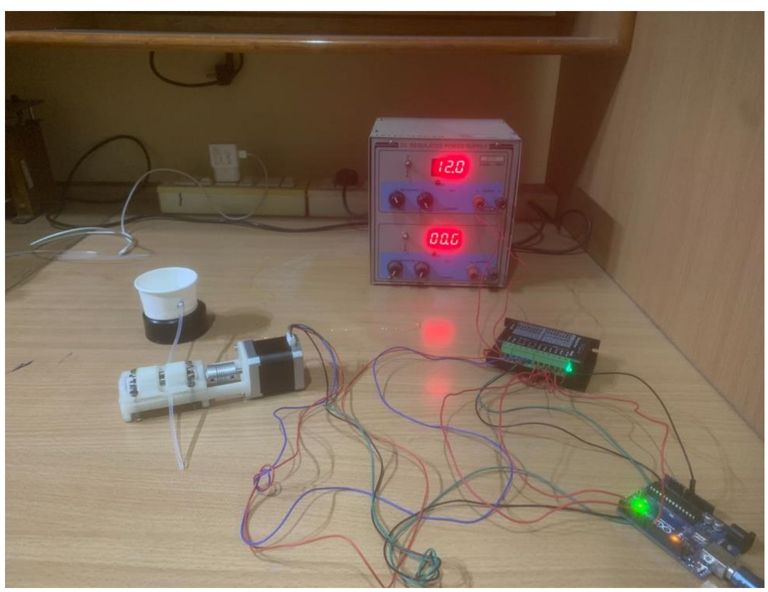


Fig. 3.34 Testing of peristaltic pump

The peristaltic pump circuit was built and tested in the lab using an Arduino to control a stepper motor through a TB6600 stepper motor driver. Despite successful assembly and initial testing, several challenges were encountered. The stepper motor heated up rapidly, which posed a risk of overheating and reduced efficiency. Additionally, achieving precise flow control across all six silicone tubes proved difficult, leading to inconsistent performance. Due to these issues, the decision was made to transition from the peristaltic pump to a more traditional IV control method for regulating flow, ensuring more reliable and stable operation.

3.4 IV FLOW REGULATOR

In the traditional flow control method, a gravity-fed system was implemented. A water tank was positioned at the top of the panel, connected via a silicone tube. This tube featured a flow control valve which is shown in Fig. 3.35 and a syringe for precise adjustments. By manipulating the valve, the flow rate could be accurately controlled to deliver continuous flow rates of 0.075 ml/min, 0.15 ml/min, 0.3 ml/min, 0.6 ml/min, and 0.9 ml/min. This setup provided a reliable and straightforward solution for consistent fluid delivery, overcoming the challenges faced with the peristaltic pump.

Fig. 3.35 Flow control regulator

The flow control is calibrated using a calibration vial as shown in Fig 3.36

Fig 3.36 Calibration vial used

3.5 PANEL WIRING

The panel wiring done is discussed in detail in this section

3.5.1 Control system wiring

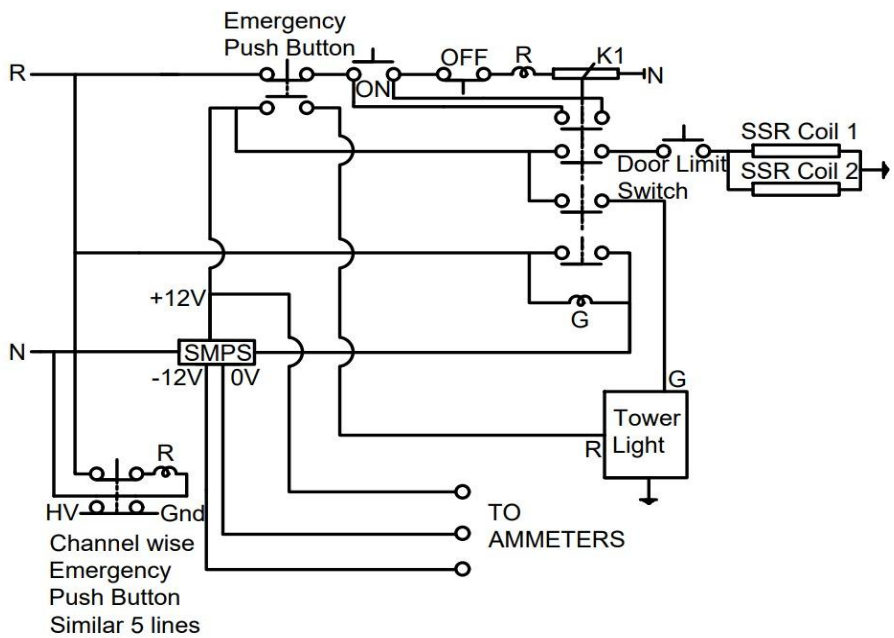


Fig: 3.37 Control wiring circuit diagram

The diagram represents a control system where the SMPS provides the necessary power, and the relay K1 controls the main power flow. The emergency push button can cut off the system in case of an emergency. The door limit switch ensures that certain conditions (like the door being closed) are met before allowing the SSR coils to energize, thereby controlling other connected devices. The tower light serves as an indicator, and the ammeters monitor the current in different channels, each having its own emergency push button for safety.

1. Power Supply (SMPS):
    - The SMPS (Switched-Mode Power Supply) provides three outputs: +12V, 0V, and -12V.
    - The AC mains supply (denoted as R and N) is fed into the SMPS, which converts it to the required DC voltages.
2. Emergency Push Button:
    - The emergency push button is normally closed (NC).
    - It is connected between the R line and the ON/OFF switch. When pressed, it breaks the circuit, cutting off power to the subsequent components.
3. ON/OFF Switch:
    - This switch controls the main power supply to the rest of the circuit.
    - When in the ON position, it allows current to flow from the R line through the switch and to the relay (K1).
4. Relay (K1):
    - The relay K1 is an electromechanical switch that controls the power flow to the door limit switch and SSR coils.

- When energized, K1 closes its contacts, allowing current to flow to the connected components.

5. Door Limit Switch:
    - The door limit switch is normally closed (NC) and is connected in series with the SSR coils.
    - This switch ensures that the door must be in a certain position (closed) for the SSR coils to be energized.
6. SSR Coils (SSR Coil 1 and SSR Coil 2):
    - These solid-state relay coils are connected in series with the door limit switch.
    - When the door limit switch is closed, and K1 is energized, the SSR coils are powered, allowing the control of other high-power devices.
7. Tower Light:
    - The tower light is connected to the G (ground) and R (hot) lines.
    - It is used as an indicator, likely to show the status of the system (whether it is powered on or off).
8. Ammeter Connections:
    - There are connections leading to ammeters, which are used to measure the current flowing in the different channels.
    - This setup indicates that the system monitors current flow, likely for safety and operational purposes.
9. Channel-wise Emergency Push Buttons:

- There are multiple lines (five similar lines indicated) for channel-wise emergency push buttons.
- Each of these channels has its own emergency push button connected to the HV (high voltage) and Gnd (ground).

Chapter 4

RESULTS AND DISCUSSION

The inclined plane test setup has been successfully designed and developed .The testing of the key components designed has been completed and the results obtained are explained below.

1. Leakage current measuring ammeter and data acquisition system

The leakage current measuring ammeter and data acquisition system has been successfully designed and developed.

The PCB was tested for an input voltage of 6mV and it is seen that according to the calculations described above the output obtained should be 60mA . It is seen that the output obtained after testing the PCB is 64.78 mA as shown in Fig. 4.1.

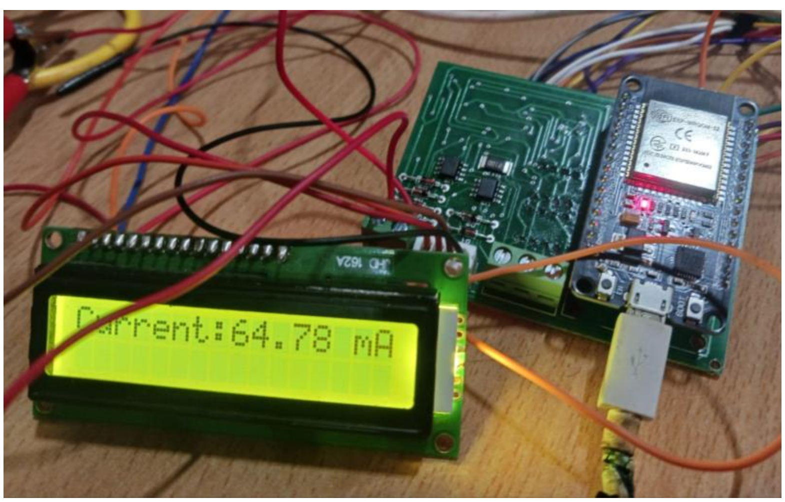


Fig. 4.1 PCB testing done

The percentage error calculations using (Eq. 4.1) are given below

Error %=((Practical value -Theoretical Value))/Theoretical value)*100   (Eq. 4.1)

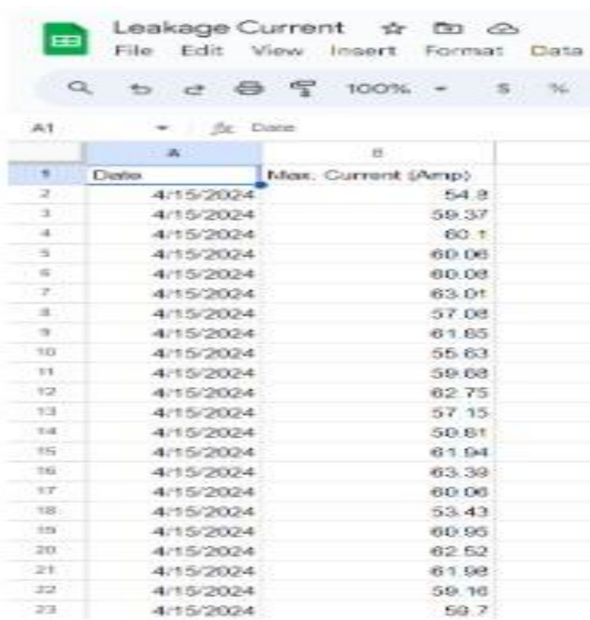
Error % = ((64.78mA - 60mA)/60 mA) * 100

Error % = 7.96%

Hence percentage accuracy is given by

Accuracy % = 100 - 7.96 = 92.033%

The data collection represents a real-time scenario where the information displayed on the LCD screen is simultaneously pushed into a Google Sheet tracking leakage current. Fig. 4.2 illustrates the collected data as seen on the leakage current Google Sheet.



	A	B
1	Date	Max. Current (Amp)
2	4/15/2024	54.8
3	4/15/2024	59.37
4	4/15/2024	60.1
5	4/15/2024	60.06
6	4/15/2024	60.08
7	4/15/2024	63.01
8	4/15/2024	57.08
9	4/15/2024	61.85
10	4/15/2024	55.63
11	4/15/2024	59.68
12	4/15/2024	62.75
13	4/15/2024	57.15
14	4/15/2024	50.81
15	4/15/2024	61.94
16	4/15/2024	63.39
17	4/15/2024	60.06
18	4/15/2024	53.43
19	4/15/2024	60.95
20	4/15/2024	62.52
21	4/15/2024	61.98
22	4/15/2024	59.16
23	4/15/2024	59.7

Fig. 4.2 Data acquisition system

2. Potential divider

A 1000:1 potential divider has been successfully designed and developed and the following results were obtained

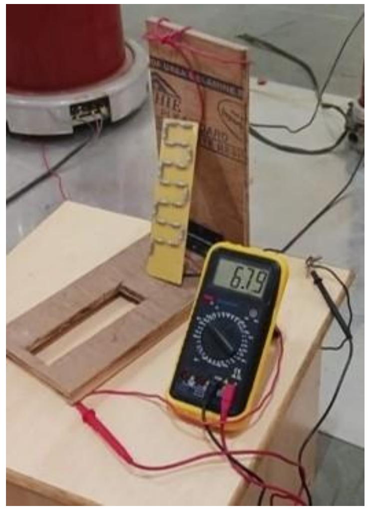


Fig. 4.3 Potential divider testing results

From Fig. 4.3, it is observed that for an input voltage of 7.5 kV, the output voltage obtained across the low voltage arm is 6.79 V, while the expected output voltage should be 7.2 V. The error is calculated using (Eq. 4.2) and the percentage error is calculated using (Eq. 4.3)

Error = Expected value - Observed value (Eq. 4.2)

= 7.2V - 6.79V

= 0.41V

Percentage error =(error/expected value) * 100 (Eq. 4.3)

=(0.41V / 7.5V)*100

= 5.4%

Hence the percentage accuracy of the developed potential divider is calculated below

Percentage accuracy = 100 - 5.4 = 94.6%

Fig 4.4 shows the final panel developed after incorporating all the key components like leakage current measuring ammeter, potential divider, flow control and so on.

Fig.4.4 Final panel

Further the panel is tested for various conditions which are described below.

When the green push button is pressed, the panel is in ON state. In this ON state the LED light and exhaust fans are in ON position as shown in Fig. 4.5

Fig. 4.5 Panel in ON state

When the emergency push button is pressed the entire system is shut down as indicated in Fig. 4.6

Fig 4.6 Panel in OFF state

When high voltage supply is given to the panel, effective scintillation is obtained as shown in Fig. 4.7

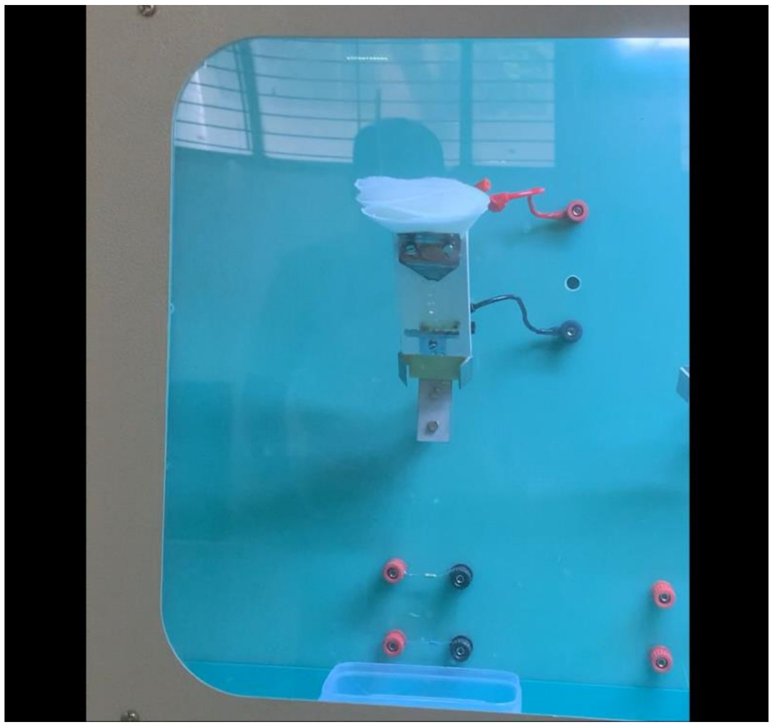


Fig. 4.7 Scintillation

Chapter 5

CONCLUSION

In conclusion, an inclined plane test setup has been successfully designed and developed. The setup incorporates essential components such as an IoT enabled leakage current data acquisition system and a potential divider, both of which have been meticulously designed and implemented. The leakage current measurements demonstrated an accuracy of 92.033%. The leakage current data was also successfully pushed to the cloud for remote access. Additionally, the 1000:1 potential divider exhibits an error percentage of 5.4% and an accuracy percentage of 94.6%. The comprehensive testing of the setup, including its performance under normal and emergency conditions is done. This test setup can be used to determine the tracking and erosion performance of Polymeric housing materials used for outdoor insulation.

FUTURE SCOPE

The future scope of the developed panel is given below

- The panel designed can be used for rigorous testing of various polymeric materials with different compositions to evaluate their suitability as insulators.
- The peristaltic pump for flow control of saline water can be further improved and incorporated.
- Automatic flow control for saline water flow can be developed.

REFERENCES

[1] Sharif F. Kaaiye and Cuthbert Nyamupangedengu "Comparative study of AC and DC inclined plane tests on silicone rubber (SiR) insulation" High Volt., 2017, Vol. 2 Iss. 2, pp. 119-128.School of Electrical and Information Engineering, University of Witwatersrand, Johannesburg, South Africa

[2] "Standard Test Methods for Liquid-Contaminant, Inclined-Plane Tracking and Erosion of Insulating Materials"(2021).

[3] M. A. Douar, A. Mekhaldi and M. C. Bouzidi "Flashover Process and Frequency Analysis of the Leakage Current on Insulator Model under non-Uniform Pollution Conditions" vol 17,No 4; August 2010.

[4] B.X.Du, Yong Liu, H.J.Liu and Y.J.Yang "Recurrent Plot Analysis of Leakage Current for Monitoring Outdoor Insulator Performance"IEEE Transactions on Dielectrics and Electrical Insulation Vol. 16, No. 1; February 2009.

[5] James P. Grinias,† Jason T. Whitfield, Erik D. Guetschow,† and Robert T. Kennedy "An Inexpensive, Open-Source USB Arduino Data Acquisition Device for Chemical Instrumentation."

[6] Alexander Jönsson, Arianna Toppi, Martin Dufva "The FAST Pump, a low-cost, easy to fabricate, SLA-3D-printed peristaltic pump for multi-channel systems in any lab"

[7] Huda Farooq, Mustafa F Mahmood, Suhair Mohammed Yassen "Design and Implementation of a Peristaltic Pump Based on an Air Bubble Sensor"

[8] Radek Procházka,Jan Hlaváček ,Karel Draxler , Renata Styblíková "Precise 10 and 20 kV DC/AC Resistive Divider "2013

[9] Zhou Mu,Shijun Xie , Ping Shu, weidong Ding,Zhenbo Wan ,Hanyu Wang "Development of the 10 kV Wideband Combined Resistance-capacitance Voltage Divider Unit " 2020

APPENDIX I

CODE FOR LC AND DATA ACQUISITION SYSTEM

The code is organized into several sections: setup, loop, WiFi connection, data acquisition, processing, and data transmission.

Setup: In the setup() function, we initialize the necessary components such as the LCD display, configure pin modes, and set up serial communication for debugging. The code snippet is shown below.

```
void setup() {
  pinMode(zeroCrossingPin1, INPUT);
  pinMode(zeroCrossingPin2, INPUT);
  lcd.init(); // Initialize the LCD
  lcd.backlight(); // Turn on the backlight
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Current: ");
  Serial.begin(9600);
}
```

WiFi Connection: The connectToWiFi() function handles the connection to a WiFi network. It attempts to connect to the specified SSID and prints the connection status. The code snippet is shown below.

```
void connectToWiFi() {
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(1000);
    Serial.println("Connecting to WiFi...");
  }
  Serial.println("Connected to WiFi");
}
```

Data Acquisition and Processing: In the loop() function, read analog values from the zero-crossing detectors, calculate the root mean square (RMS) value of the current, and update the maximum current reading. The code snippet is shown below.

```
void loop() {
  int ZeroCrossing1 = analogRead(zeroCrossingPin1);
  int ZeroCrossing2 = analogRead(zeroCrossingPin2);

  float analogValue = analogRead(analogPin);
  float voltage = analogValue * (3.3 / 4095); // Adjusted for ESP32's ADC resolution
  sum += voltage * voltage;
  count++;

  if(ZeroCrossing2==0){
    float rms = sqrt(sum / count);
    current1 = ((rms / 36) * 1000);
    cnt++;

    if(current1>maxcurrent){
      maxcurrent = current1;
    }

    sum = 0;
    count = 0;
  }
    if(ZeroCrossing1==0){
    float rms = sqrt(sum / count);
    current2 = ((rms / 36) * 1000);
    cnt++;
```

```
  if(current2>maxcurrent){
    maxcurrent = current2;

}

  sum = 0;
  count = 0;
}

if(cnt == 20){
  // starttime = millis();
  Serial.println(maxcurrent);
  lcd.setCursor(8, 0);
  lcd.print(maxcurrent, 2);
  if (WiFi.status() != WL_CONNECTED) {
    connectToWiFi();
  }
```

Data Transmission: The sendDataToGoogleSheet() function sends the processed data to a Google Sheets document via an HTTP POST request. It checks if the WiFi is connected before attempting to send data. The code snippet is shown below.

```
void sendDataToGoogleSheet(float data) {
  if (WiFi.status() == WL_CONNECTED) {
   HTTPClient http;
   http.begin(serverName);
   http.addHeader("Content-Type", "application/x-www-form-urlencoded");
   String postData = "data=" + String(data);
   int httpResponseCode = http.POST(postData);
```

```
    if (httpResponseCode > 0) {
      String response = http.getString();
      Serial.println(httpResponseCode);
      Serial.println(response);
    } else {
      Serial.print("Error on sending POST: ");
      Serial.println(httpResponseCode);
    }
    http.end();
  }
}
```

APPENDIX II

Code for peristaltic pump

```
#define MOTOR_STEPS 200
#define DIR_PIN 2
#define STEP_PIN 5
#define MICROSTEPS 1.9
#define RPM 100
#define FLOW_RATE 1.705 // ml/min
#define STEPS_PER_ML ((MICROSTEPS * MOTOR_STEPS) / FLOW_RATE)

Stepper stepper(MOTOR_STEPS, DIR_PIN, STEP_PIN);

unsigned long previousMillis = 0;
const long interval = 2000 / FLOW_RATE; // Interval in milliseconds for 1 ml flow rate

void setup()
{
  Serial.begin(9600);
  mySerial.begin(9600);
  pinMode(DIR_PIN, OUTPUT);
  pinMode(STEP_PIN, OUTPUT);
  digitalWrite(DIR_PIN, HIGH);
  stepper.setSpeed(RPM);
}

void loop()
{
```

```
    unsigned long currentMillis = millis();
    if (currentMillis - previousMillis >= interval)
    {
        // Time to move the stepper motor by the required number of steps
        previousMillis = currentMillis;
        stepper.step(STEPS_PER_ML); // Move the stepper motor by the steps required for 1 ml
    }
}
```