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A Project Phase II Report
On,

"Solar Laboratory Setup for Academic and Research Application"

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF VIII SEMESTER FOR THE AWARD OF

BACHELOR OF TECHNOLOGY IN
ELECTRICAL ENGINEERING

SUBMITTED BY

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DEPARTMENT OF ELECTRICAL ENGINEERING
Dr. D. Y. Patil Pratishthan's College of Engineering
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2025-26

Dr. D. Y. Patil Pratishthan's College of Engineering Salokhenagar Kolhapur 416007

DEPARTMENT OF ELECTRICAL ENGINEERING

CERTIFICATE

Certified that a Project Phase-II entitled **"Solar Laboratory Setup for Academic and Research Application"** has been successfully carried out by the project group no **03**

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are the Bonafide Students of **Dr. D. Y. Patil Pratishthan's College of Engineering Salokhenagar, Kolhapur** in partial fulfilment for the award of Bachelor of Technology in **Electrical Engineering** of **Shivaji University, Kolhapur, Maharashtra, India** for the year **2025-26**. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated. The project report has been approved as it satisfies the academic requirements prescribed for the Bachelor of Technology Degree.

Dr. Uttam S. Satpute	Prof. A. B. Jadhav	Dr. V. N. Abdulpur	Dr. S. D. Mane
Project Guide	Project coordinator	HOD	Principal

Date of Examination	Name of Examiner	Affiliation	Signature

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ABSTRACT

This project focuses on the design and development of a solar laboratory setup for academic and research applications; to study the performance and behaviour of photovoltaic (PV) systems. The project enables experimental analysis of I–V and P–V characteristics of PV panels under varying load and environmental conditions. A sun emulator is incorporated to simulate controlled irradiance, allowing consistent indoor testing independent of natural sunlight.

The laboratory also includes the implementation of Maximum Power Point Tracking (MPPT) algorithms using DC-DC converters to optimize power extraction efficiency. Practical interfacing of PV systems with batteries and DC loads such as pumps is carried out to analyze real-time performance and energy utilization. Additionally, the effect of partial shading on series and parallel configurations of PV cells is examined to understand performance variations.

The project further evaluates solar insolation and performs life cycle analysis to assess environmental impact and sustainability. Overall, the Solar Laboratory provides a cost-effective, scalable, and hands-on platform that bridges the gap between theoretical concepts and practical implementation, enhancing learning and research in renewable energy systems.

The solar laboratory is useful in catering the demand of trained human resources to achieve the ambitious target of total renewable energy generation of Viksit Bharat Mission by 2030 and to address the Sustainable Development Goals (SDGs). The laboratory also can be utilized as Add-on Course, Workshop, and Internship etc. with experiential learning in align with NEP 2.0.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

CHAPTER 1

1.1. INTRODUCTION

The rapid global demand for sustainable energy sources has placed photovoltaic (PV) technology at the forefront of renewable power generation. Accurate characterization of a PV panel is essential for system design, performance prediction, and fault diagnosis. The I–V (Current–Voltage) and P–V (Power–Voltage) characteristic curves are fundamental tools for assessing PV performance, as they graphically represent the panel's operational limits and efficiency across its possible load range. Furthermore, the push toward autonomous electric vehicles (EVs) highlights the need for hands-free charging solutions, as future self-driving vehicles will require fully automatic energy replenishment systems. Wireless charging, when integrated with solar-based systems, holds the potential to provide a seamless, contactless, and maintenance-free charging experience.

The I–V curve illustrates the relationship between the current output and the voltage across the panel terminals, while the P–V curve highlights the existence of the Maximum Power Point (Pmax), where the panel delivers its highest power. Key performance indicators derived from these curves include Open-Circuit Voltage (Voc), Short-Circuit Current (Isc), and the Fill Factor (FF). This study aims to experimentally determine the I–V and P–V characteristics of a 20Wp PV solar panel under two different illumination scenarios:

Natural Sunlight: Testing the panel under real-world, variable environmental conditions.

Sun Emulator: Utilizing a controlled laboratory device to simulate standardized illumination for repeatable testing.

The insights gained from comparing these two scenarios are vital for understanding the influence of testing environments on PV characterization. In addition, this work addresses the existing curriculum gap in many academic institutions, where limited access to practical solar laboratory setups restricts hands-on learning and real-time system analysis. To overcome this limitation, the proposed system can be introduced as an add-on course, enabling students to gain practical exposure to modern solar technologies such as MPPT, energy storage, and system integration. Furthermore, the setup can be utilized to conduct workshops and training programs for students and industry professionals, promoting skill development in renewable energy systems

Future scope of this work includes integration with advanced technologies such as IoT-based remote monitoring, artificial intelligence for performance optimization and fault detection, and hybrid renewable systems combining solar with energy storage and EV charging infrastructure. The system can also be expanded to support research in smart grids, wireless power transfer, and sustainable energy solutions for next-generation applications.

1.2. PROBLEM STATEMENT

Despite the growing importance of solar photovoltaic (PV) systems in renewable energy generation, many academic institutions face limitations in providing practical exposure to students due to the lack of affordable and comprehensive solar laboratory setups. Existing learning is often restricted to theoretical concepts, resulting in a significant gap between academic knowledge and real-world application. Additionally, accurate characterization of PV panels under varying environmental conditions requires controlled testing environments, which are not readily available in conventional laboratories.

Moreover, the performance of PV systems is highly dependent on factors such as irradiance, temperature, and shading, making it essential to study I–V and P–V characteristics using both natural and simulated conditions. There is also a growing need to incorporate modern technologies such as Maximum Power Point Tracking (MPPT), energy storage integration, and real-time monitoring into educational platforms.

Furthermore, with emerging applications like solar-powered systems and autonomous electric vehicle charging, there is a demand for hands-on training and skill development through structured add-on courses and workshops. However, the absence of such integrated, cost-effective, and scalable training systems limits the ability of students and professionals to gain practical expertise in renewable energy technologies.

Hence, there is a need to develop a comprehensive solar laboratory setup that enables accurate PV analysis, bridges the curriculum gap, and supports practical learning through experiments, add-on courses, and workshops.

1.3. METHODOLOGY

The overall study of photovoltaic (PV) systems is carried out through a series of experiments to analyse performance, control techniques, and practical applications. Initially, the I–V and P–V characteristics of the PV panel are obtained by connecting it to a variable load and measuring voltage and current under different loading conditions, from open circuit to short circuit. The corresponding power is calculated, and characteristic curves are plotted to determine key parameters such as open-circuit voltage, short-circuit current, and maximum power point. To ensure controlled testing conditions, a sun emulator is used to simulate solar irradiance, where the intensity of light is varied and measured using a solar power meter to study the panel's response under different illumination levels. Solar insolation is estimated by recording irradiance values at regular intervals throughout the day using a pyranometer, and the total solar energy is calculated by integrating these readings over time.

Further, Maximum Power Point Tracking (MPPT) algorithms such as Perturb and Observe and Incremental Conductance are implemented using a DC-DC converter to optimize the power extraction from the PV panel under varying environmental conditions, and their performance is evaluated in terms of efficiency and response time. The interfacing of the PV system with practical loads is also studied by connecting the panel to a battery through a charge controller to analyse charging characteristics and energy storage behaviour, as well as by connecting it to a DC pump to evaluate real-time operation and performance based on solar intensity. Additionally, the effect of shading is examined by configuring PV cells in series and parallel combinations and introducing partial shading conditions to observe variations in output voltage and current, along with the role of bypass diodes in minimizing power losses. Finally, a life cycle analysis of the solar panel is conducted by assessing energy consumption, carbon emissions, and environmental impact across all stages, including manufacturing, transportation, operation, and disposal, thereby evaluating the overall sustainability and efficiency of the PV system.

CHAPTER 2

2.1. LITERATURE REVIEW

Solar photovoltaic (PV) technology has emerged as one of the most promising renewable energy solutions due to its modularity, long-term reliability, and rapidly reducing cost. Characterization of PV modules through I–V and P–V measurements is a fundamental requirement for understanding their performance under various operating conditions. According to Solanki (2015), parameters such as open-circuit voltage (Voc), short-circuit current (Isc), maximum power point (MPP), fill factor (FF), and efficiency (η) are essential for evaluating PV behaviour under real-world conditions.

Studies by Umanand (NPTEL) highlight that PV characteristics are highly dependent on irradiance, temperature, and electrical loading. Accurate laboratory setups are therefore necessary to simulate and analyse PV performance. Traditional outdoor measurements suffer from variability in environmental conditions such as intermittent sunlight, dust, temperature fluctuations, and shading. To overcome these limitations, researchers have introduced solar emulators, which replicate sunlight in a controlled indoor environment. These systems allow repeatable experiments by providing stable irradiance levels and spectral distribution.

Esrom and Chapman (2007) emphasize the importance of determining MPP for maximizing the efficiency of PV systems, especially when integrating technologies such as Maximum Power Point Tracking (MPPT). MATLAB-based studies by Patel and Agarwal (2008) further reinforce the need for controlled testing environments to analyse shading effects, nonlinearities, and dynamic irradiance conditions.

Despite available research, many academic institutions lack affordable and comprehensive solar laboratory setups. Existing commercial systems are either too complex, costly, or lack flexibility for academic experimentation. Hence, there remains a strong need for a low-cost, scalable, and educationally focused solar lab that enables students to study PV characteristics, sun emulation, boost converters, and MPPT techniques.

2.2. OBJECTIVE

- To design and develop a functional solar energy training system for practical understanding of photovoltaic (PV) systems.
- To simulate real-world solar conditions using a solar emulator and adjustable irradiance levels.
- To study and implement advanced techniques like Maximum Power Point Tracking (MPPT) for efficient energy extraction.
- To enable real-time monitoring and measurement of key parameters such as voltage, current, power, irradiance, and temperature.
- To analyze the performance of PV systems when interfaced with batteries and practical loads.
- To study the effects of shading on series and parallel configurations of PV cells.
- To bridge the gap between theoretical knowledge and practical application in renewable energy education.
- To develop a cost-effective, scalable, and user-friendly solar laboratory setup for academic use.
- To introduce this solar laboratory setup as an add-on course to enhance student’s practical skills in renewable energy systems.
- To organize workshops and training programs based on the developed system, providing hands-on experience to students and professionals.

2.3. BACKGROUND WORK

The background work for this project centres on an in-depth exploration of solar photovoltaic (PV) technologies and educational laboratory systems designed to facilitate hands-on learning in renewable energy. Solar energy research has advanced significantly since the early development of silicon-based PV cells, evolving into highly efficient and modular systems widely deployed in residential, commercial, and industrial applications.

Recent technological progress has introduced sophisticated techniques such as Maximum Power Point Tracking (MPPT), which optimizes power extraction from solar panels under varying irradiance and temperature conditions. Modern PV systems also incorporate advanced charge controllers, sun emulators, and real-time monitoring tools that simulate dynamic environmental factors and support comprehensive performance analysis. These innovations have become standard in industry-grade solar installations, yet remain largely inaccessible in many academic environments due to high equipment costs and limited laboratory infrastructure.

Studies on solar laboratory training platforms emphasize the value of real-time data acquisition, environmental simulation, and system behaviour analysis for effective learning. Research efforts have also highlighted the necessity of exposing students to practical PV system design, load integration, and safety considerations to prepare them for the rapidly expanding renewable energy sector.

Commercial solar training kits and research-grade emulation platforms demonstrate the feasibility of creating compact, controlled environments for teaching solar principles. However, most existing solutions either lack affordability, fail to cover advanced technologies like MPPT and environmental emulation, or are unsuitable for full classroom integration.

Building upon these foundational insights, this project aims to design and develop a comprehensive solar energy training system that integrates real-time monitoring, sun emulation, and modern PV technologies. This background work forms the basis for creating an accessible, efficient, and pedagogically effective laboratory platform for electrical engineering students.

2.4. LIST OF EXPERIMENT AND COSTING

Sr. No	List of experiment	Cost
1.	Study of I-V & P-V Characteristics of PV Panel	6000.00
2.	Sun Emulator	10000.00
3.	Estimation of solar insolation	Nil
4.	Study of MPPT Algorithms	4000.00
5.	Study of interfacing of PV & Battery	3500.00
6.	Study of interfacing of PV & Pump	2000.00
7.	Study of effect on series and parallel connection of PV cells under shading condition	500.00
8.	Life Cycle Cost analysis of solar panel	Nil
9.	Posters	3000.00
10.	Miscellaneous	3000.00
-	Total Expenditure	32000.00

CHAPTER 3

3.1. APPARATUS

Experiment No: 1 Study of I-V and P-V characteristics of the Solar panel.

Sr. No	Apparatus Name	Specification	Quantity
1.	PV Solar panel	20Wp	1
2.	Rheostat	100W,1.2A	1
3.	Voltmeter	Digital (0-200V) DC	1
4.	Ammeter	Digital(0-2A) DC	1
5.	Multimeter	-	1
6.	Connecting Wires	-	As require
7.	Plywood	1.8mm, 8 Sq.m	1

Table 3.1.1: Expt. No. 1 Components list.

Experiment No: 2 Solar Emulator

Sr. No	Apparatus Name	Specification	Quantity
1.	PV Solar panel	20Wp	1
2.	Rheostat	100W,1.2A	1
3.	Voltmeter	Digital (0-200V) DC	1
4.	Ammeter	Digital(0-2A) DC	1
5.	Bulb	200W	6
6.	Connecting Wires	-	As require
7.	Plywood	1.8mm, 18 Sq.m	1

Table 3.1.2: Expt. No. 2 Components list

Experiment No: 4 Study of MPPT Algorithm

Sr. No	Apparatus	Specifications	Quantity
1.	PV Panel	20Wp	1
2.	Sun emulator	$1000W/m^2$, 25°C	1
3.	MPPT Kit (with Buck & Boost)	Boost-CA-150W; Buck-CA-300A	1
4.	Variable Resistive Load	100ohm, 100W, 1.2A	1
5.	Connecting Wires	-	As Requirement

Table 3.1.3: Expt. No. 4 Components list.

Experiment No: 5 Study of interface of a PV Panel with a Battery

Sr. No	Apparatus	Specification	Quantity
1.	Lead acid battery	12V, 8.0Ah	1
2.	ESP32	Devkit V1	1
3.	Charge Controller	6V/12V, 3A	1
4.	Exhaust Fan	12VDC to 12/5VDC	1
5.	DHT 11	3V to 5VDC / 20% to 90% RH	1
6.	Power converter	230VAC to 12/5VDC	1
7.	Voltage Sensor	<25VDC	1
8.	LCD Display 16x2	5VDC	1
9.	Battery Level Indicator	-	1

Table 3.1.4: Expt. No. 5 Components list.

Experiment No: 6 Study of interfacing of Solar Panel with Water Pump

Sr. No	Apparatus name	Specification	Quantity
1.	PV Solar Panel	20Wp	1
2.	DC Water Pump	12V DC	1
3.	Voltmeter	Digital (0–200V) DC	1
4.	Ammeter	(0–2A)	1
5.	Multimeter (for verification)	-	1
6.	MPPT kit	Buck Converter	1
7.	Connecting Wires	-	As per Required

Table 3.1.5: Expt. No. 6 Components list.

Experiment No: 7 Study of Series and parallel connection of PV cells under shading condition

Sr. No	Apparatus	Specification	Quantity
1.	PV Panel (small modules)	10W-20Wp	2
2.	DC Voltmeter	0-50V	1
3.	DC Ammeter	0-5A	1
4.	Potentiometer	100ohm	1
5.	Multimeter	Digital	1
6.	Connecting Wires	-	As required
7.	Artificial shading material	Cardboard / cloth	1

Table 3.1.6: Expt. No. 7 Components list

3.2. CIRCUIT DIAGRAM

Experiment No.1: Study of I-V and P-V characteristics of the Solar Panel.

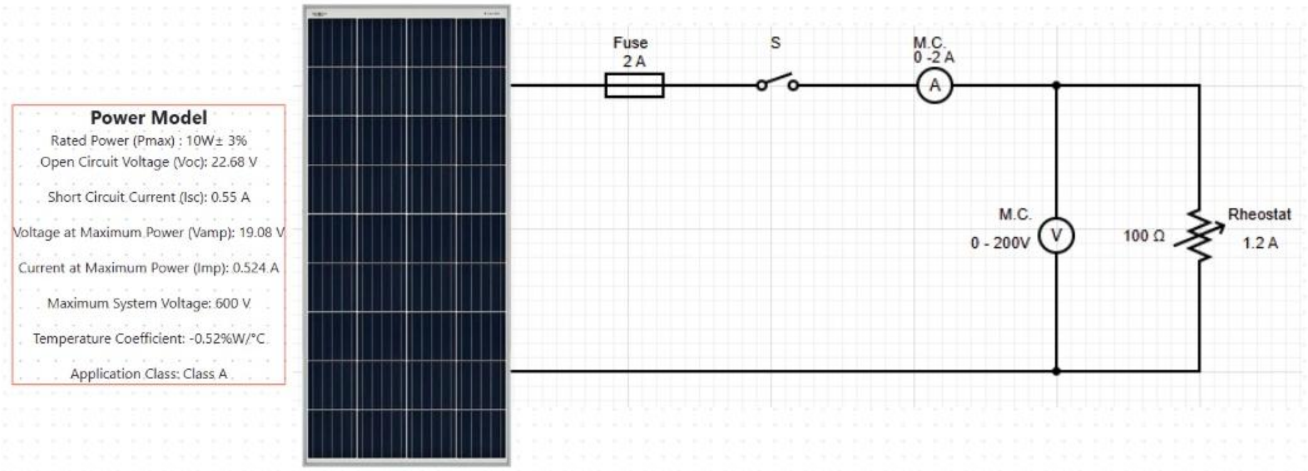


Fig. 3.2.1: Expt. No.1 Circuit Diagram.

Experiment No.2: Solar Emulator.

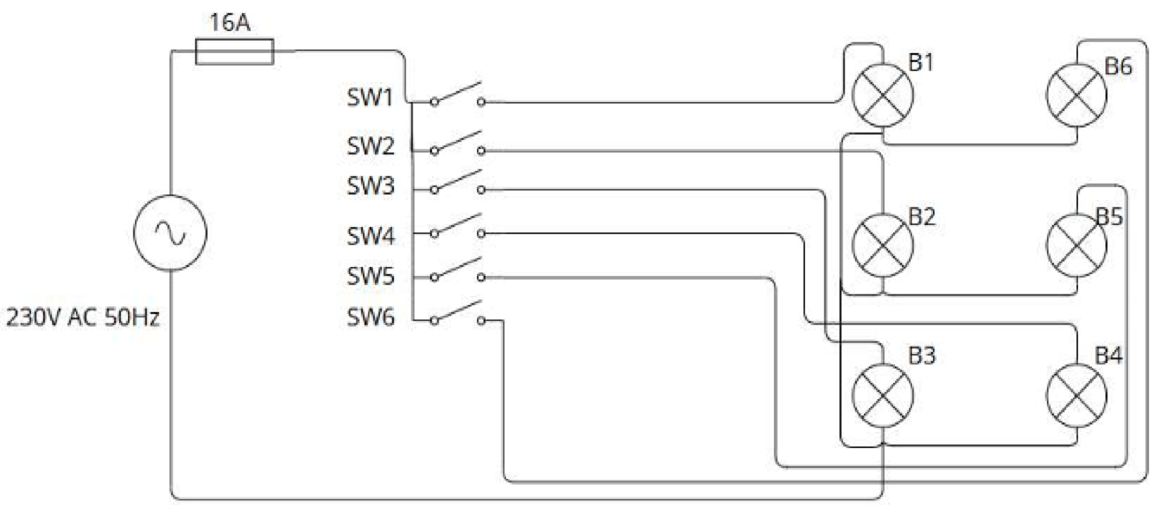


Fig. 3.2.2: Expt. No.2 Circuit Diagram.

Experiment No.4: Study of MPPT Algorithm.

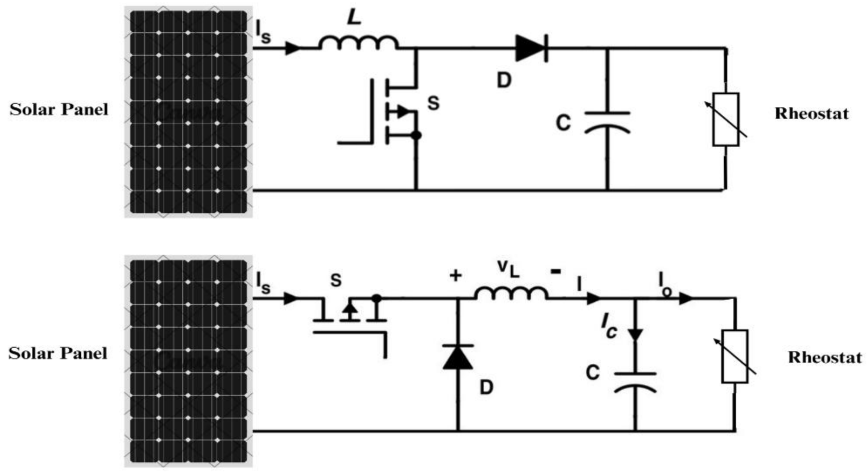
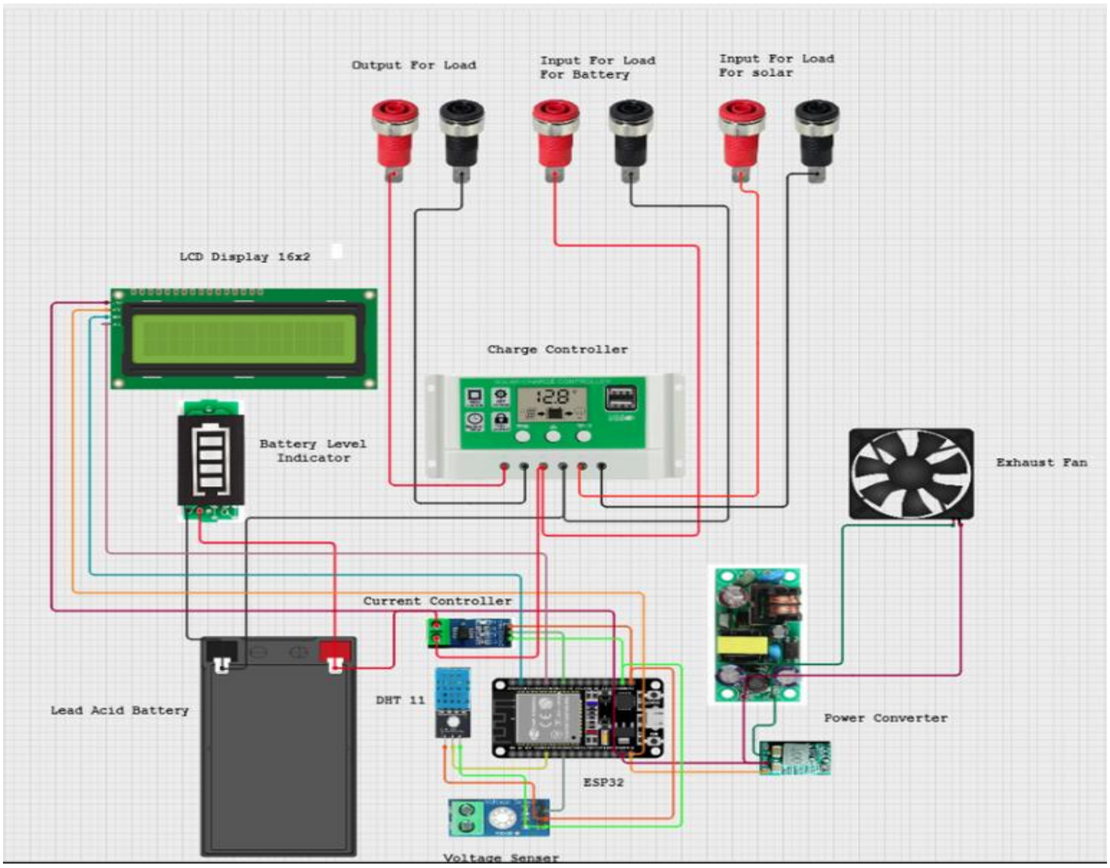


Fig. 3.2.3: Expt. No.4 Circuit Diagram.

Experiment No.5: Study of interfacing of a PV panel and battery.



3.2.4: Expt. No.5 Circuit Diagram.

Experiment No.6: Study of interfacing of solar panel and water pump.

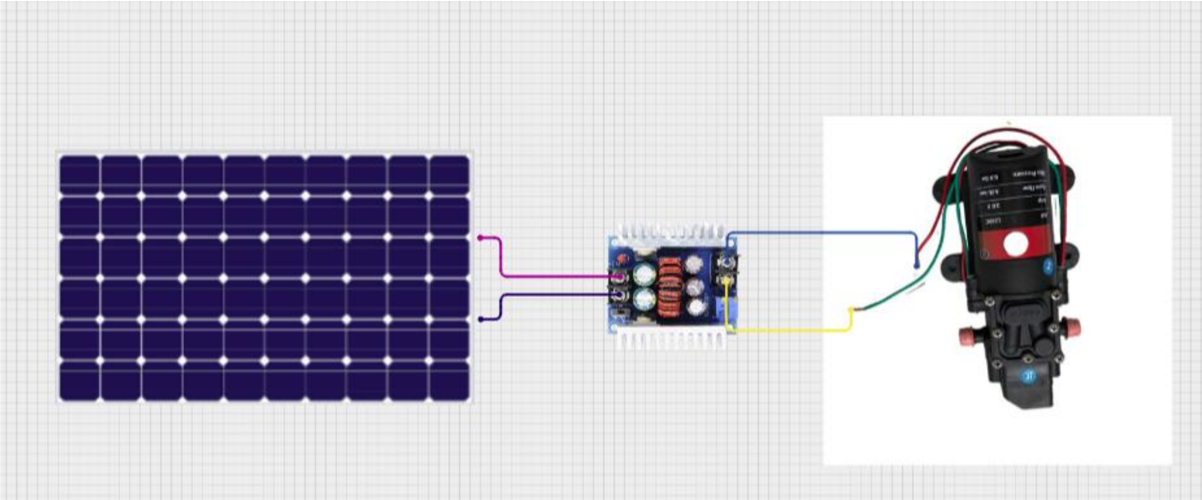


Fig. 3.2.5: Expt. No.6 Circuit Diagram.

Experiment No.7: Study of Series and parallel connection of PV cells under shading condition.

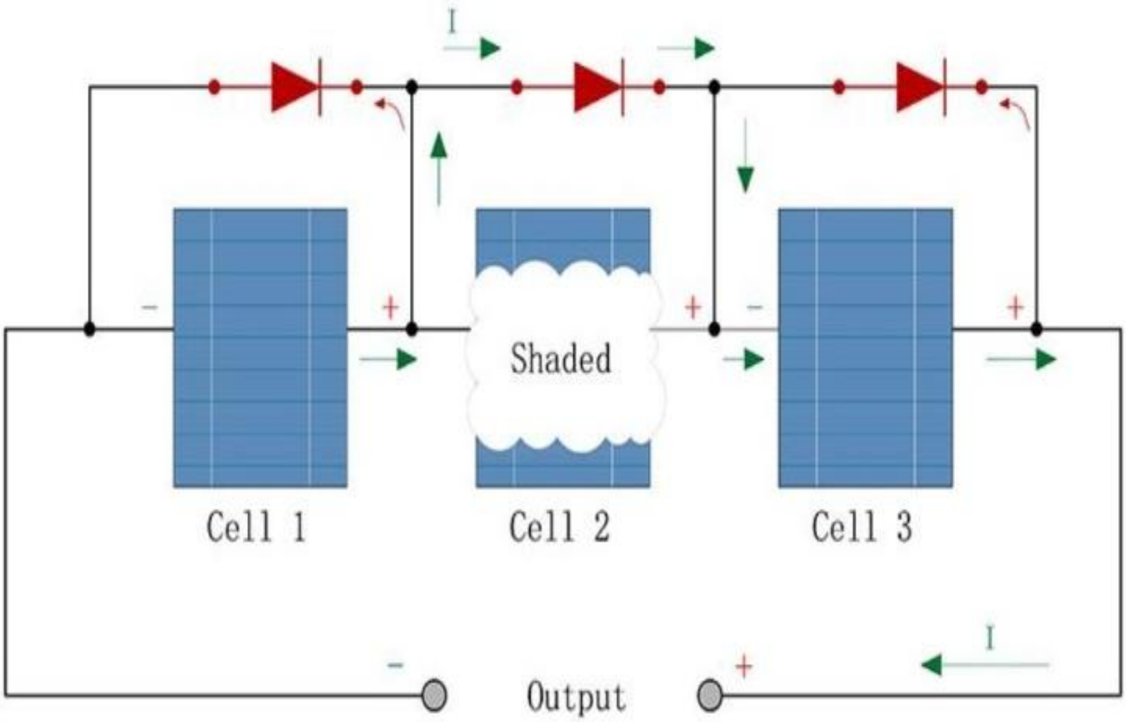


Fig. 3.2.6: Expt. No.7 Circuit Diagram.

3.3. PROCEDURE

Experiment No: 1

Procedure:

1. Circuit Setup: Connect the wires and components according to the given circuit diagram.
2. Illumination: Place the photovoltaic (PV) panel under direct sunlight to provide uniform illumination.
3. Load Variation: Gradually vary the load resistance connected across the PV panel. For each resistance value, measure and record the corresponding voltage (V) and current (I) from the PV panel.
4. Power Calculation: For each set of readings, calculate the power output using the formula: $P = V \times I$.
5. Graphical Analysis: Plot the following graphs from the recorded data:
   1. I–V Curve: Current (I) vs. Voltage (V)
   2. P–V Curve: Power (P) vs. Voltage (V)

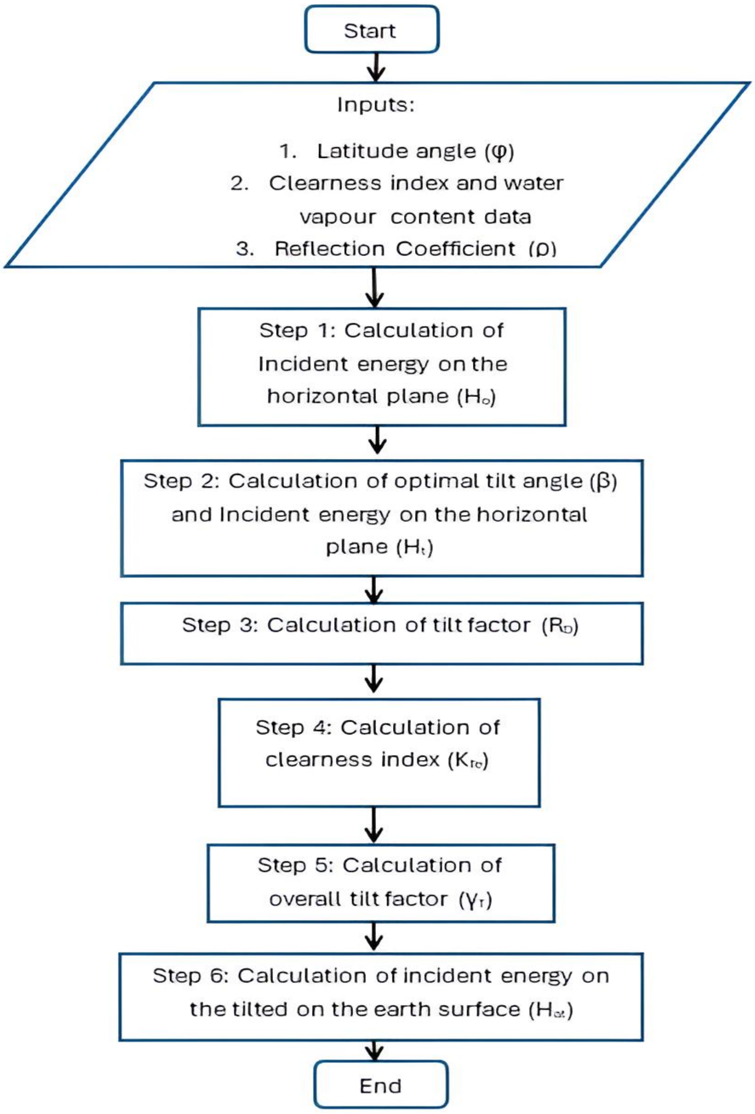
Experiment No: 2

Procedure:

1. Setup and Illumination: Securely mount the PV panel inside the solar emulator, ensuring its surface is perpendicular to the incident light for uniform illumination.
2. Emulator Stabilization: Switch on the sun emulator and allow it to stabilize to steady light intensity and spectrum. Set the desired irradiance level and record the conditions (e.g., LUX/W/m^2 and temperature).
3. Circuit Check: Ensure the ammeter, voltmeter, and variable resistive load are correctly connected according to the circuit diagram and all instruments are properly calibrated.
4. Load Variation & Recording: Start the experiment with the load resistance at its maximum (near open-circuit condition). Gradually decrease the resistance in small steps to draw increasing current. At each setting, record the corresponding Voltage (V) and Current (I) readings until the short-circuit condition is reached.
5. Power Calculation: Calculate the output power for every data set using the formula P = V * I. Tabulate V, I, and P, and identify the Maximum Power Point (Pmax).
6. Graphical Analysis: Plot the I–V Curve (I vs. V) and the P–V Curve (P vs. V). From these plots, determine the key performance parameters: Voc, Isc, Vmp, Imp, Fill Factor (FF), and Efficiency (ή).

Experiment No: 3

- **Flow Chart:**



Experiment No: 4

Procedure:

Part A: Boost Converter

1. Connect the equipment as per circuit diagram.
2. Select the **Boost Converter** using the toggle switch.
3. Place the Solar Panel under uniform sunlight or sun emulator.
4. Switch ON the setup.
5. Set the duty cycle to minimum.

6. Gradually increase the duty cycle.

For each step, record:

Output Voltage (V)

Output Current (I)

7. Calculate power using:

$$P = V \times I$$

8. Identify the duty cycle at which maximum power is obtained.

Plot:

- I–V Graph
- P–V Graph

Part B: Buck Converter

1. Reset the duty cycle to minimum.
2. Select the **Buck Converter** using the toggle switch.
3. Repeat the same steps as in Boost mode.
4. Record readings.
5. Calculate power.
6. Identify the duty cycle corresponding to MPP.
7. Plot:
   - I–V Graph
   - P–V Graph

Experiment No: 5

Procedure:

1. Ensure the battery is properly connected inside the kit.
2. Connect the PV panel or DC supply to the solar input terminals.
3. Switch ON the system and allow the battery to charge.
4. Observe battery voltage, temperature, and humidity status on the LCD display.
5. Measure and record the charging current and battery voltage at regular time intervals (e.g., every 30 minutes) until the battery reaches full charge voltage level.

Experiment No: 6

Procedure:

1. Place the solar panel in direct sunlight or in the sun emulator.
2. Connect the solar panel to the MPPT charge controller (input terminals).
3. Connect the output of MPPT controller to the water pump.
4. Set MPPT toggle switch to buck converter.
5. Connect the ammeter in series with the pump.
6. Connect the voltmeter in parallel across the pump terminals.
7. Switch ON the setup and allow the pump to operate.
8. Note down voltage, current and Solar irradiance readings.
9. Observe the pump speed and water discharge.
10. Repeat the readings under different sunlight intensity conditions.
11. Calculate power using formula: $P = V \times I$.
12. Record all observations in the table.
13. Draw the IV and PV characteristics graph.

Experiment No: 7

Procedure:

1. Connect the PV modules in **series configuration**.
2. Place the setup under sunlight or laboratory light source.
3. Measure and record:

   Output voltage (V)

   Output current (I)

4. Now partially cover (shade) one PV module using cardboard.
5. Record the new voltage and current readings.
6. Repeat the same steps for **parallel configuration**.
7. Compare the performance of both connections under shading condition.
8. Tabulate all readings and plot graphs.
9. Tabulate all readings and plot graphs.

3.4. CALCULATION OF RATING:

Experiment No: 1

PV Panel Ratings: P = 20Wp

Voc = 22.57V Isc = 1.23A Vmp = 19.48V Imp = 1.09A

Rheostat = 100ohm, 100W, 1.2A

according to this Voltmeter and Ammeter ratings decided.

Experiment No: 2

Step 1: Total Power 6 bulbs × 200 W

$$\boldsymbol{P = 6 \times 200 = 1200}\ \text{W}$$

Step 2: Luminous Efficacy of Tungsten Bulbs

For incandescent/tungsten lamps:

Typical efficacy ≈ 12–15 lumens/W

Take average ≈ 14 lm/W

$$\text{Total lumens} = \mathbf{1200 \times 14 = 16800}\ \text{lumens}$$

Step 3: Convert Lumens → Lux

Lux depends on area:

$$\text{Lux} = \frac{\text{Lumens}}{\text{Area}}$$

If light falls on 1 m² area:

$$\text{Lux} = \mathbf{16800}\ \text{lx}$$

Step 4: Convert Lux → Irradiance

For tungsten light:

$$\mathbf{1}\ \text{W/m}^2 \approx \mathbf{15}\ \text{lux}$$

$$\text{Irradiance} = \frac{\mathbf{16800}}{\mathbf{15}} \approx \mathbf{1120}\ \text{W/m}^2$$

Experiment No: 4

- PV Panel:

$$P_{max} = 20\,W$$

$$V_m = 19.48\,V$$

$$I_m = 1.09\ A$$

- Load: $R = 100\Omega$(we can use this for verification)
- Desired output voltage: $V_{out} = 48\ V$
- Maximum duty cycle: $D_{max} \approx 57.7\%$
- Assume switching frequency: $f_s = 20\ kHz$

Step 1: Verify Duty Cycle

Boost relation:

$$V_{out} = \frac{V_{in}}{1 - D}$$
$$D = 1 - \frac{V_{in}}{V_{out}} = 1 - \frac{19.48}{48} \approx 0.594$$

Very close to your **desired max duty cycle ~58%**. Perfect.

Step 2: Inductor Design

Inductor ripple current:

$$\Delta I_L = \frac{V_{in} \cdot D}{L \cdot f_s}$$
$$\Delta I_L = \frac{19.48 \cdot 0.594}{0.0022 \cdot 20000} = \frac{11.57}{44} \approx 0.263\ A$$

- PV panel max current $I_m = 1.09\ A$
- Ripple current $\Delta I_L \approx 0.26\ A$ (<30% of Im)

Step 3: Capacitor Design

Output voltage ripple:

$$\Delta V = \frac{I_{out} \cdot D}{C \cdot f_s}$$

Assume PV delivers $I_{out} \approx 1.09\ A$, C = 6.8 μF, D = 0.594, f = 20 kHz:

$$\Delta V = \frac{1.09 \cdot 0.594}{6.8 \times 10^{-6} \cdot 20000} = \frac{0.647}{0.136} \approx 4.76\ V$$

Ripple voltage ~5 V (acceptable for 48 V output)

Calculation No: 5

Step 1: Selection of Battery Voltage

Voc =22.57V

Vmp = 19.48V

This is suitable for charging a 12V lead-acid battery, whose charging voltage requirement is about 14–14.4V.

Step 2: Selection of Battery Capacity

Safe charging current for a lead-acid battery is:

Icharge=10% to 20% of battery capacity

Let battery capacity = C

0.1C < 1.23 < 0.2C

Solution:

C = 1.23/0.1 = 12.3Ah

C = 1.23/0.2 = 6.15Ah

Selected battery:

12V 8Ah Lead Acid Battery

Step 3: Charging Time Calculation

Charging Time = (Battery Capacity/Charging Current) x 1.2

(1.2 factor accounts for charging losses)

Charging Time = (8/1.23) x 1.2

= 7.8 ≈ 8 hours

Step 4: Energy Consumption

Battery Energy: 12V x 8Ah = 96Wh

Panel Daily Energy: 20W x 5h = 100W

3.5. SIMULATION

Experiment No: 1

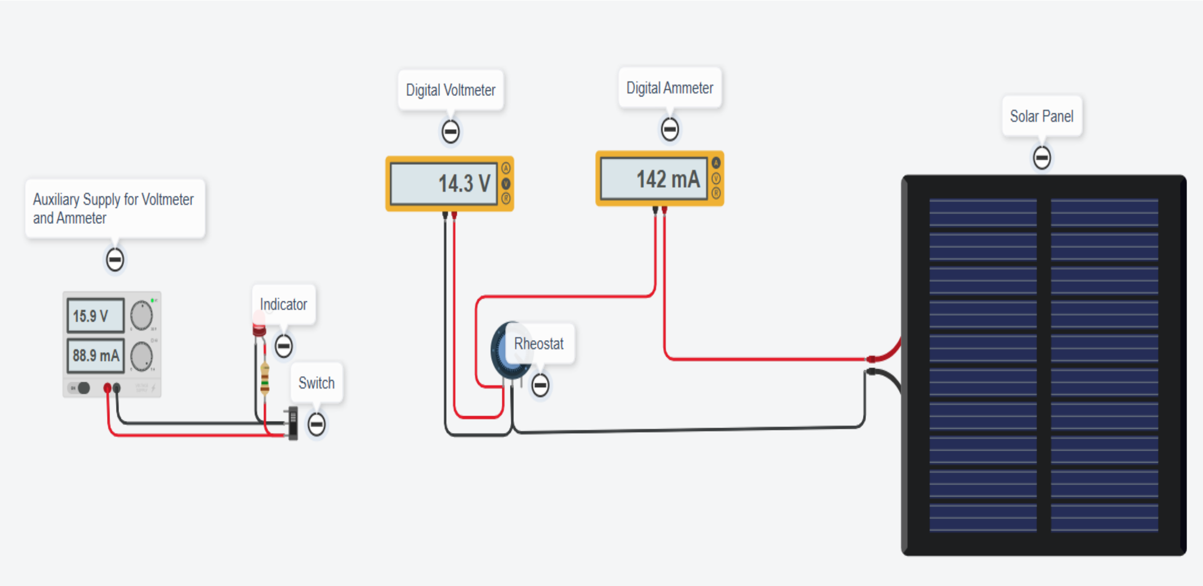


Fig. 3.5.1: Expt. 1 simulation.

Experiment No: 2

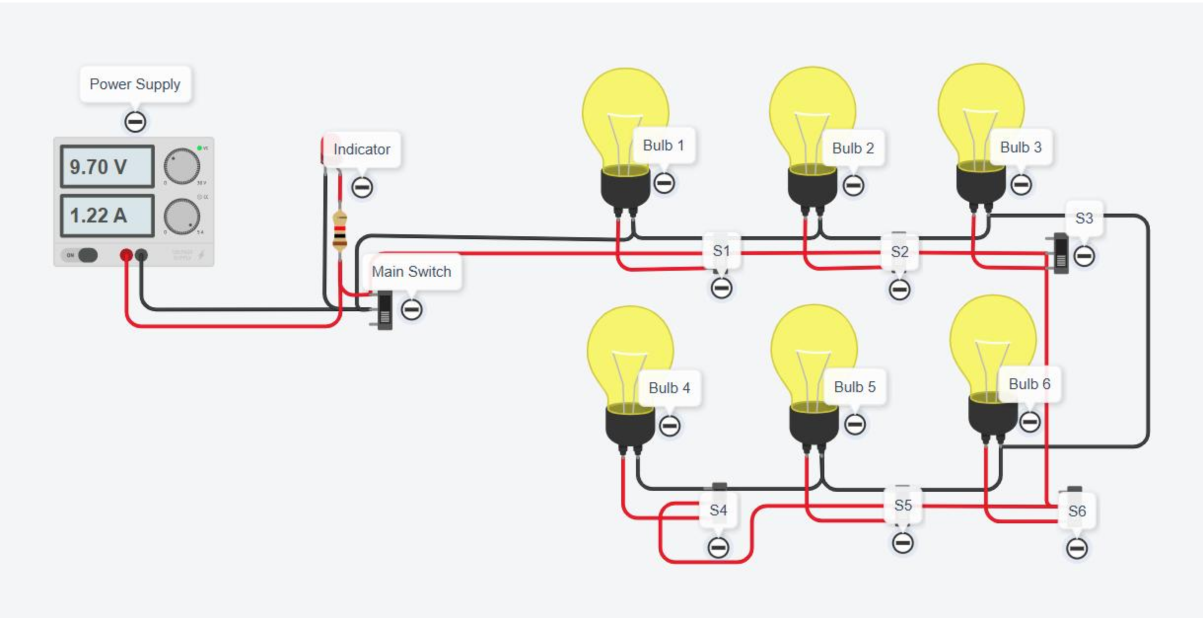


Fig. 3.5.2: Expt. 2 simulation.

Experiment No: 4

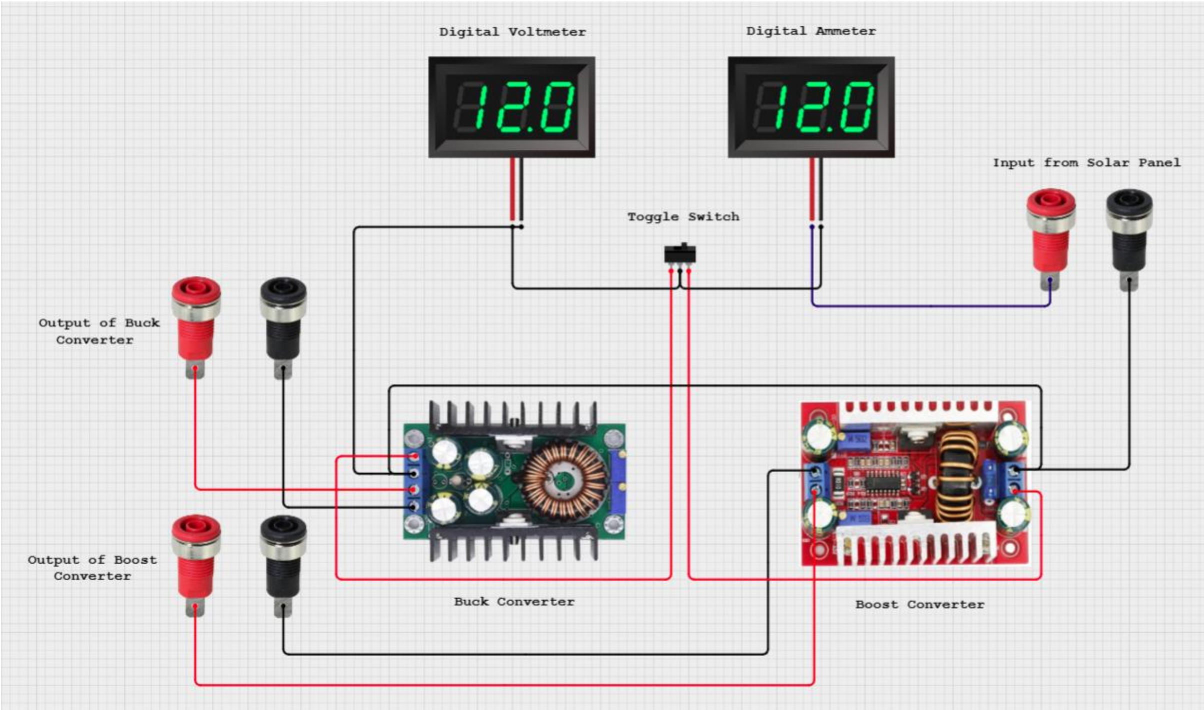


Fig. 3.5.3: Expt. 4 simulation.

Experiment No: 5

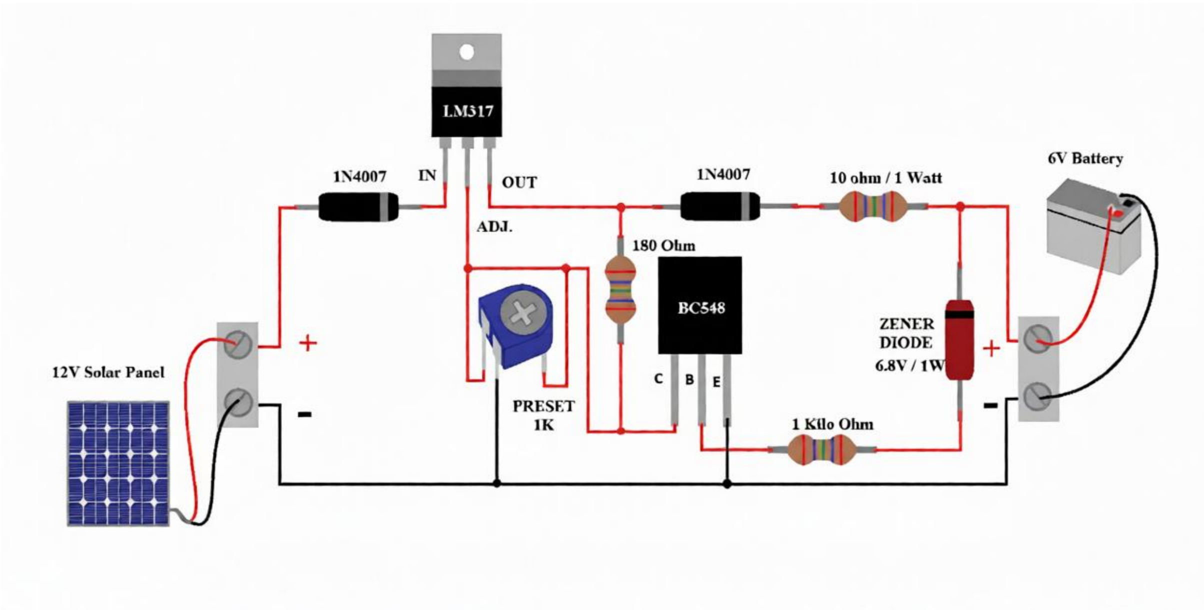
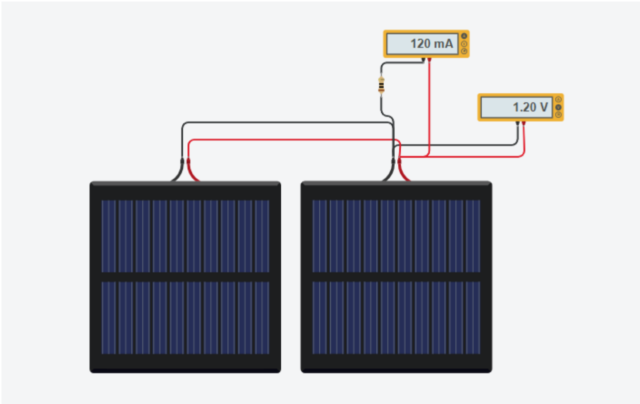
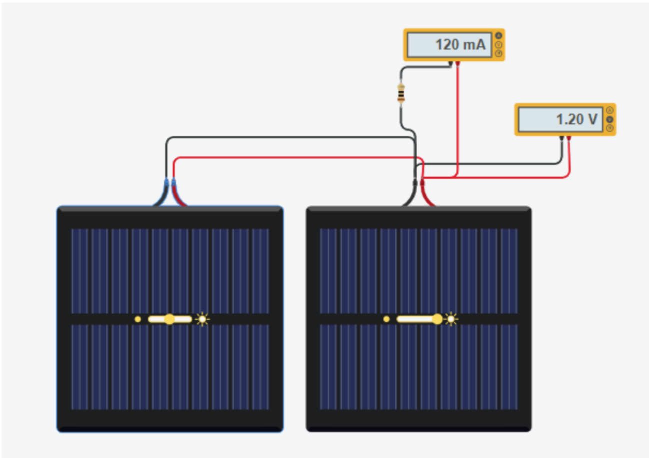


Fig. 3.5.4: Expt. 5 simulation.

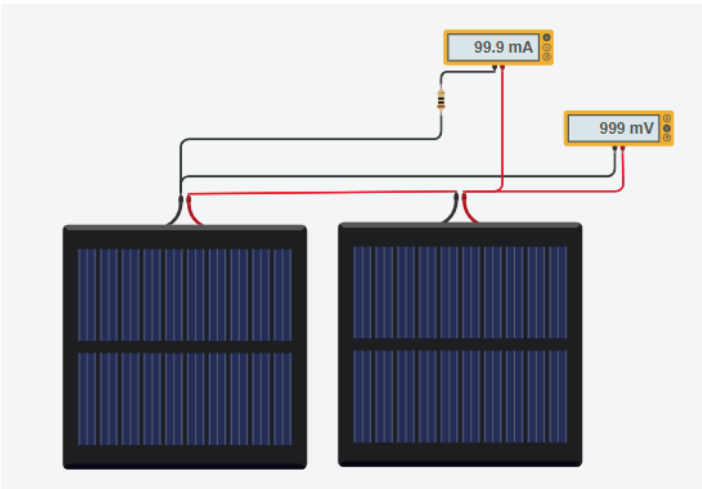
Experiment No: 7



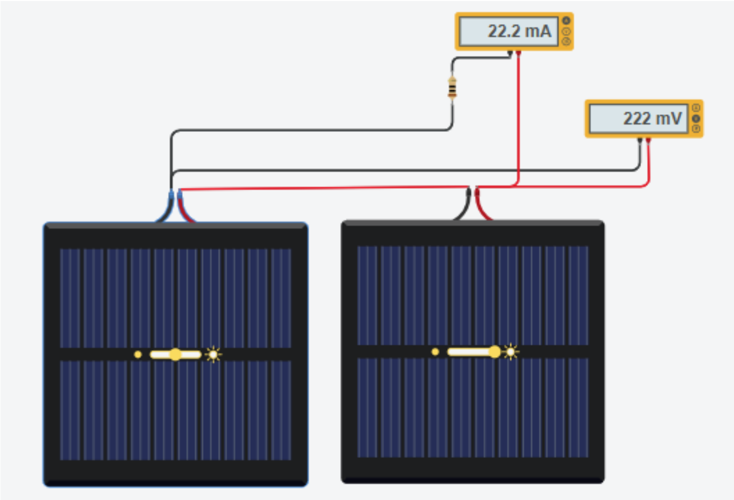
(A) Solar panel with Series Connection



(B)Series Solar Panel Shading



(C) solar panel with parallel Connection



(D)Parallel solar panel Shading

Fig. 3.5.5: Expt. 7 simulation.

CHAPTER 4

4.1 Results

Experiment No: 1

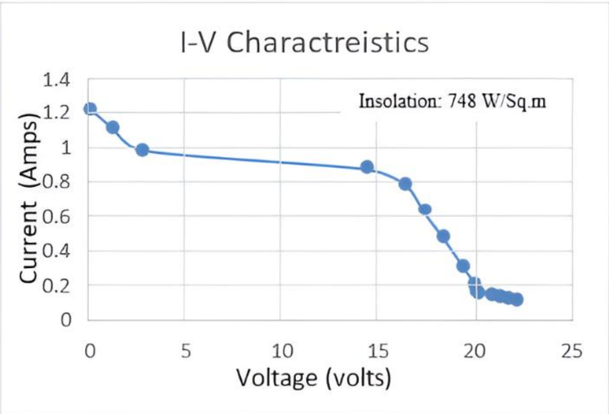
The experimental investigation revealed clear differences in PV performance under natural sunlight and solar emulator illumination.

Under **natural sunlight**, the 20Wp PV panel achieved:

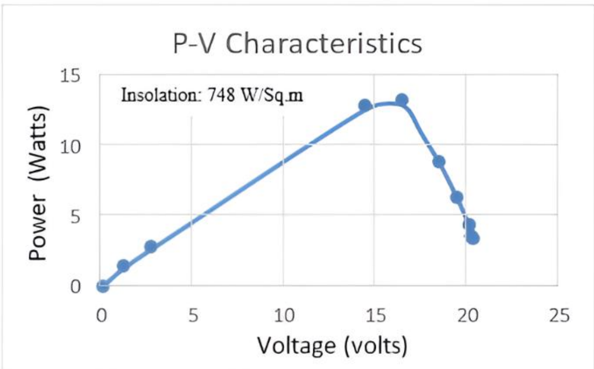
- The I–V and P–V characteristics of the PV panel are successfully plotted.
- From the curves, the following parameters are obtained:
  - Open-circuit voltage (Voc) – maximum voltage when current is zero.
  - Short-circuit current (Isc) – maximum current when voltage is zero.
  - Maximum Power Point (MPP) – point where P = V × I is maximum.
  - Maximum voltage (Vmax) at MPP.
  - Maximum current (Imax) at MPP.

These results help determine panel output capability and performance.

Graphs:



Expt. No.1 Graph 1.



Expt. No.1 Graph 2.

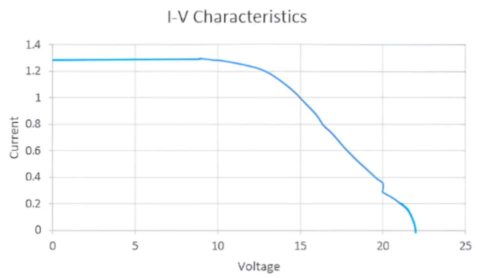
Experiment No: 2

- The solar emulator successfully provides **controlled and stable irradiance**, enabling indoor PV panel testing without dependence on sunlight.
- The **I–V** and **P–V** curves of the PV panel are plotted under standard testing conditions (STC: 1000 W/m², 25°C).
- The following parameters are determined:
    - **Open-circuit voltage (Voc)**
    - **Short-circuit current (Isc)**
    - **Maximum Power Point (MPP)**
    - **Maximum voltage (Vmax)**
    - **Maximum current (Imax)**
    - Additional performance parameters such as **Imp, Vmp, Fill Factor (FF), and Efficiency (η)**

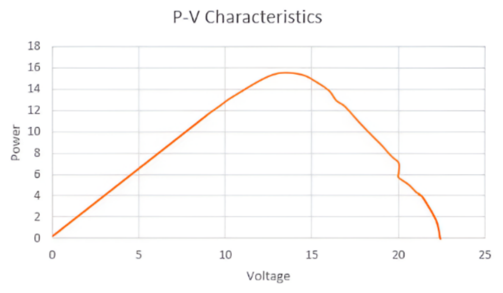
The experiment confirms that the sun emulator can accurately simulate sunlight for reliable PV performance analysis.

The I–V and P–V curves obtained from both tests distinctly showed the variation in slopes, knee points, and maximum power regions. The results validated that PV panel performance is highly sensitive to illumination quality, making controlled sun emulation essential for laboratory-based studies.

Graphs:



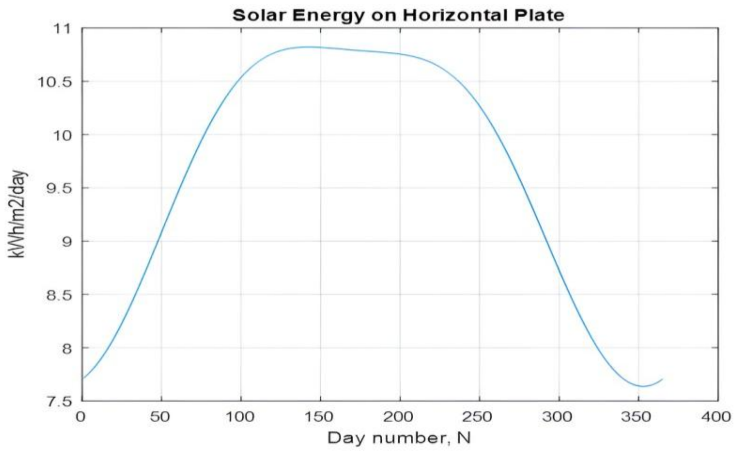
Expt. No.2 Graph 3.



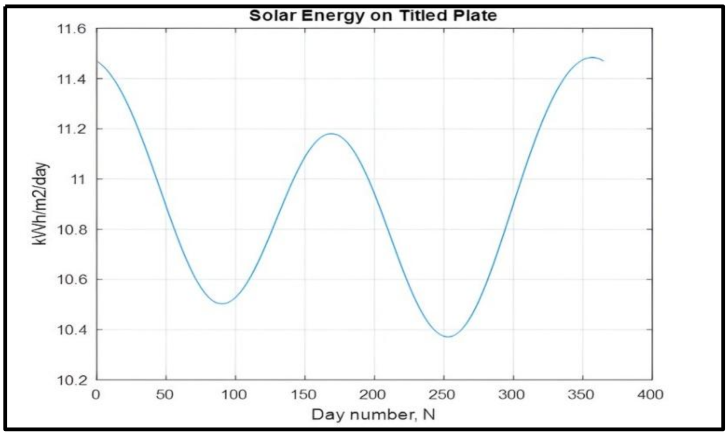
Expt. No.2 Graph 4.

Experiment No: 3

Graphs:



Expt. No.3 Graph 5.

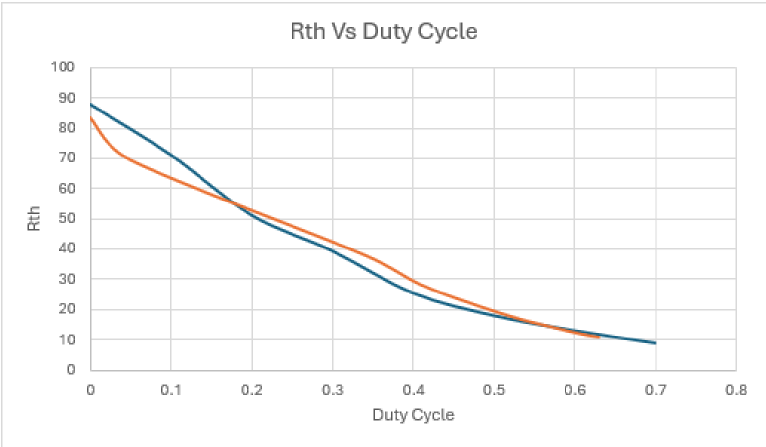


Expt. No.3 Graph 6.

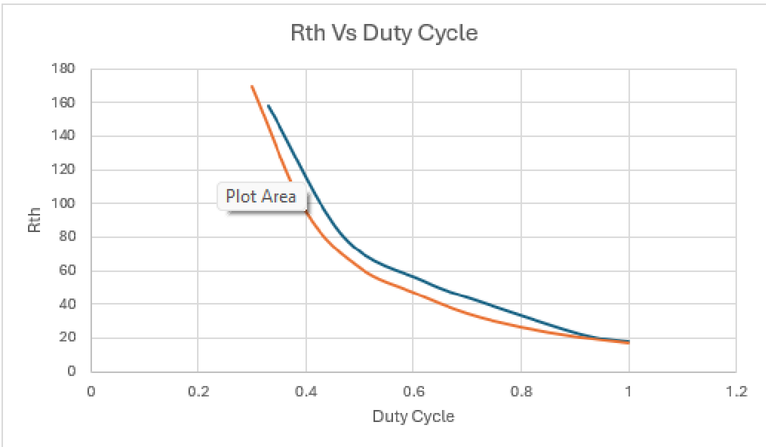
Experiment No: 4

- The I–V and P–V characteristics of the PV panel were studied.
- The.. Maximum Power Point (MPP) was identified.
- The duty cycle corresponding to maximum power was determined for both Boost and Buck converters.
- It is observed that MPPT effectively extracts maximum available power by adjusting the duty cycle.

Graphs:



Expt. No.4 Graph 7.



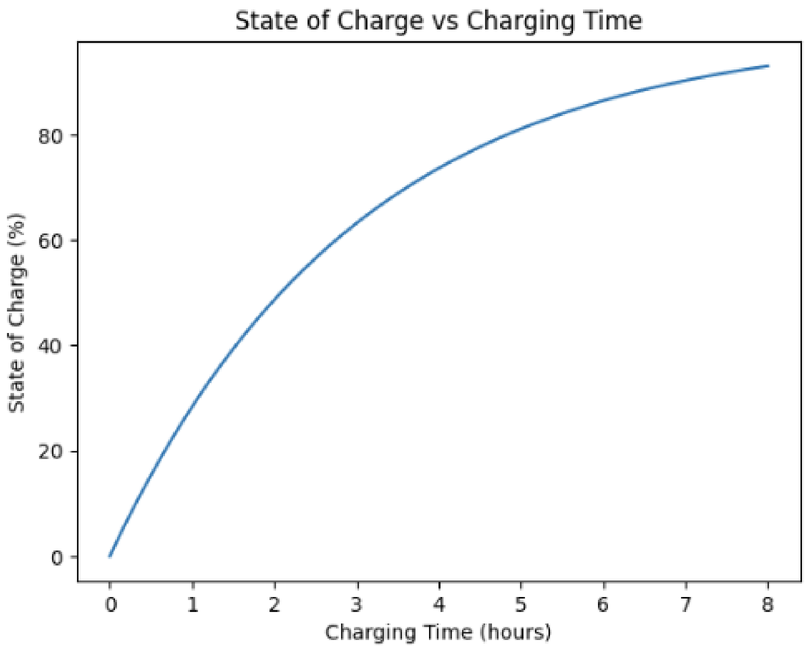
Expt. No.4 Graph 8.

Experiment No: 5

Charging Characteristics Graph

- Voltage increases become constant
- Current decreases with time
- Power depends on solar irradiance

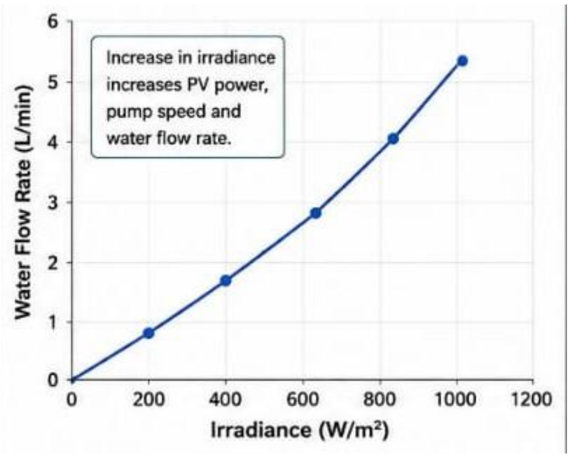
Graphs:



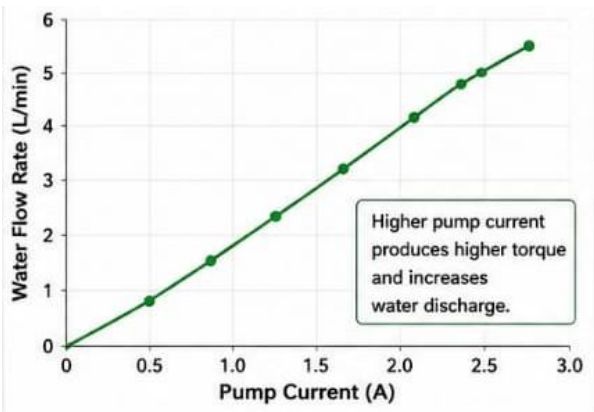
Expt. No.5 Graph 9.

Experiment No: 6

- The experiment demonstrates the interfacing of a solar panel with a DC water pump using an MPPT controller.
- It is observed that increasing solar irradiance increases the output power of the PV panel.
- Higher solar irradiance increases the pump speed and water flow rate.
- The graph also shows that higher pump current produces greater torque and increases water discharge.
- Thus, the performance of the solar water pumping system depends mainly on solar irradiance and pump current.



Expt. No.6 Graph 10.

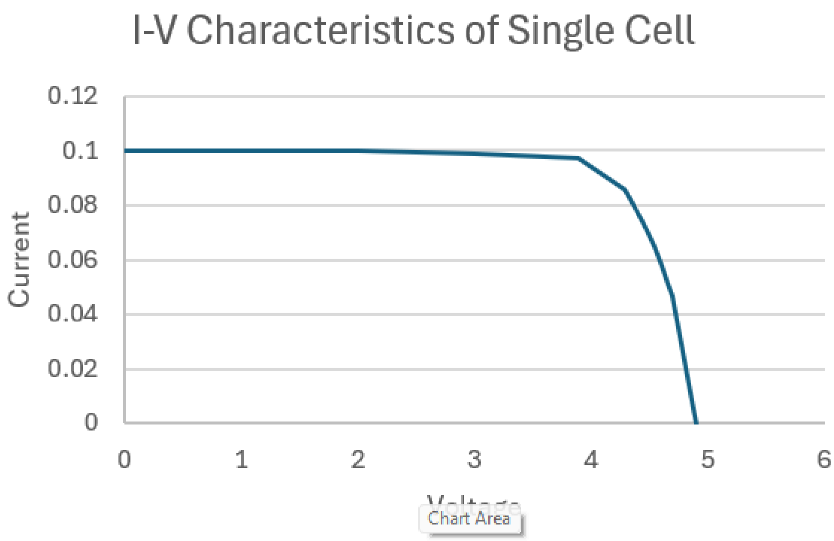


Expt. No.6 Graph 11.

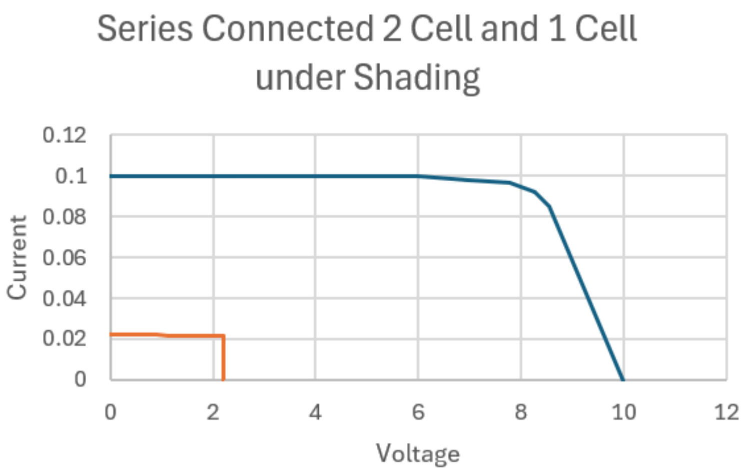
Experiment No: 7

- In **series connection**, shading of one panel significantly reduces the total current and power output.
- In **parallel connection**, the effect of shading is less severe, and the system continues to produce power efficiently.
- Therefore, **parallel configuration is more suitable under partial shading conditions**.

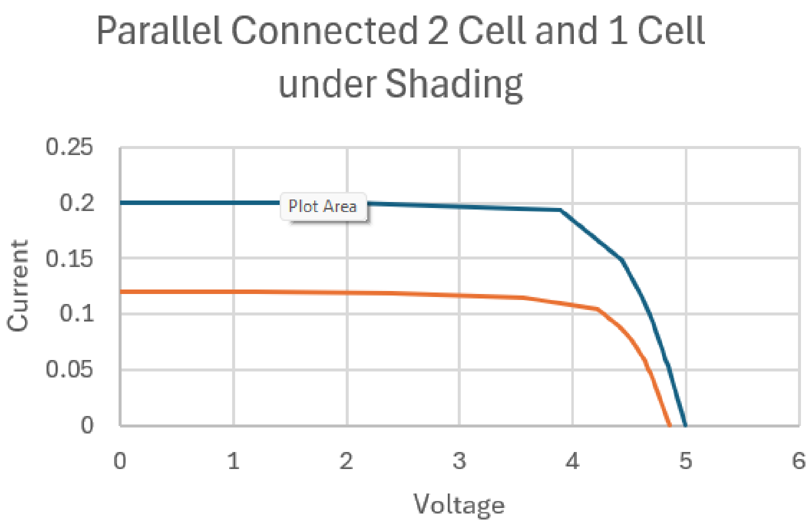
Graphs:



Expt. No.7 Graph 12.



Expt. No.7 Graph 13.



Expt. No.7 Graph 14.

4.2. CONCLUSION

This project successfully developed and demonstrated a functional solar laboratory setup capable of evaluating the performance of photovoltaic panels under both natural sunlight and controlled indoor conditions. The comparative analysis confirmed that irradiance intensity and spectral characteristics significantly influence the maximum power output and efficiency of PV systems.

The designed setup offers an accessible and cost-effective platform for students and researchers to study I–V and P–V characteristics, understand real-time PV behaviour, and explore the effects of varying environmental conditions. It also allows controlled experimentation using a solar emulator, making it suitable for academic laboratories where consistent sunlight availability is limited.

Future enhancements may include integrating MPPT hardware, temperature sensors, data-logging systems, and advanced microcontroller-based monitoring for real-time analysis. Overall, the project bridges the gap between theoretical learning and practical solar energy applications, contributing to improved renewable energy education.

4.3. REFERENCES

1. Prof. L Umanand. – "Design of Photovoltaic Systems, IISc Bangalore"(NPTEL Course).
2. Esram, T. & Chapman, P. – "Comparison of Photovoltaic MPPT Techniques" (IEEE, 2007)For modelling and analytical estimation of MPP based on PV module theory.
3. Patel, H. & Agarwal, V. – "MATLAB-Based Modeling to Study Partial Shading Effects" (IEEE, 2008).
4. Chetan Singh Solanki – "Solar Photovoltaics: Fundamentals, Technologies and Applications, IIT Bombay " (NPTEL Course + Book).

4.4. APPENDIX A: Project Development Photographs

Fig A.1: Development of Sun Emulator

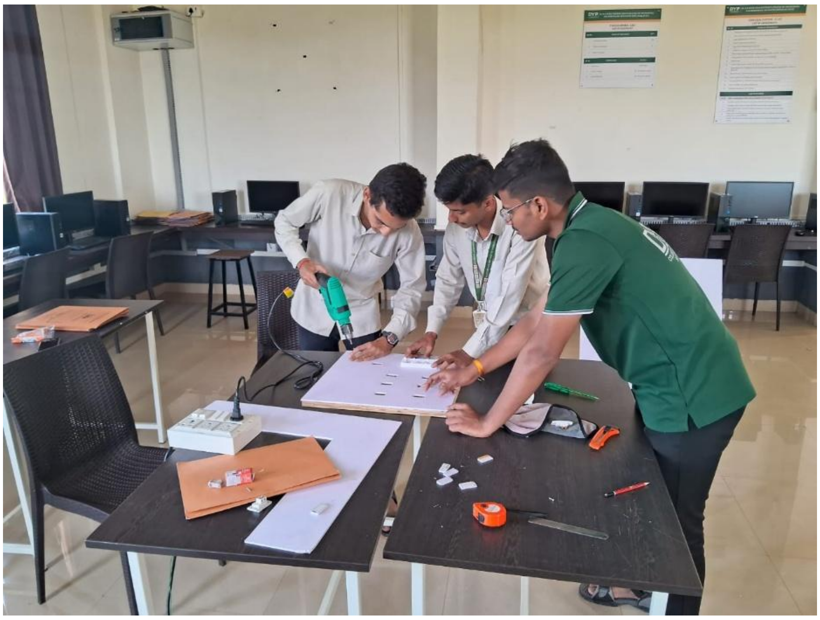


Fig A.2: Development of Buck and Boost Converter

Fig A.3: Measuring Solar Irradiance