Horizon Solar Trainer

Experiment Booklet

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Horizon Educational

ABSTRACT

In this booklet, we explain widely used renewable energy production method. Our set is designed to teach the methods of electrical energy production using Solar Energy. To facilitate use in applied courses in Technical Education, we provide detailed instructions through visual drawings on how to conduct experiments. The booklet outlines how to generate electrical energy using this energy source and describes the method used during production, testing, and experimentation.

The experiments are presented in a straightforward manner, progressing from the simplest to the most complex. The booklet is interactive, with designated spaces for recording data during experiment construction.

CONTENTS

ABSTRACT 2

CONTENTS 3

1. Horizon Solar Trainer 5

2. Modules 6

- 2.1 Light Angle Adjustable Solar Panel 6
- 2.3 Solar Charge Regulator Module 7
- 2.4 Accumulator Module 8
- 2.5 Diode Module 9
- 2.6 PC Interface Module 10
- 2.7 AC/DC Measurement Module 11
- 2.8 Potentiometer Module 12
- 2.9 Lamp Module (12V DC) 13
- 2.10 Lamp Module (220V AC) 14
- 2.11 Light Source Control Module 15
- 2.12 Off-Grid Inverter Module 16

3. Applications of Photovoltaic Training Box 19

- 3.1 Experiment-1 Measurement of Photovoltaic Panel Open Circuit Voltage 19
- 3.2 Experiment-2 Measurement of Photovoltaic Panel Short Circuit Current 24
- 3.3 Experiment-3 Photovoltaic Panel Current-Voltage Characteristics 28
- 3.4 Experiment-4 Examination of the No-Load Outputs of the Photovoltaic Panel Depending on the Sun's In-Day Movement 35
- 3.5 Experiment-5 Examination of the Photovoltaic Panel's Loaded Outputs Depending on the Sun's In-Day Movement 40
- 3.6 Experiment-6 Examination of the No-Load Outputs Due to the Season Change of the Photovoltaic Panel 43

3.7 Experiment-7 Examination of the Loaded Outputs Due to the Season Change of the Photovoltaic Panel 48

3.8 Experiment-8 Examination of the Series Connection of Photovoltaic Panel 51

3.9 Experiment-9 Examination of the Parallel Connection of Photovoltaic Panel 56

3.9 Experiment-10 Examination of Shadow Effect in Photovoltaic Panel 61

3.10 Experiment-11 Examination of Effect of Bypass Diode in Photovoltaic Panels 68

3.12 Experiment-12 Direct Load Connection to Photovoltaic Panels 75

3.13 Experiment-13 No-Load Commissioning of Off-Grid Inverter 79

1. Horizon Solar Trainer

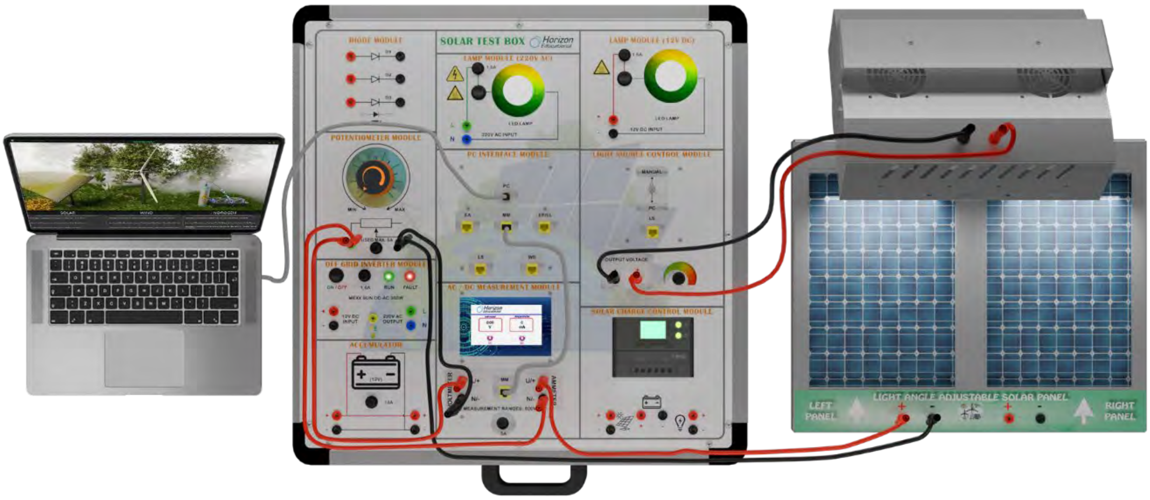


Figure-1. Components of Horizon Solar Trainer

The Horizon Solar Trainer is a computer-assisted training tool designed for conducting experiments on the generation of electrical energy from solar resource. This versatile set consists of modular components, enabling a wide range of experiments using the same modules.

In the design of these modules, careful attention has been given to utilizing industrial-grade components that are currently employed in the field. The entire system has been developed with a focus on aligning with educational environments and methodologies, prioritizing ease of use, safety, expandability, and modularity.

2. Modules

2.1 Light Angle Adjustable Solar Panel

Figure-2. Module Image

Weight	2,8kg
V_{OC}	2 x 23,8V
I_{SC}	2 x 0,6A
LED Projector	300 W
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-1

To conduct photovoltaic experiments, the module includes two 12W-12V-0.6A monocrystalline photovoltaic panels and two 300W LED projector. To simulate the seasonal and daily movements of the sun, the module can be adjusted both horizontally and vertically, and the light intensity can be adjusted to facilitate experiments under different illumination levels.

The module is constructed using a 45x45 aluminum profile and is equipped with lockable wheels, allowing for easy mobility within the classroom. Module connections are established using 4mm binding posts, and there is also an earth connection to ensure safety during use. Figure 2 provides a visual representation of the module, and Table 1 outlines its features.

2.3 Solar Charge Regulator Module

Figure-3. Module Image

System Input Voltage	12V / 24V Automatically
Charge /Discharge Current	10A
Battery Types	LiFePo4-Lithium
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-2

This module utilizes smart PWM technology to charge batteries with the energy received from the solar panels. Additionally, it offers the option to connect DC loads directly. The module's charge regulator features automatic 12V/24V recognition technology, allowing for the application of panel voltages of up to 50 volts.

Module connections are established using 4mm binding posts. Figure 3 provides a visual representation of the module, and Table 2 outlines its features.

2.4 Accumulator Module

Figure-4. Module Image

Model Number	RES-007
Weight	2kg
Voltage	12V
Capacity	10Ah
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-3

The module has a rated current and voltage of 12V/10Ah. It is equipped with a Battery Management System (BMS) and features a package structure made from Li-ion battery cells. To protect the module from short circuits, an external glass fuse is included.

For proper experimentation, it's essential to ensure that the battery is charged. The BMS controls the charge and discharge of the package. To charge the module, set the DC Power Supply Module to 15V with a current of 1.5A. Connect the positive terminal of the module to the corresponding positive terminal of the Accumulator Module and the negative terminal to its negative terminal. If the Accumulator Module is not yet charged, you will observe a charging current displaying. The BMS control ensures that charging continues until the Accumulator Module is fully charged, at which point the BMS will cut off the current. Regularly repeating this process ensures the long life of the Accumulator Module.

When the module reaches the lower limit of its battery capacity, the BMS will cut the circuit current for safety.

Module connections are established using 4mm binding posts. Figure 4 provides a visual representation of the module, and Table 3 outlines its features.

2.5 Diode Module

Figure-5. Module Image

Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-4

The diode module includes three independent 40V/3A Schottky diodes, each of which can be used according to the experimental requirements. Module connections are established using 4mm binding posts. Figure 5 provides a visual representation of the module, and Table 4 outlines its features.

2.6 PC Interface Module

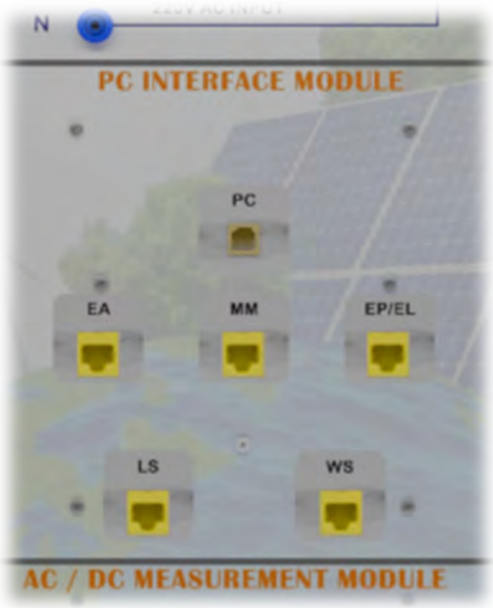


Figure-6. Module Image

Operating Voltage	220V / 50Hz
PC Connection	USB port
Data Collection Entry	4 x RS485 – RJ45
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-5

This module controls the training set modules through computer software designed for seamless integration. It communicates with the computer via the USB port and communicates with the other four peripheral modules using the RS485 protocol. The connection connectors are of the RJ45 type.

The connectors used for specific modules are as follows:

- EA: Energy Analyser Module communication connector
- MM: AC/DC Measurement Module communication connector
- EP/EL: Electronic Pot / Electronic Load Modules communication connector

Additionally, there are two analogue outputs available for controlling peripheral modules:

- LS: Light Source Control Module connection connector
- WS: Wind Simulator Module connection connector

Figure 6 provides a visual representation of the module, and Table 5 outlines its features.

2.7 AC/DC Measurement Module

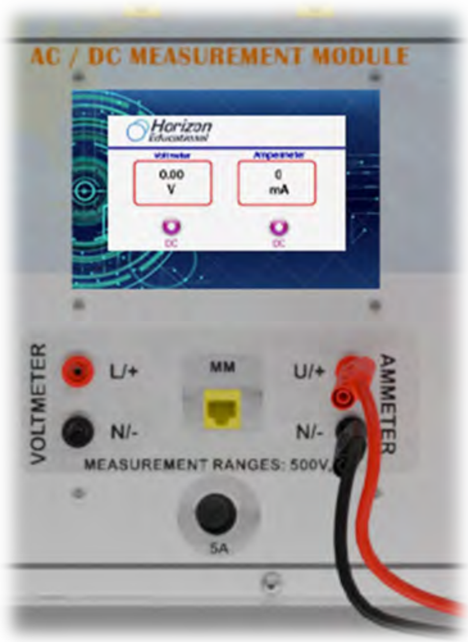


Figure-7. Module Image

AC/DC Ammeter Measure Range	0-5000mA ± 4mA
AC/DC Voltmeter Measure Range	0-500 V ± 400mV
LCD Colour Touch Screen	5 inch / HMI TFT / 800x480
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-6

The AC/DC Measurement Module has been developed for conducting precise measurements during experiments. The results of each measurement are displayed on a 5-inch TFT LCD screen. This module is versatile, capable of measuring both AC and DC values. The user can easily select which type of measurement to perform through touchscreen controls on the screen.

Furthermore, to ensure accurate measurements, the Voltmeter and Ammeter chassis are insulated from each other. The data collected is transmitted to the computer via the Computer Interface Module, utilizing the RS485 remote connection function. To transfer data to the computer, simply connect the (MM) RJ45 type connector to the appropriate port on the Computer Interface Module.

For safety, a fuse is utilized to protect the ammeter input from overcurrent. Additionally, the module itself is equipped with a fuse to safeguard against overcurrent, and an LED indicator displays its power status. Module connections are established using 4mm binding posts. Figure 7 provides a visual representation of the module, and Table 6 outlines its features.

2.8 Potentiometer Module

Figure-8. Module Image

Adjustable Resistance Value	0-1 KΩ
Maximum Resistance Power	200W
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-7

The Potentiometer Module has been designed as a manually adjustable analog load for use in experiments. The module features a 1KΩ / 200W potentiometer that can be precisely adjusted by hand to various resistance values.

From the module, you can achieve:

- A maximum of 5A across the 0-50 ohms range.
- A maximum of 2A across the 51-200 ohms range.
- A maximum of 600mA across the 201-1K ohms range.

It's important to set up the experiments in a way that ensures safe circuit current flow during operation. Module connections are established using 4mm binding posts. Figure 8 provides a visual representation of the module, and Table 7 outlines its features.

2.9 Lamp Module (12V DC)

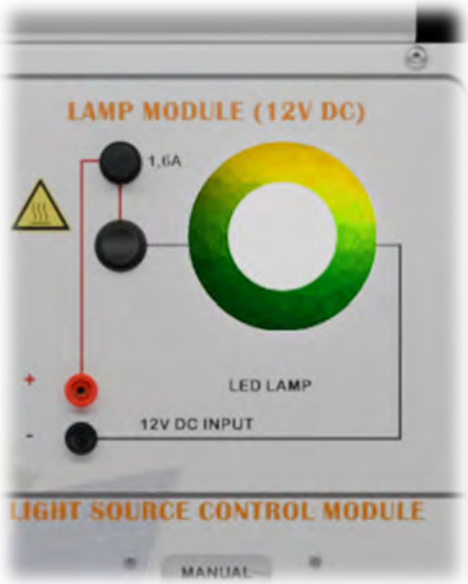


Figure-9. Module Image

Weight	2,9kg
Operating Voltage	$12V_{DC}$
Halogen Bulb	20W
LED Bulb	2W
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-8

This versatile load module feature a LED bulb. The lamp can be controlled independently, and each lamp is equipped with a fuse to protect against high current values. It's crucial to ensure that the 12VDC operating voltage is not exceeded to prevent damage to the lamps. Additionally, please note that the lamps can become hot during operation.

Module connections are established using 4mm binding posts. Figure 9 provides a visual representation of the module, and Table 8 outlines its features.

2.10 Lamp Module (220V AC)

Figure-10. Module Image

Operating Voltage	220V / 50Hz
Bulb Type	LED Bulb
Bulb Socket	E27
Connecting Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-9

This versatile load module feature a LED bulb. The lamp can be controlled independently, and each lamp is equipped with a fuse to protect against high current values. It's crucial to ensure that the 220VAC operating voltage is not exceeded to prevent damage to the lamps. Additionally, please note that the lamps can become hot during operation.

Module connections are established using 4mm binding posts. Figure 10 provides a visual representation of the module, and Table 9 outlines its features.

2.11 Light Source Control Module

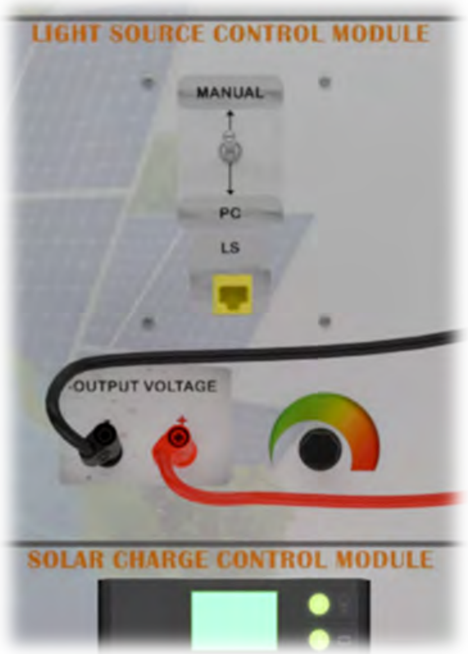


Figure-11. Module Image

Output Power	0-300W
Output Voltage	0-36V
Connection Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-10

The Light Source Control Module is designed to work in conjunction with the Light Angle Adjustable Solar Panel Module for laboratory experiments. The Light Angle Adjustable Solar Panel Module features a 300W LED projector, essential for conducting photovoltaic experiments. To ensure precise and accurate experimentation, it's necessary to adjust the intensity of this light source, and that's where the Light Source Control Module comes into play.

This module allows for solar simulation within a laboratory environment, offering a light intensity range of 0-100000 lux. Users can switch between manual and PC mode using a two-position switch. In manual mode, the light intensity is adjusted through the potentiometer on the module, while in PC mode, the light intensity can be controlled via the PC Interface Module. For computer use, simply connect the RJ45 connector to the appropriate port on the PC Interface Module.

For added safety, the module is equipped with a fuse to protect against overcurrent, and an LED indicator displays its power status. Module connections are established using 4mm binding posts. Figure 11 provides a visual representation of the module, and Table 10 outlines its features.

2.12 Off-Grid Inverter Module

Figure-12. Module Image

Input Voltage	$12V_{DC}$
Output Voltage	220-240V AC ±5%
Output Frequency	50Hz ±5%
Output Power	Full Sine- 300W
Connection Terminals	4mm Binding Post
Operating Temperature	0-55°C (0-131°F)

Table-11

The Off-Grid Inverter Module has the capability to operate independently from the grid. It efficiently converts a 12V DC input voltage into a 220V-240V AC / 50Hz full sine signal. The module is equipped with an on/off switch and an energy indicator in the form of a green LED. Additionally, it features a red LED and a buzzer to indicate fault conditions.

In the event of a malfunction, the module provides the following indications:

- Low voltage switch-off protection: LED light and buzzer beep 3 times intermittently.
- Input high voltage protection: LED light and buzzer beep 4 times intermittently.
- Over-temperature protection: LED light and buzzer beep 5 times continuously.
- Overload protection: LED light and buzzer beep 3 times continuously.
- Short circuit protection: LED light and the module switches on and off.

It's crucial to avoid connecting the inputs in reverse to ensure safe and proper operation. The module includes an earth connection and output fuse for added safety. Module connections are established using 4mm binding posts. Figure 12 provides a visual representation of the module, and Table 11 outlines its features.

Photovoltaic Energy Systems

Photovoltaic (PV) cells are electronic components that directly convert solar radiation into electrical energy through the photovoltaic effect. This effect is characterized by the generation of a potential difference between two electrodes when exposed to light. Solar PV cells typically consist of a p-n junction formed from semiconductor materials.

To create an efficient PV cell, several specific requirements must be met, including:

1. Absorption Feature: The material should have a strong ability to absorb sunlight.
2. Window Feature: Materials used as windows must transmit light to the semiconductor and create a structural electric field.
3. Non-Reflective Surface Feature: Materials intended for anti-reflection coatings should minimize light reflection.
4. Contact Feature: The contact material should efficiently collect the current generated by light absorption.

Among these criteria, the absorption feature is of utmost importance. While any semiconductor can potentially serve as an absorbing material for solar PV cells, certain semiconductors are better suited for this purpose.

These criteria collectively contribute to the efficiency and effectiveness of photovoltaic cells in harnessing solar energy.

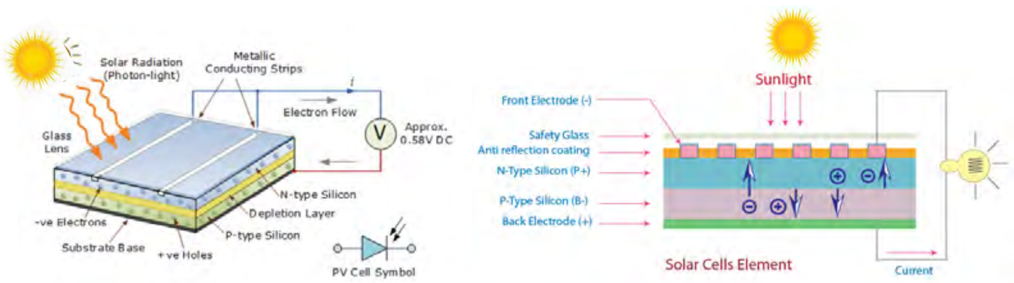


Figure-13. Working Principle of PV Cell and PV Cell Structure

Figure-13 illustrates a solar photovoltaic (PV) cell with a p-n junction configuration. In this diagram, one of the electrical contacts is formed by the bulbars, which also serves the dual purpose of allowing sunlight transmission.

Additionally, an anti-reflection layer is strategically positioned between the finger contacts. This layer plays a crucial role in increasing the amount of transmitted light to the semiconductor component, thereby enhancing the efficiency of the PV cell.

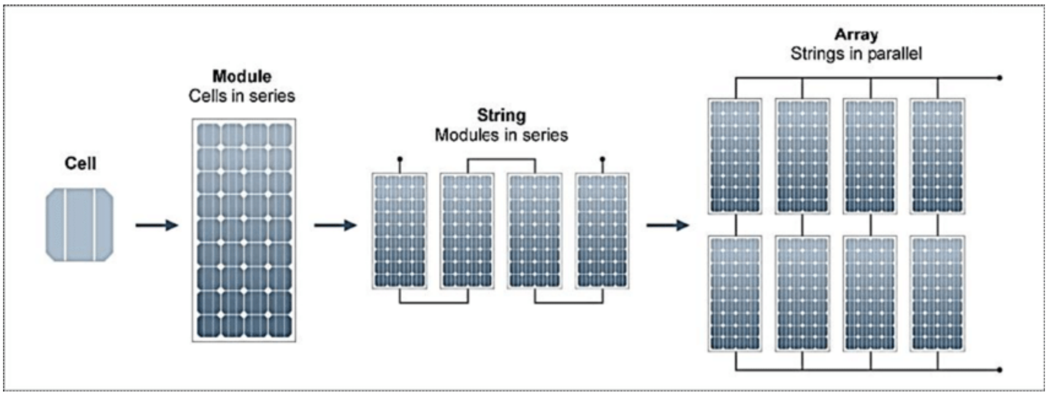


Figure-14. PV Cell, Module and Array Designs

The photovoltaic cells illustrated in Figure-14 are electronic systems designed to directly convert solar radiation into electricity. These cells are distinguished by their lack of moving mechanical components, ease of maintenance, and long lifespan. They are constructed using semiconductor materials, which facilitate the transformation of solar energy into electrical energy.The operation of a photovoltaic (PV) cell is akin to that of a semiconductor diode, where sunlight energy triggers a photoelectric reaction that results in the generation of electric current. The efficiency of this conversion process typically ranges between 5% and 20%, depending on the specific PV cell structure.

PV cells are commonly found in square, rectangular, or circular shapes, with areas typically falling within the range of 60-160 cm^2 and an average of around 100 cm^2. They possess a thickness ranging from 0.2 to 0.4 mm. To enhance the power output, multiple PV cells are often connected in series or parallel configurations and mounted on a surface. This assembly, as depicted in Figure-14, is known as a PV module. Depending on the desired power requirements, PV modules shown in Figure-14 can be connected to each other in either series or parallel fashion, giving rise to PV arrays with capacities ranging from a few watts to several megawatts.

3. Applications of Photovoltaic Training Box

3.1 Experiment-1 Measurement of Photovoltaic Panel Open Circuit Voltage

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module,
- Light Source Control Module,
- AC/DC Measurement Module,

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the AC/DC Measurement Module from the voltmeter (+) terminal to the photovoltaic panel (+) terminal, and from the voltmeter (−) terminal to the photovoltaic panel (−) terminal using a banana jack cable.
4. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

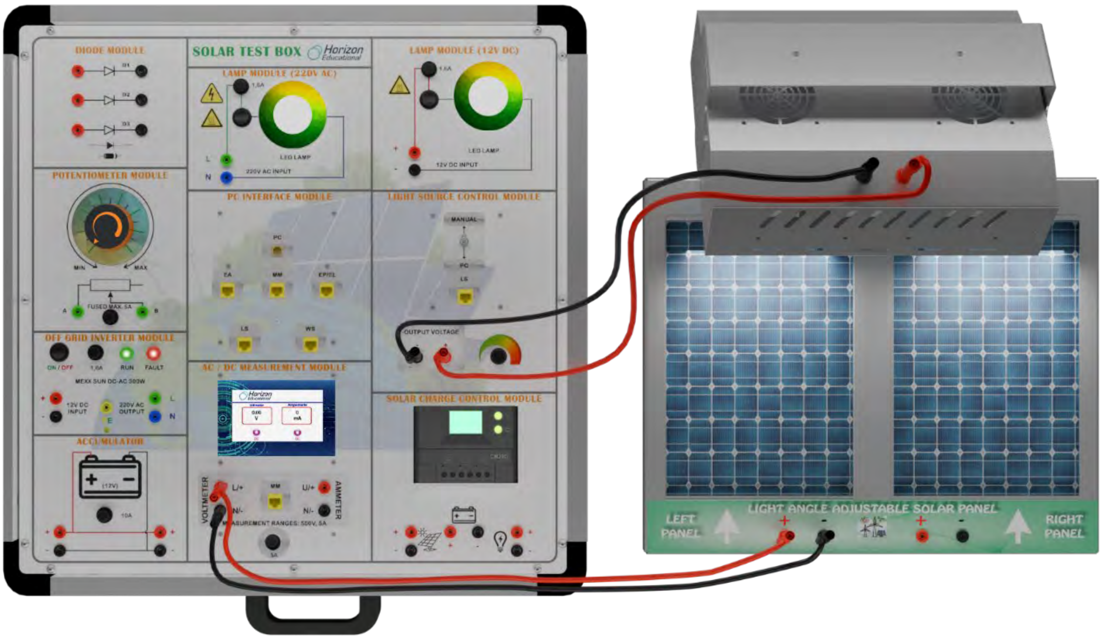


Figure-15. Installation Image of PV Panel Open Circuit Voltage Measurement Experiment

Stages of the Experiment;

1. Locate the open circuit voltage (VOC) provided by the manufacturer for the photovoltaic panels used in the set. You can find this information on a label located on the bottom of the panel. Please note that these values are obtained through testing under 1000W/m2 outdoor sun conditions. However, during training, a halogen lamp is used, resulting in an average light power of only 100W/m2. Record the VOC value as provided on the label in Table-12.

2. Set up the connections as specified in Figure-15. Ensure a consistent level of light in the laboratory to create an average scenario. Any changes to the positions of the lamps or curtains may affect the experimental outcomes.

3. Adjust the angle of incidence of light on the photovoltaic panel to 90° (summer season) and make sure the panel's surface is parallel to the ground. To achieve this, make the necessary adjustments by releasing the pins on the module and placing them in their correct positions.

4. Locate the open circuit voltage (VOC) provided by the manufacturer for the photovoltaic panels used in the set. You can find this information on a label located on the bottom of the panel. Please note that these values are obtained through testing under 1000W/m2 outdoor sun conditions. However, during training, a halogen lamp is used, resulting in an average light power of only 100W/m2. Record the VOC value as provided on the label in Table-12.
5. Set up the connections as specified in Figure-15. Ensure a consistent level of light in the laboratory to create an average scenario. Any changes to the positions of the lamps or curtains may affect the experimental outcomes.
6. Adjust the angle of incidence of light on the photovoltaic panel to 90° (summer season) and make sure the panel's surface is parallel to the ground. To achieve this, make the necessary adjustments by releasing the pins on the module and placing them in their correct positions."

Open Circuit Experiment	V_{OC} (Label Value)	V_{OC} (Measured Value)	Light Intensity (lux)
PV Panel 1			
PV Panel 2			

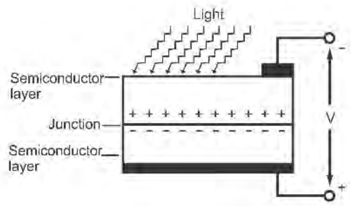
Table-12

Research Questions about the Experiment;

1. Please explain the reasons for the discrepancy between the V_{OC} value measured in the laboratory and the labelled value.
2. Explain the term solar energy.
3. Explain the importance of photovoltaic panels by explaining the greenhouse effect.
4. Explain the cellular structure of a solar panel by providing a diagram.
5. Explain the types and properties of photovoltaic panels.
6. Draw the circuit equivalent of the photovoltaic cell and provide a mathematical model explanation.
7. Explain how the connection of solar panels in series or parallel affects the V_{OC} value.

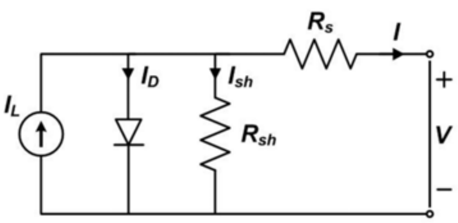
Answers to the Research Questions;

1. The values provided on the label are typically obtained from tests performed under outdoor conditions with a light intensity of 1000 W/m². However, the halogen lamps used in the laboratory emit a lower light intensity (100 W/m²) compared to sunlight, which results in a lower measured VOC value.
2. Solar energy is a type of energy that converts sunlight into electricity or heat. Photovoltaic cells convert this energy directly into electrical energy through the photovoltaic effect.
3. The greenhouse effect is the phenomenon where gases in the atmosphere trap sunlight, warming the planet's surface. Burning fossil fuels contributes to this effect, impacting the climate negatively. Photovoltaic panels produce clean energy and reduce greenhouse gas emissions, making them crucial for environmentally-friendly energy production.
4. A solar panel consists of numerous solar cells made from semiconductor materials. Each cell contains a p-n junction formed between n-type and p-type semiconductor layers.



Solar Cell or Photo Voltaic Cell

5. Photovoltaic panels are mainly classified into monocrystalline, polycrystalline, and thin-film technologies. Monocrystalline panels are highly efficient, polycrystalline panels are more cost-effective, and thin-film panels are flexible and used in specific applications.
6. A photovoltaic cell is typically represented by a current source, a diode, and a parallel resistor. The current generated by the cell is proportional to the light intensity. The diode represents the p-n junction, and the equivalent circuit also accounts for electrical losses.



$I=I_L-I_D-I_{sh}$

7. When solar panels are connected in series, the V_{OC} values add up. In parallel connections, the V_{OC} value remains the same, but the current increases.

3.2 Experiment-2 Measurement of Photovoltaic Panel Short Circuit Current

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module,
- AC/DC Measurement Module,

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the AC/DC Measurement Module as follows: from the ammeter (+) terminal to the photovoltaic panel (+) terminal, and from the ammeter (−) terminal of the AC/DC Measurement Module to the photovoltaic panel (−) terminal using banana jack cables.
4. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

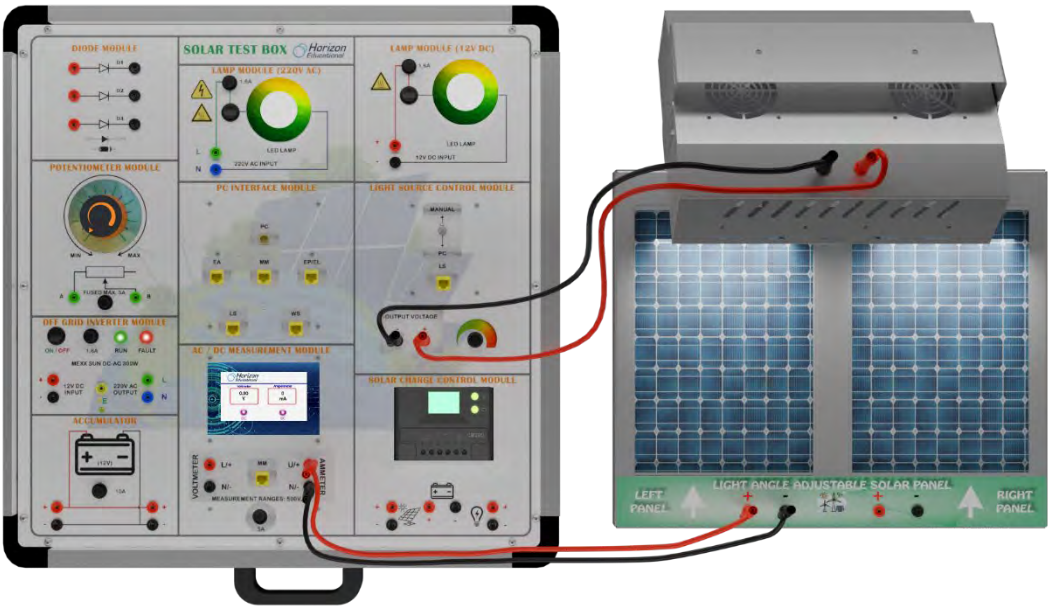


Figure-16. Installation Image of PV Panel Open Circuit Voltage Measurement Experiment

Stages of the Experiment;

1. The manufacturer is provided the open circuit voltage for the photovoltaic panels used in the set on a label located on the bottom of the panel. These values are obtained through testing under 1000W/m2 outdoor sun conditions. During training, a halogen lamp is used resulting in a average light power of only 100W/m2. Please record the open circuit voltage value (I_{SC}) as provided on the label in Table-13.
2. Set up the connection as specified in Figure-16. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
3. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and the panel surface to be parallel to the ground. To achieve this, make the necessary adjustments by pulling the pins on the module and placing them in their correct positions.

4. Position the digital lux meter at the center of the panel. Adjust the Light Source Control Module's DIMMER potentiometer to its maximum position to set sunlight's maximum brightness. In this instance, determine the highest value on the lux meter by adjusting the light source angle with precision and record the value in Table-13. (Since the distance between the sun and the earth is much greater than the distance between the trainer set and the panel, applying the light source to the panel at an angle less than 90 degrees may cause a higher light intensity than 90 degrees.)
5. Take the lux meter reading from its position and read the value indicated on the Ammeter displayed by the AC/DC Measurement Module. Record the obtained value in Table-13 accordingly. This value denotes the ISC value measured.

Short Circuit Experiment	I_{SC} (Label Value)	I_{SC} (Measured Value)	Light Intensity (lux)
PV Panel 1			
PV Panel 2			

Table-13

Research Questions about the Experiment;

1. Please explain the reasons for the discrepancy between the I_{SC} value measured in the laboratory and the labelled value.
2. Draw the electromagnetic spectrum and explain the relation between energy and wavelength using the mathematical equation.
3. Explain how the electric current is generated in the photovoltaic panel.
4. Explain how the connection of solar panels in series or parallel affects the I_{SC} value.

Answers to the Research Questions;

1. I_{SC} values are tested under outdoor conditions with a light intensity of 1000 W/m², while the laboratory uses a lower light intensity (100 W/m²). This results in a lower I_{SC} value measured in the lab.

3.3 Experiment-3 Photovoltaic Panel Current-Voltage Characteristics

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Electronic Potentiometer Module (EP),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the Potentiometer Module terminal (A) to the AC/DC Measurement Module voltmeter (+) terminal, and the Potentiometer Module terminal (B) to the AC/DC Measurement Module voltmeter (−) terminal using banana jack cables.
4. Connect the photovoltaic panel (+) terminal to the AC/DC Measurement Module ammeter (+) terminal, and the photovoltaic panel (−) terminal to the Potentiometer Module terminal (B) using banana jack cables.
5. Connect the AC/DC Measurement Module ammeter (−) terminal to the Potentiometer Module terminal (A) using a banana jack cable.
6. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

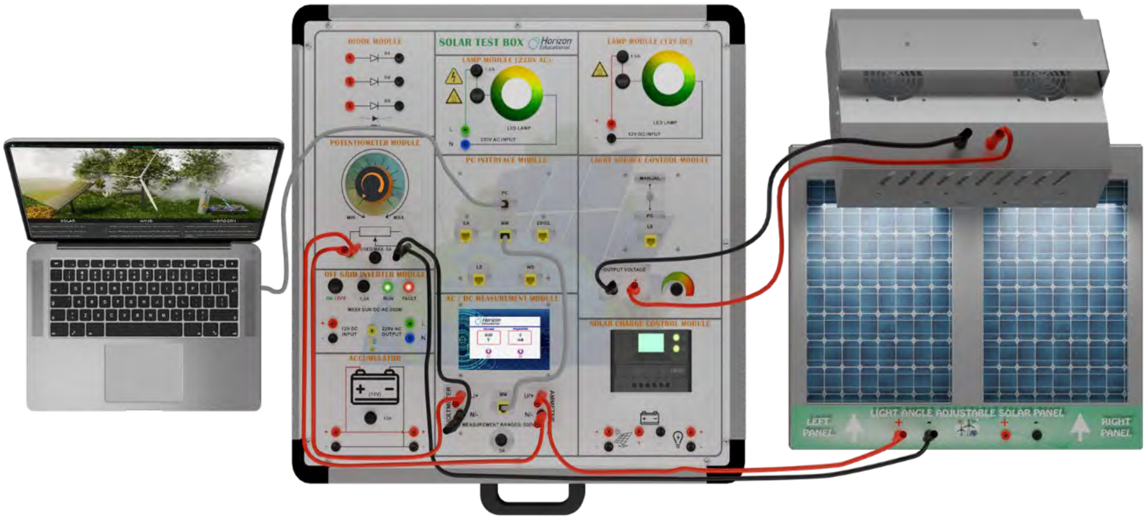


Figure-17. Installation Image of PV Current-Voltage Characteristic Extraction Experiment

Stages of the Experiment;

1. Set up the connection as specified in Figure-17. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will impact the experimental outcomes.

2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and ensure the panel surface is parallel to the ground. Achieve this by making the necessary adjustments with the module's pins, placing them in their correct positions.

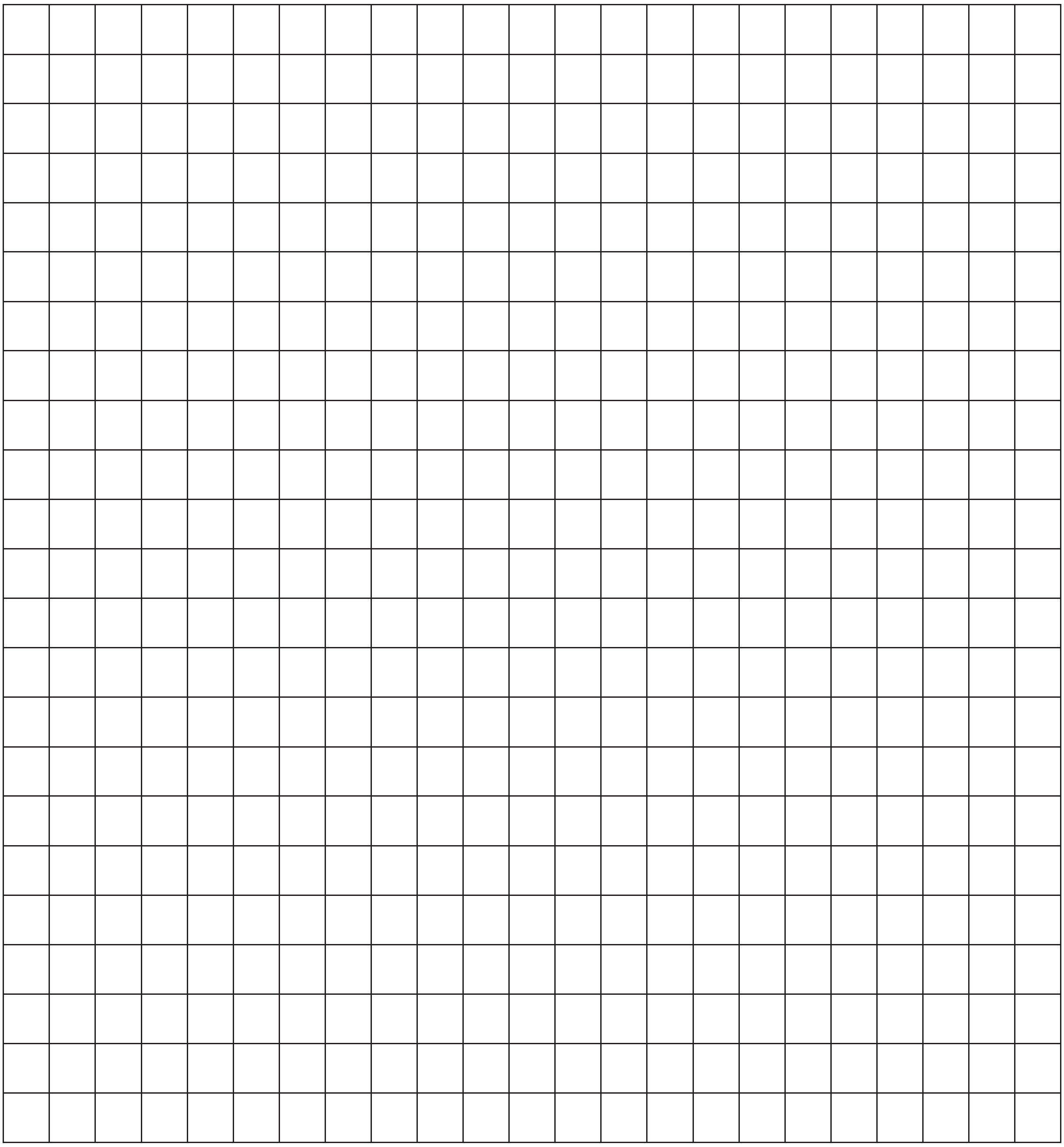
3. Position the digital lux meter at the center of the panel. Adjust the Light Source Control Module's DIMMER potentiometer to its maximum position to set sunlight's maximum brightness. In this instance, determine the highest value on the lux meter by precisely adjusting the light source angle. Record this value in Table-14. (Note: Due to the vast distance between the sun and the earth compared to the trainer set and the panel, applying the light source to the panel at an angle less than 90 degrees may result in a higher light intensity than 90 degrees.)

5. Adjust the Electronic Potentiometer (EP) Module to decrease the load value from 1000 ohms, decreasing it by 100 ohms per step.
6. Record the values displayed on the voltmeter and ammeter of the AC/DC Measurement Module (MM) for each step in Table-14.

R_L (Ohm/Ω)	Voltage (V)	Current (mA)	Power (mW)
1000			
900			
800			
700			
600			
500			
400			
300			
200			
100			
0			

Table-14

7. Plot the current-voltage relationship on the graph provided in Graph-1, utilizing the current and voltage data obtained from Table-14.



Graph-1

8. Based on the results obtained, plot the power characteristics on the graph provided in Graph-2.

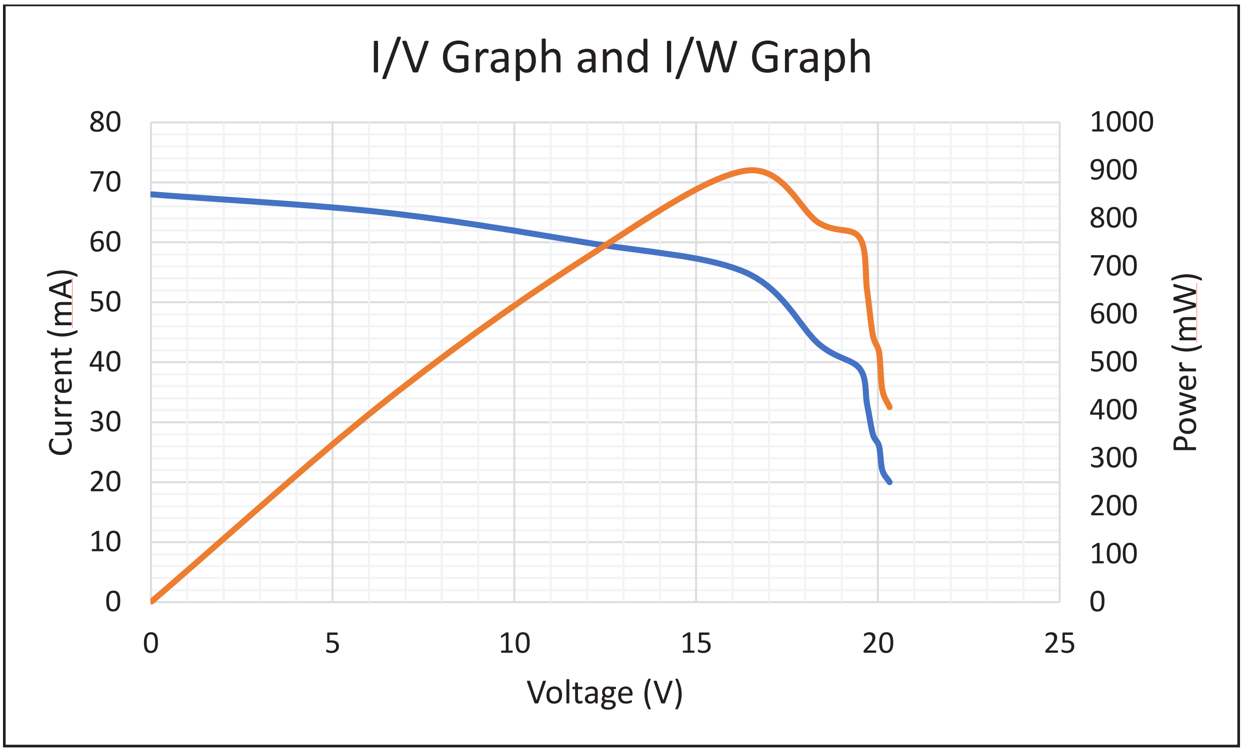
Graph- 2

Research Questions about the Experiment;

1. Discuss the information provided by the IV characteristic of a photovoltaic panel.
2. Identify and explain the point on the graph that corresponds to the maximum power point.
3. Explain what Maximum Power Point Tracking (MPPT) is and its significance in photovoltaic systems.

Answers to the Research Questions, with the provided Graph I:

1. The IV characteristic shows the relationship between current and voltage for a photovoltaic panel under varying load conditions. It indicates the maximum power point (MPP), where the panel operates most efficiently. As voltage increases, current decreases, showing the trade-off between the two.
2. The Maximum Power Point (MPP) is the point on the IV curve where the product of current and voltage (P = I * V) is at its highest, representing the panel's most efficient operating point.
3. MPPT is a technique used to ensure that a photovoltaic system extracts the maximum possible power from solar panels under varying environmental conditions. It adjusts the operating parameters to match the MPP, optimizing energy output.
4. The graph drawn from the experiment should align with the standard IV characteristic provided in Graph I. Deviations could be due to experimental conditions or light intensity variations.



Graph I

3.4 Experiment-4 Examination of the No-Load Outputs of the Photovoltaic Panel Depending on the Sun's In-Day Movement

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the AC/DC Measurement Module from the ammeter (+) terminal to the photovoltaic panel (+) terminal, and from the ammeter (−) terminal to the photovoltaic panel (−) terminal using banana jack cables.
4. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

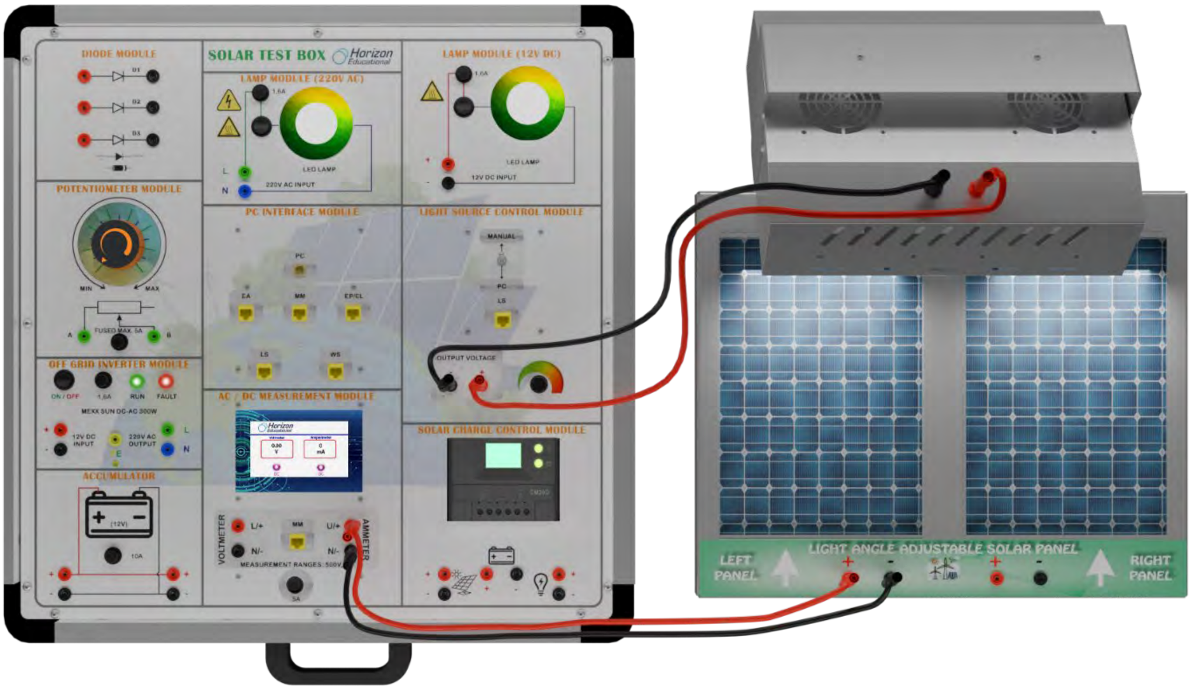


Figure-18. Installation Image of Examination of the No-Load Outputs of the Photovoltaic Panel Depending on the Sun's In-Day Movement (For Current)

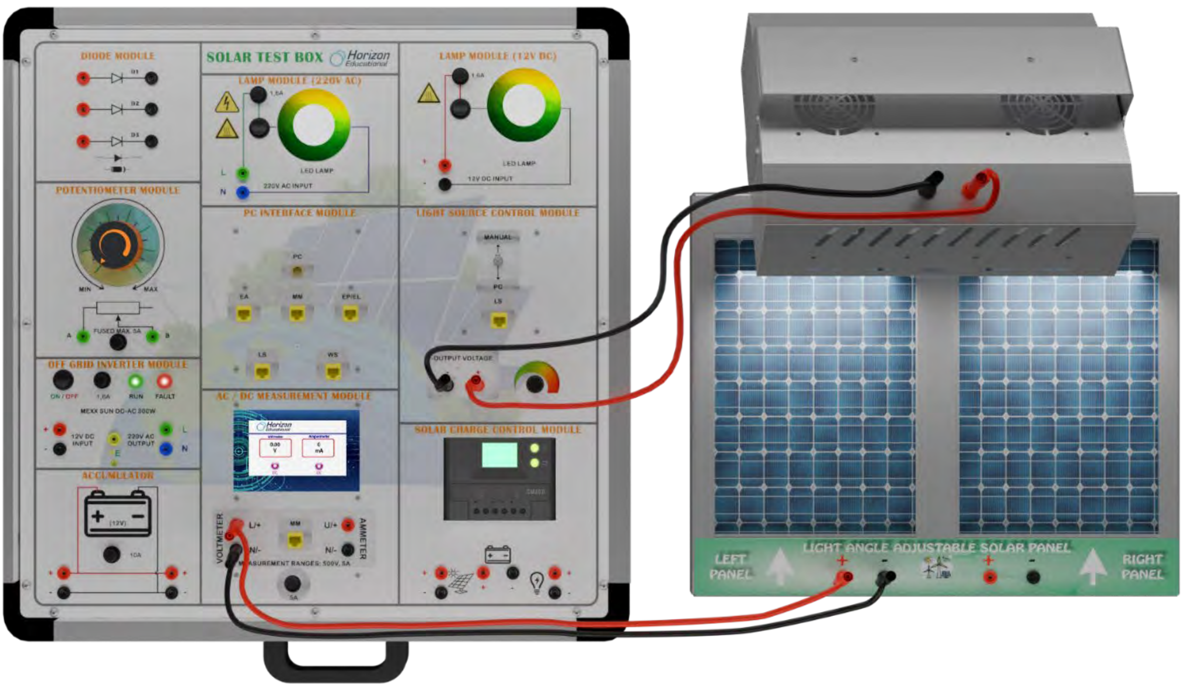


Figure-19. Installation Image of Examination of the No-Load Outputs of the Photovoltaic Panel Depending on the Sun's In-Day Movement (For Voltage)

Figure-20. Photovoltaic Panel Depending on the Sun's In-Day Movement, the panels are moved along this axis

Stages of the Experiment;

1. Set up the connection as specified in Figure-18. Ensure a consistent level of lighting in the laboratory by maintaining an average scenario. Any changes to the positions of the lamps or curtains may affect the experimental results.
2. Set the potentiometer on the LSC module to the highest level.
3. Adjust the incoming light angle to the panel between 0° and 90° using the mitre pins on the module as indicated in the table. Record the corresponding light intensity for each angle measurement in Table-15.
4. Record the voltage and current values that correspond to each angle and light power in Table-15.

Panel Angle According to Light Source	Light Intensity (lux)	V_{OC}	I_{SC}
90°			
60°			
30°			
0°			

Table-15

Research Questions about the Experiment;

1. How can the highest efficiency of the photovoltaic panel against daylight variations be ensured?
2. Explain the impact of varying daylight on the equivalent circuit and mathematical model of solar cells.
3. Explain the solar tracking system by drawing a block diagram.

Answers to the Research Questions;

1. The highest efficiency of the photovoltaic panel can be ensured by using solar tracking systems. These systems adjust the angle of the panel to always face the sun perpendicularly, maximizing the absorption of sunlight throughout the day.
2. Variations in daylight affect the current and voltage produced by the solar cell. As light intensity decreases, the current decreases, while the voltage remains relatively stable. This results in a decrease in power output. Mathematically, the generated current is directly proportional to the light intensity, while the voltage stays almost constant.
3. A solar tracking system consists of the following components:

    - Sensors (detect the position of the sun),
    - Control system (activates the motors to adjust the panel),
    - Motors (move the panel to maintain optimal orientation),
    - Solar panel (receives the sunlight at the best angle)

3.5 Experiment-5 Examination of the Photovoltaic Panel's Loaded Outputs Depending on the Sun's In-Day Movement

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Potentiometer Module,

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the Potentiometer Module terminal (A) to the AC/DC Measurement Module voltmeter (+) terminal, and the Potentiometer Module terminal (B) to the AC/DC Measurement Module voltmeter (−) terminal using banana jack cables.
4. Connect the photovoltaic panel (+) terminal to the AC/DC Measurement Module ammeter (+) terminal, and the photovoltaic panel (−) terminal to the Potentiometer Module terminal (B) using banana jack cables.
5. Connect the AC/DC Measurement Module ammeter (−) terminal to the Potentiometer Module terminal (A) using a banana jack cable.
6. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

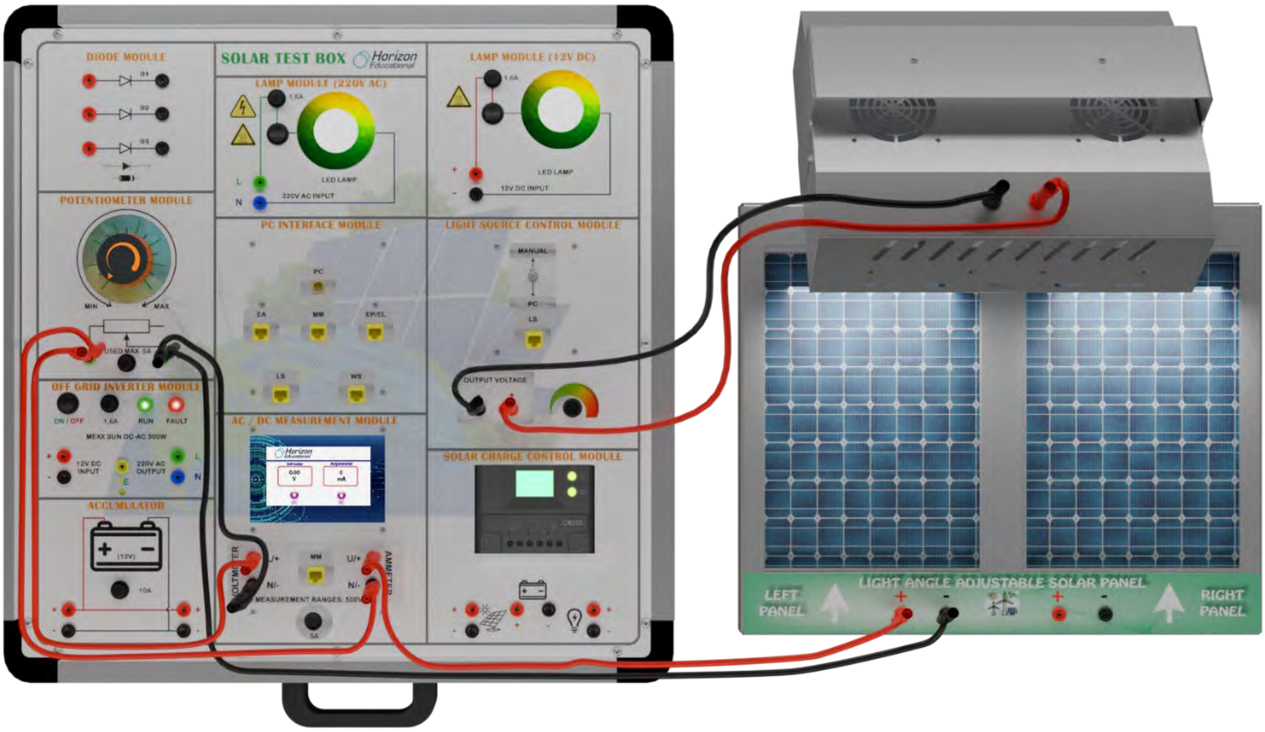


Figure-21. Installation Image of Examination of the Photovoltaic Panel's Loaded Outputs Depending on the Sun's In-Day Movement

Stages of the Experiment;

1. Set up the connection as specified in Figure-21. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Set the Potentiometer Module to a resistance value of 200Ω.
3. Adjust the panel's incoming light angle between 0° and 90° using the mitre pins on the module as specified in the table. Record the corresponding light intensity for each angle measurement in Table-16.
4. Please record the voltage and current values that correspond to each angle and light power within Table-16.

Panel Angle According to Light Source	Light Intensity (lux)	V_{OC}	I_{SC}
90°			
60°			
30°			
0°			

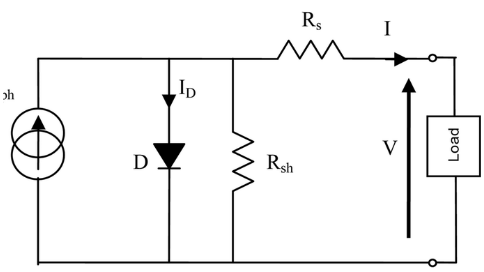
Table-16

Research Questions about the Experiment;

1. Describe the manner in which the panel output voltage varies in response to the load, based on the intensity of the light.
2. Explain the effect of the battery current determined by the load on the cell equivalent circuit and mathematical model.

Answers to the Research Questions;

1. As the intensity of the light increases, the panel generates higher voltage and current. Under load, higher light intensity leads to increased current flow through the circuit. However, if the load is too high, the panel's voltage can drop as it tries to supply sufficient current.
2. The load determines the current flowing through the panel. As the load decreases (lower resistance), the current increases, affecting the internal losses and reducing the output voltage. In the equivalent circuit model, lower resistance loads result in a larger current, which can increase voltage drop across internal resistances.



3.6 Experiment-6 Examination of the No-Load Outputs Due to the Season Change of the Photovoltaic Panel

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the AC/DC Measurement Module as follows: from the ammeter (+) terminal to the photovoltaic panel (+) terminal, and from the ammeter (−) terminal of the AC/DC Measurement Module to the photovoltaic panel (−) terminal using banana jack cables.
4. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

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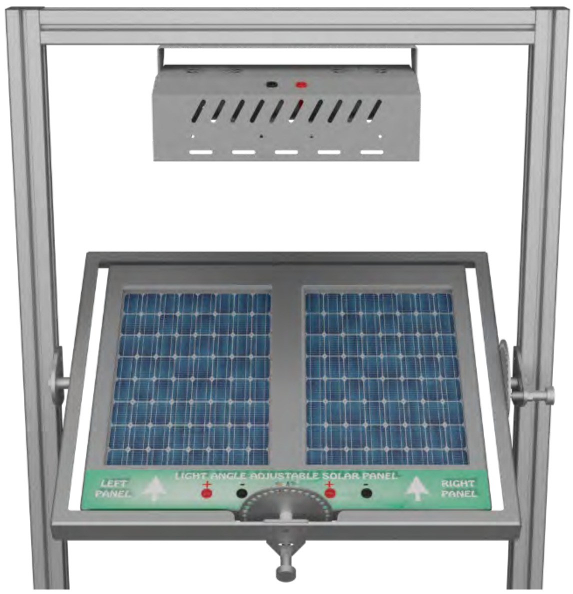


Figure-24. Due to the Season Change of the Photovoltaic Panel, the panels are moved along this axis.

Stages of the Experiment;

1. Set up the connection as specified in Figure-22. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Set the potentiometer to the highest level on the LSC module.
3. Adjust the panel's incoming light angle between 30° and 90° using the mitre pins on the module as specified in the table. Record the corresponding light intensity for each angle measurement in Table-17.
4. Please record the voltage and current values that correspond to each angle and light power within Table-17.

Panel Angle According to Light Source	Light Intensity (lux)	V_{OC}	I_{SC}
90° (Summer)			
60° (Spring)			
30° (Winter)			

Table-17

Research Questions about the Experiment;

1. Explain how the efficiency of photovoltaic panels changes with the seasons.
2. Find the daylight map by researching the seasonal solar power in your region.
3. Identify the countries that benefit most from solar energy, examine their seasonal characteristics and compare them with your own.

Answers to the Research Questions;

1. The efficiency of photovoltaic panels varies with the seasons due to changes in the angle of sunlight and the length of daylight. During summer, the sun's rays are more direct, resulting in higher energy production. In winter, the sun is lower in the sky, and shorter daylight hours reduce the overall efficiency of the panels.
2. To answer this question, consult local meteorological or renewable energy databases to find a daylight map. These maps show the amount of sunlight available during different seasons, helping optimize the placement and orientation of solar panels.
3. Countries like Germany, China, the United States, India, and Japan benefit greatly from solar energy due to their high solar power potential. These countries invest in large solar energy projects and have varying seasonal characteristics. Compared to ….

3.7 Experiment-7 Examination of the Loaded Outputs Due to the Season Change of the Photovoltaic Panel

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Potentiometer Module,

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the Potentiometer Module terminal (A) to the AC/DC Measurement Module voltmeter (+) terminal, and the Potentiometer Module terminal (B) to the AC/DC Measurement Module voltmeter (−) terminal using banana jack cables.
4. Connect the photovoltaic panel (+) terminal to the AC/DC Measurement Module ammeter (+) terminal, and the photovoltaic panel (−) terminal to the Potentiometer Module terminal (B) using banana jack cables.
5. Connect the AC/DC Measurement Module ammeter (−) terminal to the Potentiometer Module terminal (A) using a banana jack cable.
6. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

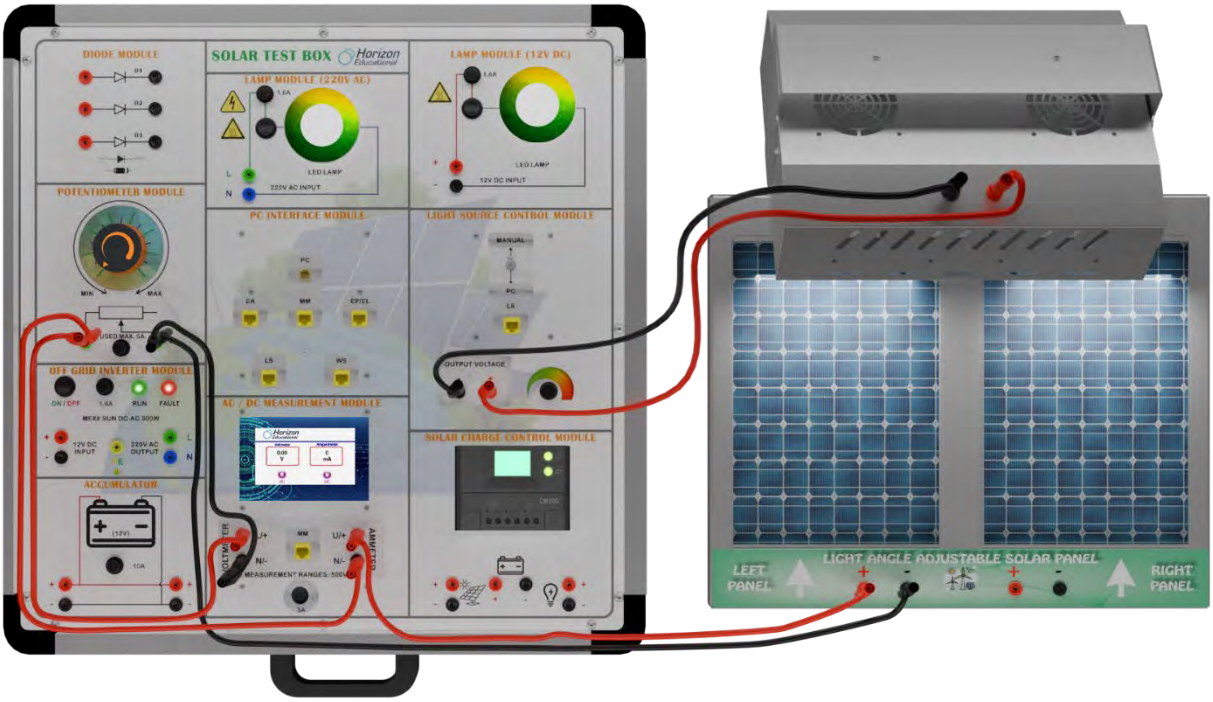


Figure-25. Installation Image of Examination of the Loaded Output Voltage Due to the Season Change of the Photovoltaic Panel

Stages of the Experiment;

1. Set up the connection as specified in Figure-25. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Set the potentiometer to the highest level on the LSC module.
3. Set the Potentiometer Module to a resistance value of 500Ω.
4. Adjust the panel's incoming light angle between 30° and 90° using the mitre pins on the module as specified in the table. Record the corresponding light intensity for each angle measurement in Table-18.
5. Please record the voltage and current values that correspond to each angle and light power within Table-18.

6. The load value should be reduced from 500 ohms to 200 ohms. The subsequent measurements should be repeated and recorded in Table-18.

Panel Angle According to Light Source	Light Intensity (lux)	V (500 Ω)	I (500 Ω)	V (200 Ω)	I (200 Ω)
90° (Summer)					
60° (Spring)					
30° (Winter)					

Table-18

Research Questions about the Experiment;

1. Analyse the effect of a load change on the outputs.
2. Explain how the temperature change will affect the output voltage of the panel.

Answers to the Research Questions;

1. Increasing the load (decreasing resistance) causes more current to flow, but the panel's voltage output will decrease. This can reduce the overall power output if the load exceeds the panel's capacity to generate enough current without significant voltage drops.
2. As temperature increases, the output voltage of the panel decreases. This is because the semiconductor material's bandgap decreases with rising temperature, allowing for easier electron movement but reducing the potential difference. Typically, there is a 0.5% reduction in voltage for every degree Celsius increase in temperature.

3.8 Experiment-8 Examination of the Series Connection of Photovoltaic Panel

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Electronic Potentiometer Module (EP),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the photovoltaic panels in series using banana jack cables.
4. Connect the AC/DC Measurement Module from the voltmeter (+) terminal to the photovoltaic panel (+) terminal, and from the voltmeter (−) terminal to the photovoltaic panel (−) terminal using banana jack cables.
5. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

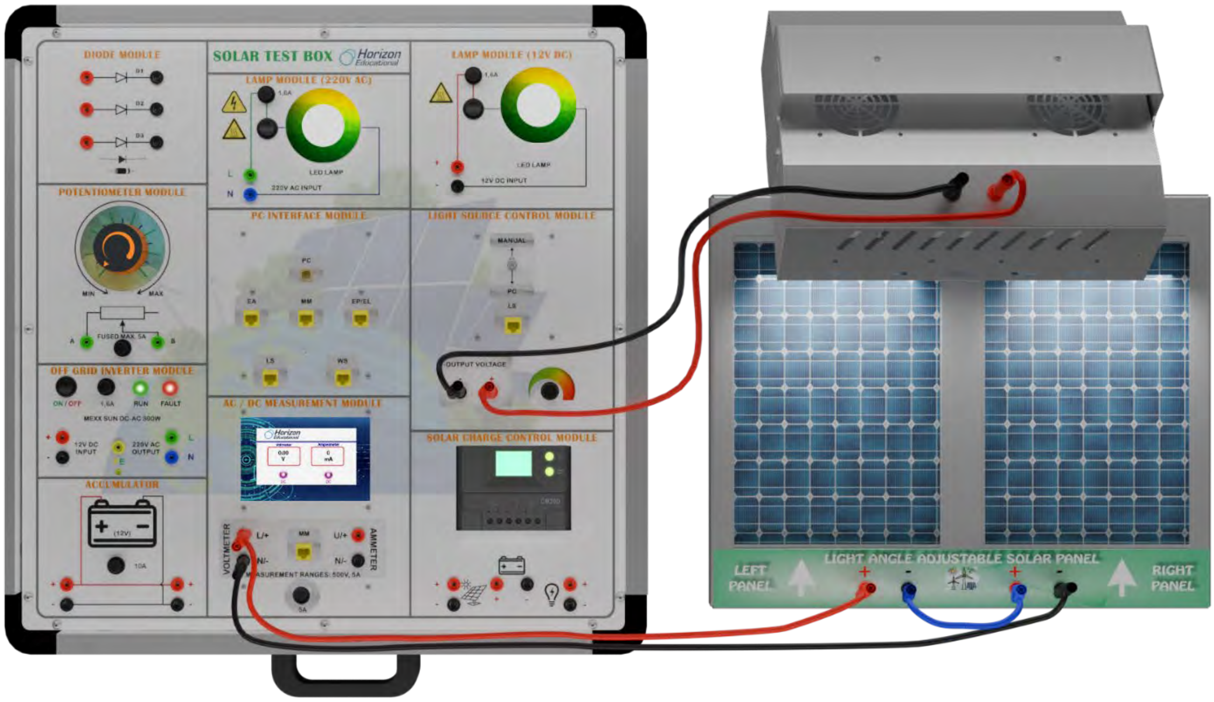


Figure-26. Installation Image of Examination of the Series Connection of Photovoltaic Panel

Stages of the Experiment;

1. Set up the connection as specified in Figure-26. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and the panel surface to be parallel to the ground. To achieve this, make the necessary adjustments by pulling the pins on the module and placing them in their correct positions. Set the potentiometer to the highest level on the LSC module.
3. Record the value displayed by the voltmeter in the MM module in Table-19. Remove the Banana Jacks from the voltmeter, connect them to the ammeter, and record the short-circuit current in Table-19.
4. By setting the potentiometer module to 1000Ω, connect it to the series-connected panel output terminals as shown in Figure-27.
5. Measure the output voltage and current by reducing the load by 100Ω. Record the values in Table-19.

V_{OC}	I_{SC}

Table-19

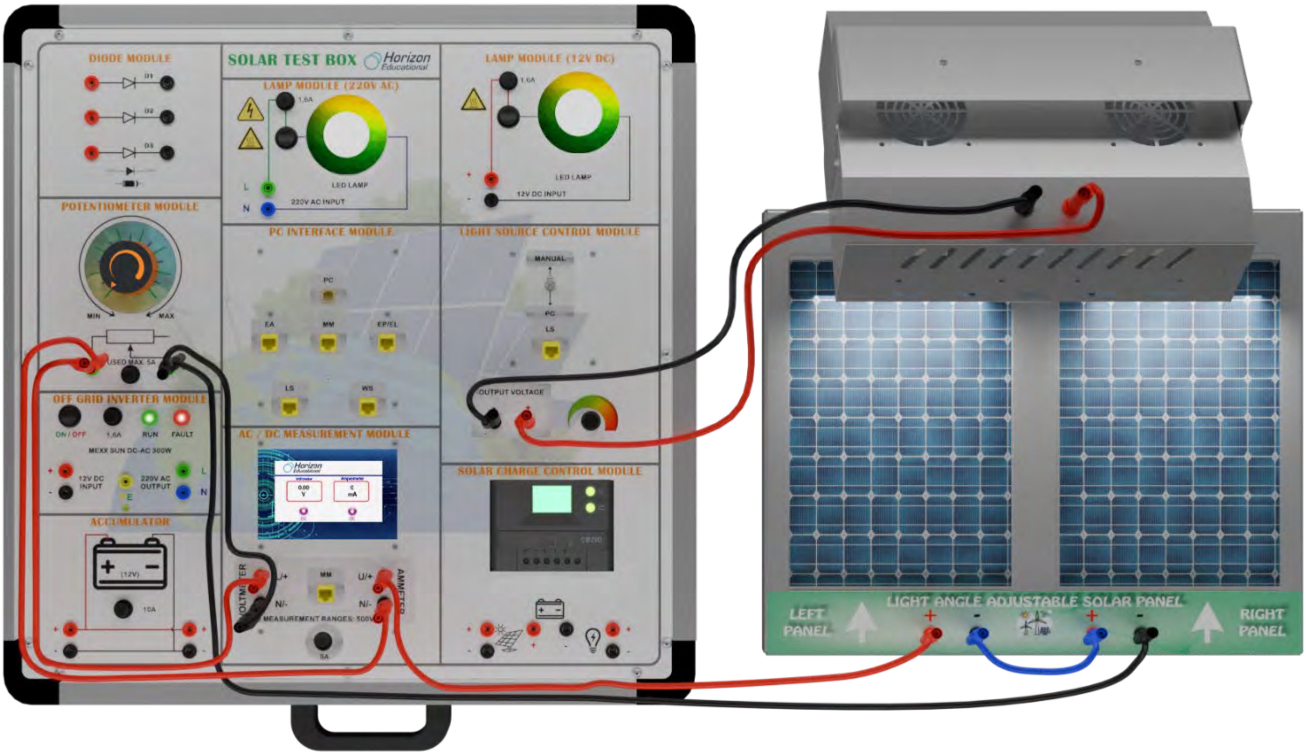


Figure-27. Installation Image of Examination of the Series Connection of Photovoltaic Panel (Loaded)

R_L (Ohm/Ω)	Voltage (V)	Current (mA)	Power (mW)
1000			
900			
800			
700			
600			
500			
400			
300			
200			
100			
0			

Table-20

6. Explain the effect of series connection of photovoltaic panels on equivalent parallel resistance.

7. Draw the current and voltage curves of the photovoltaic panels on Graph-1 and determine the MPPT point.

Graph-1

3.9 Experiment-9 Examination of the Parallel Connection of Photovoltaic Panel

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Electronic Potentiometer Module (EP),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the photovoltaic panels in parallel using banana jack cables.
4. Connect the AC/DC Measurement Module from the voltmeter (+) terminal to the photovoltaic panel (+) terminal, and from the voltmeter (−) terminal to the photovoltaic panel (−) terminal using banana jack cables.
5. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

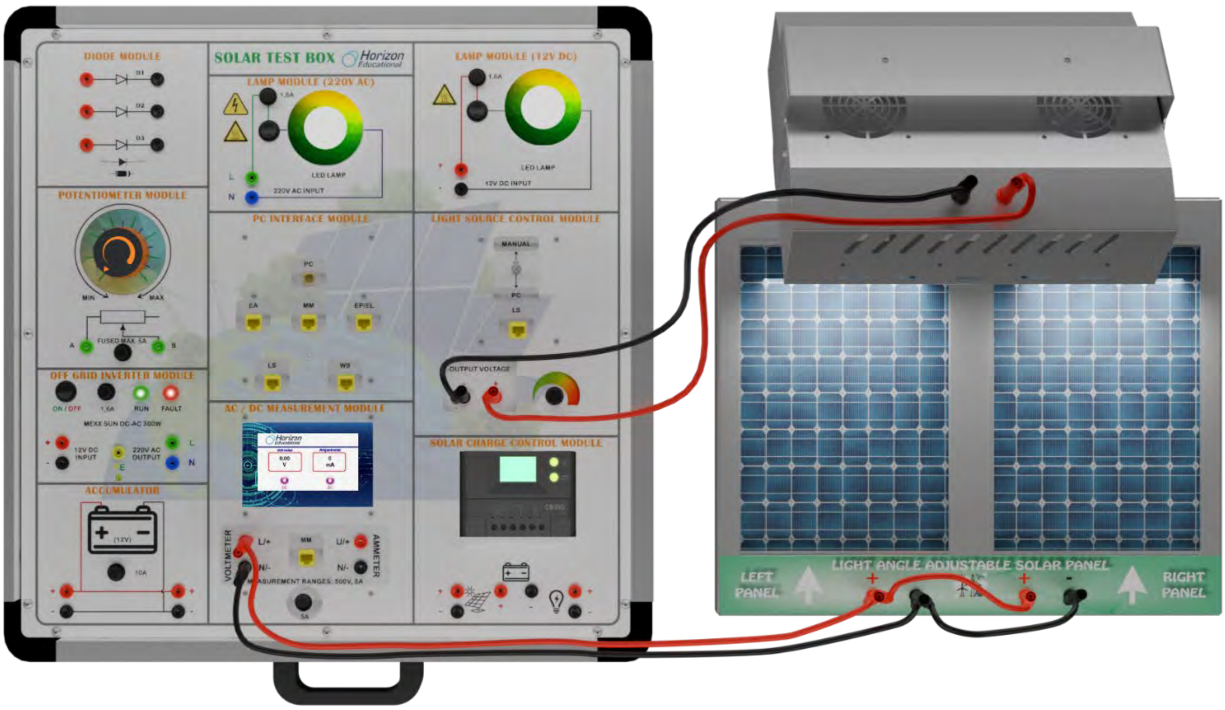


Figure-28. Installation Image of Examination of the Parallel Connection of Photovoltaic Panel

Stages of the Experiment;

1. Set up the connection as specified in Figure-28. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and the panel surface to be parallel to the ground. To achieve this, make the necessary adjustments by pulling the pins on the module and placing them in their correct positions. Set the potentiometer to the highest level on the LSC module.
3. Record the value displayed by the voltmeter in the DM module in Table-21. Remove the Banana Jacks from the voltmeter, connect to the ammeter and record the short-circuit current in Table-21.

V_{OC}	I_{SC}

Table-21

4. By setting the potentiometer module to 1000Ω, connect to the series connected panel output terminals Figure-29 as shown in.
5. Measure the output voltage and current by reducing the load by 100Ω. Record the values in Table-22.

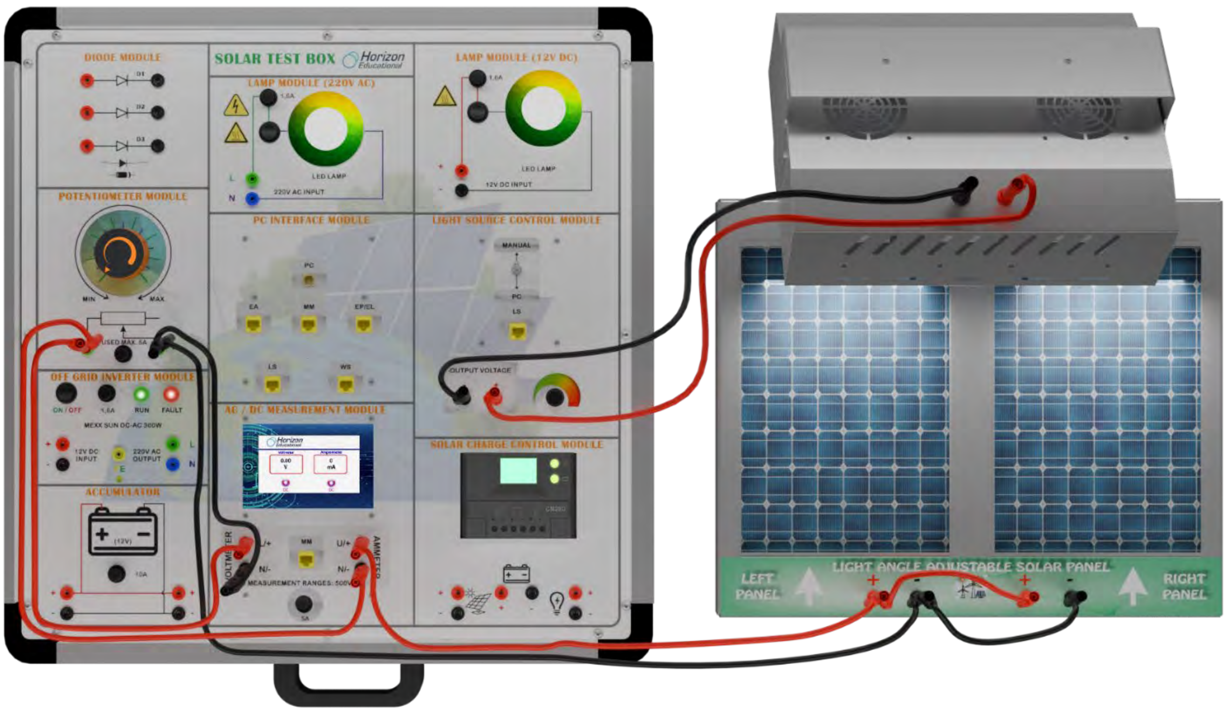
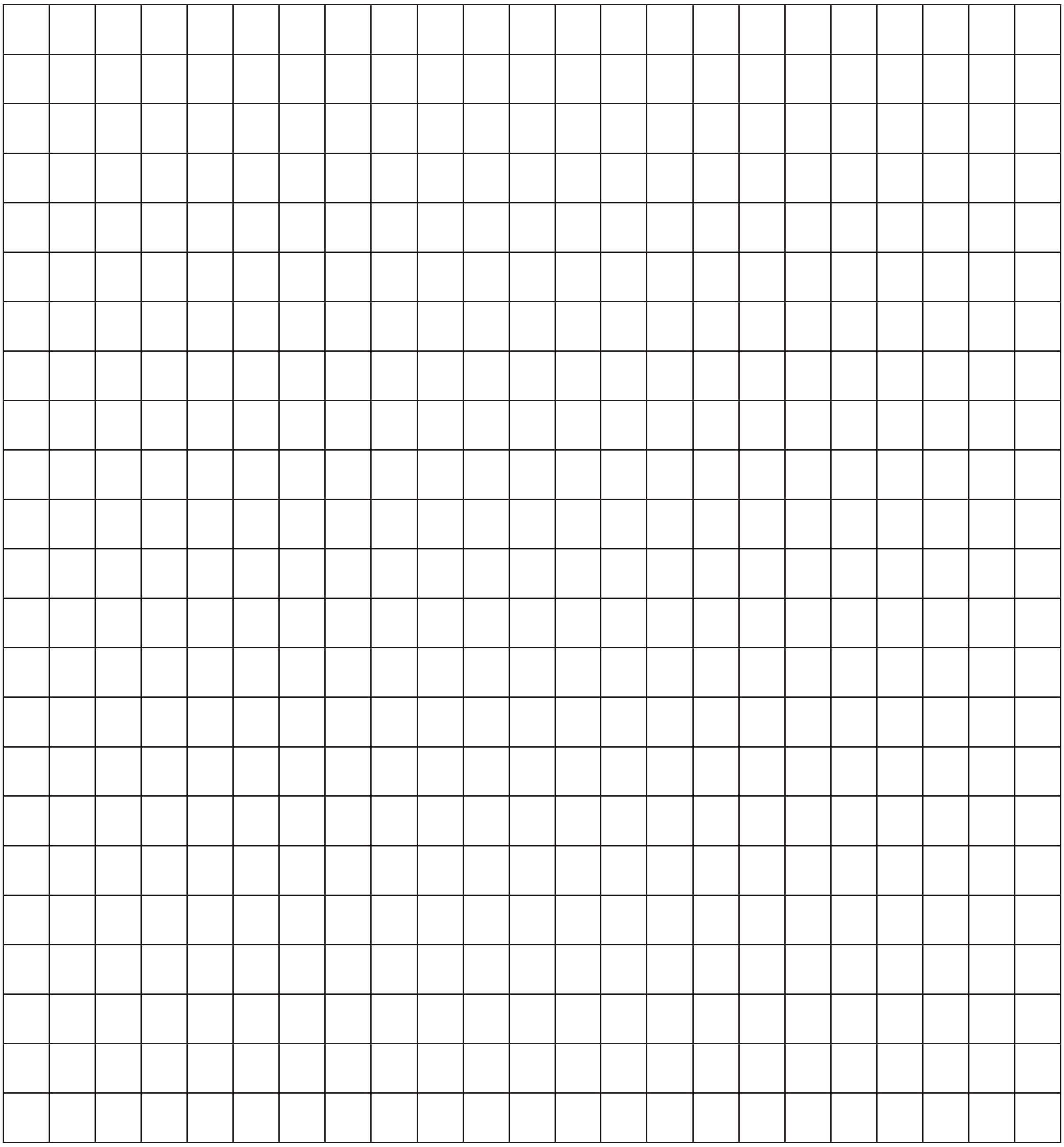


Figure-29. Installation Image of Examination of the Parallel Connection of Photovoltaic Panel (Loaded)

R_L (Ohm/Ω)	Voltage (V)	Current (mA)	Power (mW)
1000			
900			
800			
700			
600			
500			
400			
300			
200			
100			
0			

Table-22

6. Explain the effect of connecting photovoltaic panels in parallel on the equivalent parallel resistance.
7. Draw the current and voltage curve of the photovoltaic panels on Graph-1 and determine the MPPT point.



Graph-1

3.9 Experiment-10 Examination of Shadow Effect in Photovoltaic Panel

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Electronic Potentiometer Module (EP),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the photovoltaic panels in series using banana jack cables.
4. Connect the Potentiometer Module terminal (A) to the AC/DC Measurement Module voltmeter (+) terminal, and the Potentiometer Module terminal (B) to the AC/DC Measurement Module voltmeter (−) terminal using banana jack cables.
5. Connect the photovoltaic panel (+) terminal to the AC/DC Measurement Module ammeter (+) terminal, and the photovoltaic panel (−) terminal to the Potentiometer Module terminal (B) using banana jack cables.
6. Connect the AC/DC Measurement Module ammeter (−) terminal to the Potentiometer Module terminal (A) using a banana jack cable.
7. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

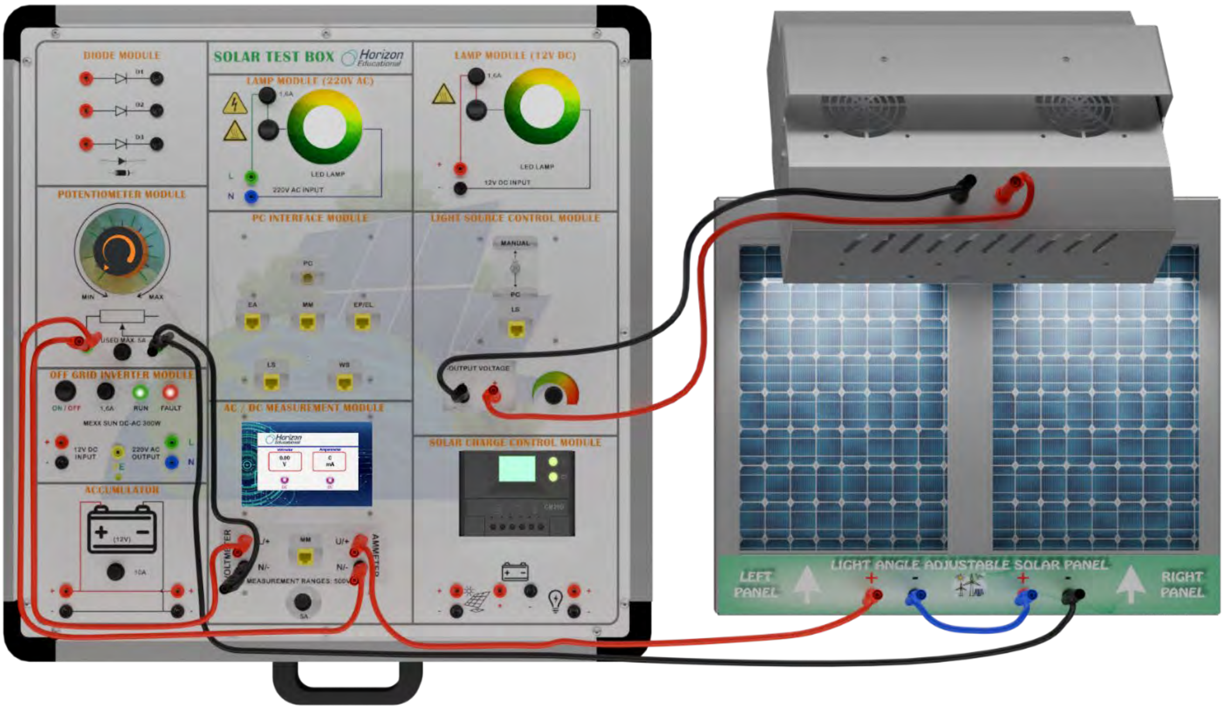


Figure-30. Installation Image of Examination of Shadow Effect in Photovoltaic Panel

Stages of the Experiment;

1. Set up the connection as specified in Figure-30. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and the panel surface to be parallel to the ground. To achieve this, make the necessary adjustments by pulling the pins on the module and placing them in their correct positions. Set the potentiometer to the highest level on the LSC module.
3. By setting the potentiometer module to 1000Ω, connect to the series connected panel output terminals as shown in Figure-30.
4. Cover one side of the PV panel with a paper-like shading device as shown in Figure-31.
5. Measure the output voltage and current by reducing the load by 100Ω. Record the values in Table-23.

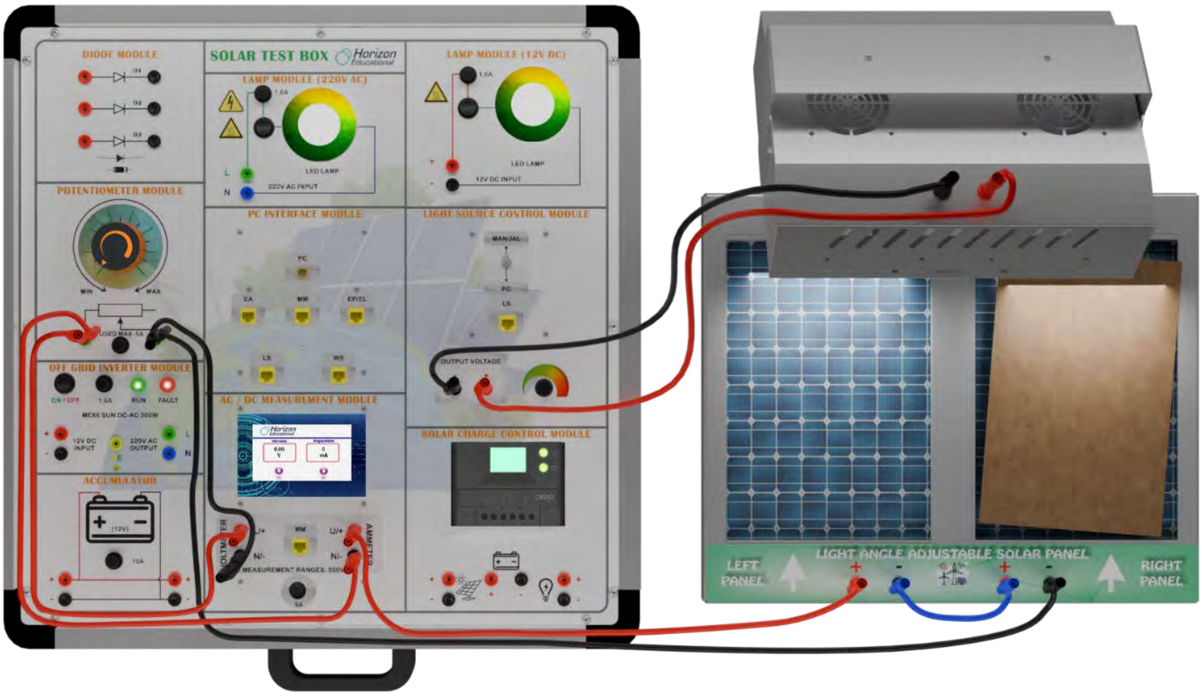


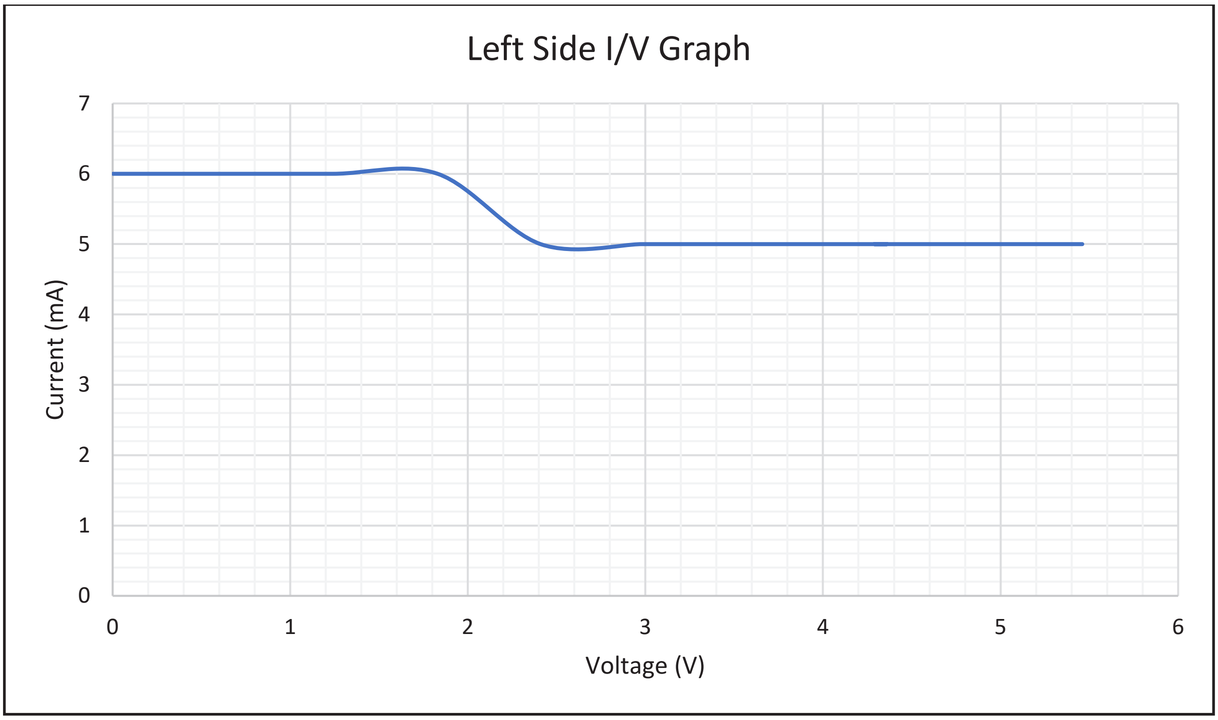
Figure-31. **Installation Image of Examination of Shadow Effect in Photovoltaic Panel**

6. Open the panel that was covered in the previous step, cover the other panel, and record the voltage and current values of the MM module in this state in Table-23.

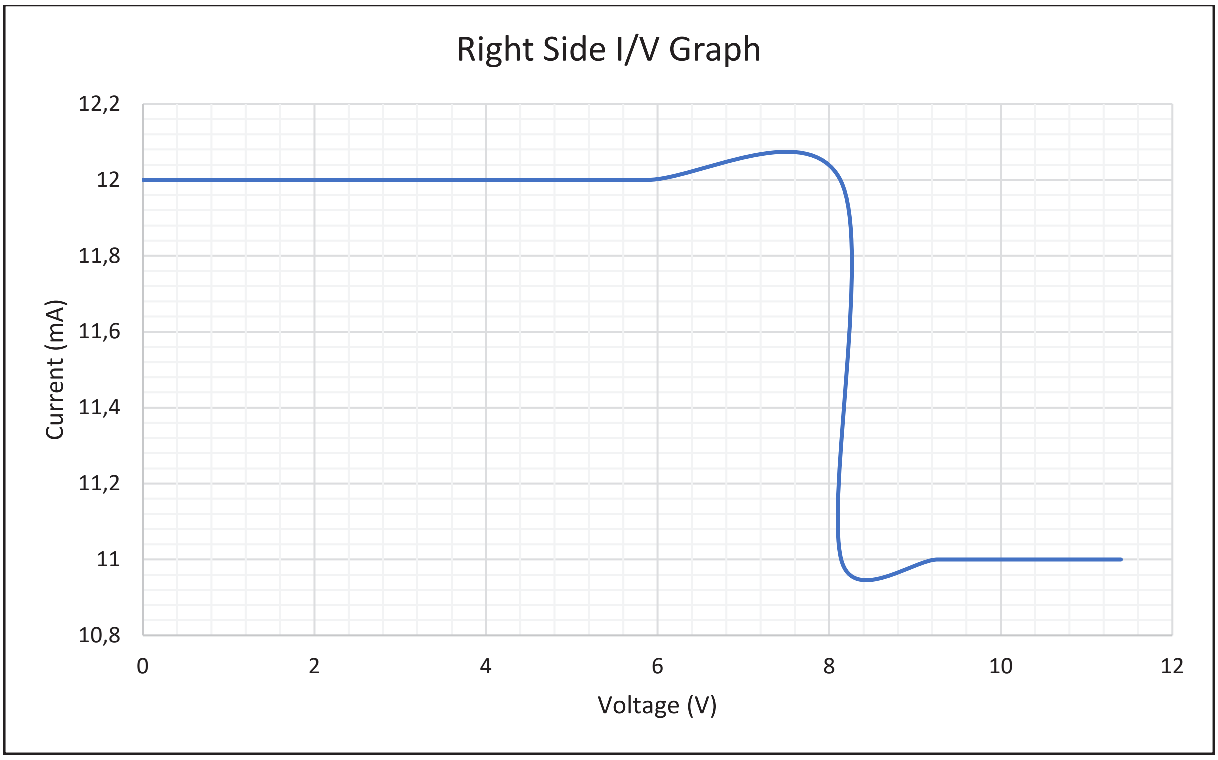
Series Connection	Left side open - Right side shaded		Left side shaded - Right side open	
R_L (Ohm/Ω)	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
1000				
900				
800				
700				
600				
500				
400				
300				
200				
100				
0				

Table-23

7. Explain the shadow effect.
8. Carry out the same experiment by connecting the panels in parallel. Record the measurements in Table-24.
9. Analyse the given graphs.



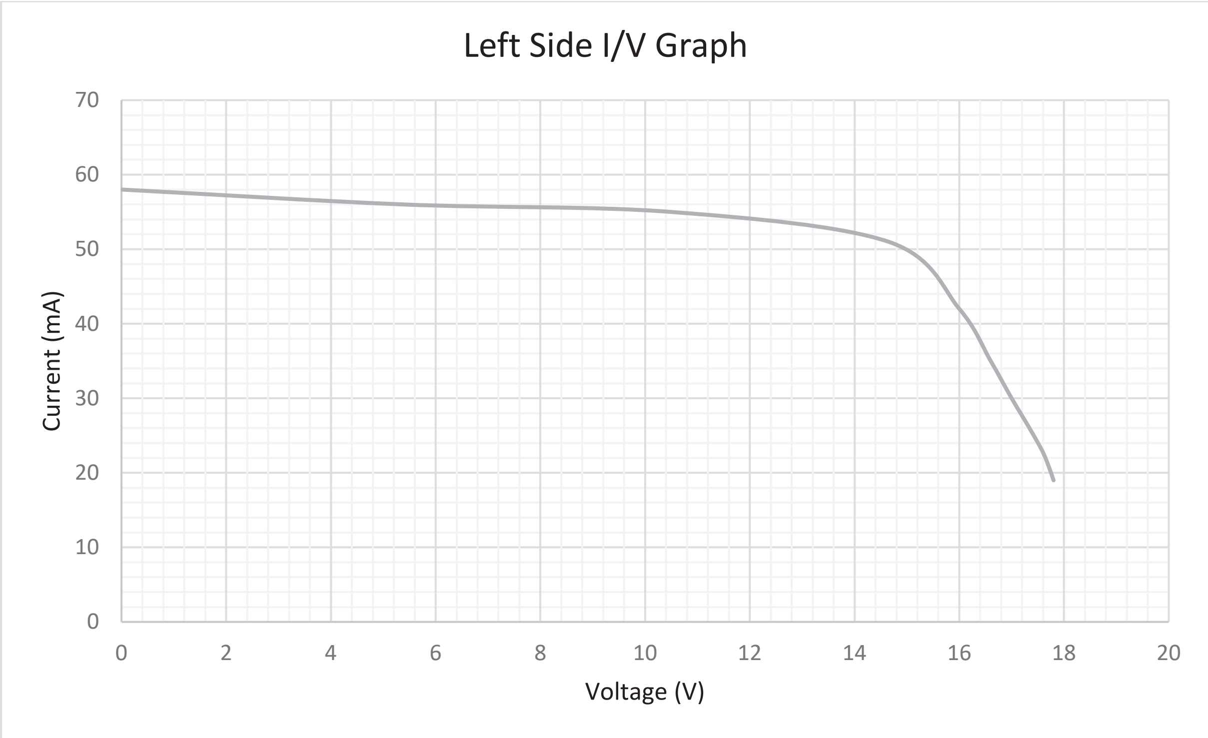
Graph II



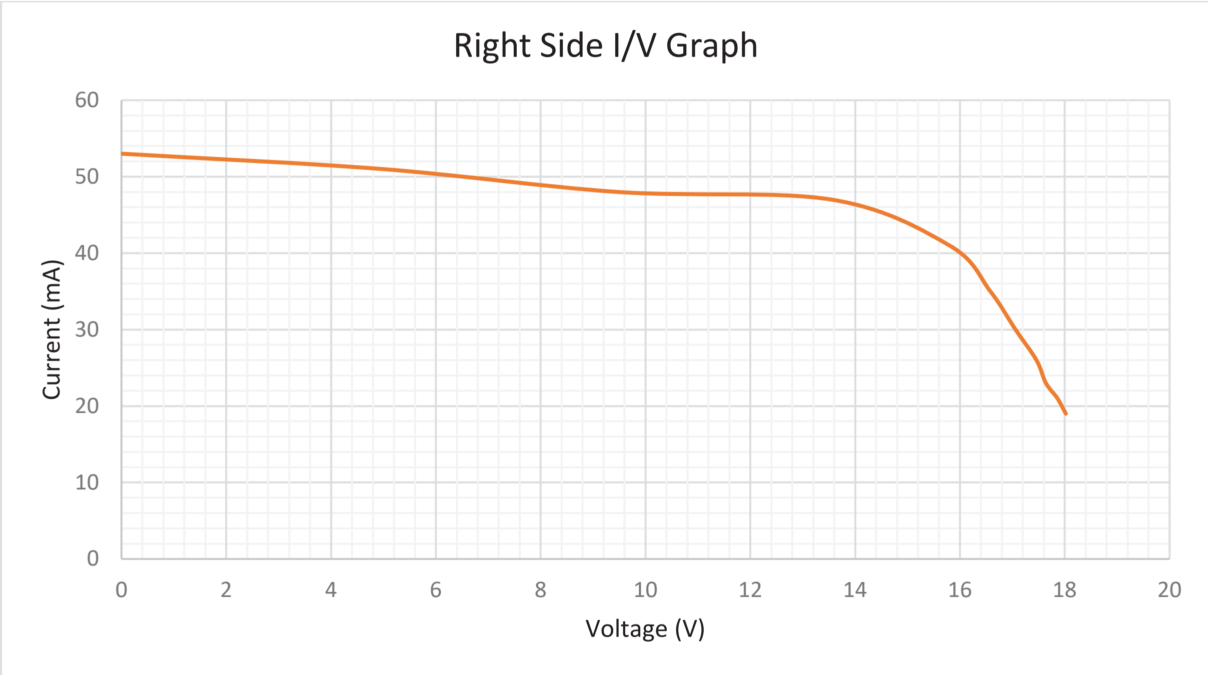
Graph III

Parallel Connection	Left side open - Right side shaded		Left side shaded - Right side open	
R_L (Ohm/Ω)	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
1000				
900				
800				
700				
600				
500				
400				
300				
200				
100				
0				

Table-24


Left Side I/V Graph
Current (mA)
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
Voltage (V)

Graph IV


Right Side I/V Graph
Current (mA)
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
Voltage (V)

Graph V

3.10 Experiment-11 Examination of Effect of Bypass Diode in Photovoltaic Panels

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Electronic Potentiometer Module (EP),
- Diode Module

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the photovoltaic panels in series using banana jack cables.
4. Connect the (+) terminal of the first photovoltaic panel to the cathode of the D1 diode, and the (−) terminal of the first panel to the anode of both the D1 and D2 diodes. Then, connect the (−) terminal of the second panel to the cathode of the D2 diode using banana jack cables.
5. Connect the (+) terminal of the photovoltaic panel to the AC/DC Measurement Module ammeter (+) terminal, and connect the ammeter (−) terminal to terminal (A) of the Potentiometer Module using a banana jack cable.
6. Connect the (−) terminal of the photovoltaic panel to terminal (B) of the Potentiometer Module using a banana jack cable.
7. Connect the voltmeter (+) terminal of the AC/DC Measurement Module to terminal (A) of the Potentiometer Module, and the voltmeter (−) terminal of the AC/DC

Measurement Module to terminal (B) of the Potentiometer Module using banana jack cables.

8. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

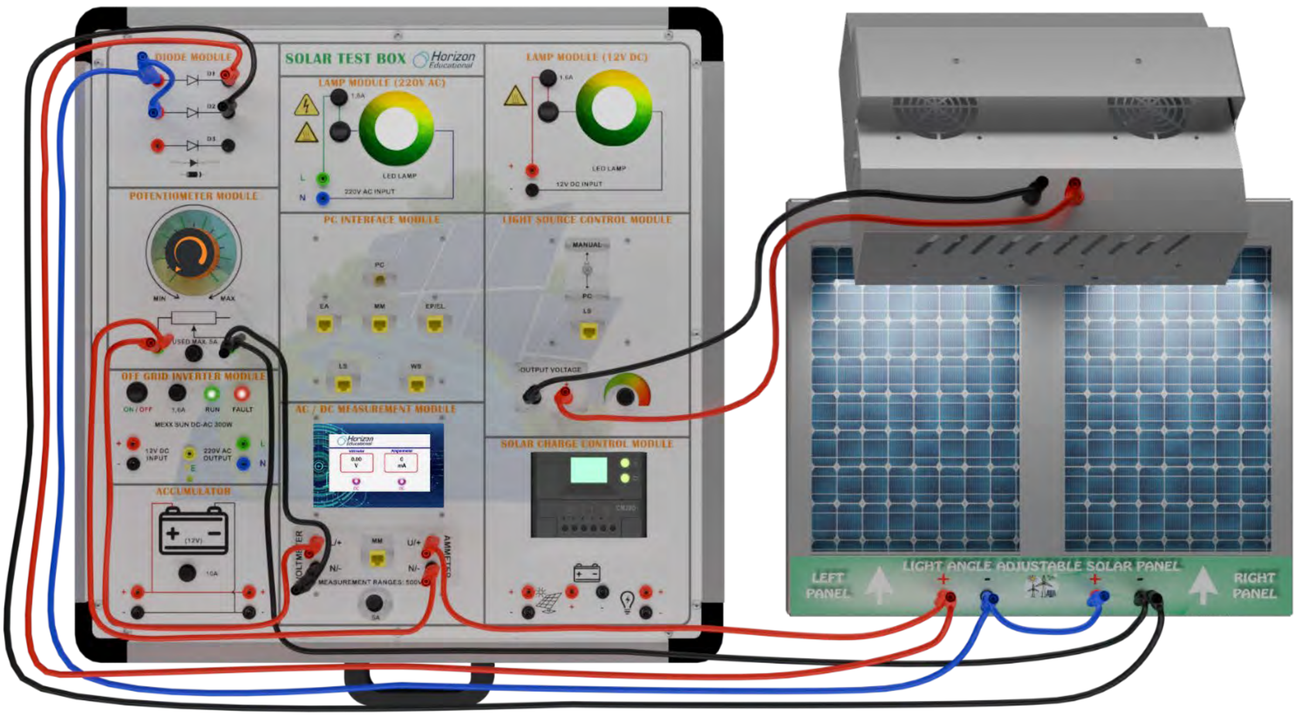


Figure-32. Installation Image of Examination of Effect of Bypass Diode in Photovoltaic Panels

Stages of the Experiment;

1. Set up the connection as specified in Figure-32. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and ensure that the panel surface is parallel to the ground. To achieve this, make the

necessary adjustments by pulling the pins on the module and placing them in their correct positions. Set the potentiometer to the highest level on the LSC module.

3. Set the Potentiometer Module to 1000Ω.
4. Ensure the bypass diodes are connected in reverse.
5. To conduct the experiment, cover one panel with paper or a non-transparent material, as demonstrated in Figure-32. Then, reduce the load by 100Ω and record the voltage and current measurements from the MM Module in Table-25.
6. Afterward, cover the other panel as shown in Figure-33. Record the values displayed by the voltmeter and ammeter in the DM Module in Table-25.

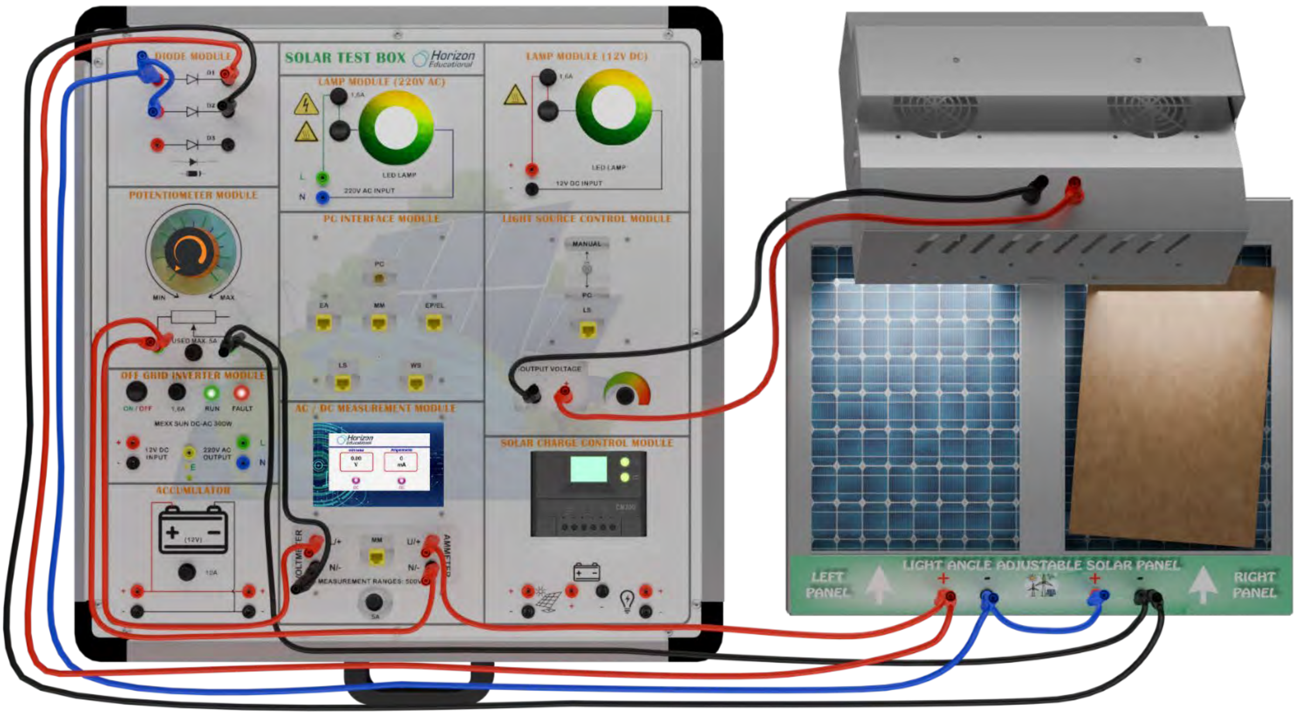


Figure-33. Installation Image of Examination of Effect of Bypass Diode in Photovoltaic Panels (with Shadow Effect)

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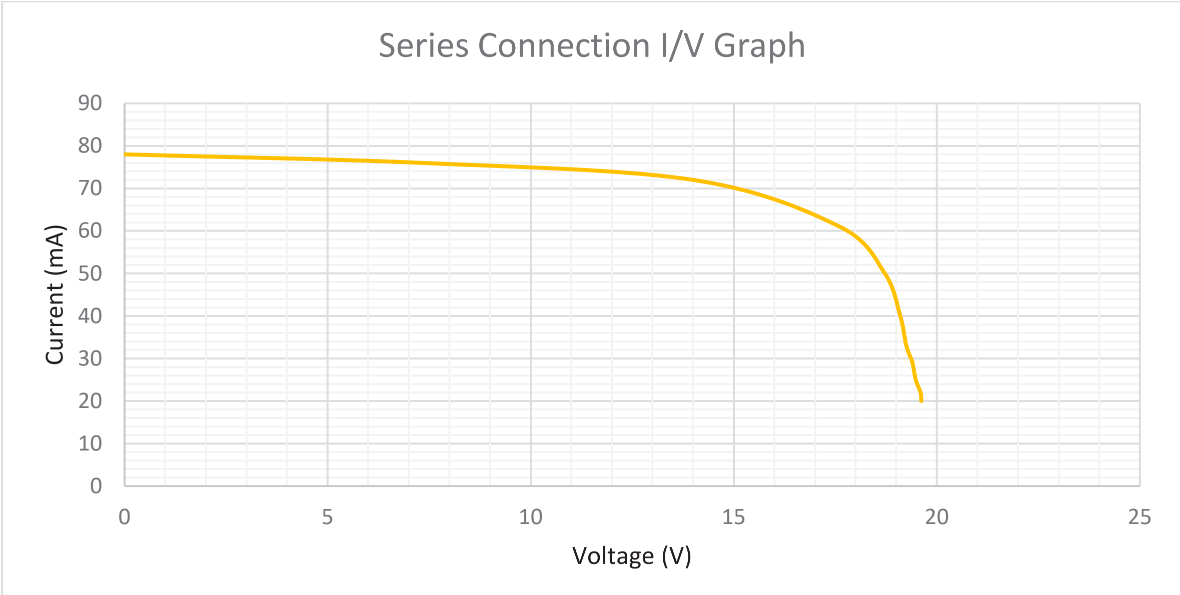
Figure-34. Installation Image of Examination of Effect of Bypass Diode in Photovoltaic Panels (with Shadow Effect)

Series Connection	Left side open - Right side shaded with Bybass Diode		Left side shaded - Right side open with Bybass Diode	
R_L (Ohm/Ω)	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
1000				
900				
800				
700				
600				
500				
400				
300				
200				
100				
0				

Table-25

Graph-1

7. Draw the current/voltage curve of PV panel with bypass diode from the measured data.



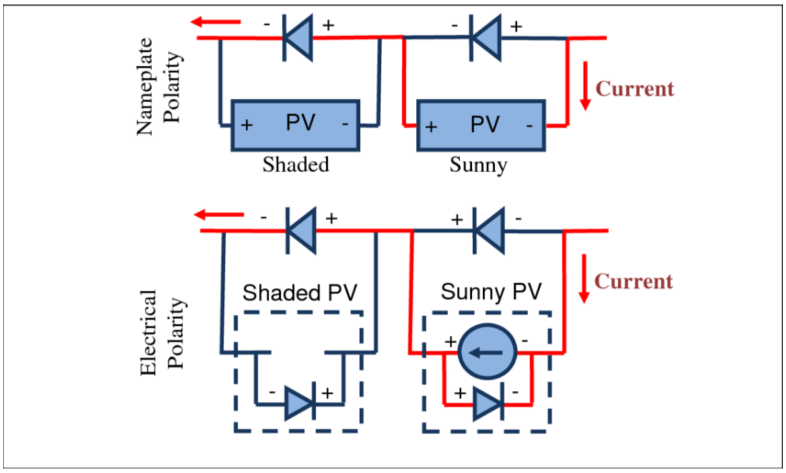
Graph VI

Research Questions about the Experiment;

1. Explain the connection direction of the bypass diode.
2. Show the effect of the bypass diode by drawing an equivalent circuit.
3. Compare the graphs you have drawn with the graphs given.

Answers to the Research Questions;

1. The bypass diode is connected in parallel with the photovoltaic cell or a series of cells, but in reverse polarity relative to the normal current flow. Under normal operation, the diode does not conduct because the voltage generated by the solar cells forward biases the diode. However, if a cell becomes shaded or damaged, causing its voltage to drop, the diode becomes forward biased and allows current to bypass the affected cell, preventing the overall current from being significantly reduced.
2. In an equivalent circuit, the bypass diode is shown in parallel with each solar cell or string of cells. When the cell is functioning properly, the current flows through the cell. If the cell is shaded or malfunctioning, the diode becomes forward biased and conducts, allowing current to bypass the cell. The circuit would consist of the solar cell as a current source in series with a diode (representing the solar cell itself), and a second diode (bypass diode) placed in parallel across the solar cell.



3. Compare the graphs.

3.12 Experiment-12 Direct Load Connection to Photovoltaic Panels

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- AC/DC Measurement Module (MM),
- Lamb Module (12V DC),

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the photovoltaic panels in parallel using banana jack cables.
4. Connect the Lamp Module (12V DC) from the (+) terminal to the AC/DC Measurement Module voltmeter (+) terminal, and from the (−) terminal to the AC/DC Measurement Module voltmeter (−) terminal using banana jack cables.
5. Connect the photovoltaic panel (+) terminal to the AC/DC Measurement Module ammeter (+) terminal, and connect the AC/DC Measurement Module ammeter (−) terminal to the Lamp Module (12V DC) (+) terminal using banana jack cables.
6. Connect the AC/DC Measurement Module voltmeter (−) terminal to the photovoltaic panel (−) terminal using a banana jack cable.
7. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

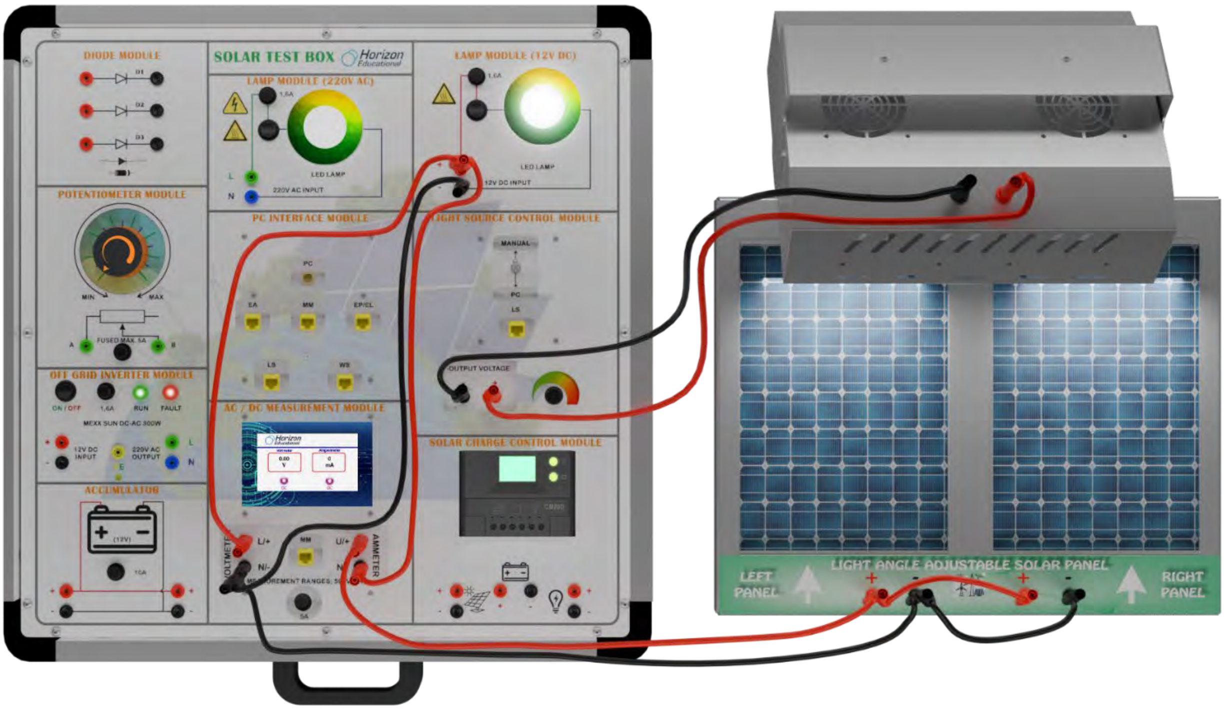


Figure-35. Installation Image of Direct Load Connection to Photovoltaic Panels

Stages of the Experiment;

1. Set up the connection as specified in Figure-35. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and the panel surface to be parallel to the ground. To achieve this, make the necessary adjustments by pulling the pins on the module and placing them in their correct positions. Set the potentiometer to the highest level on the LSC module.
3. Use the ammeter (I1) to measure the current transferred from the panel to the load. Accordingly, switch the Led lamp switch on the lamp module to the "on" position when the LSC Module is at the minimum light level. In this case, the LED will emit a weak light depending on the light level in the laboratory.
4. Record the values of the voltmeter (V1) and ammeter (I1) in the MM module in Table-26.

2. Connecting the panel output directly to the load is generally not recommended. There are several reasons for this:
    a. **Voltage Drop:** If the load resistance is too low, the output voltage of the panel will drop, which can prevent devices from operating properly.
    b. **Overcurrent:** If the load exceeds the panel's capacity, it will draw excessive current. This can lead to panel damage or overheating.
    c. **Efficiency Loss:** Direct connection may cause the panel to operate away from its optimal working point, leading to reduced energy efficiency.
    d. **Safety Issues:** Overloading poses a short-circuit risk, which can result in safety hazards.

    For these reasons, it's better to use a regulator or MPPT (Maximum Power Point Tracking) controller between the panel and the load to ensure safe and efficient operation

3.13 Experiment-13 No-Load Commissioning of Off-Grid Inverter

Modules required for the experiment;

- Light Angle Adjustable Solar Panel,
- Monophase Switching Module,
- Energy Distribution Module,
- PC Interface Module, (Optional)
- Light Source Control Module (LSC),
- Off-Grid Invertor Module,
- Solar Charge Regulator Module,
- Isolated Measurement Module,
- Accumulator Module,

Experiment Connection;

1. Open the lid of the Horizon Solar Trainer. Connect the Horizon Solar Trainer to the IEC connector using the power cable and energize the box.
2. Connect the Light Source Control Module on the Horizon Solar Trainer to the LED projector above the photovoltaic panels using a banana jack cable.
3. Connect the photovoltaic panels in parallel using banana jack cables.
4. Connect the (+) terminal of the photovoltaic panel to the Panel (+) terminal of the Solar Charge Control Module, and the (−) terminal of the photovoltaic panel to the Panel (−) terminal of the Solar Charge Control Module using banana jack cables.
5. Connect the (+) terminal of the Battery Module to the Battery (+) terminal of the Solar Charge Control Module, and the (−) terminal of the Battery Module to the Battery (−) terminal of the Solar Charge Control Module using banana jack cables.
6. Connect the Battery (+) terminal of the Solar Charge Control Module to the 12V DC Input (+) terminal of the Off-Grid Inverter Module, and the Battery (−) terminal of the Solar Charge Control Module to the 12V DC Input (−) terminal of the Off-Grid Inverter Module using banana jack cables.

7. Connect the 220V AC Output (L) terminal of the Off-Grid Inverter Module to the (L) terminal of the Lamp Module (220V AC), and the 220V AC Output (N) terminal of the Off-Grid Inverter Module to the (N) terminal of the Lamp Module (220V AC) using banana jack cables.

8. If you want to display the measured data and control the light source via a computer, connect the power supply of the PC Interface Module and connect both the AC/DC Measurement Module and the Light Source Control Module to the PC Interface Module using a CAT6 cable.

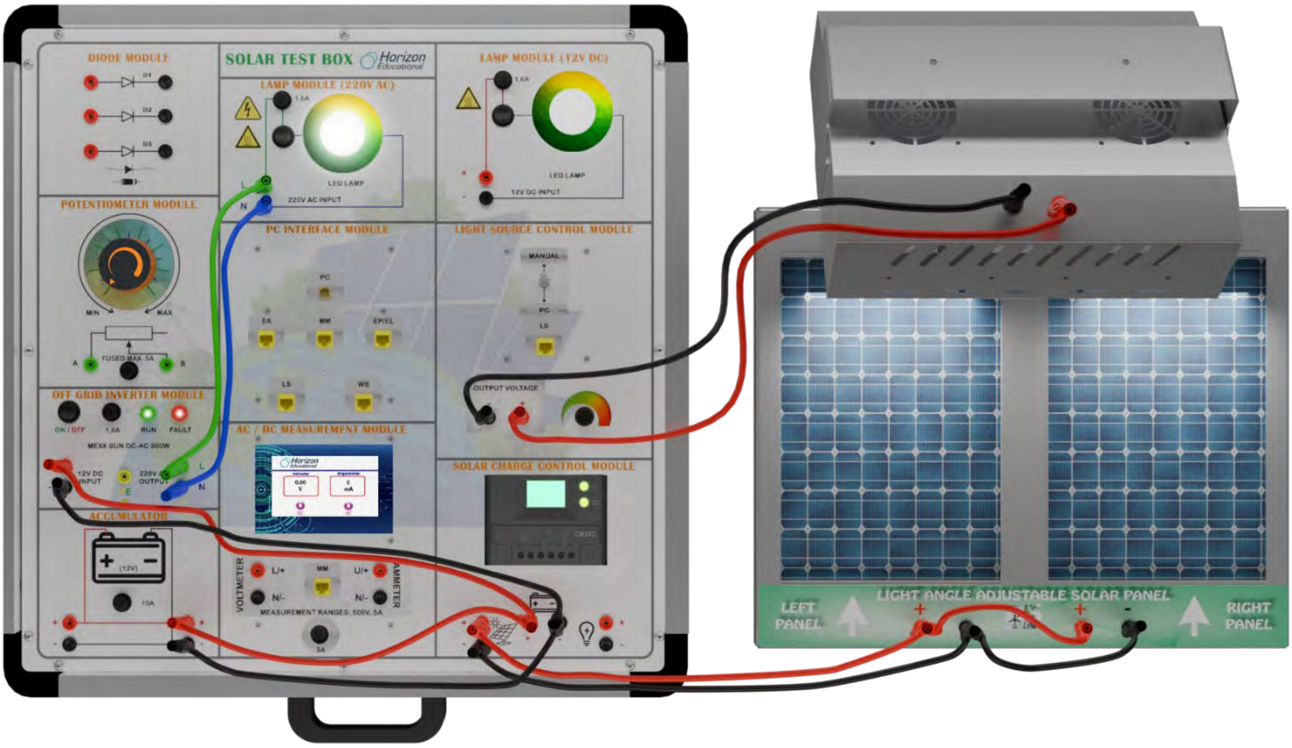


Figure-36. Installation Image of No-Load Commissioning of Off-Grid Inverter

Stages of the Experiment;

1. Set up the connection as specified in Figure-61. Ensure a constant level of light in the laboratory by creating an average scenario. Any alterations to the positions of the lamps or curtains will have an impact on the experimental outcomes.
2. Align the angle of incidence of light to the photovoltaic panel to 90° (summer season) and ensure that the panel surface is parallel to the ground. To achieve this, make the necessary adjustments by pulling the pins on the module and placing them in their correct positions. Set the potentiometer to the highest level on the LSC module.
3. Turn on the Off-Grid Inverter power switch. Two LEDs, one red and one green, are located next to the power switch. The red LED signals a low battery voltage with an audible warning, while the green LED indicates that the battery is charged to the appropriate level and that the output voltage is being generated.
4. The LED next to the power button on the Off-Grid Inverter module should illuminate green. If the red LED is illuminated and an audible warning is emitted, it indicates that the battery is not sufficiently charged. In this situation, the battery must be charged.
5. Set the commutator on the Isolated Measurement Module to X0.01. This will isolate and attenuate the inverter output signal by a factor of 1:100.
6. Analyse the shape of the signal for the inverter output voltage using the Isolated Measurement Module. Draw the signal shape in the space provided in Graph-1. Record the peak-to-peak (Vpp), effective (Vrms) and frequency of the inverter output voltage in the space provided below the graph. (Multiply the measurements made with the oscilloscope by 100 considering the attenuation of 1:100. Make sure that the probe attenuation is at X1 position.)

Graph-1

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Thank You for Reading!
We hope you found this manual
informative and useful.

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