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Abstract:

I. INTRODUCTION

To meet world energy demands, world heavily relies on fossil fuels. Fossil fuels account for around 79% of total energy consumption in world [1]. This heavy consumption of fossil fuel results in large amount of greenhouse gas emissions, which end up heating the Earth and changing the climate. We have to switch from fossil fuels to other renewable sources of energy, which are available in abundance in the world. Although we cannot directly switch from fossil fuels, as some of the industries rely heavily on fossil fuels but we can switch in the areas where we can. One of the major sector where we can decrease our dependence on fossil fuels is electricity and one of the most abundantly available renewable energy is solar energy. To convert solar energy into electricity there are many technologies available at present, and one of them is Solar Photovoltaic. Solar PV is responsible in converting solar energy (sunlight) into electricity.

In this experiment, we have conducted various experiments to see the effects of different parameters and environmental conditions on the performance of Solar PV module, with the help of artificial conditions produced in our lab. In our lab, we have generated effects of change in radiation intensity, temperature variations, shading, and effect of tilt angle. We have also seen the effect and advantage of using bypass and blocking diodes.

One of the major environmental condition in the performance of Solar PV module is radiation intensity [2]. Radiation depends upon the day, year and location on Earth and it is the major factor on performance of Solar PV module. Temperature of modules also influence performance to great extent [3]. Another factor which effect the performance would be the tilt angle as it can make a difference in electricity production from module due the angle of incidence radiation falling on the solar PV modules [4]. We have investigated I-V and P-V characteristics under different parametric conditions in which we have changed radiation levels, tilt angles and at different temperatures. This study helps us understand better the effect of these external factors on fill factor, efficiency and power generation of the under observation solar PV modules.

II. METHODOLOGY

(A) Setup Description:

ECOSENSE's solar PV training and research methodology is used for parametric analysis of solar PV modules, which are nothing more than an actual solar power plant that is scaled down to scale to improve these experiments in the laboratory. It is an indoor system consisting of many halogen bulbs that help simulate solar radiation in an artificial laboratory environment.

This setup has several plug-in points that each work on and we are going to set each unique point for our experimental purposes which include -- study of solar PV characteristics, interconnection of solar modules, tilt, radiation and temperature effects on solar modules, and a Use of diodes in solar modules. This The technology allows adjusting the irradiance to simulate daytime sunlight conditions to test I-V and P-V characteristics under different irradiances. This has an additional effect on the temperature of the solar module. Data collection is performed using a data logger and plotter.

(B) Experimental Techniques:

1. Measuring I-V & P-V Characteristics: This I-V curve is displayed by varying the load resistance and measuring the current and voltage of the module at each point as shown in the circuit diagram. Such I-V curves determine the short circuit current (I_{sc}) and open voltage current (Voc). Where the P-V curve is obtained by multiplying the current and voltage across various load resistances plotted against the applied voltage. In this case we measured our solar radiation effect on solar module panel and using pyranometer our solar radiation is around 110, 220, 330 W/m2 respectively which helps to find global radiation (beam + diffuse) on solar panel, so we use radiation level These derived P-V and I-V curves are nothing but the average radiation levels from three positions mainly top, middle, and bottom of the module.

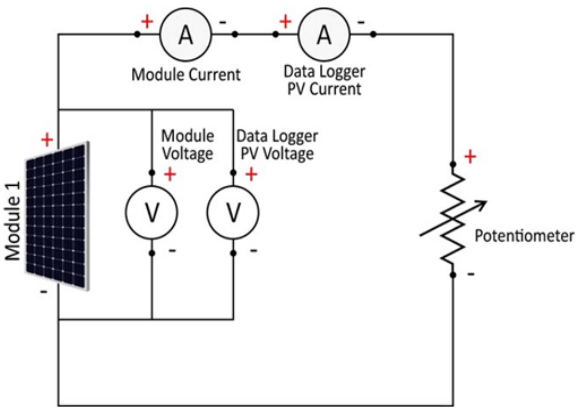

Figure 1 Circuit diagram for evaluation of I-V and P-V characteristics

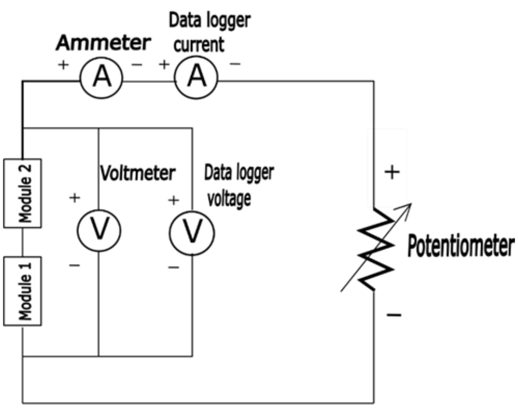

Figure 2 Circuit diagram for Series Connection

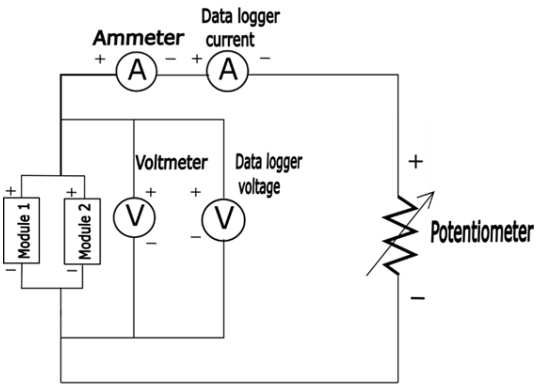

Figure 3 Circuit Diagram for Parallel Connection

2. Interconnection of solar panel modules: According to the circuit diagram Figure 2 and Figure 3 solar panels are connected in series and parallel to determine the P-V and I-V curves, adjust the load resistance and observe the interconnection of voltage and current. Multiply the measured current and voltage across the load resistance and plot against the applied voltage and the obtained P-V curve. The I-V and P-V curves are measured at an average radiation intensity of 110, 220, and 330 W/m2, respectively.

3. Variation with Tilt angle: As in Figure 4, there is only one panel in the setup. We **change** the angle of incidence of the light source while maintaining the light intensity at 330W/m2. Now to create the tilt angle effect we change the angle from 0 to 35^0 with an adjustable step of 5 degrees. Throughout the test, the load resistance is kept constant for the load conditions.

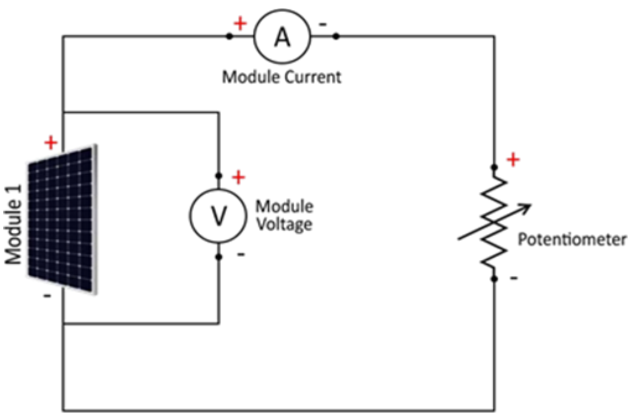

Figure 4 Effect of change in tilt angle on the output of PV modules

4. Effect of Temperature: The effect of temperature on the module can be measured by keeping the panel radiation and tilt angle constant. This can be done by solar PV under 330W/m2, the average radiation level until the solar panel temperature reaches 40^0 C., If it reaches 40 degrees Celsius, we must cool it down using a fan. Voltage and current are noted for every two-degree increase in temperature. Power output for the panel is calculated and plotted against temperature. The circuit diagram is shown in figure 5.

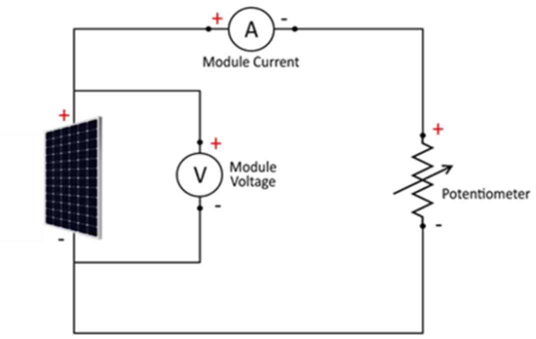

Figure 5 Effect of Temperature on Efficiency of module

5. Effect of shading and working of bypass diode: To establish the concept of shading, we need to connect the module in series, so it is first connected without the bypass diode, then it relates to the bypass diode as shown in Figure 6 and 7, where the module voltage and current are specified. For both setups. The radiation level is kept constant at 330 W/m2.

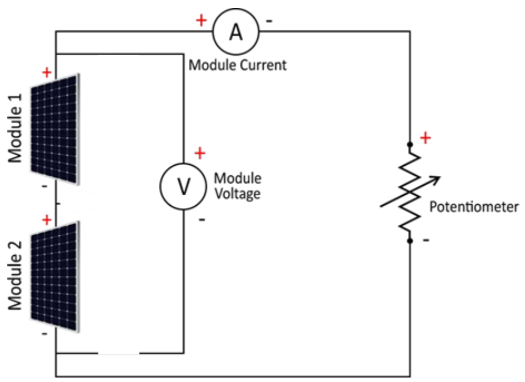

Figure 6 Series connected modules without bypass diode

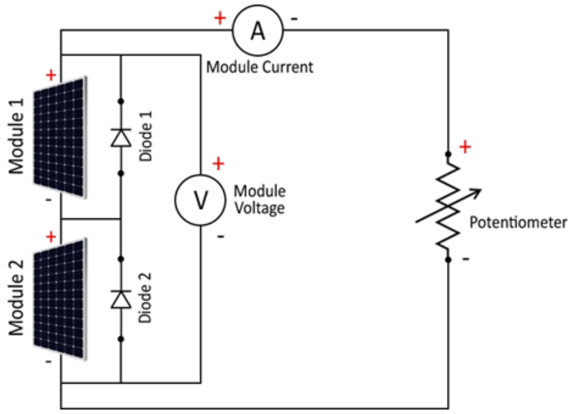

Figure 7 Series connected modules with bypass diode

III. RESULT AND DISCUSSION

1. Measuring the I-V and P-V characteristics of PV modules with varying radiation

Result-

The maximum power output of the PV module used in this experiment was 40 W. Experiments have shown that there is a change in I-V and P-V characteristics by changing the irradiance level. Maximum power output increases with increasing radiation intensity in the open state. The circuit voltage was relatively stable (16-19 volts). For example, at a maximum irradiance level of 330 W/m^2, the PV module produced a maximum power output of 6.2 W and an open-circuit voltage of 16 V. Various graphs depicting I_{sc}, V_{oc}, F.F., Pmax and efficiency were plotted versus irradiance level (see figures 8-14).

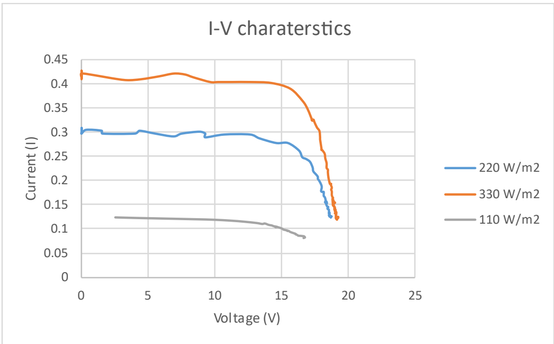

Figure 8 I-V characteristics

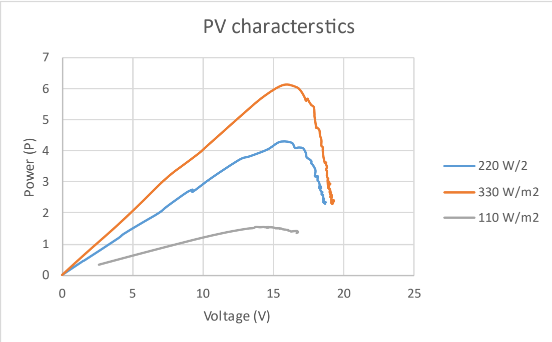

Figure 9 P-V characteristics

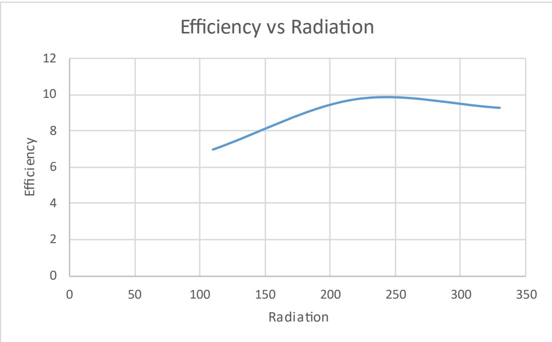

Figure 10 Efficiency v/s Radiation

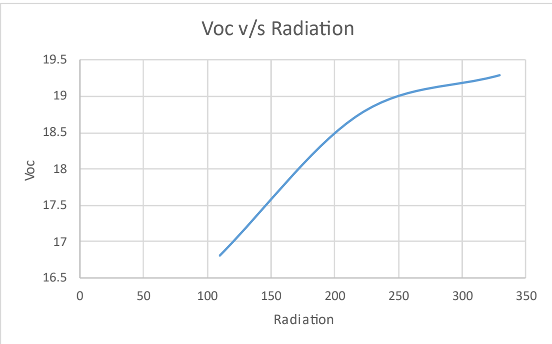

Figure 11 Voc v/s Radiation

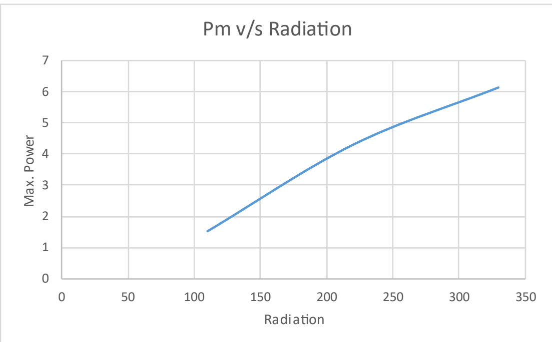

Figure 12 Pm v/s Radiation

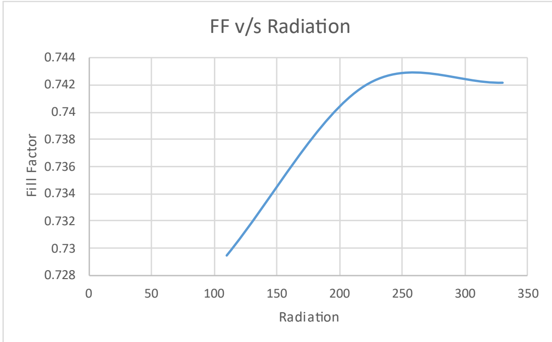

Figure 13 Fill factor v/s Radiation

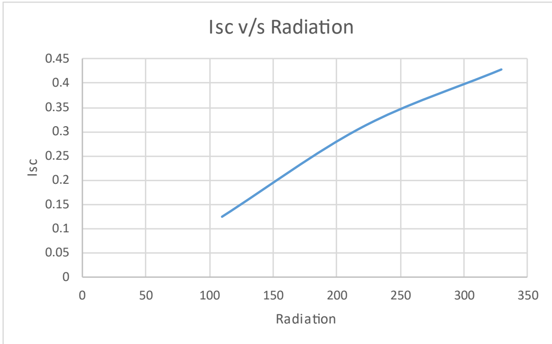

Figure 14 Isc v/s Radiation

Analysis-

The results show that the current generated by a solar PV module is directly proportional to the incident irradiance, and the efficiency increases with solar irradiance. This is because higher radiation levels provide more photons to be absorbed by the module so when additional radiation hits the solar cells, more charge carriers are excited, resulting in more current. Solar PV modules are most effective when exposed to high levels of solar radiation.

The open-circuit voltage (V_{oc}) of a solar PV module increases slightly with irradiance intensity due to variations in external factors such as ambient temperature. This trend is illustrated by the I-V curve (Fig). However, the maximum power point voltage (V_{MPP}) limits the voltage produced. The fill factor (FF) of a solar PV module is defined as the ratio of the maximum power output of the module to the product of its open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}). initially increases to maximum then decreases because as radiation increases the maximum power output increases but at higher radiation the radiation intensity factor dominates over maximum power produced.

2. To demonstrate the I-V and P-V characteristics of series and parallel combinations of PV modules.

Result-

When comparing the I-V and P-V curves of series and parallel combinations, the series combination gives a greater maximum power output than the parallel combination. This occurs because the series configuration has a larger open-circuit voltage, resulting in a higher power output at the peak of the P-V curve. Conversely, the parallel configuration has a higher short-circuit current, making it more suitable for applications requiring high current. The solar panels are connected in parallel, meaning that their output currents add up to create a higher overall current. Additionally, variations of other parameters such as I-V, PV characteristics, I_{SC}, V_{OC}, F.F., Pmax, Efficiency versus Radiation level for Series and Parallel are shown in Figures 15-21 and Figure 22-28, respectively.

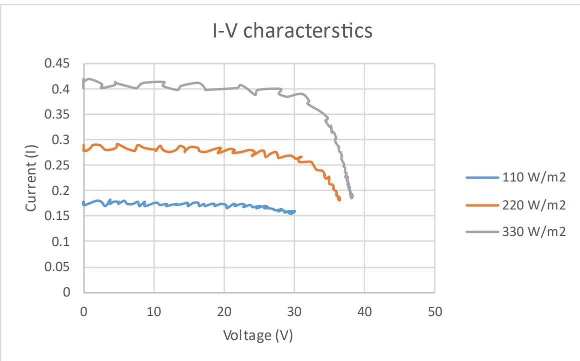

Figure 15 I-V characteristics

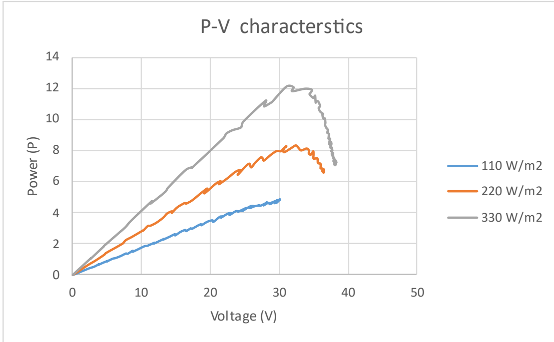

Figure 16 P-V characteristics

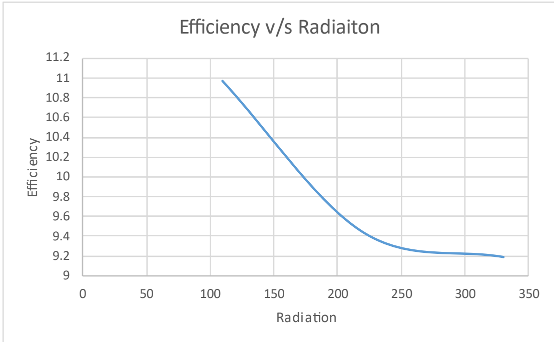

Figure 17 Efficiency v/s Radiation

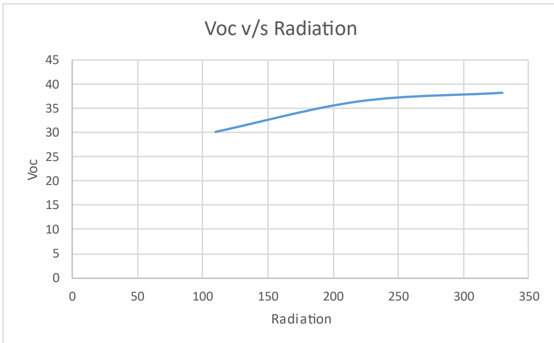

Figure 18 Voc v/s Radiation

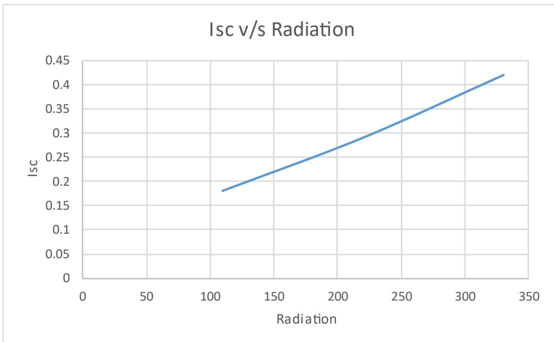

Figure 19 Isc v/s Radiation

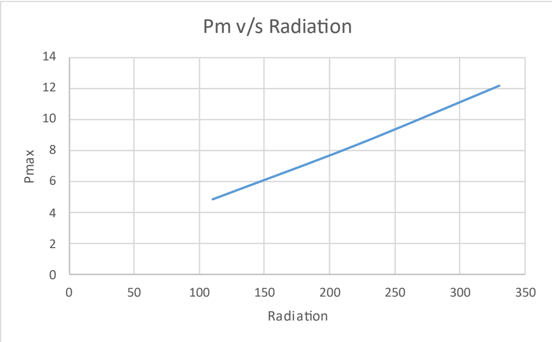

Figure 20 Pm v/s Radiation

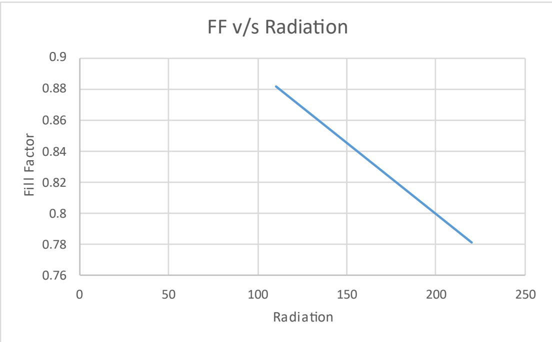

Figure 21 FF v/s Radiation

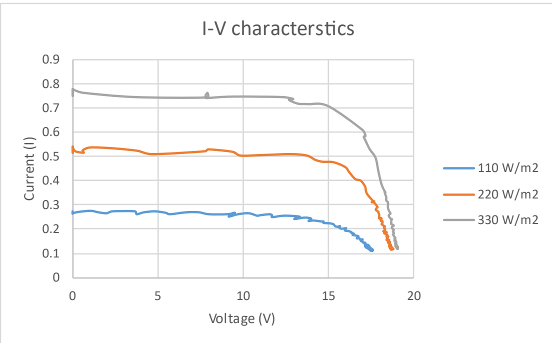

Figure 22 I-V characteristics

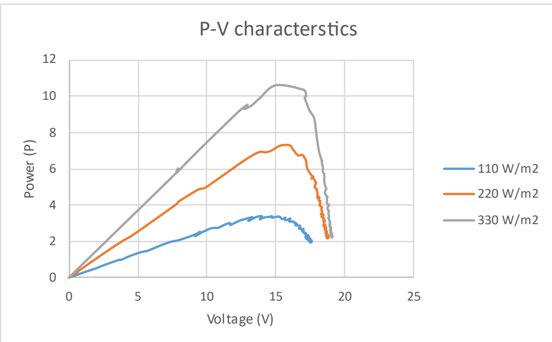

Figure 23 P-V characteristics

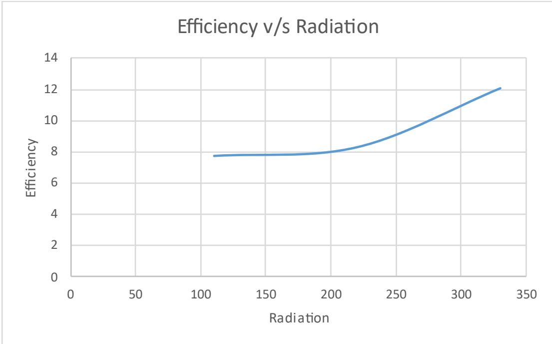

Figure 24 Efficiency v/s Radiation

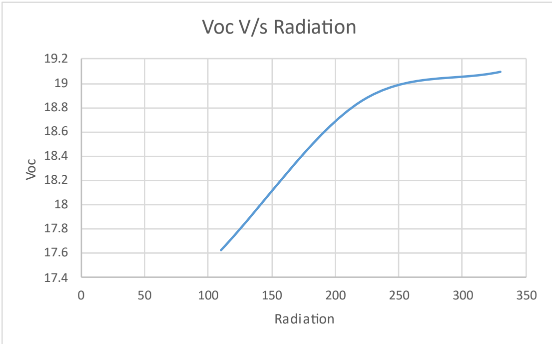

Figure 25 Voc v/s Radiation

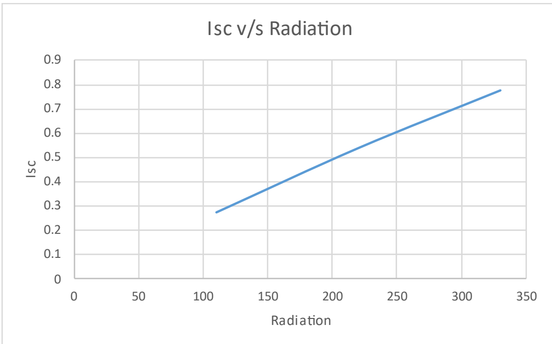

Figure 26 Isc v/s Radiation

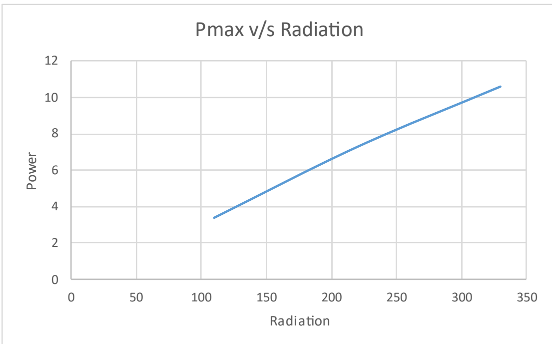

Figure 27 Pm v/s Radiation

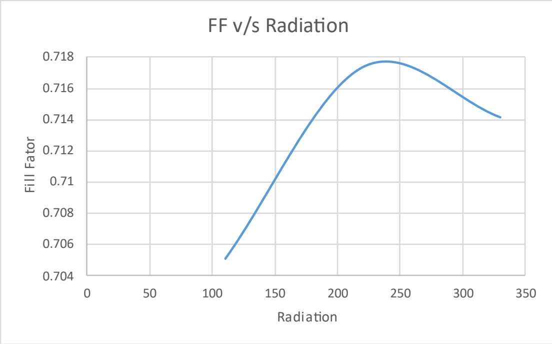

Figure 28 FF v/s Radiation

Analysis-

Solar PV modules are connected in series, where their combined voltages create a higher overall voltage. Since the current is constant across all modules, the total current output is limited by the module with the lowest output. This is due to Kirchhoff's current law, which states that the current is the same in all parts of a series connection.

Solar panels are connected in parallel, meaning the total current is the sum of the output currents from each panel, resulting in a higher overall current. This is because in a parallel connection, according to Kirchhoff's voltage law, the voltage across each panel must remain constant for the overall voltage output to remain constant.

3. To demonstrate the effect of change in tilt angle on the output of PV modules.

Result-

During the test, the angle between the source and the module is kept at 0 degrees. This changes the maximum power produced by the amount of intensity falling on the solar photovoltaic module to ensure that the entire module receives approximately the same amount of radiation. In this experiment the power is maximum (about 7W) when the tilt angle is zero degree and it decreases as the angle increases, as seen in the figure 29. It shows that the output of PV modules varies with time of day and season.

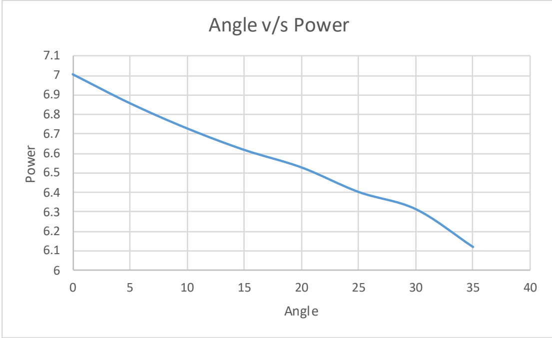

Figure 29 Angle v/s Power

Analysis-

As the angle of inclination increases, some parts of the module receive more radiation, while others receive less. Since the cells within the modules are connected in series, the total current output is limited by the output of the weakest cell in the series, which is the cell receiving the lowest radiation intensity. Due to this the overall module current decreases as the angle of inclination increases. This relationship is clearly shown in the figure, where the maximum power decreases with increasing tilt angle. So to maximize the daily solar radiation falling on the PV module, it must be installed with optimal orientation and tilt angle. Consequently, the tilt angle depends on the latitude of the location where the solar panel is installed.

4. To demonstrate the Effect of Shading on the Efficiency of the module.

Results-

When shading occurs, the shaded module produces no output power. However, when the shaded module is bypassed using a diode, the other modules can still generate power. This is because the bypass diode allows current to flow around the shaded module, enabling the other modules to function normally and generate power.

Analysis-

When a single module is shaded without a bypass diode, the output drops to zero because there are no effective charge carriers, essentially behaving like an open circuit. As a result, the functionality of the module drops to zero. However, when the shaded module is bypassed with a bypass diode, the other modules can still generate power because charge carriers are being generated. The current bypasses the shaded module, effectively behaving like a closed circuit. However, due to the resistance of the bypass diode, the overall power output will be less than in single module applications.

5. To demonstrate of blocking diode

Results-

When the blocking diode is not connected in the circuit, LED glows up and when the blocking diode is introduced in the circuit, LED stops to glow.

Analysis-

When the blocking diode was not in circuit, the battery was draining because the solar module drew power from the battery during the night because it behaved like a closed circuit.

Now when the blocking diode was introduced in the circuit, the LED stops flashing because the diode blocks the current supply from the battery to the module as it is in reverse bias.

6. To demonstrate the effect to temperature on power output:

Results-

It has been found that the output power of solar PV modules varies with temperature changes. The output power decreases almost linearly with increasing temperature. This trend can be seen in figure 30.

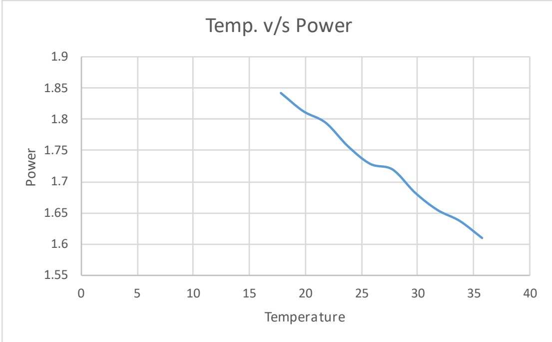

Figure 30 Temperature v/s Power

Analysis-

The output power of solar PV modules decreases with increasing temperature. This is because the internal carriers of the material increase exponentially as the module temperature increases, leading to an increase in the dark saturation current. This increase in dark current results in a decrease in the open-circuit voltage (V_{oc}). However, increasing the temperature also decreases the band gap of the material. As a result, the material can absorb low-energy carriers, thereby increasing the photocurrent (I_{sc}). Despite this increase in I_{sc}, the loss in V_{oc} is greater than the gain in I_{sc}, resulting in a net reduction in the module's power output.

IV CONCLUSION

V ACKNOWLEDGEMENT

We would like to express our sincere gratitude towards Department of Sustainable Energy Engineering, Indian Institute of Technology, Kanpur for providing us with the opportunity to conduct our research experiment in the lab. We would also like to express our gratitude to our esteemed professors, Dr. Sudarshan Narayanan and Dr. Jishnu Bhattacharya for their input during the experiment and Mr. Chandan and Dr. Deepika Jhajharia for setting up the system. Lastly, we would like to thanks our lab teaching assistant, Ashutosh Shandilya for his support during experiment.

VI REFERENCES

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