PERFORMANCE OF PHOTOVOLTAIC SYSTEMS IN SERIES AND PARALLEL CONNECTION: A COMPREHENSIVE RESEARCH STUDY

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ABSTRACT. This comprehensive research study investigates the performance of photovoltaic (PV) systems in series and parallel connections. The study explores the theoretical aspects and electrical characteristics of these connection configurations, including voltage-current (V-I) curves, power-voltage (P-V) curves, and maximum power points (MPPs). Experimental investigations are conducted using a real-life PV system setup solar module. Detailed measurements of current, voltage, and power are recorded under varying resistance. The collected data are analysed to compare the performance of series and parallel connections in terms of system efficiency and power output. The research findings reveal that series connection yields higher voltages, while parallel connection provides higher currents. Series connection demonstrates higher overall system efficiency, particularly in low solar irradiance situations. On the other hand, parallel connection is less efficient than series connection regarding to this experiment. Overall, this research study offers valuable insights into the performance characteristics of PV systems in series and parallel connections. The findings provide guidance for optimizing the configuration of solar modules based on specific environmental and operational conditions. This contributes to enhancing the efficiency, and power output of PV systems, promoting the widespread adoption of solar energy as a sustainable solution for a greener future.

KEYWORDS : photovoltaic; series; parallel; current; voltage

1 INTRODUCTION

The utilization of renewable energy sources has become increasingly crucial in addressing the pressing challenges posed by climate change and the global demand for sustainable power generation. Among the various renewable energy technologies available, photovoltaic (PV) systems have emerged as a promising solution, harnessing the power of sunlight to generate clean electricity. The performance optimization of PV systems has garnered significant attention as researchers and engineers strive to improve their efficiency, reliability, and overall power output (Muhammad Hafeez Mohamed Hariri, 2020)In terms of deployment rate, solar photovoltaic, or PV, is the most exploited RE source, alongside hydro and wind power, and it is considered a very promising source of future electrical power generation due to the abundance of sunlight over a large area of the earth's surface, giving rise to several applications of PV systems.

A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light (A. S. Sedra 2006). Photovoltaic systems can be interconnected in two primary configurations: series and parallel connections. The choice of connection scheme has a profound impact on the system's overall performance, including its electrical characteristics, power output, and resilience against various factors such as shading, module mismatch, and aging effects. In order to increase the voltage and current and eventually the overall output power of the system, modules in the strings or cells in a single module are connected in series and parallel respectively. (S.K. Sahoo, 2020). However, a comprehensive understanding of the performance of PV systems in both series and parallel configurations is essential for designing efficient and reliable solar power installations.

In a series-connected PV system, individual solar modules or panels are linked together in a sequence, forming a chain-like configuration. This arrangement allows the current passing through each module to be the same, while the total voltage across the system is the sum of the individual module voltages. The advantage of a series connected cell string is the increased voltage values but the problem arises when one or more cells in a string are subjected to full or partial shading due to passing clouds and neighbouring houses. (Moein Jazayeri,2013)

On the other hand, parallel-connected PV systems involve connecting multiple modules or panels in parallel, creating multiple current paths while maintaining the same voltage across each module (Campbell, 2007). This configuration allows the system to mitigate the effects of shading or module mismatch, as the shaded or underperforming modules do not substantially affect the output of the other modules. (Ahmad, 2018)Parallel connection provides higher current output, which can be advantageous in applications where high current demands exist, such as charging electric vehicles or powering specific appliances. However, the voltage output of parallel-connected systems is limited to that of a single module, which can impact efficiency in applications requiring higher voltage levels.

This research will involve rigorous experimentation and simulation to evaluate the performance of PV systems under various operating conditions, including different levels of irradiance, temperature, shading scenarios, and module characteristics. By analyse the data obtained, we aim to determine the impact of series and parallel connections on system efficiency, maximum power point tracking (MPPT) accuracy, and overall power output.

2 OBJECTIVES

Hybrid or standalone solar PV system harvesting solar energy through the solar PV panel. The solar PV panel generate electricity and stored the energy in the storage medium like battery. When the sunray going off, the energy supply to the consumer using a typical system includes solar PV modules, battery, inverter, charge controller and load. The performance of the solar PV system can be observed in various specification and one of them is the type of solar PV Panel Connection. The objectives in this research study are:

i. To connect the two PV modules in series and parallel combinations
ii. To determine the specification of different configuration two PV Modules.
iii. To compare the data specification of different configuration two PV Modules.
iv. To determine the efficiency of PV based on measured data specification different configuration two PV modules

3 PROCEDURE / METHODOLOGY

The arrangement or configuration of solar photovoltaic module output characteristics provide the most trustworthy and valuable information throughout system analysis and design operations (Srinivasan. V, 2017). In this investigation, numerous experiments have been conducted according certain considerable parameter and provided equipment.

3.1 Setting of Experiments

The thin film 50W 20V 2 A PV module that was used in the experiment. Two units of PV modules are being used. A minimum of two PV module units are needed to conduct performance testing on PV modules in series or parallel.

To alter the circuit's resistance and hence the current, a rheostat is employed. The rheostat used as a load in this experiment was set at 450 ohms and will be reduced by 50 ohms to get the results for current and voltage.

The exact coordinates for this experiment's site are 3.125761 latitude and 101.655535 longitude. Because each experimental coordinate that is used will yield different findings, determining the coordinates is crucial.

The ambient temperature for this experiment was between 32 and 35 degrees Celsius, which was between 10.00 am to 11.00 am in the morning. The current and voltage at different resistances are measured using additional tools like DC and AC voltmeters.

3.2 Experiment Parallel Connection PV Modules

In carrying out the test of PV modules connected in parallel, the PV connection, rheostat and ammeter and voltmeter are connected as shown in Figure 1. The voltage and current reading is recorded when the rheostat used as an adjustable load is set to a reading of 450 Ω. The voltage and current readings are continuously recorded until the minimum or zero resistance is set on the rheostat. When the resistor set on the rheostat approaches zero, record the current reading. The current is short current, I_{SC} of this experiment. In order to get a clear characteristic of connecting PV modules in parallel, I-V curve and P-V curve are plotted. The maximum power, Pm also can obtained from the graph plotted.

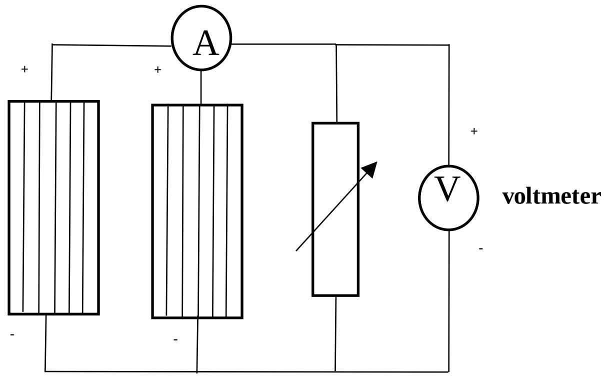

Figure 1: Circuit for parallel connection combination of PV modules

3.3 Experiment Series Connection PV Modules

This section describes the experiment of PV modules connected in series. PV module connection, rheostat ammeter and voltmeter are connected as shown in Figure 2. At the beginning of the experiment, the current and voltage values are recorded when the rheostat is set to 450 Ω. The process of recording the current and voltage values is repeated by changing the resistance value until it approaches zero. When the resistance value set on the rheostat is zero, the resulting current value is the short current, I_{sc} value of this experiment. Similarly with previous method, I-V curve and P-V curve are plotted to get summarize the characteristic of connecting PV modules in series. The maximum power, Pm also can obtained from the graph plotted.

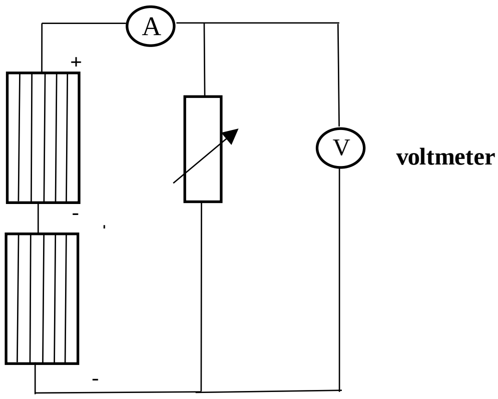

Figure 2: Circuit for series connection combination of PV modules

4. RESULT AND ANALYSIS

This part of the paper includes analyses of the data obtained from the measured parameter during the period of the experimental works. The analysis divided into 2 main groups as follow :

i) Analysis of Series Connection of two PV Modules.
ii) Analysis of Parallel Connection of two PV Modules.

4.1 Analysis of Series Connection of Two PV Modules

From the experiment, two PV Modules are connected in series and parallel with rheostat which act as dummy load, the configuration shown in Figure 1. This dummy load used for monitoring the power transfer from source of power to the designation load.

The PV module specification used in Series Connected Two PV Modules are presented in Table 1. This parameter is according to the average Solar Irradiance 520.8 W/m^2, 52% of Solar Irradiance for Standard Testing Condition.

Table 1: Series Connected PV Modules Data Specification

Electrical Parameter	**Data Obtained**
Short-circuit current (Isc)	1.073A
Open-circuit Voltage (Voc)	39.01 V
Maximum Power (Pmax)	26.9W
Maximum Voltage (Vmax) @ Vmp	36.5V
Maximum Current (Imax) @ Imp	0.737A
Fill Factor (FF)	0.643
Efficiency (η)	61.2%

The I-V and P-V characteristics of the Two Series PV Module are obtained from the highest resistance level to the lowest resistance level under various solar irradiance value. The output characteristics of the PV modules were measured for and the results are illustrated in Figure 3.

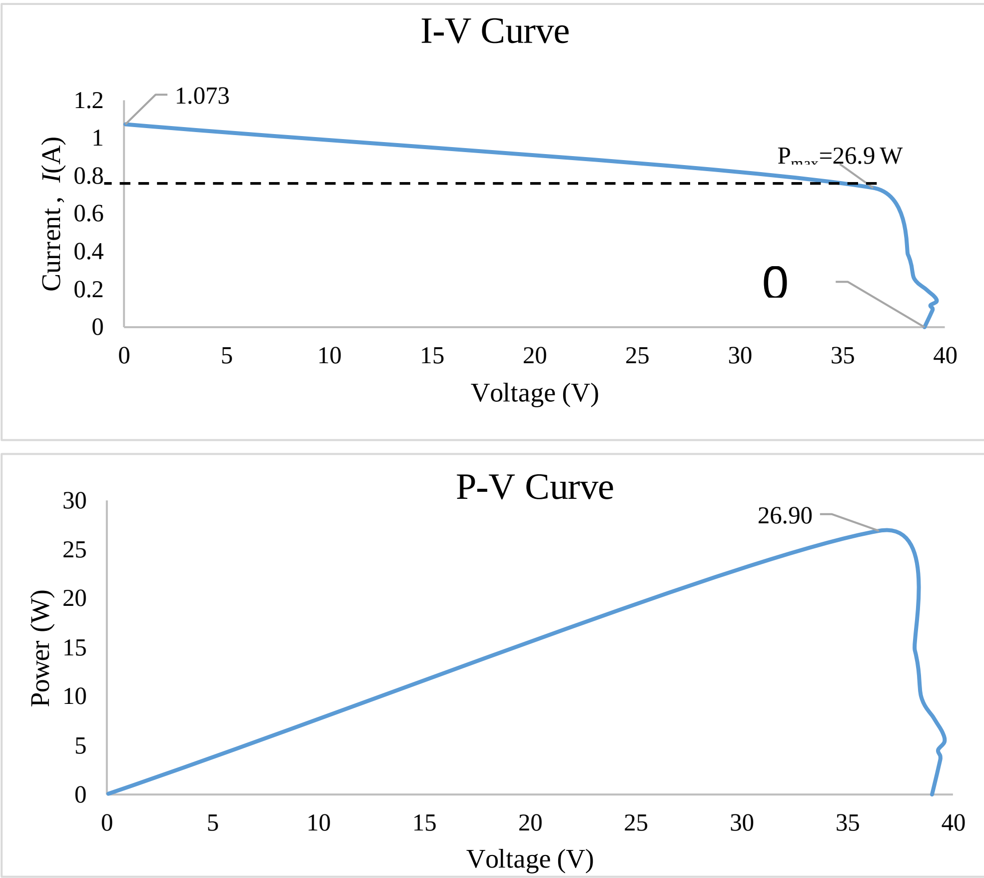

Figure 3: Characteristic *I-V & P-V Curve for Series Connection of Two PV Modules*

According to the results, series connection of the modules has created the opportunity to obtain higher voltage output while the output current of the two series connected PV Module proportionally inverse to the output voltage. The result show that the power obtained from experiment achieve maximum value 26.9 W, at the maximum voltage of 36.5 V. It is observed that during the peak value of output voltage and current, the resistance of the load at minimum value.

4.2 Analysis of Parallel Connection of Two PV Modules

In another experiment, two PV Modules connected parallel. Similar with the series of two PV Modules, the parallel PV Modules connected parallel with the rheostat which act as load to determine the power transfer to the simple load. The circuit configuration of two parallel PV modules shown in Figure 2.

The PV module specification used in Parallel Connected Two PV Modules are presented in Table 2. This parameter is according to the average Solar Irradiance 412.4 W/m^2, 41.2% of Solar Irradiance for Standard Testing Condition.

Table 2: Parallel PV Modules Data Specification

Electrical Parameter	Data
Short-circuit current (I_{sc})	1.852 A
Open-circuit Voltage (V_{oc})	19.35V
Maximum Power (P_{max})	7.3W
Maximum Voltage (Vmax) @ Vmp	18.95V
Maximum Current (Imax) @ Imp	0.385A
Fill Factor (FF)	0.204
Efficiency (η)	η =17.3%

The I-V and P-V characteristics of the Two Parallel PV Module are obtained from the highest resistance level to the lowest resistance level under various solar irradiance value. The output characteristics of the PV modules were measured for and the results are illustrated in Figure 4.

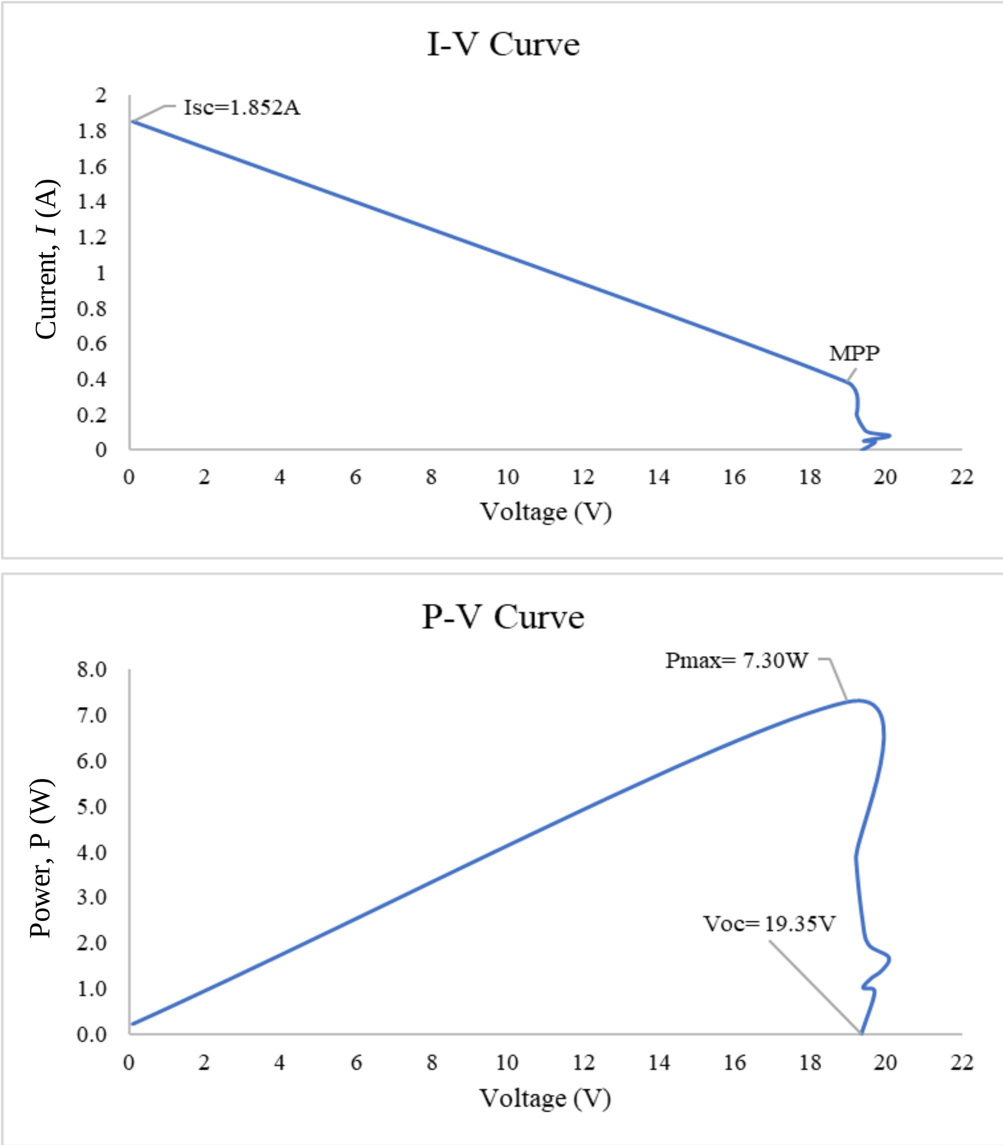

Figure 4: Characteristic *I-V & P-V Curve for Parallel Connection of Two PV Modules*

According characteristic I-V curve, two parallel PV modules connection generate lower maximum voltage output but the maximum output current higher than output current on Figure 4. This result obtained at the average solar irradiance. The output voltage was similar to each PV Modules output voltage under average solar radiance. The result show that the power obtained from experiment achieve maximum value 7.3 W, at the maximum voltage of 18.9 V. Based on the P-V Characteristic at 50Ω resistance, the power is at the maximum point.

The numerical measurement results obtained with series and parallel two PV Modules are presented and compared in Table 4.

Table 4: Comparison of Measurement Between Two PV Modules Configuration

Pv Module Configuration	V_{oc}(V)	I_{sc}(A)	P_{max}(W)	Average Solar Irradiance (W/m^2)
Series Connection Two PV Modules	39.01	1.073	26.9	520.8
Parallel Connection Two PV Modules	19.35	1.852	7.3	412.4

As summary of result obtain from the experiment, it is found that there had comparison of data specification measured from two types of Two PV Modules Configuration. The data measured are affected by the energy harvested from the source of solar irradiation which is sunray. The series configuration two PV Modules generate higher maximum power as compare to parallel two Modules

5 RECOMMENDATION AND CONCLUSION

From the experiments, it is recommended to connect panels in series of the same current than in parallel connection between the PV modules. This is because the experiments prove series connection almost produce 4 times greater than parallel connection maximum power generated by two PV modules under the average solar irradiation.

Solar modules are interconnected with different configurations to meet the desired application requirements (Moein Jazayeri, 2013). The results of the experimental analyses in this study confirm the direct relationship between power generation in solar modules and connection of two PV Modules in series or parallel configuration. Parallel connection of modules leads to higher amounts of current under identical illumination but in the case of partial or full shading of modules, the current output is subjected to reductions while the output voltage remains unchanged.

The findings of this research are expected to contribute valuable knowledge and insights to the field of photovoltaics, helping system designers, installers, and policymakers make informed decisions regarding the optimal configuration and operation of PV systems. Ultimately, this research aims to advance the adoption of photovoltaic technology, enabling more efficient and reliable solar energy utilization on a global scale

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