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Experimental Performance Characterization of Photovoltaic Modules Using DAQ

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Abstract

This paper presents a simple electronic circuit for testing the photovoltaic (PV) modules by tracing their I-V characteristics. A precise PV module electrical model is also introduced. The circuit consists of a fast varying electronic load based on power MOSFET and operational amplifier. A DAQ system with LabVIEW application was developed for controlling the MOSFET gate-source voltage. The circuit is designed, implemented and tested under real conditions. The experimental results verified with simulation results and another way of testing which is resistor method.

Keywords: Photovoltaic Modules; I -V and P -V Characteristics; LabVIEW

1. Introduction

Photovoltaic (PV) is a clean and reliable source of energy and can be found in urban and rural areas where no grid is available. PV installations have been growing with a significant increase in many countries over the past five years with average annual growth rate of over 50% as reported in [1].

As the growth in the PV sector, it is essential to have accurate measuring system to evaluate the PV module performance and reliability especially for PV module designer and manufacturers to improve their modules during development. On the other hand operators and customers are targeting a faultless operation of the PV modules.

The manufacturer's current voltage characteristics are utilized to obtain the PV module parameters as short circuit current (I_{SC}), open circuit voltage (V_{OC}), maximum power (P_{max}) and fill factor (the ratio of

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the actual maximum obtainable power to the product of the open circuit voltage and short circuit current). This is carried out under a standard test condition (STC) 1000 W/m^2 of irradiance, 25 $^{\circ}$C cell temperature and air mass 1.5. However, this process is executed outdoor where the environmental conditions are distant from these conditions.

The measurements of I-V Characteristics have been developed over the past decade. In [2] a personal computer, data acquisition system with its software and programmable electronic load were proposed to trace the I-V characteristics each two hours automatically. A low cost measuring system was designed by [3] for measuring the I-V characteristic of seven modules. A set of mechanical relays are used to select a parallel combination of resistors to act as resistive load another set of mechanical relays are used for PV module selection. A MOSFET based electronic load circuit was introduced in [4] where a fast scanning monitoring system was achieved. In [5] the work was based on the electronic load circuit presented in [4] but with designing and implementing data acquisition system using AVR microcontroller. An improved MOSFET based electronic load was attained in [6] through controlling the gate voltage by a Pulse width modulation circuit. The circuit was developed in [7] with low-cost DAQ system in order to enhance the trace of the I-V characteristic.

Another way is considered in studying the photovoltaic effect by modeling and simulation using two methods. The first method is mathematical modeling where the photovoltaic diode characteristic is used to study the PV behavior as in [8]. The second one is circuit modeling where the photovoltaic is represented by a combination of passive circuit components such as diode, resistors and capacitors. Using a circuit simulator the photovoltaic behavior could be determined as in [9].

In this paper, a measurement system is implemented to trace the I-V and P-V characteristics for PV modules. MOSFET acting on the active region is used as electronic load where its equivalent resistance is controlled through the gate voltage by generating a saw-tooth signal using a low cost NI-DAQ. This process is done under different configurations. The effect of fully and partially shaded PV modules is also taken into consideration.

2. Experimental setup

The I-V and P-V characteristics of four polycrystalline PV modules were traced using the circuit shown in Fig. 1. The circuit is based on MOSFET IRFP260N as a varying electronic load with heat sink to dissipate the power. The characteristics of the MOSFET in both linear and saturation region are described respectively by [10]:

$$I_D = K_N(2(V_{GS} - V_t)V_{DS} - V_{DS}^2) \quad (1)$$

$$I_D = K_N(V_{GS} - V_t)^2 \quad (2)$$

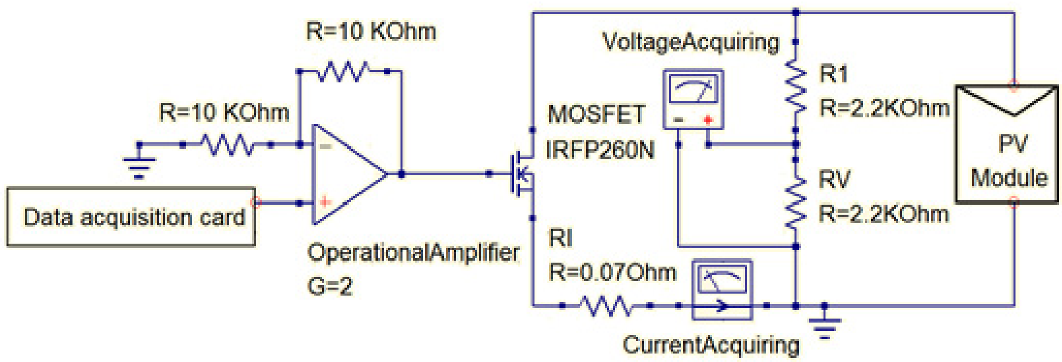

Fig. 1. Electronic circuit for tracing I-V and P-V characteristics of photovoltaic modules

Where V_{GS} is the gate-source voltage, V_{DS} the drain-source voltage, K_N the device constant, V_t the threshold voltage and I_D the drain current of the MOSFET. As V_{GS} is less than the threshold voltage V_t, the MOSFET will be OFF. When V_{GS} is increased above V_t, the MOSFET will operate in the saturation region and the drain current rises quadratically with V_{GS}. At lower solar module voltage the operating point of the MOSFET shifts to the linear region where the drain current changes linearly with V_{GS}. Thus, by sweeping the gate voltage the operating point of the MOSFET sweeps the I-V characteristic of the module between V_{OC} and I_{sc} as shown in Fig. 2.

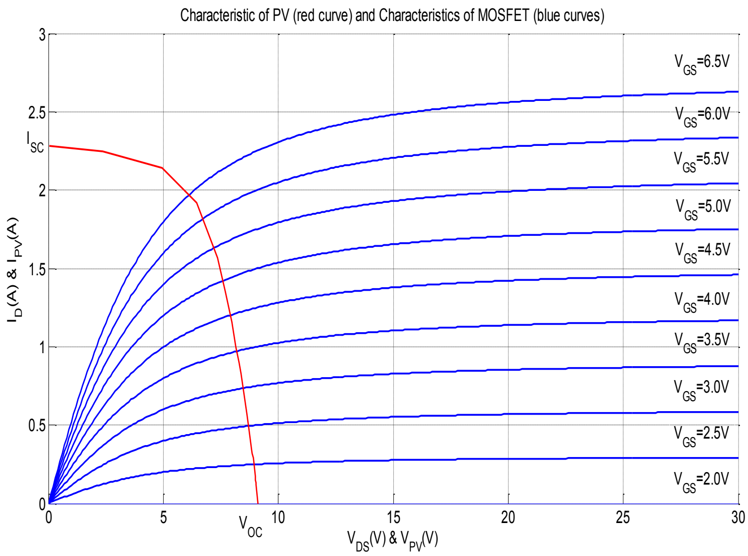

Fig. 2. Characteristic of a PV module (red curve) and characteristics of MOSFET (blue curves)

The gate voltage is controlled using DAQ system. This system is based on NI-USB 6008 with a sample rate of 10Ks/s, laptop and LabVIEW application. The LabVIEW application shown in Fig. 3 is used to generate a saw-tooth signal to vary the gate voltage from 3.4V to 5.5V through the analog output of the NI-USB 6008. This range cannot be obtained as the analog output maximum voltage swing is 5V so an amplifier circuit LM741 with gain two was used and the voltage generated was adjusted to vary from 1V to 3V. Since the MOSFET cannot withstand a high power for more than some milliseconds the signal varied with high frequency about 0.166Hz and 1000 points per cycle.

The PV voltage is acquired through two high power resistors (R_1 & R_v) with high value comparable with that of the electronic load to draw small current, in order not to affect the PV operating point. As the maximum input voltage allowed by the DAQ is 10V, the two resistors are connected as voltage divider to avoid exceeding the input range. The PV current is acquired through high power resistor with low value (R_I) so that its voltage drop could be neglected.

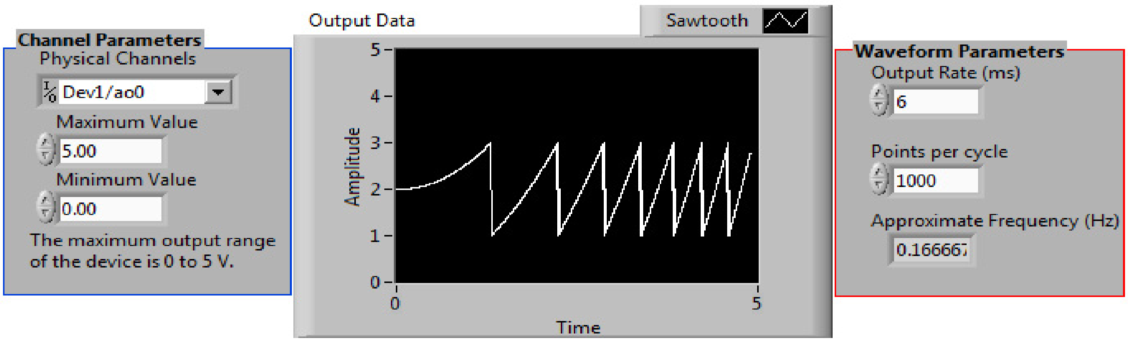

Fig. 3 Saw-tooth signal generated by LabVIEW application

3. Simulation

In this section Matlab/Simulink simulation for a single PV is presented. The equivalent circuit of the PV model is shown in Fig. 4, where it consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow. The voltage-current characteristic equation of a solar cell is given as [11].

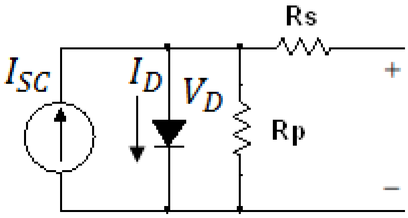

Fig. 4. The circuit diagram of PV model

$$I_D = I_o[e^{(\frac{V_D}{V_T})} - 1] \quad (3)$$

Current-input PV module is presented in modeling the characteristics of a PV module. The Simulink functional block diagram is shown in Fig. 5 where the system inputs are the isolation and PV current while the output are PV voltage and power. The developed model considers the number of cells, series resistor and shunt resistor. Fig. 6 shows a masked block diagram for the model developed in Fig. 5.The I-V and P-V characteristics outputs are shown in Fig. 7 and 8 respectively.

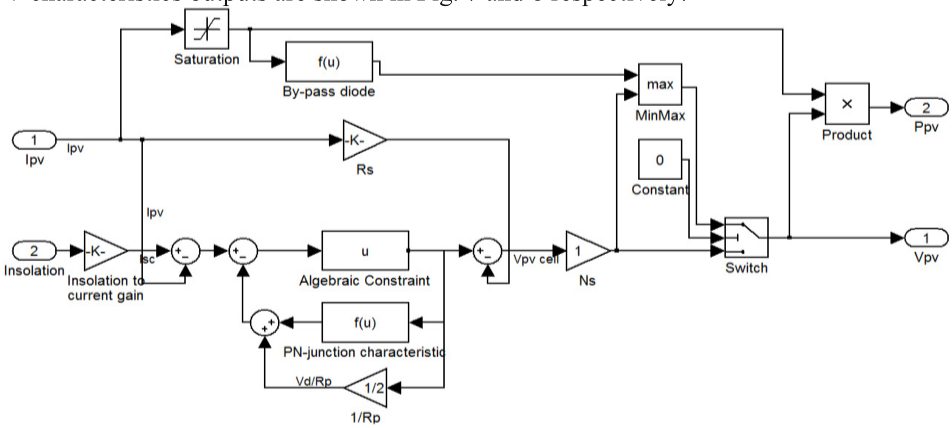

Fig. 5. Current input PV module Simulink block diagram

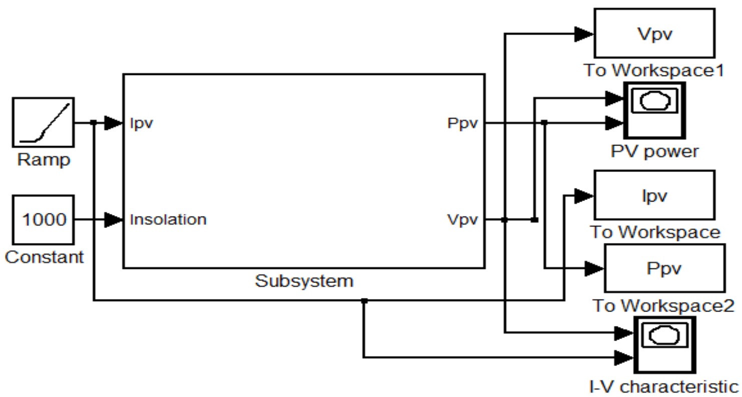

Fig. 6. Current input PV module Simulink block diagram (Mask)

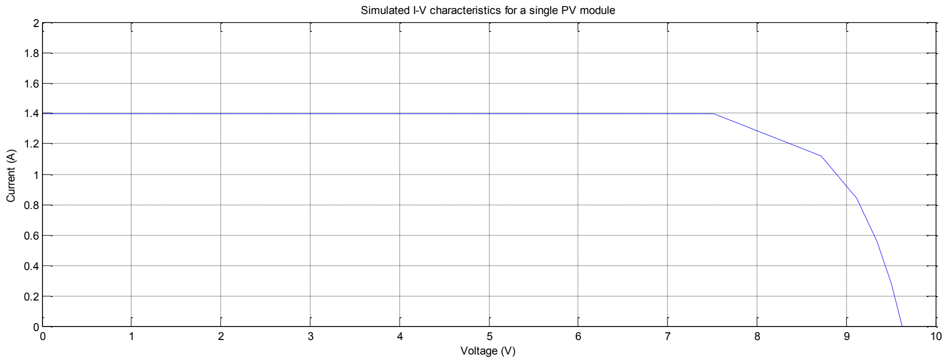

Fig. 7. I-V characteristics using Simulink

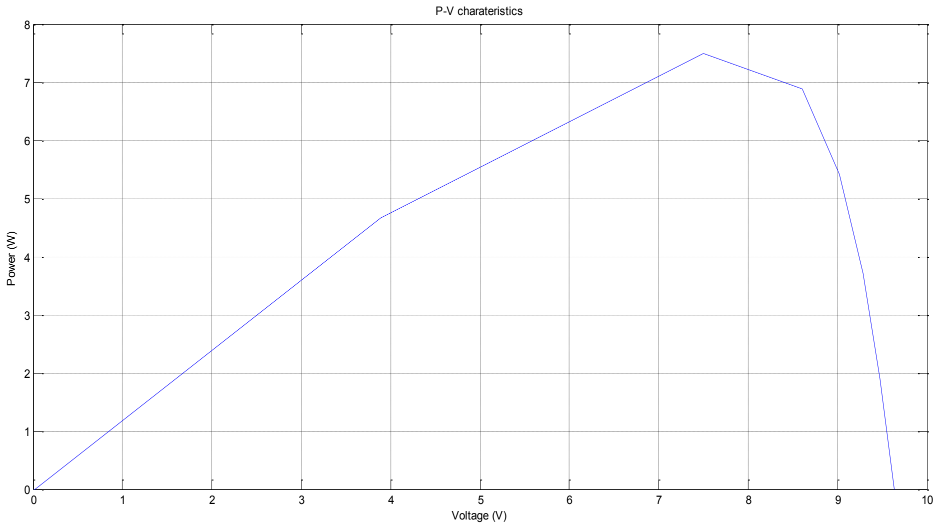

Fig. 8. P-V characteristics using Simulink

4. Results and discussion

With the aid of the electronic circuit described in the experimental setup section, the I-V characteristics was traced for polycrystalline PV modules which have the following parameters at standard test conditions AEG-TSG 20 cells in series 12 W, I_{sc}=2.28 A, V_{oc}=9.6 V. The modules placed on the roof of a building with 30° inclination, in order to achieve the best performance. The measurement was performed on single module, two modules in series, two modules in parallel and four modules connected as shown in Fig. 9 with and without shadowing.

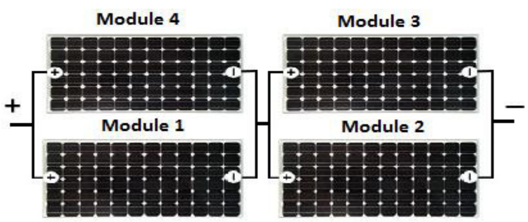

Fig. 9. Parallel – series connection

A comparison between two different I-V tracing methods was illustrated in Fig. 10 using either an electronic load circuit or a combination of high power resistors. These output characteristics are taken under irradiance 920 W/m^2 where the maximum power observed was about 7.9 W, I_{SC}=1.4 A and V_{oc}=9.4 V. The first method outperforms the second one regarding accuracy and tracing speed however, more ripples appears due to high frequency and sampling rate. Power and irradiance variation across day was observed in Fig. 11 where a maximum power of 8 W was detected.

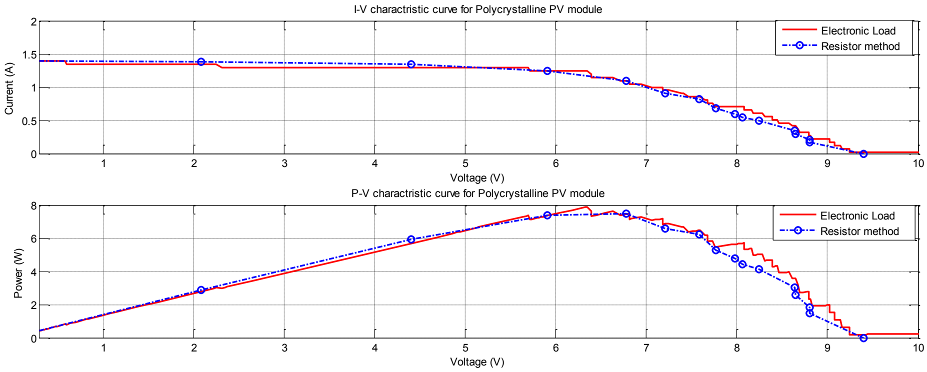

Fig. 10. I-V and P-V characteristics for a single PV module the red curve measured with the electronic load and the blue measured with a combination of resistors.

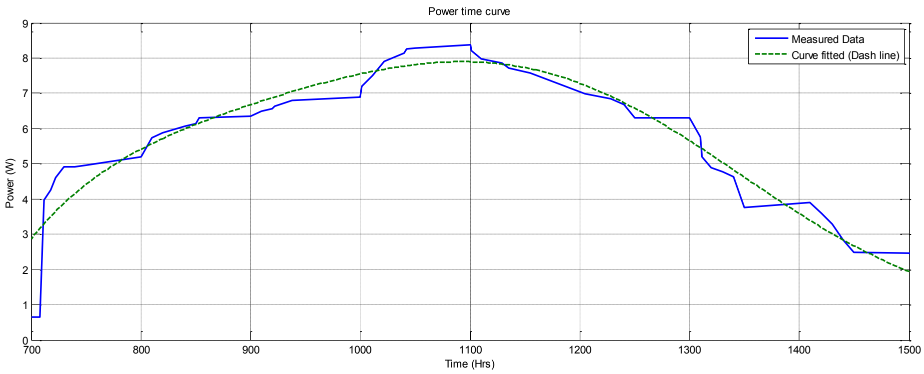

Fig. 11. Power variation across day for a single PV module

Fig. 12 and 13 shows the I-V and P-V characteristics of two PV modules connected in parallel and series respectively. Fig. 14 and 15 show I-V and P-V characteristics under the effect of shadowing on same connections. As expected the shadowing effect is clearer in the case of series connected PV modules rather than the parallel connected one. This is due to the fact that shadowing in the series connected branch causing current limitation on the branch which reflects on the total output power observed.

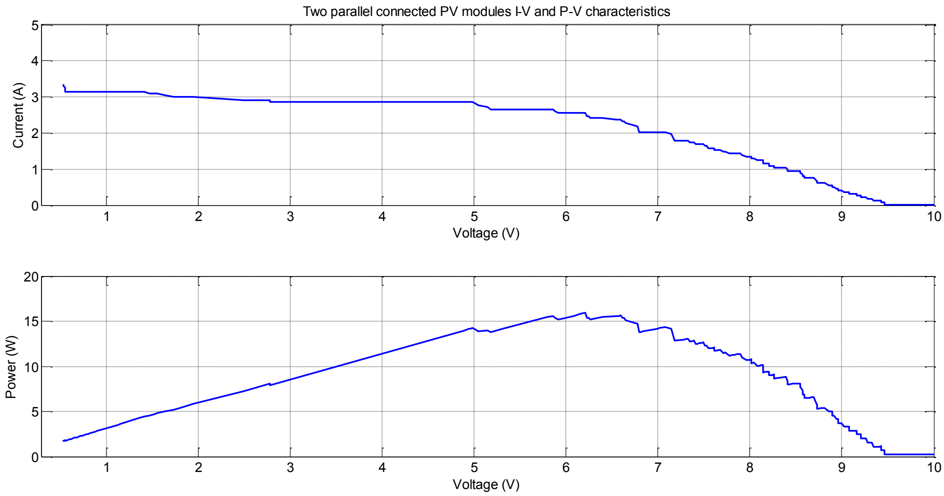

Fig. 12. I-V and P-V characteristics of two parallel connected PV modules

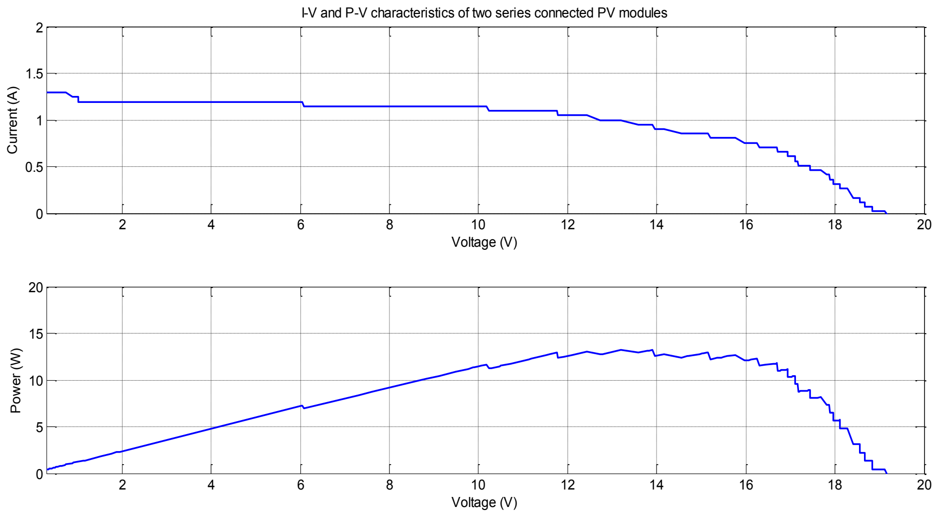

Fig. 13. I-V and P-V characteristics of two series connected PV modules

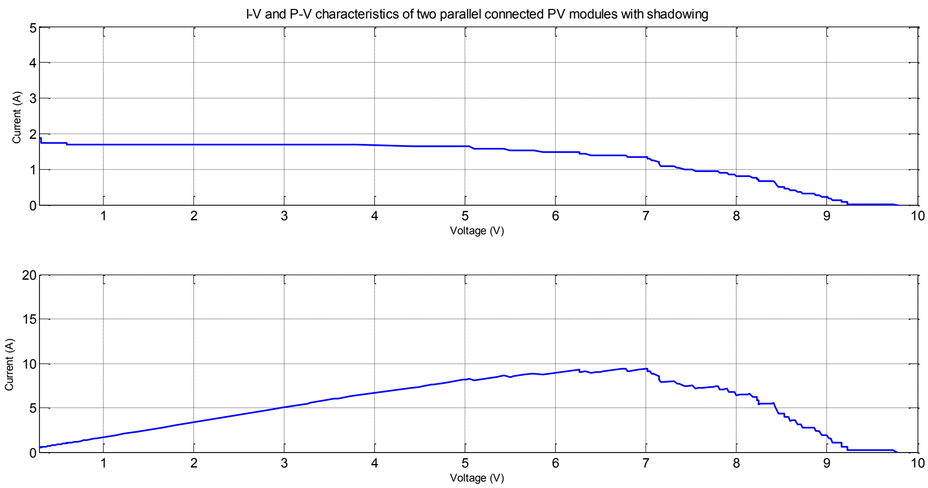

Fig. 14. I-V and P-V characteristics of two parallel connected PV modules with shadowing

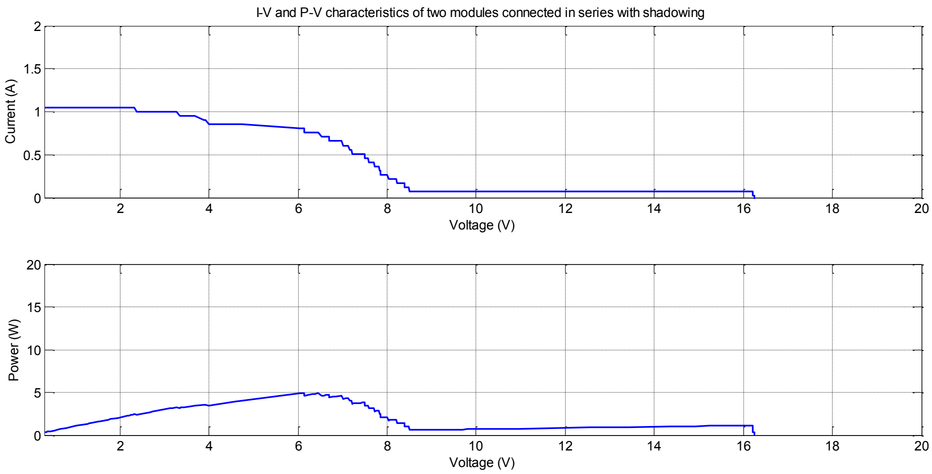

Fig. 15. I-V and P-V characteristics of two series connected PV modules with shadowing

The I-V and P-V characteristics of four PV modules connected as shown in Fig. 9 are shown in Fig. 16. The short circuit current is found to be I_{sc}= 3.2 A, the open circuit voltage V_{oc}= 18.38 V, and the maximum power about P_{max}=32 W. while Fig.17 shows the I-V and P-V characteristics for the same configuration with shadowing effect on module 1 and 3, where the observed reduction in the I_{SC} and V_{OC} is reflected on the maximum power.

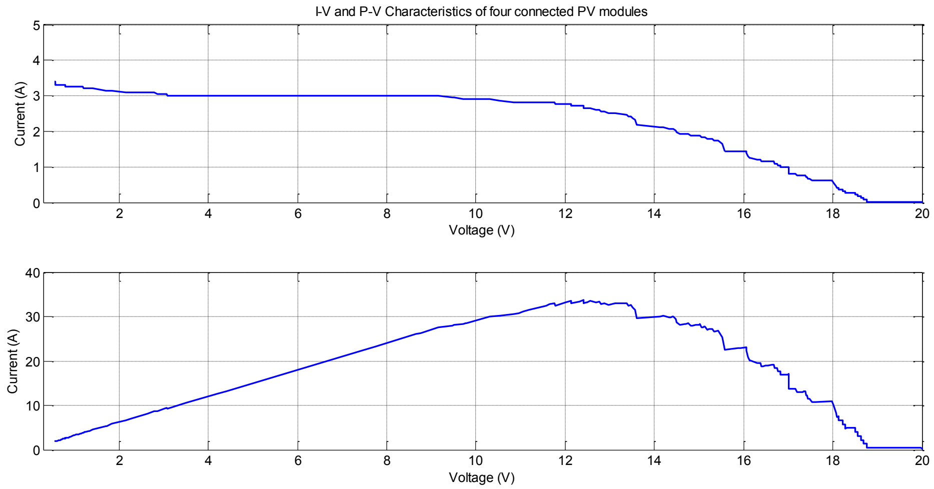

Fig. 16. I-V and P-V characteristics of four connected PV modules

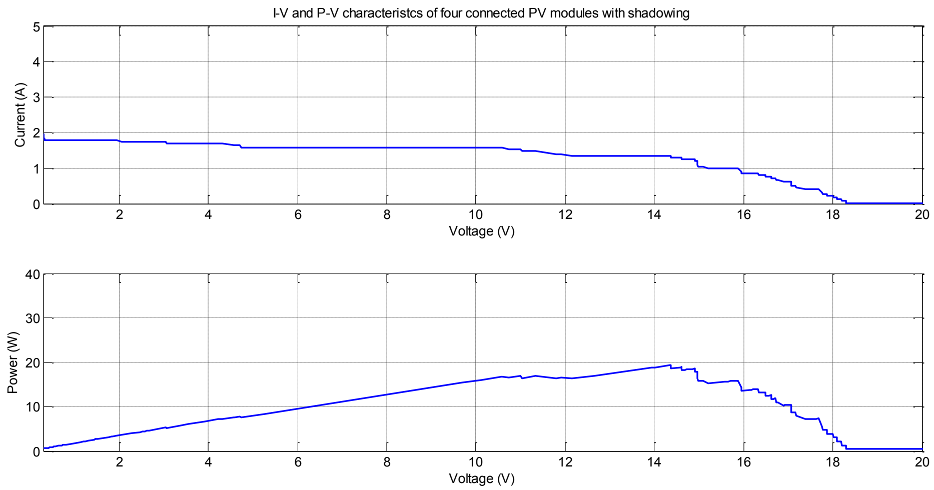

Fig. 17. I-V and P-V characteristics of four connected PV modules with shadowing

5. Conclusion

This paper presents an electronic circuit for monitoring the I-V and P-V characteristics of photovoltaic modules as that introduced in [7] with simpler circuit design, lower cost and higher tracing frequency. An electronic load based on MOSFET is used to trace the characteristics of photovoltaic modules. The MOSFET is controlled by sweeping the gate-source voltage through a saw-tooth signal. The saw-tooth signal is generated by using a LabVIEW application. For this purpose, a low-cost NI-DAQ was used. A large number of experiments with various configurations of PV modules have been conducted in actual field conditions to ensure the utility and robustness of the proposed electronic measuring setup under different field condition such as irradiance and shadowing. A current input PV model is developed using Matlab/Simulink in modeling the photovoltaic behaviour for AEG TSG panel. Given the solar insolation and the PV current, the model returns the I-V and P-V graphs using the Parameters obtained from AEG TSG photovoltaic panel.

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