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Analysis of I-V Characteristics of Photovoltaic Modules using microcontroller based Electronic Loading Arrangement

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***Abstract*— In the photovoltaic industry it is required to analyze and determine the operating properties of the solar panels to understand their working in practical environment. I-V and P-V Characteristics are used to determine the performance parameter. There are various methods/instruments available to determine above parameters. This paper presents a low cost microcontroller based design for characterizing PV modules. This design can be used to determine I-V, P-V, I max, Vmax, P max, File factor and efficiency within few seconds. It consists of an electronic fast varying load based on a power MOSFET controlled by means of PWM generated by the microcontroller. Also one op-amp is used to trigger gate by variable voltage in order to improve the tracking of the I-V characteristics. The design is also having PC Connectivity for plotting characteristics between Voc, Isc and Power. The design is battery operated and very handy so that it can be used at any remote site.**

***Index Terms*— Photovoltaic modules, Solar Panel, I-V Characteristics, MOSFET electronic load, Isc, Voc, Power, fill factor, Efficiency, PV analyzer**

I. INTRODUCTION

Photovoltaic (PV) energy is booming technology. The growth of the annual market regarding PV industry was evident in many Countries as support programmers begin to take effect [1]. Installations of PV cells and modules around the world have been growing at an average annual rate of more than 35% since 1998 and, by the end of 2007, the cumulative installed capacity of all PV systems around the world had surpassed 9.2GW [2]. Moreover, the capacity of annually installed PV systems would reach 281GW by 2030. By analyzing these two reports [1] and [2], it becomes evident that one can expect a very strong transformation and expansion of the PV industry sector over the coming decades. Considering the advanced scenario presented in [2] the average growth rate in the periods of 2007-2010, 2011-2020 and 2021-2030 will be respectively 40%, 28% and 18%. Even in a moderate scenario the average growth will be 30%, 21% and 12% in those periods .In spite of their well known reliability, some PV modules degrade or even fail when operating outdoors for extended periods and that can occur in a number of ways [3]. In cells' Degradation diagnosis of PV modules or arrays, the current voltage (I-V) characteristics are usually used as well as Parameters obtained from them like short circuit current (ISC), Open-circuit voltage (VOC), maximum power (Pmax) and fill factor (FF=Pmax/ISCVOC). On the other hand, the I-V characteristics can be monitored and the results used to Investigate and compare the actual power produced by modules under realistic operating conditions [4]. Thus, I-V Characteristics are not only used by designers in power converter systems, but also in PV system design to make Systems more cost effective. Manufacturers of PV modules provide the I-V characteristics and the main parameters under the well known Standard Test Conditions (STC: 1000W/m2 of irradiance, 25ºC cell temperature and air mass 1.5). However, PV modules experiment field conditions very different from those standard ones because of the temperature of the atmosphere is change and the parameters are temperature dependent. Photovoltaic modules are usually tested using electronic dc loads, which can vary the resistance (load) over the entire range in a very short time. However, the ones available on the market are often expensive. Anyway, by using quite simple and much cheaper circuits, it is also possible to build an electronic dc load taking advantage of a suitable operation of a power Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET). In fact, a power MOSFET operating in its linear region and mounted on a heat sink to dissipate the power, if necessary, can be used as an electronic load to test PV modules [4] – [6]. Some simple and/or low cost electronic circuits have been being developed along this decade. In [7] simple and low cost electronic circuits that facilitate the data acquisition of I-V characteristics of PV cells were proposed. The I-V characteristics of PV modules were measured in [8] with a swept method by charging a capacitor. In [4] it is reported the design of a low-cost measuring system used to monitor the IV characteristics of PV modules. The system was previously developed in [9] and measures I-V characteristics of seven different modules sequentially by selecting a module through mechanical relays. Other set of relays are used to select a Parallel combination of resistors used as resistive loads for a particular I-V pair of values. By using a combination of resistors, several resistances are achieved to measured I-V pairs. A more interesting electronic circuit, being a fast varying load is presented below. The circuit is based on a MOSFET operating in its linear region and the proposed Circuit traces the I-V and P-V characteristics of PV modules by quickly scanning the load by varying the VGS (gate to source voltage) of the MOSFET with the help of generating PWM using Microcontroller. In this paper an improved electronic circuit is presented to test PV modules by tracing their characteristics. The MOSFET dissipates the power in terms of heat because of the current flowing through the MOSFET. The heat sink is used to avoid thermal breakdown of the

MOSFET. The scanning voltage (VGS) is generated in an improved way to improve I-V plotting. This can be used to test PV modules connected in any combination of series and parallel. The design can be expanded for higher rating of power by increasing the power rating and heat dissipation area of heat sink.

II. PRINCIPLE OF OPERATION

The basic circuit utilized to test PV modules using a MOSFET as an electronic load is shown in Fig. 1. V_{GS} is the Gate-source voltage, V_{DS} the drain-source voltage and I_D the drain current of the MOSFET. V_{PV} is the output voltage of the PV module, I_{PV} the output current, I_{SC} the short circuit current and V_{OC} the open circuit voltage. The characteristics of a MOSFET are shown in Fig.1

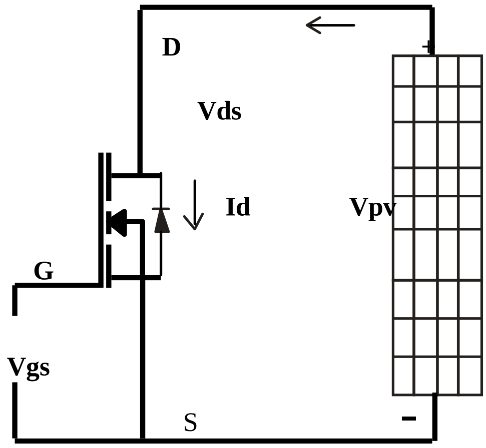


Fig 1 Test circuit for testing PV modules in which MOSFET is used as an electronic load.

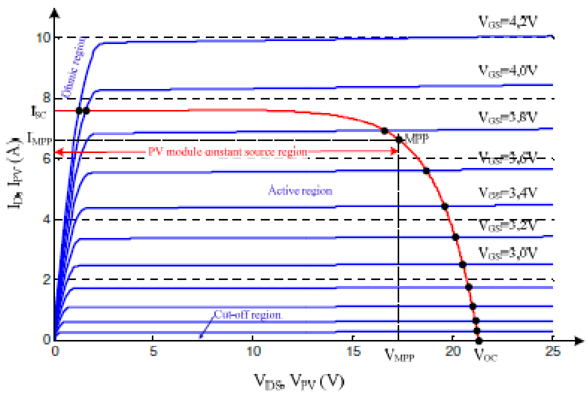


Fig 2 Characteristic of a PV module at STC (red curve) and characteristics of a MOSFET (blue curves).

Where each curve ID-VDS (blue curves) was drawn for a given gate-source voltage (VGS). The IPV-VPV characteristic of a PV module at STC is also shown in Fig. 2 (red curve). In fact, as the currents ID and IPV are the same, the operating point is given by equalizing the current of the MOSFET which is given by

$$I_D = K(2(V_{GS} - V_{th})V_{DS} - V^2{}_{DS}) \approx 2K(V_{GS} - V_{th}) \tag{1a}$$

$$I_D = K(V_{GS} - V_{th})^2(1 + \lambda V_{DS}) \tag{1b}$$

and current of the PV module which is given by

$$I_{PV} = I_L - I_{diode} \tag{2a}$$

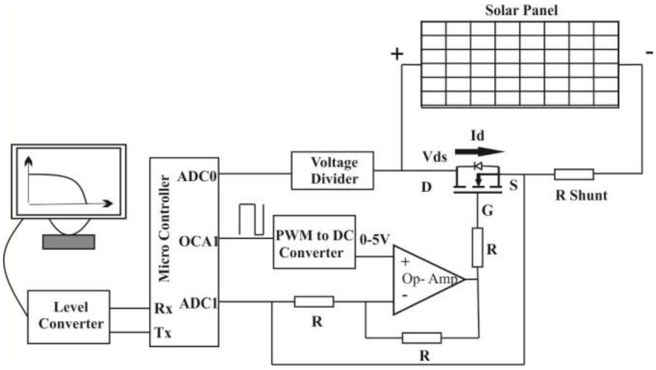
Where

$$I_{diode} = I_O(e^{V_{PV}/nV_T} - 1) \tag{2b}$$

Equations (1a) and (1b) are valid in the ohmic region (also referred as triode region or linear region where $V_{ds} < V_{gs} - V_{th}$) and active region (also referred as Saturation region, where $V_{ds} > v_{gs} - V_{th}$), respectively [10]. K and λ are device parameters and V_{th} is the threshold (gate) voltage. I_L is the light-generated current (=ISC) and I diode given by (2b) is the ideal diode law where IO is the dark-saturation current, n is the diode ideality factor (a number between 1 an 2) and V_T the thermal voltage [11]. Thus, the operating point corresponds to the intersection of the PV module characteristic with the MOSFET for a given voltage V_{GS}. By varying V_{GS} with a suitable signal the operating point of the MOSFET sweeps the I_{PV}- V_{PV} characteristic between V_{OC} and I_{SC}. While V_{GS} is less than the threshold voltage V_{th}, the MOSFET will be OFF. When V_{GS} is increased above Vth, the device will operate in its active region where I_D rises approximately in a linear way with V_{GS}. As far as the PV module is concerned, for V_{PV} higher than the voltage at the maximum power point (V_{MPP}), the characteristic will be similar to a voltage source one. At voltages below V_{MPP} the PV module will behave as a current source. In this flat region, indicated in Fig. 2, the voltage V_{PV} is sensitive to small variations in current (I_{PV}) and hence to small variations in V_{GS}.

III. THE ELCTRONIC CIRCUIT

This design uses variable dc load whose resistance is varied by varying ON and OFF time of MOSFET by PWM which is generated by microcontroller. By using a power MOSFET in its linear region this is achieved. It uses Opamp to maintain a feedback loop to allow a current drain in current-regulation mode. We use current regulation mode when they are characterizing voltage sources, in which the power source must deliver current value that is set in the electronic load.



They use voltage-regulation mode with current sources because it forces the sources to Operate at a voltage that the load sets. In current mode, R_{SHUNT} senses I_{LOAD}, and the resultant voltage feeds back to the inverting input of op amp. And it's goes to parallel to ADC channel to the micro controller to read the current. Because the dc gain of this amplifier is high In the linear-feedback operating range, the inverting input stays equal to the non inverting input, which corresponds to V_{IREF}. The amplifier establishes its output value to operate MOSFET in a linear region and, therefore, dissipate the power from the source. The value of the source current is proportional to the current-loop reference, V_{IREF}, and is $I_{LOAD}=V_{IREF}/R_{SHUNT}$. Set V_{IREF} Using a PWM to DC converter circuit those are controlled by the microcontroller. For measuring the panel voltage using divider circuit and output of divider circuit goes to the ADC pin of the microcontroller. By using parallel MOSFET to increase the current-handling capabilities.

IV. CONCLUSION

This paper presented an automatic electronic load using microcontroller circuit for testing photovoltaic (PV) modules or strings by tracing their I-V and P-V characteristics. A power MOSFET was used as an electronic fast varying load controlled by means of an optimized PWM generating through microcontroller gate-source voltage, which provide variable DC level for different threshold voltages. The Microcontroller based circuit includes the data acquisition systems and hand held battery operated system; advantageous in case of testing at remote place. I-V and P-V characteristics were monitored and store in PC based software system with date and time. The circuit can also be used for testing high voltage strings by replacing the low voltage and current MOSFET by a high voltage and current one or an IGBT and selecting a different measurement resistor. The proposed circuit is suitable to be used for analyzing the influence of field conditions like temperature, irradiance and partial shadowing on the PV module performance.

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