Sunlight based I-V Characterization of Solar PV Cells

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***Abstract*—A family of current as a function of voltage (I-V) curves under different illumination conditions as specified in standards are needed to characterize a photovoltaic (PV) cell. Instead of using an artificial light as the source, a method of using sun light through fiber optic cables is described to obtain the I-V characteristics of a PV cell. Moreover, an electronic load realized with a MOSFET as a variable resistor, in conjunction with microcontroller based instrumentation automates the testing process. A prototype I-V curve tracer, developed and tested, establish the efficacy of the proposed method.**

Keywords-* *Solar photovoltaic cells; I-V characteristics; P-V characteristics; MOSFET as load; Electronic load; Polymer optical fiber.

I. INTRODUCTION

To compare different photovoltaic (PV) systems; as well as to achieve an optimal PV system design, the current versus voltage (I-V) characteristic of the individual PV module employed in the PV system is essential. The I-V characteristics of PV modules help a designer to render the design to be optimal for the maximum power point ($P_{max.}$) as well as to ensure that the designed system tracks P_{max} during operation in the field. P_{max} is a function of several input parameters, namely, (i) the total irradiance incident upon the PV cell, (ii) the spectral content of irradiance, (iii) the spatial and temporal nature of the irradiance and (iv) the temperature of the PV cell [1]. Hence determination of P_{max} is not straight forward and simple. From the recorded I-V characteristic, apart from P_{max}, the values of equivalent series and parallel resistances (R_S and R_P) of a PV cell also can be easily evaluated. Normally PV Cell I-V characteristic is measured in laboratories employing a standard light source and a temperature controlled chamber. The light source intensity and the operating temperature of the PV cells are varied as per Standard Test Condition (STC) [2]. Either a Continuous or a pulsed light source can be used during testing of PV cells [3]. Continuous light sources are mostly based on xenon short arc lamps and have poor spatial uniformity. The intensity from these lamps may vary as much as 20% over a target area. Pulsed light sources are based on xenon large arc lamps which have good spatial uniformity, but have short measurement time in the 1 to 20 ms range. Since the standard spectral irradiances cannot be reproduced in the laboratories with the light sources like xenon arc lamp, the total irradiance from the source is set with a calibrated reference cell that has the same or similar spectral response as the test device. The set point is achieved by varying the output irradiation level of the source till the short circuit current of the reference cell (which is also kept along with the PV cell under test) is equal to its calibrated value under standard test condition (STC). Once the irradiance is set as per STC, the I-V curve of the test device is plotted by varying the load connected to the PV cell under test. Without the knowledge of the spectral response of a cell, a standard cell possessing identical response characteristics can not be obtained. Without an equivalent standard PV cell, PV cells with unknown spectral response can not be tested under STC utilizing such artificial light sources. On the other hand, if sunlight itself is used as the light source then the need for a calibrated standard PV cell, possessing identical or similar spectral response as that of the test cell is dispensed with and the complexity of test procedure reduces [4]. Use of sunlight as the source provides better uniform illumination (less than 1% spatial variation is feasible) compared to the artificial light source. Moreover, the uniformity can be easily achieved over extended periods of illumination (up to several minutes is possible) [4], [5]. An added advantage is that, new PV cells with unknown spectral response can be tested easily if sunlight is used for illumination.

In the field, several PV cells are connected in series to realize required output voltage. If a particular PV cell in that string receives lower irradiation (due to partial shading) compared to the other cells connected in series, the shaded PV cell is found to operate in the reverse biased condition. If a PV cell in the series circuit is reverse biased then it consumes power (dissipates power as heat) generated by other PV cells in series with it. Hence to analyze such situations, it is important that the I-V curve of a PV cell be obtained also under the reverse bias condition with varying illumination levels [6], [7].

It is popular to use a capacitor as the load for I-V measurement of a PV cell [8]. The capacitor is initially discharged and then connected to the PV cell to be tested. When the PV cell is illuminated, the capacitor is charged by the cell current, and hence both the capacitor voltage and the PV cell voltage increases, thereby sweeping through the I-V curve. However, with this simple sweep method it is not possible to control the sweep speed. Moreover it is also not possible to obtain I-V characteristics under reverse bias condition. It had been established that the evaluated values of P_{max}, *fill factor* and series resistance may be erroneous if a simple capacitor is used as the load [9]. It was observed that if sweep rate is high, then the error in I-V curve measurement of PV cell is also high [10], [11]. It is also difficult to obtain linear sweep with high sweep rates. The ability of DC-DC converter to emulate a resistor has been applied to obtain I-V curves of solar PV modules [12], [13]. However, the use of DC-DC converter introduces current ripple and thus leads to poor resolution in the I-V current characteristics obtained with such converters.

Apart from the use of sunlight (indoor) for illumination for the very first time, a novel method of I-V Curve tracer that uses a power MOSFET as a load (acting as variable resistor) is proposed in this work. Methods based on MOSFET as a load, presented earlier [14] are applicable only for obtaining the I-V

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characteristics under forward bias condition. The method presented here enables plotting of the I-V characteristic not only under forward bias but also under reverse bias condition. In the prototype developed, the use of a microcontroller results in the acquiring of the PV cell voltage at identical current points for various illumination levels so that any comparison study becomes meaningful.

II. THE PROPOSED I-V CURVE TRACER FOR PV CELLS

The block schematic of the proposed I-V curve trace system is shown in Fig.1. The system is made of four major subsystems, namely, (A) the light source, (B) environmental chamber, (C) the load, (D) the hardware for the digital controller and (E) the software for operation of the overall system.

A. The Light Source

Light from the sun is collected and coupled to a fiber optic cable through a collector that is made of transparent convex lenses (one per fiber strand). The collector lenses are fixed on a two axis rotational system. The axis shafts are driven by a sun tracking system so as to align the axes of the lenses with the sun all the time and thus enable collection of maximum available sunlight. The fiber cable itself is only few meters in length and hence has negligible attenuation over the spectrum. The light from the fiber illuminates the PV cell and a standard PV cell (utilized for measuring the irradiance level) kept in an environmental chamber through a light dispenser. The dispenser uniformly disperses the light over a chosen area. Fig. 2 shows the photographs of the collector and the dispenser employed. The collector, dispenser and the fiber cable assembly were developed by Polymer Optical Fiber Application Center of Georg Simon Ohm University, Nuremberg, Germany. The solar PV cells used for terrestrial applications have spectral response from 300 nm to 1200nm [15] and polymer optical fibers used in the prototype unit also have uniform spectral characteristics in this region. The level of irradiance impinging on the PV cell under test is indicated by the calibrated reference solar cell kept along with it. The intensity of irradiation falling on the PV cell under test is

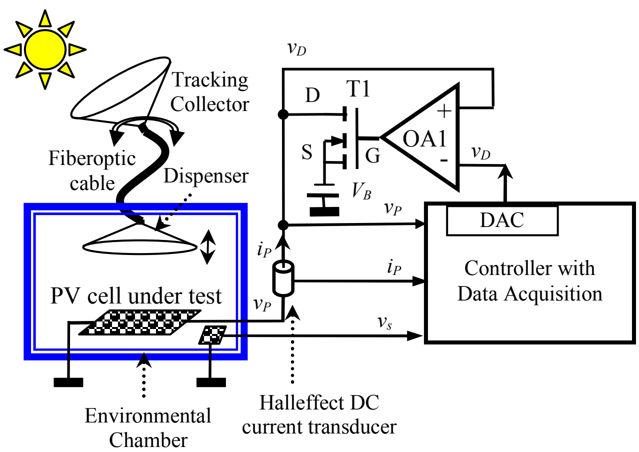

Fig.1 Block diagram of the prototype I-V curve tracer

Fig. 2. Photograph of the sunlight collector and dispenser
Courtesy: Polymer Optical Fiber Application Center of Georg Simon Ohm University, Nuremberg, Germany

adjusted to the required level by varying the distance between the disperser and the P-V cell standard cell combination.

B. The Environmental chamber

The standard testing procedure envisages the I-V and P-V characteristics be obtained with the temperature of the PV cell under test be kept at pre-fixed ambient temperature levels. In order to achieve this condition, the cell under test and the standard cell are kept in an environment chamber wherein the required ambient temperature and humidity are maintained. The WK-111 Weiss Technik environmental chamber was used for this purpose. The WK-111 environmental chamber provides stable temperature adjustable in the range -10°C to 90°C with an accuracy of $\pm$ 1°C and the humidity of the chamber can be set within the range 0 to 99 % Rh with an accuracy of $\pm$ 3 %.

C. MOSFET as variable Load

The PV cell under test is connected to a variable resistive load realized using an N-Channel MOSFET (IRF 150), whose gate is controlled by an opamp OA1 (an OP07) as shown in Fig. 1. The inverting input of the opamp is fed from the output of the digital to analog converter (DAC) of the digital controller unit. The non-inverting input is connected to the drain terminal D of the MOSFET (T1 in Fig. 1) whose source terminal S is connected to circuit ground through a dc voltage source of value V_B. The insertion of the voltage source facilitates the testing of the PV cell under reverse bias condition also. The opamp suitably drives the gate of the MOSFET such that that the voltage at its non-inverting terminal is equal to the voltage at its inverting terminal, which is nothing but the output of the DAC. Hence the terminal voltage of the PV cell under test is made to follow the output of the DAC. The output of the DAC is controlled to obtain a ramp voltage spanning the range required (from $-V_B$ to $+ V_{OC}$) for testing the PV cell. The effective resistance R_o between the drain and the source of the MOSFET is

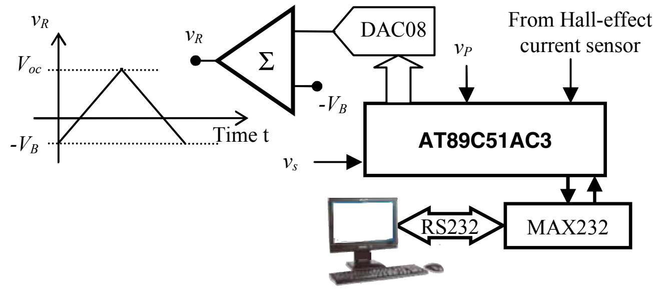

Fig.3 Block diagram of the digital controller

$$R_o = \frac{V_{DS}}{I_P} = \frac{V_D}{I_P}. \quad (1)$$

From (1), it is seen that R_o can be set to any value by adjusting the voltage V_D (value of the variable voltage v_D at a given instant) for the particular value (I_P) of the current i_P. The current drawn from the PV cell under test is sensed by a Hall current probe. Along with the Hall current probe output, the output of the test PV cell and the standard cell are fed as input to a digital controller unit.

D. The hardware of the digital controller

The block schematic of the digital controller is shown in Fig. 3. The heart of the digital controller is AT89C51AC3, an 8-bit microcontroller from Atmel Corporation. An 8-bit digital to analog converter (DAC, DAC0800) is interfaced to one of the ports of the microcontroller. The bias voltage $-V_B$ is added to the output of the DAC and is fed to the inverting input of the opamp as the ramp voltage v_D. The microcontroller is also interfaced to a personal computer (PC) through its serial port suitably buffered with a MAX232 IC as indicated in Fig. 3. The output i_p of the hall current sensor, the output voltage v_p of the PV cell under test and the output v_s of a standard PV cell are given as inputs to the inbuilt analog to digital converter of the AT89C51AC3 microcontroller.

E. The software for operation of the overall system

The operation of the digital controller and the sequence of operations to obtain the I-V characteristics of a given PV cell are implemented through appropriate software. Fig. 4 shows the flowchart of the I-V data acquisition routine. After initialization, the controller obtains the set value of the illumination level (V_S) at which the test needs to be performed and the open circuit voltage (V_{OC}) of the test PV cell. The digital controller acquires v_p, i_p and $v_{s,}$. The output of the standard cell is compared with the set value V_S. If $v_s < V_S$ then the controller prompts the operator to decrease the distance between the dispenser and the test bed. If $v_s > V_S$ then the controller prompts the operator to increase the distance between the dispenser and the test bed. Once the condition $v_s = V_S$, the controller prompts the operator to stop and proceeds with obtaining the I-V characteristic at that particular illumination level. The digital value written into the DAC, say N_D is set at 0 and the test SPV cell voltage v_p and the cell current i_p are acquired. The value of v_p is compared with V_{OC}. If

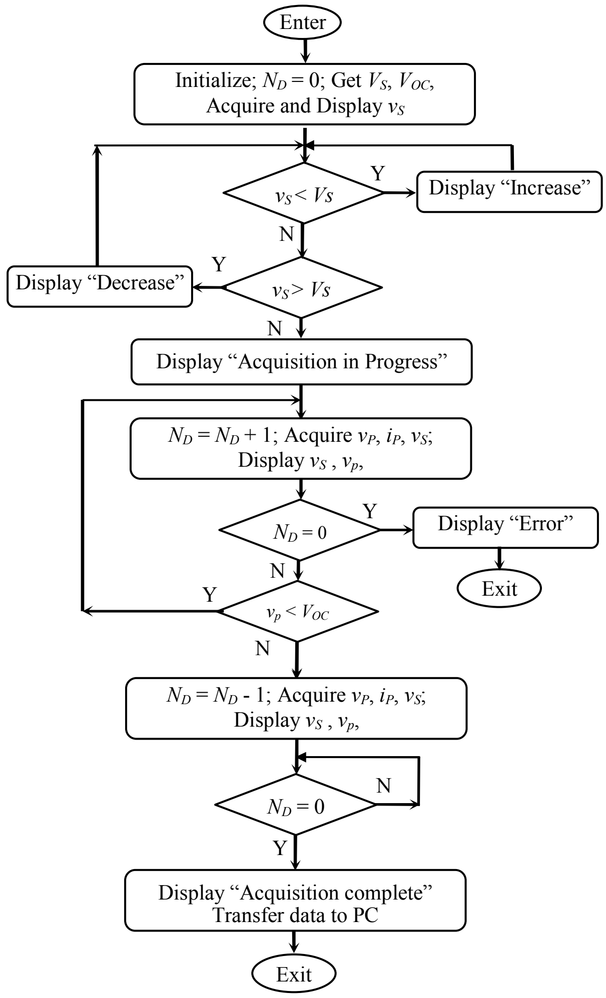

Fig. 4 Flowchart showing the software developed for the prototype

$v_p < V_{OC}$ then the controller increments the value written to the DAC and repeats the procedure till $v_p \geq V_{OC}$. Once V_{OC} is reached, the value written to the DAC is decremented by one till it reaches zero and for each DAC value v_p and i_p are acquired. For any reason the value written into the DAC rolls over at 255 and goes to zero, in the incrementing stage an error message is displayed. By this procedure, the cell voltage is varied from $-V_B$ to V_{OC} and back to $-V_B$. During every incremental step, the corresponding cell voltage v_p and current i_p are acquired. The waveform of v_D generated by this procedure is also portrayed in Fig. 3. Utilizing the acquired values of v_p and i_p the I-V characteristics and the P-V characteristics of the SPV cell are computed and plotted.

III. EXPERIMENTAL RESULTS

Employing the prototype unit developed, experiments were conducted on different SPV cells. The results obtained for a 3 cm by 3 cm polycrystalline solar cell at 40 °C ambient temperature and 1000 W/m^2 irradiation is shown in Fig. 5. Here the cell voltage of the polycrystalline PV cell is swept from –0.5 to +0.5 V, and the I-V and P-V characteristics of the PV cell are obtained both in the forward and reverse bias conditions, in one sweep. In order to ascertain that the

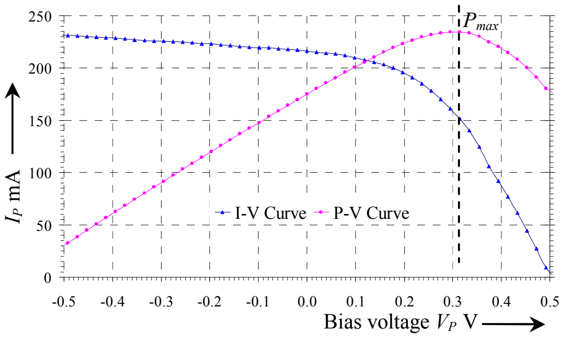

Fig.5 The result of I-V and P-V characteristic of poly silicon solar cell tested with proposed I-V curve tester.

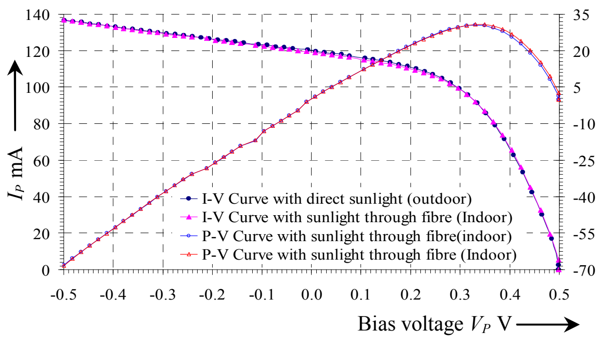

Fig. 6 I-V and P-V characteristics of polycrystalline silicon PV cell obtained with direct sunlight and sunlight through optical

collector-fiber-dispenser system does not introduce changes in the spectrum, experiments were also conducted with direct sunlight and employing the prototype collector-fiber-dispenser system. Fig. 6 shows the comparison of the I-V characteristic of a 3 cm by 3 cm polycrystalline silicon PV cell under direct sunlight (outdoor) and that obtained with sunlight taken through the collector-fiber-dispenser system (indoor). The irradiation level for this experiment is 600 W/m^2 at an ambient temperature of 40°C. It is clearly seen from Fig. 6, that the proposed system introduces negligible changes in the spectrum.

IV. CONCLUSION

A complete fiber optic based system to obtain the I-V and P-V characteristics of a photovoltaic cell utilizing sunlight through fiber is presented. Use of a MOSFET as a variable load, digitally controlled using a microcontroller, automates the data acquisition and plotting of the characteristics. An added advantage of the proposed method is that the I-V and P-V characteristics are obtained even in the reverse biased condition. Obtaining the I-V and P-V characteristics of a photovoltaic cell under test in the reverse biased condition is achieved in a very simple way by inserting a dc voltage source in series with the MOSFET load. Based on the method presented here, a prototype was developed and tested. The results obtained with sunlight through optical fiber as light source and with direct sunlight for a typical polycrystalline silicon PV cell establishes that the proposed system does not introduce significant changes in the spectrum. Further work is in progress to carryout tests on other types of solar PV cells and also to compare the results obtained from this system with that obtained from a xenon lamp.

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