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Modeling, Simulation and Implementation of PV Cell/Modules Using PSpice

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This paper presents a Spice model of a photovoltaic cell. This model is based on mathematical equations and is described through an equivalent circuit including a photocurrent source, a diode, a series resistor and a shunt resistor. The PSpice is used to simulate a circuit based model for PV cells then to conduct behavioral study under varying conditions of solar insolation including shading effect, temperature, diode model parameters, series and shunt resistance . The study is very helpful in clearly outlining the principles and the intricacies of PV cells and may surely be used to verify impact of different topologies and control techniques on the performance of different types of PV system. In order to validate the developed model, an experimental test bench was built and the obtained results exhibited a good agreement with the simulation ones.

Keywords: PV Cells, Circuit Simulator, Modeling and simulation, Electronic Component, Diode model parameters, Insolation, PSpice, Shading.

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1. INTRODUCTION

Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming. Solar energy is abundantly available that has made it possible to harvest it and utilize it properly [1, 2]. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby.

Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever wherever necessary. In order to tackle the present energy crisis one has to develop an efficient manner in which power has to be extracted from the incoming solar radiation. The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand [3, 4]. They can hardly compete in the competitive markets as a prime power generation source. The PV cell represents the fundamental power conversion unit of PV generator system. The output characteristics of PV cell depends on the solar radiation, the cell temperature and output voltage of PV module. The purpose of using PSpice for simulation is that system study as a whole can be undertaken as it can simulate both PV Cells and the associated power electronics under different operating conditions and load [5, 6].

the main objective of present paper is to shed further light on the modeling techniques applied for photovoltaic cells characterizations and investigating the effects of the cells physical parameters (series - and shunt – resistances), as well, the environmental ones (temperature - and irradiance -levels) [7].

2. PHOTOVOLTAIC CELL MODEL

A mathematical description of current-voltage terminal characteristics for PV cells is available in literature. The single exponential equation (1) which models a PV cell is derived from the physics of the PN junction and is generally accepted as reflecting the behavior of the PV cell. A double exponential equation may be used for the polycrystalline Silicon cells [8, 9].

$$I = I_{PH} - I_S(\exp\left(\frac{q(V + I.R_S}{N.K.T} - 1\right) - \frac{(V - I.R_S)}{R_{SH}} \qquad (1)$$

Working backwards from the equations, an equivalent circuit can be easily determined, and this aids to the development of the simulation model [10]. This equivalent circuit model is shown in Fig. 1

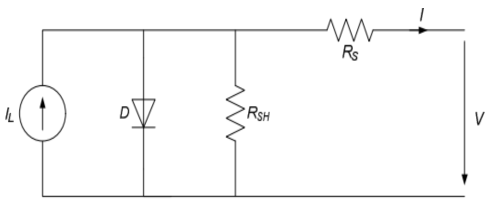

Fig. 1 – PV Cell circuit model

The complete behavior of PV cells are described by five model parameters (I_{ph}, N, I_s, R_s, R_{sh}) which is representative of a physical PV cell/module [4]. These five parameters of PV cell/module are in fact related to two environmental parameters of solar insolation & temperature and owing to non-linear nature of equation (1) their determination is not straight forward [11].

3. SOLAR CELL: A DIODE PERSPECTIVE

Solar cells are photodiodes on a large scale and therefore have some basic characteristics of a PN junction diode [12]. The non linearities in PV Cell V-I characteristics is basically due to presence of device diode in circuit model of Fig. 1. It is therefore logical to begin with four quadrant study of diode characteristics under dark and also when illuminated. The circuit simulator PSpice is used as an effective tool to carry out such behavioral examination and the schematic used for this purpose is shown in Fig. 2.

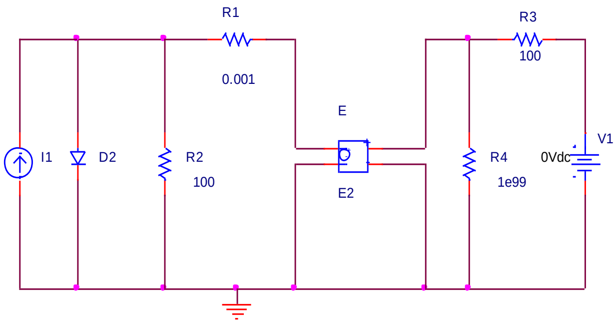

Fig. 2 – Schematic for generating diode curve both under dark and when illuminated

3.1 Diode Characteristics under Dark

The schematic of Fig. 2 is simulated for obtaining PV Cell characteristics under Dark and simulation result is shown in Fig. 3. Under Dark the photon generated current is zero which under PSpice is achieved by setting 'value' attribute of Spice source I_{DC} as zero. Obviously, the PV cell under Dark is a passive device and behaves like an ordinary diode.

The PV cell behavior under dark is thus the V-I characteristic curves of diode under forward and reverse bias conditions respectively. The noteworthy point here is that the device diode behaves with positive current and positive voltage in Ist-quadrant and with negative current and negative voltage in IIIrd–quadrant.

3.2 PV Cell under Illumination

The effect of solar insolation (Illumination) on a PN junction can be studied by increasing the value of source current I_{dc} in Fig. 2 from its zero value (for dark), to a value of 4 amp, taken to be an equivalence of 100% solar radiation or 1 sun. Since the photon current I_{ph} or equivalent I_{dc}, is directly proportional to the incident solar insolation, a value of 3 Amp will represent 75% or 0.75 sun, a value of 2 Amp will correspond to 50% and likewise. The family of characteristic curves of Fig 2(c) can be produced for varying

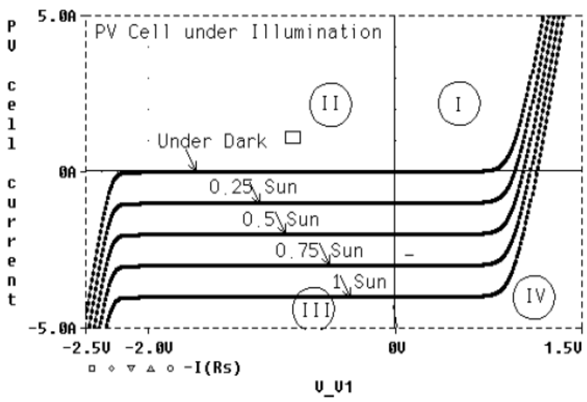

Fig. 3 – PV cell characteristics under illumination

insolation level under PS pice by "dc sweep" analysis of voltage source V1.

3.3 I-V Characteristics of PV Cell

The effect of solar insolation is actually to shift diode characteristic curve downward along current axis; making it to operate in IVth-quadrant as shown in Fig. 3. The shifting of diode characteristic curve with increasing insolation along current axis reveals that current is proportional to incident sunlight while voltage capability of the cell is almost constant from very low light levels. This behavior indeed enunciates that a PV-cell behaves more like a current source than a voltage source, and also PV-effect occurs in fourth quadrant only. Here it is not worthy to see that cell generates both current and voltage and acts as a photovoltaic generator. Thus, the fourth quadrant portion of diode characteristic curve is called V-I curve of PV cell in solar photovoltaic terminology. To produce a solar cell V-I curve, the fourth quadrant of characteristics curve is flipped vertically about the voltage axis into the Ist-quadrant as shown in Fig. 3. This is done so that the current direction is positive rather than negative. This is strictly in accordance with the convention that a generator must source positive current from its positive terminal.

4. DETERMINATION OF V-I CHARACTERISTICS

4.1 Experimental Set Up

Fig. 5 depicts scheme of measurement, which is used to obtain V-I characteristics of a PV module. Light source in the laboratory is an array of Diachronic halogen lamp (12V, 50W) whose distance with respect to PV module can be adjusted to get different level of Insolation. To get V-I characteristics of a PV module at different temperature, a circuit of tubes on rear side of module frame is distributed and controlled hot air is blown through to set desired temperature. Different sensors and signal conditioning unit are used to measure voltage, current, temperature and solar Insolation of the PV module [15]

A DC to DC boost converter with hysteresis band current control is used for loading of PV array as shown in Fig. 3.The arrangement makes use of PC controlled loading of solar module and scans through its V-I characteristics. As PV module is loaded, current drawn from PV panel increases and its voltage falls down as is obvious from V-I characteristics of a PV cell in Fig. 4. The reference voltage VR is generated through a 12 bit DAC of Data acquisition card for loading of PV array [15]. By varying VR, one can load PV module from open circuit to short circuit and V-I characteristics of module can be scanned through. The computer using data acquisition card and program written in 'C' language; acquires data of voltage, current, solar insolation and temperature for corresponding value of VR. The data file stores data in suitable format to be used with MS excel program for plotting the V-I characteristics of the PV module [16]. One such characteristic is shown in Fig. 4.

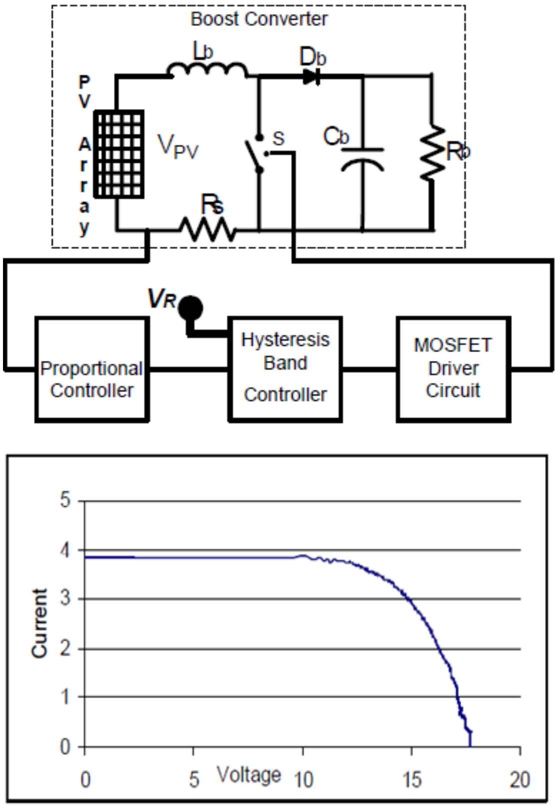

Fig. 4 – PV Loading Circuit with experimentally obtained *V-I* Characteristics

5. ENVIRONNEMENTAL PARAMETER VARIATION

5.1 PV Cell under Reduced Insolation

The two environmental conditions of Solar Insolation and Temperature govern output of a PV Cell. The circuit simulator PSpice is used to demonstrate behavior of PV cell under varying Solar Insolation. The schematic used for the purpose is same as shown in Fig. 2. The photon generated current I_{ph} is in fact related with solar insolation λ as in (2):

$$I_{PH} = \left[I_{SCR} + K_1(T-298)\frac{\lambda}{100} \right] \qquad (3)$$

where $K_1 = 0.0017$ Å/°C.

From equation (3), it can be seen that at constant temperature, the photon generated current I_{ph} is directly proportional to solar insolation. If now the rated I_{sc} of specimen PV cell is 4A under STC (solar insolation of 1sun at 25 °C), then declining values of current's such as 3, 2 & 1A will represent solar insolation's of 0.75, 0.5 &0.25 sun (at 25 °C) respectively and can accordingly beset by setting value attribute of current source I_{ph} in Fig. 2.

The effect of varying Solar Insolation on *V-I* characteristics can now be produced using 'Nested DC sweep 'analysis, where the main variable is control voltage *V*1 and nested sweep variable is 'current source I_{ph} . The simulation is produced for five different values of photon generated current I_{ph} representing varying solar Insolation from zero to 1 sun in steps of 0.25 sun. The

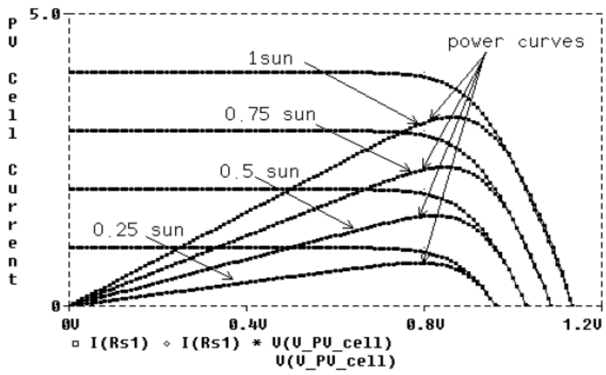

Fig. 5 – PV Cell Characteristics and power curves for varying Insolation

resultant V-I characteristics and power-curves is shown in Fig. 7.

From the simulation result it can be observed that as solar radiation falling on PV cell is reduced, both I_{sc} and V_{oc} decreases, but the change in Voc is not as prominent with incident solar radiation as with I_{sc}, which varies almost directly proportional.

5.2 PV Cell under Varying Temperature

The effect of varying temperature on PV cell output is twofold: (*i*) It affects short circuit current I_{sc} of Cell as given by (3) (*ii*) It changes saturation current of the diode in PV cell approximately as cubic power and is given by

$$I_s(T) = I_S\left[\frac{T}{T_{nom}}\right]^3 \exp\left[\left(\frac{T}{T_{nom}} - 1\right)\frac{E_g}{NV_t}\right] \qquad (4)$$

Obviously from (4) the saturation current of diode of PV Cell is highly temperature dependent and it increases with increase in temperature and is taken care by Spice diode model. The increased saturation current in fact reduces open circuit voltage as discussed in section VI. To study the effect of Temperature variation on PV Cell output, a modified version of the schematic of Fig. 2 will have to be used. This is because the photon generated current 'Iph' in Fig. 2 is temperature independent and therefore cannot describe the temperature dependency of equation (3). To include this temperature

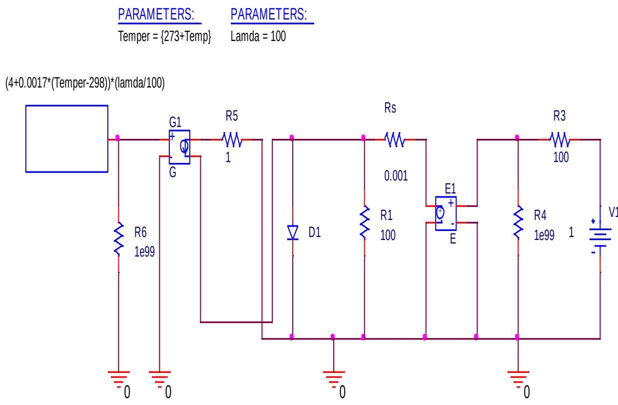

Fig. 6 – Schematic for PV Cell Characteristics at varying temperature

dependency the analog behavioral modeling (ABM) feature of PSpice is used [23]. The ABM block first simulates (3) and produces temperature dependent voltage as shown in Fig. 5(b). This output voltage of ABM block then drives a voltage controlled current source with unity gain producing a temperature dependent current as desired for simulation of (3).

The simulation result is shown in Fig. 7 The Simulator plot the behavior of the PV cell under three different temperatures of 27 °C, 57 °C and 87°C using Temperature sweep. It can be observed from simulation result that short circuit current of a PV Cell increases with increasing temperature and at the same time its open circuit voltage decreases.

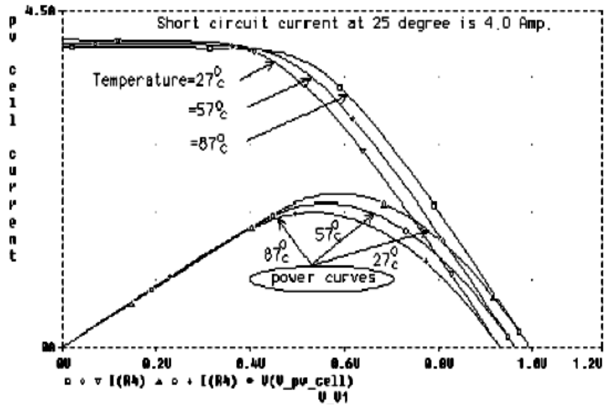

Fig. 7 – PV Cell Characteristics and power curves for varying temperature

The net effect with increasing temperature of the cell is in decreased power output as reduction in open circuit voltage is more prominent than enhancement in short circuit current. The schematic uses dc sweep and temperature analysis to produce such family of the curves of Fig. 7

6. PV MODULE CHARACTERISTICS

A Solar Photovoltaic module is a congregation of solar PV cells in series so as to produce a compatible voltage to charge a standard Battery of 12 volts. A stand-alone PV cell generates a voltage in the range of 0.5 – 0.6 volts and has non-linear voltage-current relationship as given by (1). Uphill now the focus of the study was basic unit a PV cell. To carry out simulation study of a PV module; the PV Cell voltage-current relationship in (1) is modified for PV Module by neglecting R_s & R_{sh} and is now given as(5).

$$I = n_p I_{pn} - n_p I_s(\exp\frac{q.V}{(N.K.T).ns} - 1) \qquad (5)$$

In a PV module there is only one path available for conduction of current as all the cells are connected in series, therefore $n_p = 1$. Thus the number of series connected cells ns may now be combined with Ideality factor N of a unit PV cell for simulation study and in fact can simulate a PV module if the new value of Ideality factor N for module is as many times greater as the no. of PV cells connected in series. This fact of increasing V_{oc} with N has already been studied in section VI. This is now an established fact that PV module simulation study is identical with the PV Cell study and the schematic in Fig. 2 can be used with renewed value of diode model parameter N & I_s for a compatible voltage generation of a PV module. With this formulation, the simulation result of a PV module is shown in Fig. 6 for $N = 20$ and $I_s = 14.11$ nA. The plots are very much identical to Fig. 5(a), with the exception that Voc is higher and now represent characteristics for a PV module than for a PV cell.

7. MAXIMUM POWER POINT TRACKING

On the simulation result of Fig.6, a plot of dP/dV using derivative function of the Probe window is drawn as shown in Fig. 8. The intersection of the dP/dV graph on voltage axis i.e. X-Axis gives the voltage corresponding to peak or maximum power of the PV module (since at voltage axis, the $dP/dV = 0$). The Value of dP/dV is negative on the right side of the MPP and positive on the left side.

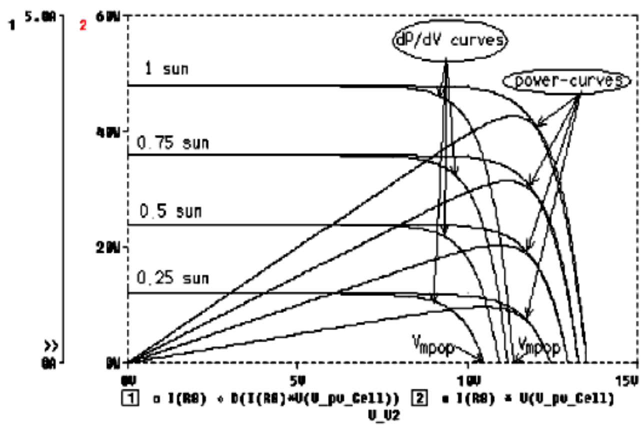

Fig. 8 – PV module power-curves and dP/dV curves for varying Insolation.

Many Maximum power point techniques and algorithms are available in Literature which can locate MPP such that $dP/dV = 0$ at any given instant and environmental conditions of Solar Insolation and Temperature.

8. SHADING

The shading effect is produced, if part of the string of PV cells does not receive full illumination due to shadow or otherwise. The shadowed portion of the string operates in third quadrant with negative voltage (reverse bias) and forward current. An arrangement to produce shading effect in PSpice has been shown in Fig. 9.

The illuminated portion of the string operates in fourth quadrant with positive voltage (forward bias) and positive current. The number of shadowed cells will therefore limit the voltage that a shadowed string can produce [23]. The shaded string produces multiple maxima as shown in PSpice simulated results of Fig. 9. The shading effect may severely limit the power produced because MPP tracking algorithms may tend to operate PV string on these multiple maxima, and if so happens it will limit the power produced.

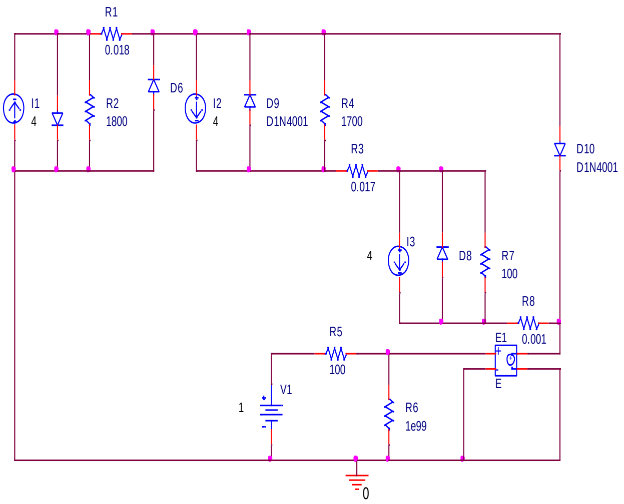

Fig. 9 – Schematic to simulate Shading Effect

9. CONCLUSION

The proposed PSpice study model of PV cells and modules for varying equivalent circuit parameters R_s, R_{sh} and diode model parameters N, I_s and their interdependencies. The *V-I* characteristics and P-V characteristics are studied for varying solar Insolation and Temperature. An Experimental set up to obtain *V-I* Characteristics is also discussed. The effect of shading and resultant multiple maxima are also clearly brought out.

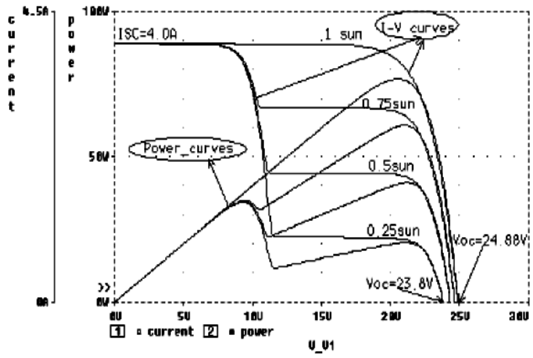

Fig. 10 – V-I Characteristics & power-curves for PV module under Shading.

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