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Performance Loss in Solar Photovoltaic Array due to Non-ideal Natural Conditions

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Performance of a SPV system is dependent on temperature, array configuration, solar insolation, and shading across it. Shading can occur when the PV arrays/modules get covered by shadows of passing clouds, buildings, etc., or even by shadows cast by other modules/arrays. As a result the ideal operation of the PV systems is severely affected the P-V and I-V characteristics. The modeling of nonlinear current-voltage characteristics of solar cells for performance prediction becomes difficult under the influence of shading. Non-uniform solar radiation due to shadows casted by the other panels/ modules, buildings, clouds, etc. can cause maximum power to change drastically. Partial shading of PV installations has an impact on its power production. For the simulated results it has been observed that 74.66% loss in I-V characteristics and 85.41% loss in P-V characteristics respectively. The power losses in the individual shaded cells would result in local heating and create thermal stress on the entire module/array resulting in hot-spot formation.

Keywords: *Maximum power point tracking (MPPT), Partial shading, Solar photovoltaic (SPV) characteristics.*

1.0 INTRODUCTION

With growing population, economic and industrial development, the need to examine alternative sources for generating electricity has become very important. Renewable energy sources such as wind energy, solar energy, and tidal energy play an important role to cover for the additional energy demands. Of these, the solar energy with irradiance levels of up to 1 kW/m^2 is abundant and photovoltaic power is a prime candidate for electrical energy generation [1]. Solar energy has the advantages of clean emission free production and continuous supply during day time while being portable and scalable. Photovoltaic is the process of converting sunlight directly into electricity using solar cells. It basically comprises of two steps. The first step is the absorption of solar radiation within the semiconductor. In the second step, transformation to electrical energy is made by generating current and voltage by the incident solar radiation on the solar cells that produces electrons-hole pairs. Solar cells are connected in different configurations depending on the current or voltage requirements to form Modules and Arrays.The modeling of nonlinear current-voltage characteristics of solar cells for performance prediction becomes difficult under the influence of shading. Non-uniform solar radiation due to shadows casted by the other panels/modules, buildings, clouds, etc. can cause maximum power to change drastically. Partial shading of PV installations has an impact on its power production. Moreover, the power losses in the individual shaded cells would result in local heating and create thermal stress on the entire module/array resulting in hot-spot formation. Under extreme cases of shading the

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i-v reverse bias on the solar cell might exceed its breakdown voltage and cause damage, which cannot be reparable. The solar modules/arrays may be rendered less efficient due to factors such as shading, bird-droppings, hot-spot formation, and cell damage due to extreme temperature and semiconductor material defects.

2.0 SOLAR ARRAY CHARACTERISTICS

A solar photovoltaic (SPV) array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array.

Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

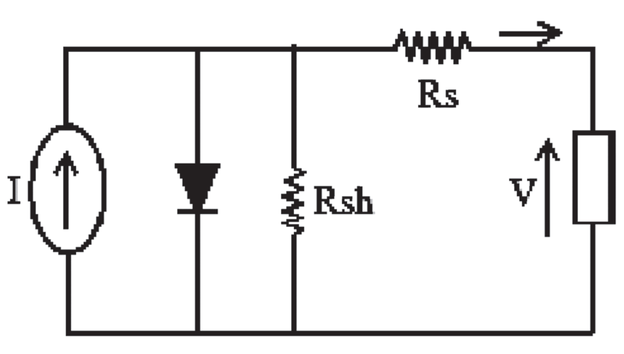

FIG. 1 SINGLE DIODE MODEL OF A PV CELL

The output current from the photovoltaic array is

$$I = I_{sc} - I_d \quad ....(1)$$

$$I_d = I_o(e^{qV_d/kT} - 1) \quad ....(2)$$

Where I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant (1.38 * 10-19 J/K) and T is the junction temperature in Kelvin (K) [2].

From equation (1) and (2)

$$I = I_{sc} - I_o(e^{qV_d/kT} - 1) \quad ....(3)$$

$$I = I_{sc} - I_o(e^{q((V+IR_s)/nkT)} - 1) \quad ....(4)$$

Where, I is the photovoltaic cell current, V is the SPV cell voltage; T is the temperature (in Kelvin) and n is the diode ideality factor.

Module parameters

Module parameters	Values
Short circuit current	3.75A
Series resistance of cell	0.001Ω
Reference cell operating temperature	20^{0}C
Reference voltage	17.1V
Reference current	3.5A
Number of modules connected in series (N_s)	60
Number of modules connected in Parallel (N_p)	4

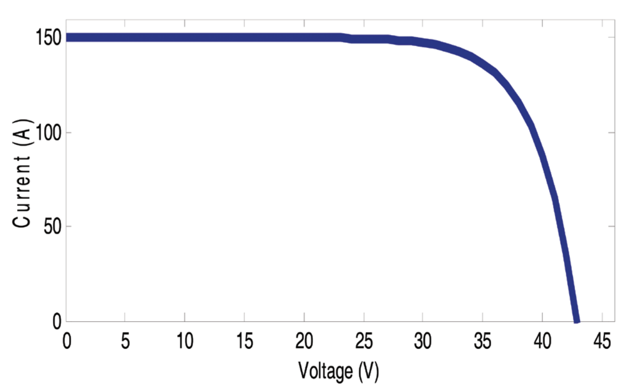

FIG. 2 I-V CHARACTERISTICS OF A SOLAR PANEL

The maximum power point of a solar panel changes in accordance with changes in the solar irradiance intensity, angle and panel temperature. The typical characteristic curves of current versus voltage, power versus voltage at different levels of solar irradiation and power versus voltage at different temperatures, are illustrated in Figure 4 and Figure 5.

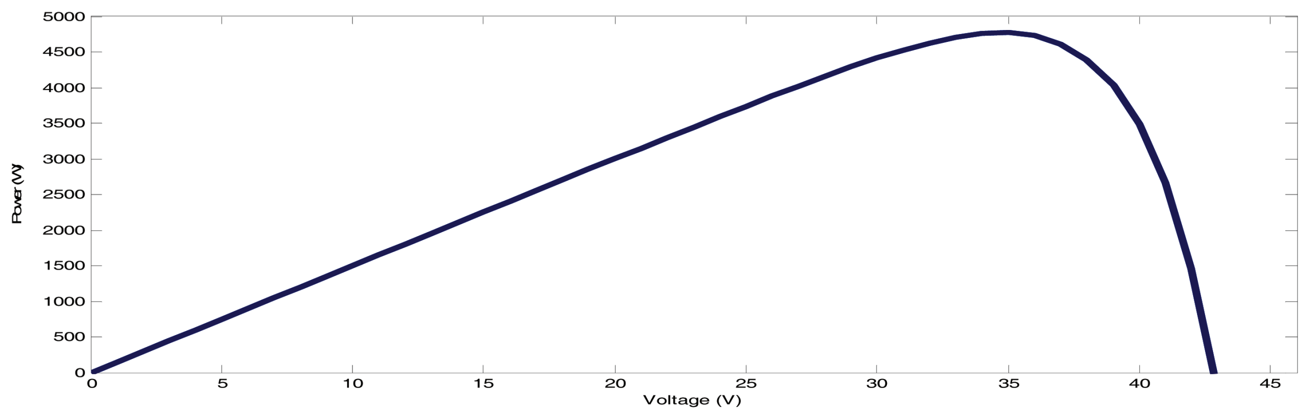

FIG. 3 P-V CHARACTERISTICS OF A SOLAR PANEL

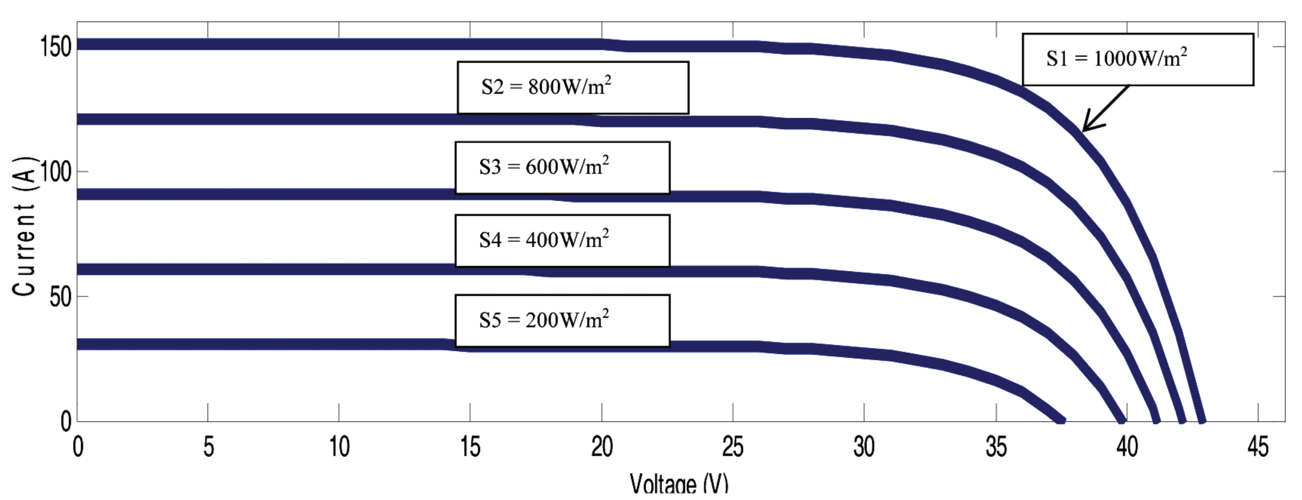

FIG. 4 I-V CHARACTERISTICS OF DIFFERENT SOLAR RADIATION LEVELS

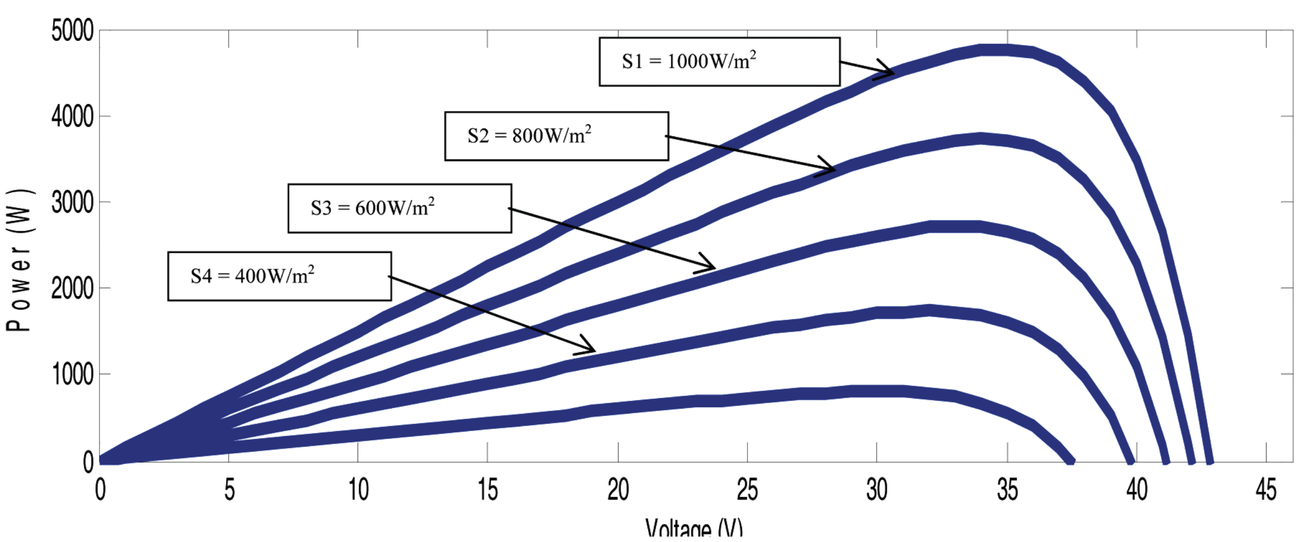

FIG. 5 P-V CHARACTERISTICS OF SOLAR RADIATION LEVELS

3.0 EFFECTS OF SHADING ON SPV ARRAY CHARACTERISTICS

Performance of a SPV system is dependent on temperature, array configuration, solar insolation, and shading across it [3]. Shading can occur when the PV arrays/modules get covered by shadows of passing clouds, buildings, etc., or even by shadows cast by other modules/arrays. As a result the ideal operation of the PV systems is severely affected the P-Vand I-Vcharacteristics.

Shading of solar cells is a critical issue in their performance because:

As the shaded cells can get reverse biased they consume power instead of generating power resulting in loss of total output power.

The power losses in the individual shaded cells would result in local heating and increase the temperature affecting surrounding cells. The increase in temperature creates thermal stress on the entire module and cause hot spots and local defects which potentially result in the failure of the entire array [5].

Under extreme cases of shading the reverse bias on the solar cell might exceed its breakdown voltage. The cell gets fully damaged, develops cracks and an open circuit can occur at the serial branch where the cell is connected [6].

3.1 Solar cells connected in series

Solar cells are connected in series so that voltage across each cell can be accumulated at the output. The cells in series carry the same current irrespective of the fact whether one or more cells under shade produce less photonic current. As the shading increases in a cell, its output voltage starts to fall. Under some shading conditions, in order to maintain the same output current a shaded cell can get reverse biased. Then the shaded cell consumes power instead of delivering power. This power is drawn from illuminated cells and thus reduces the overall power generated by the array. Power losses in the individual shaded cells would increase the temperature creating thermal stress on the entire module and cause hot spots and local defects [4]. In case of no shading a significant part of photonic current in the solar cell model flows through the diode to generate enough voltage at the output. When the cell gets shaded, the photonic current is reduced. As a result the current that was previously flowing through the diode is also reduced. This allows less current to flow through the output. In order to maintain the same output current across each cell (since the cells are in series), the shaded cell operates under reverse bias and negative voltages are generated across the output voltage.

3.2 Solar cells connected in parallel

Manufacturers build solar cells with different configurations to obtain appropriate voltages and current across the load. In order to increase the currents, solar cells are connected in parallel. In parallel connection of cells the currents across each cell is summed up while the voltage remains constant across them.

Under uniform full illumination across each cell, portion of the photonic current flows through the diode and maintains the required voltage to produce an output current. All these individual currents add up to give the final current while voltage across each cell remains constant. When one of the cells gets shaded, the amount of voltage at the diode required to produce the same output current is reduced. But in case of parallel cells this effect is very small. As the shading is increased, the photonic current of the shaded diode may not be enough to forward bias its diode.Thus the output voltage is still maintained constant but at a slightly lower value. However the total output current reduces resulting in reduced output power [7-10]. The effect of shading on I-V and P-V characteristics are shown in Figure 6 and 7 respectively. Considering three parallel connected modules shaded out of four parallel connected modules and 24 series connected modules shaded out of 60 series connected modules then there is a 74.66% loss in I-V characteristics and 85.41% loss in P-V characteristics.

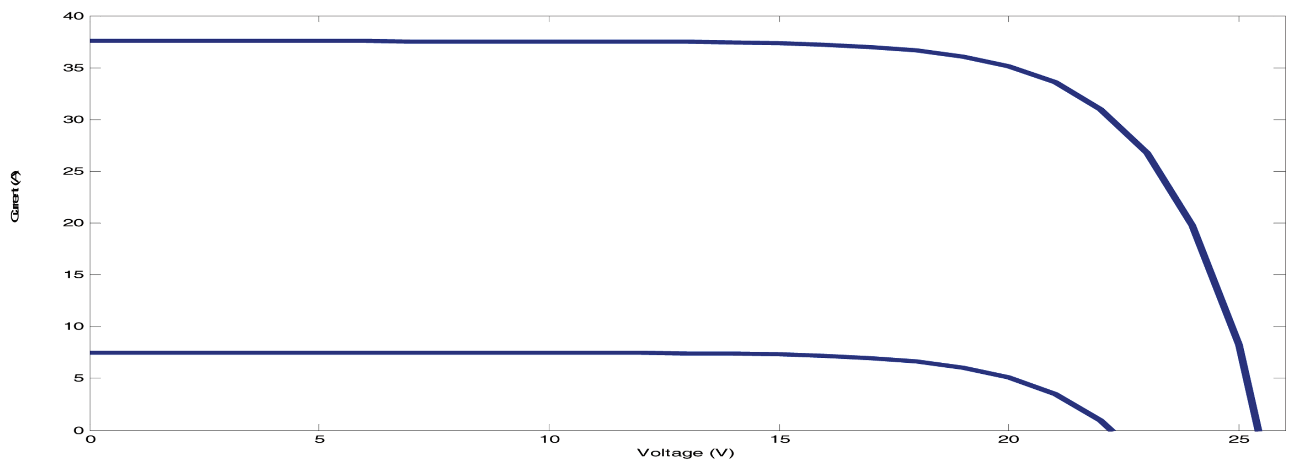

FIG. 6 EFFECT OF PARTIAL SHADING ON I-V CHARACTERISTICS OF A SINGLE SPV MODULE

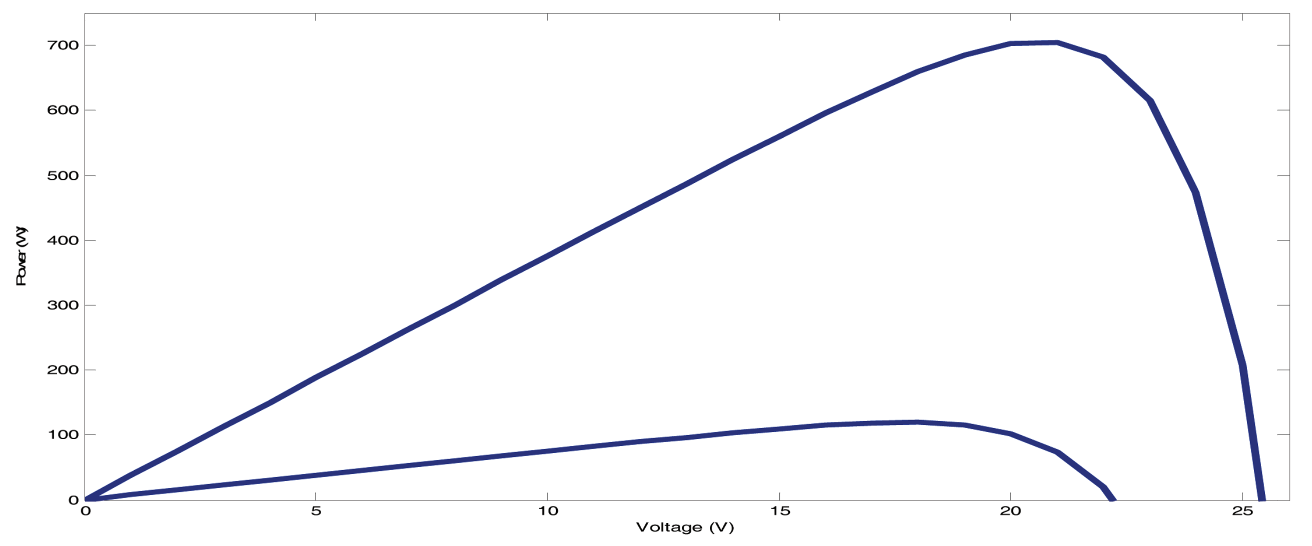

FIG. 7 EFFECT OF PARTIAL SHADING ON P-V CHARACTERISTICS OF A SINGLE SPV MODULE

3.3 Hot Spot Heating

If we have a current mismatch for series connected solar cells then power can be dissipated in bad cell with a maximum occurring when the chain is short circuited i.e. good cells bias the bad cell so large amount of power dumped into bad cell. This creates the hot spot heating. This hot spot heating can severely damage the module. Hot spot heating is big problem for series connected cells. The bad cell which is a shaded portion on the SPV module is in reverse bias; therefore it will be dissipating the power from the good cells.

3.4 Heat generation

Since module is exposed to sunlight itgenerates heat as well as electricity. Typically module is converting only 10-15% of the incident power to electricity, remaining power can be largely heat. Some factors include are reflection from top surface, operating point of solar cells, absorption of light not by solar cells, absorption of infra-red light, packing density of solar cells.

4.0 CONCLUSIONS

The open circuit P-V and I-V characteristics of the solar photovoltaic array explains in detail that it dependence of the solar radiation levels and the operating temperature.

The effect of shading on the solar photovoltaic array has been explained. The shading effect creates bad cells on the solar photovoltaic array and these bad cells will dissipate power from good cellsof SPV array instead generating the power, which reduces the conversion efficiency of the SPV module/array. For the simulated results it has been observed that 74.66% loss in I-V characteristics and 85.41% loss in P-V characteristics respectively.

The solar cells of the SPV array will be reverse biased due to the effect of shading and creates bad cell on the SPV array. This reverse bias on solar cell might exceed its breakdown voltage and cause damage which cannot be repairable.

In case of series connected solar cells, if there is a current mismatch then power can be dissipated from the bad cell due to more power dumped by good cells creating hot spot heating.

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