Performance Analysis of Different Shading Effects on Solar Photovoltaic Cells

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***Abstract*— In this paper mainly analyzes the performance of different photovoltaic array configurations under various shading patterns. A Matlab/Simulink based simulation model of a PV module is utilized as the smallest building block of the mentioned topologies. The performance and output characteristics of Series-Parallel array under different shading scenarios. The effects of bypass diodes during partial shading conditions are considered and the analysis results are presented and compared with and without bypass diodes. The results show that all the mentioned topologies have similar performances under partial shading conditions. The analyses and results provide detailed information on the characteristics of different array topologies which can be utilized by system designers to estimate the power yield and choose the most appropriate system configuration with respect to the existing environmental conditions to improve the overall efficiency.**

***Keywords*:- Series-parallel simulink, solar cell, solar energy, solar module, Photovoltaics, Partial Shading**.

I. INTRODUCTION

Solar energy is a vital and environment friendly energy. It is more flexible, cost effective and commercially widespread [1]. It can be considered to be limitless unlike the tapering conventional fossil fuel. In addition to these, they can also be used for different practical purpose in our home, society and or in industries. Furthermore, solar energy is an environmental friendly technology which helps in controlling the pollution's level as compared to conventional energy source which causes environmental pollution.
In this modern scenario, sustainable development is one of the prime concerns. Photo Voltaic (PV) drawing its source from sunlight is one of the eligible technologies for such sustainable developments. As the conventional source of energy is limited and their utilization at large scale so as to full fill the demand of energy is causing the rise in their cost. Hence, solar energy (which is abundant in nature, environmental friendly and easily available on the earth) has become a prominent alternative source of energy so as to fulfill our energy's demand. Therefore, these statements one can conclude that solar cell/photovoltaic module which converts solar energy into electrical energy is playing a vital role in present day scenario and is a developing technology. Recent researches have shown a greater emphasis towards these PV technologies so as to get higher conversion efficiency by the PV modules. Depending on the need/uses, PV modules are designed by connecting a number of solar cells/PV cells in series and parallel combinations. Electrical power generated by these PV modules depends on many atmospheric conditions e.g., solar isolation and surrounding temperature. Hence knowledge of these factors is of great concern so as to get the efficient working of them.

II. PV SYSTEM OVERVIEW

The equivalent circuit of an ideal solar cell is exhibited by a corresponding single-diode model. In the single diode model, a source of current is connected in parallel with a rectifier diode. Fig.1 shows the equivalent circuit of an ideal solar cell. For the solar cell, the I-V properties are governed by the solar cell equation given by Schockley [1-5].

$$I = I_{PH} - I_O \left(A^{\frac{qV}{TK_B}} - 1 \right) \qquad (1)$$

Where, K_B represent Boltzmann constant, T is Temperature (in K), q represent charge on electron, I_O is the saturation current and V is the voltage at the terminals of the cell. The photo generated current I_{PH} depends on photon flux which incident on solar cell and further its reliance on wavelength is represented with the help of quantum efficiency i.e., spectral response.

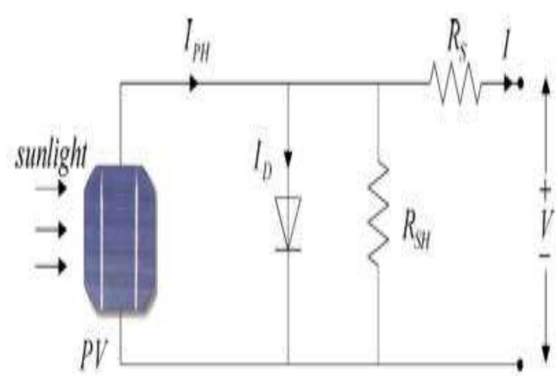

Fig. 1: Equivalent circuit of solar cell [8].

The most important electrical characteristics of a PV cell module/array are:
a) Short Circuit current (I_{SC}): For normal level of solar irradiance, it is generally related to I_{PH} and shows a slight increase with rise in temperature and is directly dependent on optical power of incidence.
b) Open circuit voltage (V_{OC}): it is the potential difference across the terminals of solar cell when no load is connected and show depends on the sunlight. It is logarithmically dependent on the solar irradiance. Further increase in temperature causes the rise in saturation current and hence decreases in open circuit voltage.

c) Fill factor (FF): It is a physical quantity with no dimension and validate the shifting in real I-V properties from the ideal one. And this shifting is more if there is the presence of parasitic components e.g., series and shunt resistance.

d) Maximum output power: Is is given as a product of I_{mp} and V_{mp}, which can be generated by a photovoltaic module and it is used to justify the performance of a photo Voltaic module and its value depends on the FF, V_{OC} and I_{SC}.

e) Efficiency: Efficiency of a solar cell is the factor which tells that the how effectively a solar cell can convert a fraction of incident solar radiation into useful electrical energy as compared to other solar cell. Hence it is nothing but the ratio of electrical energy generated by the solar cell to the solar energy incident on the solar cell.

Hence it is expected that the whole efficiency of the solar cell should increase logarithmically with incident power. But the solar cells are not very efficient because high sunlight concentration results in an increased energy loss inside the cell at higher temperature. Hence, thermal effects and electrical losses (caused due to excessive series resistance in solar cells) restrict us to achieve the desired efficiency of solar cell. Hence all around the world, obtaining a high efficiency of solar cell is biggest concern.

Fig. 2 shows the I-V and P-V characteristics of solar cell [14]. In the ideal case of solar cell,

$I_{SC} = I_{PH}$, and

$$V_{OC} = \frac{TK_B}{q} ln\left(1 + \frac{I_{PH}}{I_0}\right) \quad (2)$$

At voltage, V_{mp} and current, I_{mp} electric power generated by a solar cell is maximum i.e., P_{max} and fill factor FF can be defined by

$$FF = \frac{I_{mp}V_{mp}}{I_{SC}V_{OC}} = \frac{P_{max}}{I_{SC}V_{OC}} \quad (3)$$

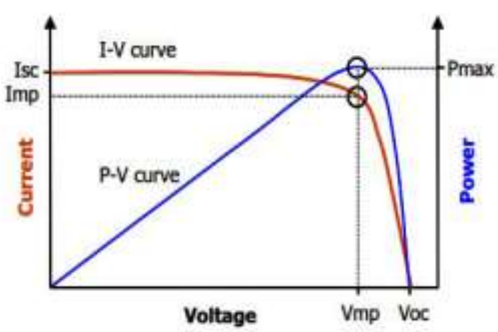

Fig.2: Shows the I-V and P-V characteristics of an ideal solar cell [6-8] whose equivalent circuit is shown in Fig.1 having a source of current (I_{PH}), a diode with internal shunt resistance (R_{SH}), an internal series resistance (R_S)

Further, the net current is given by [3-10]:

$$I = I_{PH} - I_D - \frac{V+IR_S}{R_{SH}} = I_{PH} - I_O\left(exp\left(\frac{e\,(V+IR_S)}{kT_C}\right) - 1\right) - \frac{V+IR_S}{R_{SH}} \quad (4)$$

Where, normal diode current is given by I_D.

The effect of series resistance on the fill factor is given by [9-11];

$$FF = FF_0(1 - r_S) \quad (5)$$

Where FF_0 is the fill factor of the solar cell with ideal characteristics, and $r_S = {R_S\, I_{SC}}/{V_{OC}}$.

III. PV Shading

As the solar photovoltaic array module (i.e., SPVA) comprises series and parallel connections both, the main problem in SPVA is non-linear internal impedance which is associated with cells connected in series. Further the issue even get complex when SPVA are irradiated by non-uniform solar light i.e., shading effect.

The effect of shading on SPVA of large size generally occurs due to: presence of clouds, shadows caused by nearby building/house construction, shadow by other SPVA module, due to tees etc. If any portion of SPVA is affected by the shading effect then in that portion, the solar cell produces significantly less photo-current and the result is the mismatching of current in series connection of solar cells in SPVA and this leads to the increase in non-linear impedance mismatching. Due to this the cells under the effect of shading and connect in series with fully sunlight irradiated cells are forced to carry same current (as that generated by full sun light irradiated cells). Hence, this may lead the shaded cells to be in reverse biasing and acting as an internal load for the whole SPVA which will cause a self power drain within the whole system itself and this may lead to a new phenomenon called as hot spot and can permanently damage the entire system.

In a larger SPVA, the occurrence of partial shading is common due to tree leaves falling over it, birds or bird litters on the array, shade of a neighboring construction, and so forth.

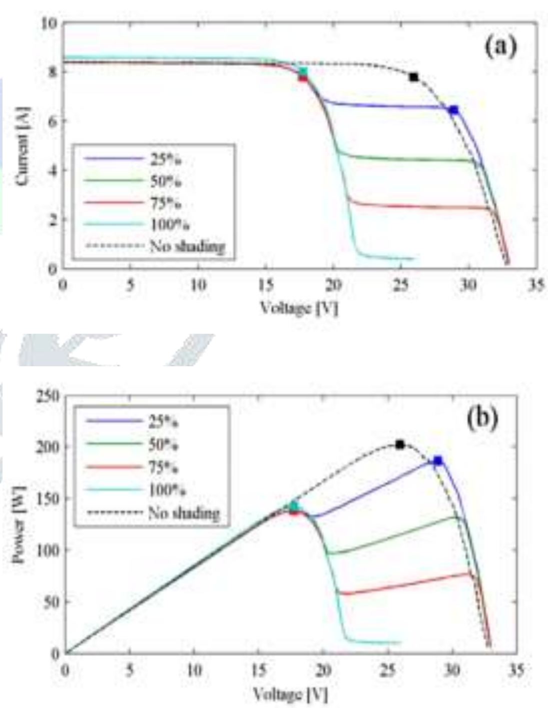

Fig. 3(a,b): Shows the effect of different shading's profiles on the value of I-V and P-V measurements of SPVA [12-14].

Hence if there is shading effect then the ideal working of the SPVA systems is highly influenced showing huge deviation in *I-V* and *P-V* characteristics as shown in graphs in Fig. 3(a-b). Hence from the graphs is clear that as the coverage are of SPVA module by shading effect is increased there is performance degradation in the system.

IV. RESULTS AND DISCUSSION

As the single module cannot produce the required power so number of modules are connected in series to attain a desired voltage and then are connected in parallel to increase the current. When the modules are connected in parallel then there is no effect of shadowed cell on the non shadowed cell but when the modules are connected in series then if shadow comes on one module, the current will be limited by the current produced by the shadowed cell or the low current cell hence the power generated by the non shaded cells are wasted. This shadow will also causes the hot spot phenomenon to occur which eventually damage the module. So to eliminate these problems a special circuitry is used which is called as bypass diode.

The obtained I-V characteristics for different shading scenario at cell level are shown in fig.4 and at module level is shown in fig. 5. It can be seen from the graph that as the shading increases from 25% of the cell or module to 100% of the cell or module, the current starts decreasing and current will become 0 at 100% shading. This result is for single module, but the single module cannot fulfill the requirement of both current and voltage so for practical use number of modules is connected in series and parallel to attain the required voltage and current respectively. The effect of shadow is negligible when modules are connected in parallel but in case of series connection the effect is very destructive. When the modules are connected in series then if there is shadow on one module, the current will be limited by the current produced by the shadowed cell or the low current cell hence the power generated by the non shaded cells are wasted.

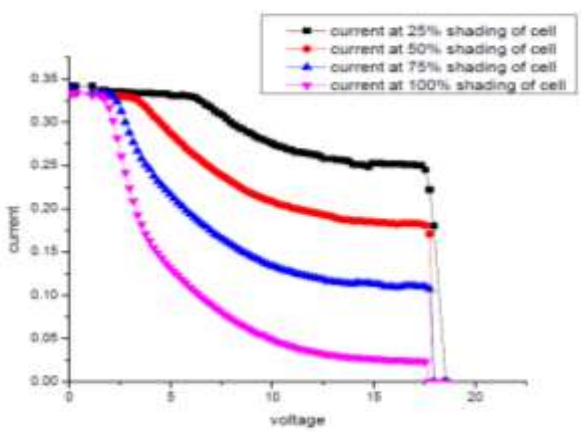

Fig.4: Effect of shading at cell level without bypass diode

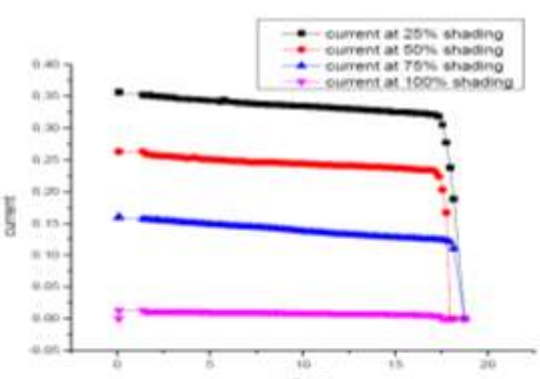

Fig.5: Effect of shading at module level without bypass diode

I-V characteristics of two modules connected in series, without bypass diode is shown in figure 29. From the figure 29 it can be seen that when there is no shadow the short circuit current is 0.17 Ampere but it reduces to 0 when one module is shaded. This effect can be minimized by using bypass diode.

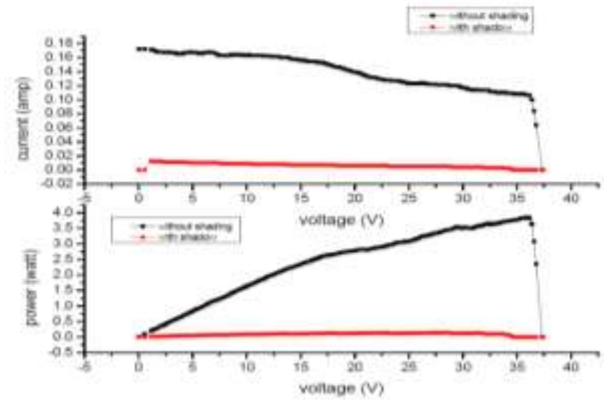

Fig. 6: I-V and P-V characteristics of test bench PV modules connected in series without Bypass diode under different shading profile.

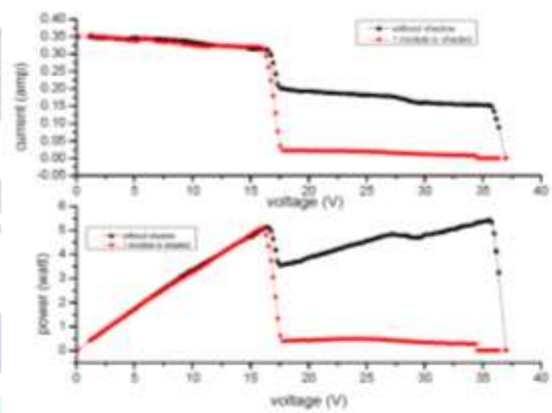

Fig. 7: I-V and P-V characteristics of test bench PV modules connected in series with bypass diode across each module, under different shading profile.

An I-V characteristic with no shadow has a step near 18 volts because of the mismatch in currents of two different modules. It can be clearly seen from the figure that when one module is completely shaded the current reduces to 0 but at the same time it bypasses the current generated by the un-shaded module. By the use of bypass diode, the power generation reduction to 0 due to shading is limited. Due to the effect of shading, the power generated will be reduced by some percentage. The maximum power point will shift towards the origin and will occur at lower voltage.

V. CONCLUSIONS

Different system topologies are utilized in PV generation plants to improve the overall system efficiency. Series-Parallel configurations are the most widely used PV array topologies in order to reduce the negative effects of partial shadings. A Matlab/SIMULINK based simulation model of a solar module has been utilized to analyze and compare the performances of each configuration type PV array. The results provide useful and reliable information on the performance of array topologies under changing shading conditions and can be utilized during system design to improve the overall efficiency of the PV system.

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