Modelling and Simulation of Solar Module under Non-Uniform Conditions and Performance Evaluation of TiO_2 Coated Cell

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Abstract

A photovoltaic (PV) module generates significant electrical energy by harnessing incident rays from suns broadband spectrum. The current –voltage characteristics of these modules are typically complex and a partially shaded PV modules exhibit additional difficulties in tracking the maximum power point. Parametric study of variation of different electrical properties with irradiance becomes necessary to estimate the conversion efficiency of a solar cell. A new polymeric conducting nano-material anti reflection coating on solar panels will enhance the conversion efficiency even on a low intensity (shadow or non-uniform conditions). A numerical model is developed to study the effects of solar irradiation under the non-uniform conditions. The model is upgraded suitably to simulate the electrical behaviour of TiO_2 coated solar cell under one sun illumination. Significant improvement in conversion efficiency is observed with TiO_2 double layer coating.

Key words: Photovoltaic array; Anti reflection coating; Nano coating; Shading; Simulation

1. Introduction

Conversion of solar energy to electrical energy (photovoltaic power) has various advantages such as safe, simple, easy installation, longer life utilization and also not harmful to environment. Renewable energy source accomplishes the demands of world energy problems. Among various renewable energy resources, photovoltaic (PV) power generation systems are expected to play a key role as an eco-friendly electrical power generation resource. It is necessary to improve its efficiency and develop the reliability of photovoltaic power generation systems [1,2].

PV system consists of photovoltaic cells which are connected in series and parallel to form PV module. In general individual cells are connected in series to get desired voltage of the module which encapsulates the cells and protects from dust, water and other damages. Modules are connected together to form a PV array. To obtain more voltage individual cells are connected in series and to get more current the cells are connected in parallel. Matching of the cells and modules and structure of the array are important in the overall performance of the array [3,4].

Energy storage devices like batteries and AC and DC converters are also integral with the PV system to store and distribute the power generated through photovoltaic module or PV array. Solar cell is the important element which absorbs the suns energy and converts directly in to electricity. It consists of a p-n junction fabricated in a thin wafer of semiconductor material usually silicon as vast data is available for silicon wafer technology from the semiconductor industry [5].

An accurate photovoltaic numerical model is developed and the electrical properties of a solar cell are retrieved for a given solar insolation and given temperature. A photovoltaic array simulation model was developed using MATLAB-Simulink GUI environment [6]. In this model, validation studies with proper load matching circuits are simulated. Circuit based MATLAB simulation study for the current and power of a PV panel depends on the array terminal operating voltage [7].Many factors like temperature, solar insolation, shading and module configuration effect the performance of the PV module [8].

Multi-crystalline silicon (mc-Si) solar cells are subjected to number of loss mechanisms. The reflection losses are more in this type of cells and these losses can be effectively compensated by coating the active cell surface with suitable anti reflective (AR) coating. Another major factor that reduces the performance of the cell is non-uniform conditions. Sun produces enormous energy which can be tapped effectively by the PV devices in a sunny day time. But in case of winter and also in case of shadow conditions the intensity of the incident irradiation reduces which caused non-uniform behaviour of the cell. The effect of non-uniform conditions (shading effect by buildings, trees and clouds) causes change in the current-voltage (*I-V*) characteristics of the system, and consequently the current decreases as the output current is directly proportional to the incident energy [9-11].

The purpose of this study is to simulate and analyze the properties of non-uniformly irradiated solar module. Several simulation programs for PV systems were developed during the last three decades. These simulation studies are useful in evaluating the performance of the solar cell under the given conditions. However studies on the dynamic behavioural simulations on the multi crystalline silica solar cell under passing cloud are scarce in literature.

Antireflection or nano-coatings like ZnO, TiO_2 and CNT on solar panel is one of the best techniques to improve the conversion efficiency of solar panel even under non-uniform conditions. In this study a numerical model is developed to simulate the effect of passing cloud on a ten by ten solar module. Further a single cell is coated with TiO_2 nano solution to form an effective anti reflection coat on the cell surface thereby increasing the effective absorbance and the current output generated for the given insolation. With this increased performance of the cell under shadow condition is observed [12,13].

2. Modelling and Formulation of the Solar Cell:

A solar cell can be modelled using a set of standard equations. The simplest equivalent circuit of a solar cell is being a single diode model as shown in figure 1 [14,15].

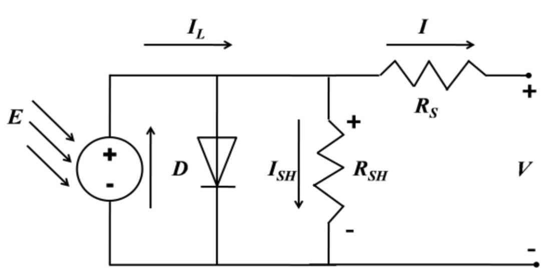

Figure 1: Equivalent circuit of a solar cell

Current source is shown parallel to the diode. Output current is directly proportional to the incident current or photon current (I_{ph}). During night times the solar cell is not an active device and it simply act as a diode (p-n junction) and neither produce current not voltage. When it is connected to an external supply it generates diode current (I_d) or dark current. The overall current-voltage characteristics are determined by the diode as shown in Figure 2.

$$I = I_{ph} - I_d$$

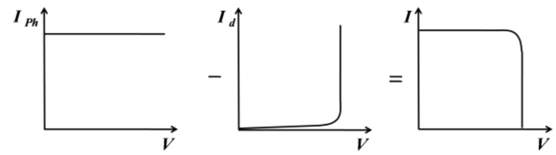

Figure 2: Current – Voltage characteristics of solar cell

The electrical properties of a solar cell can be empirically estimated by a set of equations. A non-irradiated solar cell has nearly similar behaviour of a diode. Hence, using the theoretical equations an algorithm has been developed to compute the electrical properties of a solar cell under non-irradiated and at different irradiation conditions. The algorithm is developed using the set of standard equations. The current *I* is calculated using the following equation [16-18].

$$I = -I_D = -Is \cdot \left[\exp\left[\frac{V}{m.V_T}\right] - 1\right] \quad \ldots\ldots (1)$$

In the above equation (1), *V* is voltage, I_S is saturation current, '*m*' is diode factor; 'V_T' is thermal voltage. The resulting current *I* largely depends on the solar irradiance *E*, it can be shown using the following equation. C_0 is coefficient:

$$I = C_0.E \quad \ldots\ldots (2)$$

The $\boldsymbol{C_0}$ factor is equal to 3.11e-03 and the saturation current I_{SC} factor is used as 3.4e-07.Current values are computed using different voltage values such as: 0.0 v, 0.1v, 0.2v, 0.3v, 0.4v, 0.5v, 0.6v. The different irradiation intensities considered are 200 w/m^2, 400 w/m^2, 600 w/m^2, 800 w/m^2, and 1000 w/m^2. Average cell temperature is assumed as 25°C and thermal voltage (V_T) corresponding to the cell temperature is taken as 25.7mV. The current and voltage values are tabulated in Table 1 and the corresponding *I-V* curves for different irradiance values are shown in figure 3

Table 1:Computed *I-V* values with different irradience (E) levels

V_D in Volts	E_1 = 200w/m^2	E_2 = 400w/m^2	E_3 = 600w/m^2	E_4 = 800w/m^2	E_5 = 1000w/m^2
	I_1	I_2	I_3	I_4	I_5
0.0	0.622	1.3995	2.0215	2.6435	3.2655
0.1	0.622	1.3995	2.0215	2.6435	3.2655
0.2	0.62194	1.3994	2.0214	2.6434	3.2556
0.3	0.62124	1.3987	2.0207	2.6427	3.2647
0.4	0.61209	1.3896	2.0116	2.6336	3.2556
0.5	0.49253	1.27	1.892	2.514	3.136
0.6	-21.48	-20.703	-20.081	-19.459	-18.837

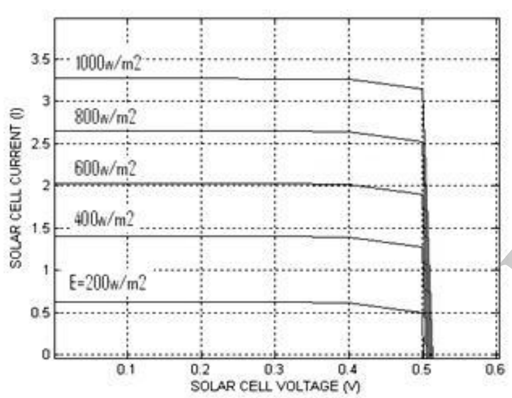

Figure 3: Influence of irradience E on the *I-V* charecterisitics of a solar cell

3. Simulation of the Photovoltaic Array:

The above simulations give the following points. The effect of incident irradiation on the output current of the solar cell is studied. Solar cell output current (short circuit current) increases with increase in incident irradiance i.e., current (*Isc*) is directly proportional to the irradiance (E). Also the current increases with the cell open circuit voltage (*Voc*) Thermal factor of 25.7mV is considered at average cell temperature of 25°C. The relation between current and voltage for different values of the irradiances and thermal factor can be studied with the developed algorithm.

3.1: *Electrical properties of a solar cell under uniform and non-uniform cloudy conditions*.

The non-uniform behaviour of the solar cell is attributed to the shadow conditions that make the efficiency of the solar module to decrease. Shadows on the cell cause hot spots on the shaded cell and it acts as a load on the rest of the resulting output current reducing the overall short circuit current. The developed algorithm is used to calculate the load on the each cell in a module and to simulate the effects due to shadow conditions. These plots are shown in figure 4.

Three dimensional images of a PV module with 'm' by 'n' configuration are modelled and simulated in this work. The magnitude of the solar irradiation is indicated by a color bar on the right side of the images. 'Blue' color indicates the moderate irradiation and 'red' color indicates lowest irradiation on the solar module. The shadow of the passing cloud results in non-uniform irradiation on the cell and this will be considered as a load in the equivalent circuit as the cell dissipates input current. Development of 'hot spots' on the cells due to the non-uniform or shadow conditions is a practical problem in the PV system installations. These 'hot spots' will reduce the overall performance of the module as the cell covered by the shadow gets over heated and fails due to damage This can be prevented effectively by connecting a by-pass diode across the cells which creates a low reverse breakdown voltage for the cell under shadow.

Due to the shadow of a passing cloud, trees and buildings the incident photon current on the surface of the module decreases, resulting in the decrease in output current of the PV system. The reduced irradiance reduces the short-circuit currents and open-circuit voltages of each cell. In this study the parameters and temperature of the solar cells are assumed as unchanged. The ratio of the irradiance in each solar cell in a 10 X 10 module at each instant of time t_1 to t_{10} values are considered in modelling the cell under passing cloud and are in accordance to irradiance standards .

The moving shadow of the cloud at the time instants t_1 to t_{10} is modelled assuming that the shadow of the cloud passes on each cell in one second. The cloud is considered brighter in the bounds and most dark in the centre. Dynamic simulation of a ten by ten solar module is carried in this work to give the better understanding of the effect of the passing cloud on the solar module At the start point of time (t_1) the centre of the cloud falls in the lowest left side of the solar cell. At the end point (t_{10}) the centre of the cloud falls in the highest right side solar cell.

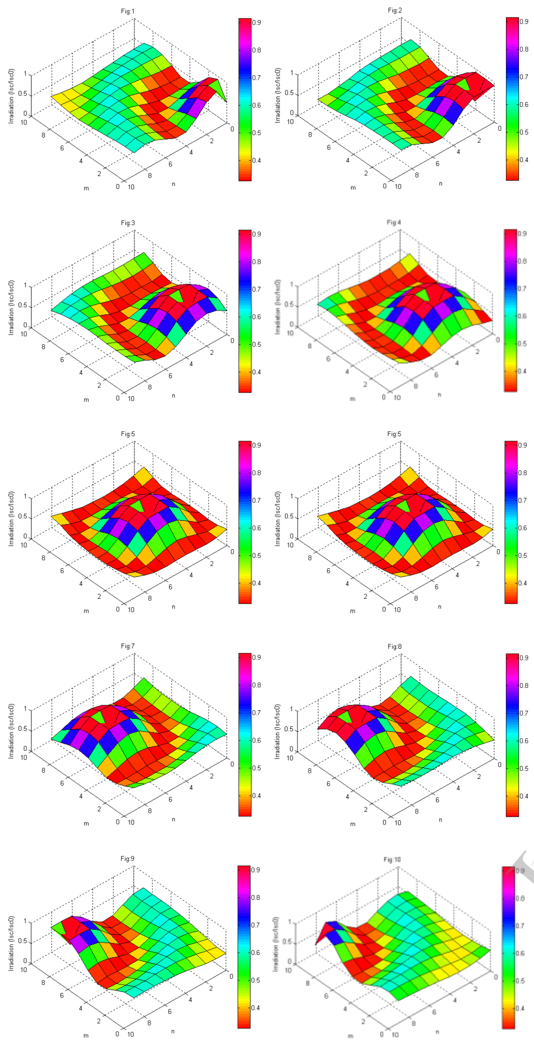

Figure 4: Simulation of solar module under non-uniform irradience.

4. Synthesis of Anti Reflection Coating (ARC) Material:

Synthesis of AR coating material through sol-gel process involves mixing of water, alcohol and titanium tetra iso propoxide in the specified proportions. TiO_2 layer is applied on mc-Si substrate by spin-coating technique. It is observed that the *I-V* characteristic with a double-layer AR coating is better than single-layer AR coatings. Table 2 shows the device performance of the mc-Si solar cells with TiO_2 AR coating structures. The efficiency of plain mc-Si solar cell without TiO_2 coating is 11.2%. The mc-Si solar cells with double and single-layer TiO_2 coating shows an increase of efficiency about 14.5 and 14.1%, respectively. Hence, the efficiency of the mc-Si solar cell with a double-layer AR coating is enhanced up to 14.5%.

Table 2: Characterization of Si solar cell with TiO_2 Anti reflection coating

Cell performance	Voc (V)	Jsc(mA/cm^2)	FF (%)	η (%)
Plain Silica (Without TiO_2 coat)	0.59	18.2	75.7	11.2
Single-layer TiO_2	0.59	25.7	75.6	14.1
Double-layer TiO_2	0.59	26.2	75.2	14.5

5. Conclusion:

This paper presents an efficient algorithm to describe the characteristics of a solar cell under non-uniform conditions. This also emphasizes the characterization of PV cell and effect of shading on a PV array. Simulations based on the developed algorithm clearly describe the effect of shadow on the PV cell. Experimental study also elucidates the performance of the mc-Si solar cell coated with TiO_2.A good enhancement of 29% in conversion efficiency is observed with double layer TiO_2 coating.

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