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Development of solar photovoltaic model for wide range of operating conditions

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ABSTRACT

Assorted climatic conditions such as irradiation, temperature and shading due to clouds, trees, buildings, communication towers etc. has an unavoidable impact on the output of solar photovoltaic (PV) system. This creates a need for the analytical performance study of solar PV system in changing atmospheric condition in order to design and install an optimized solar PV system for both, stand alone and grid connected. The present work shows the developed PV model in MATLAB codes and simulation is done under varying climate conditions showing change in irradiation and temperature using different arrangements of PV system. PV parameters are obtained in different setup and I-V and P-V characteristics of the developed model of the PV modules are analyzed. A comparative study of the parameters obtained is quite beneficial for an optimized design of the PV system under different atmospheric conditions.

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NOMENCLATURE

a_f	:	Ideality factor of diode
n	:	Number of cells in the array having one shaded cell
R_{sht}	:	Shunt reistance
V_{sd}	:	Shading voltage V
I_{str}	:	Reverse saturation current of diode A
K_b	:	Constant (Boltzman)
β_t	:	Coefficient of temperature of open circuit voltage
K_{Rsht}	:	Coefficient of Temperature of shunt resistance
γ_{Rsht}	:	Irradiance coefficient of shunt resistance
n_{sc}	:	Number of cells connected in series
T_o	:	Operating temperature
G	:	Solar irradiance
v_{th}	:	Thermal voltage V
V_{oct}	:	Open-circuit voltage V
V_{out}	:	Output voltage
VI_{out}	:	Output current A
R_{ser}	:	Resistance in series resistance Ω
I_{ph}	:	Photocurrent A
I_{sct}	:	Current (short circuit) A
α_t	:	Coefficient of temperature of short circuit current
K_{Rser}	:	Coefficient of temperature of series resistance
γ_{Rser}	:	Irradiance coefficient of series resistance
q_e	:	Charge on electron
γ	:	Photon intensity
T_{refr}	:	Reference temperature
G_{refr}	:	Reference solar irradiance
I	:	Output current

1. INTRODUCTION

Time is not far away when the present sources of fossil fuel will get depleted after few decades for the generation of electrical energy. Continuously increasing population at the global level and shortage of the current resources which are mostly used at present for the generation of electrical energy brings the attention of researchers to think about the future planning of the generation of electrical energy [1], [2]. Renewable energy sources like wind energy, tidal, biomass, solar energy (includes both solar photovoltaic and solar thermal) etc. are among those sources of energy which can be suitable alternative for the forthcoming future of electrical energy for the necessary requirements. In the family of renewable energy sources, the photovoltaic (PV) system is highly preferable due to its continuous uninterrupted, free of cost availability, low running cost and a favorable unaffected impact on global warming. Even though some limitations, like low energy conversion rate (solar to electrical) and variation of irradiation and temperature are there but still installation of PV is on the rise in different part of the world.

In PV, solar energy is directly converted in to electrical energy [3], [4]. The photons strike the p-n junction of solar cell and electrons get accelerated from the depletion layer, where potential barrier plays an important role in the flow of electrons to and fro if the load is connected [5], [6]. The commercially available PV cell consists of a p-n junction which has metal contacts at upper and lower side, which are covered by glass coating in order to facilitate the flow of charged particles. A module consists of various PV cells and a PV panel consists of various modules. Which in turn forms a desired capacity of PV array. A combination of series and parallel PV cells are organized to get the desired output of PV array. The parallel combination of PV cells increases the current level and the series combination of PV cells increases the voltage level of the PV system [7]. Figure 1. Shows a typical layout of a general PV system with stand alone and grid connected, which includes various blocks like PV panel, DC to DC converter, DC bus, and battery.

In ideal case, a current source and a diode connected in parallel form a PV cell, generally which is not the case as for the practical PV cell. However practically in addition to current source and diode series and parallel resistances Rs and R_{sh} is also incorporated. Series resistance is the resistance to the current path and metal contact while parallel resistance is occurred due to cracks and manufacturing defects. In order to ensure the maximum power output from the PV system generally maximum power point tracker (MPPT) is used. A DC-to-DC Converter is used for this purpose [8], [9].

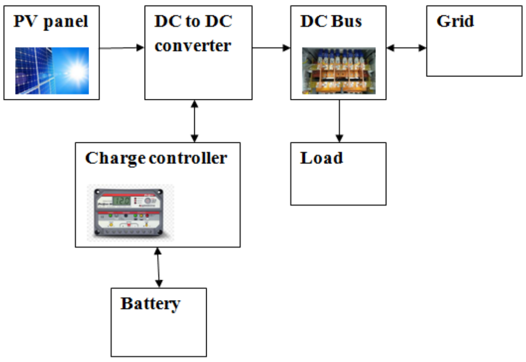

Figure 1. Typical layout of a general PV system

The PV cell receive the solar radiation and converts it into electrical energy directly, in order to achieve the desired AC/DC output an inverter and converter is used because the output of the solar cell obtained is in the form of DC. Modeling of PV cell has been a preliminary work for the researchers in order to achieve an efficient, accurate and reliable PV system. Various works has been carried out in this regard. Among which are, one diode model and two diode models, mathematical model and the model developed with MATLAB coding [10], [11]. One diode model is simple and has been used for the extraction of five parameters, which are photo current (Iph), diode reverse saturation currents (Io), series resistance (Rs), shunt resistance (Rsh) and diode ideality factor (a), these parameters are generally not provided by the manufacturer in the data sheet. Two diode model is more accurate for the low irradiation which also includes recombination and is used for the extraction of seven parameters which are; photo current (Iph), diode reverse saturation currents (Io1) of diode D1 and diode reverse saturation currents (Io2) of diode D2, series resistance (Rs), shunt resistance (Rsh) and diode ideality factor (a) [12].

In mathematical model of PV cell, equations are derived from the equivalent circuit of PV module and these equations are converted in-to block circuit using mathematical blocks in MATLAB/SIMULINK and the simulation results are obtained for different temperatures and irradiations and for partial shading conditions for series and parallel combinations of PV cells. These results are analyzed in terms of I-V and P-V characteristics in order to design an optimized PV system. In the present work MATLAB coded model is developed in two files namely: Pvcom and PARAF which are used for the simulation work and the results are obtained for various combinations of different panels and at varying environmental conditions

The organization of this paper is as follows: section II presents the information about the modeling of PV module. Section 3 presents the analytical work regarding simulation. Section 4 represents the comparative analysis of the parameters obtained in single and double panel combination and Section 5 represents the conclusion and future scope of this paper.

2. MODEL OF PV MODULE

Figure 2 shows the ideal model of a solar PV cell, which consists of a current source and a diode connected in parallel form a PV cell, generally which is not for the practical PV cell. Practically two resistances, series and parallel account their presence as shown in the above Figures 3 and 4 respectively. Series resistance is denoted by the resistance Rs in Figures 3 and 4 while the parallel resistance is denoted by the resistance R_{sh} in Figures 3 and 4 respectively. In ideal model, diode is represented by D, in one diode model by D while in two diode model; diodes are represented by D1&D2.

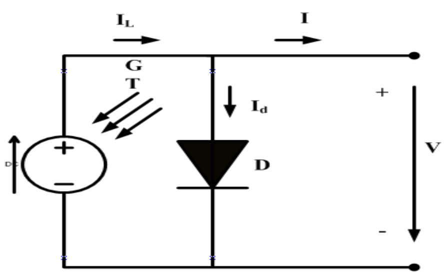

Figure 2. Ideal model of PV cell

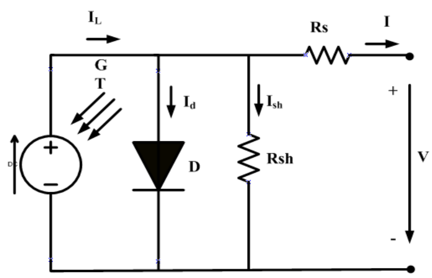

Figure 3. One diode model of PV cell

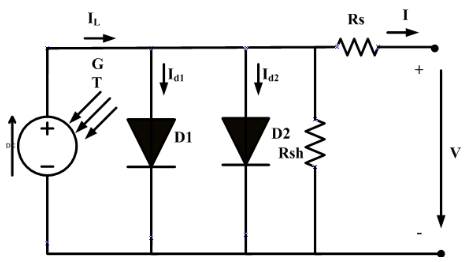

Figure 4. Two diode model of PV cell

3. LITERATURE REVIEW

Various techniques have been adopted in literature for the modeling and simulation work of PV system. Bilhan *et al.* [13] represented Matlab Simulink model and Matlab mfile PV model. The proposed model captures sunlight and cell temperature as input parameters. I-V and P-V output features are obtained under various irradiation conditions. Moreover, both models can be easily used with another PV module parameters. And the output power of the PV module enhanced with DC/DC to promote conversion and converter power is controlled by PI controller. Sarwar *et al.* [14] discussed about 5-Parameter model, is an interactive user model that receives data and demonstrates consistent performance on the SIMULINK platform to predict the output of specified cell parameters under different operating conditions. The model requires a one-time calculation of five parameters. Chedid *et al.* [15] shows an educational method for studying PV features are displayed. The PV cell model statistics are taken and compared PV layout is done using MATLAB code based on two-dimensional circuit representation. Results for irradiance, temperature and shading features of PV are read and the result of the series connection/similarity were checked. The statistics and codes shown are helpful for the students to do the simulation and the effect of various parameters on the IV and P-V curves of cells, modules, reorganization and any series/parallel combinations can be arranged. Ghosh *et al.* [16] presented the hybrid MPPT algorithm, and verifies through simulation. The combination of perturb and observe and the improvised binary sequence has improved the latter's capability to respond to slight changes in operating conditions. Improvisations of both the algorithms, helped us to obtain better results. The simulation studies show that the proposed algorithm offers high accuracy. Hiendro [17] proposes a new algorithm for metaheuristic optimization based on projectile mobility kinematics and is called projectile-target search (PTS) algorithm. PTS algorithm uses envelope projectile trajectory to find the target in the search space. It has 2 types of control parameters. The first type is set to allow for an algorithm to speed up the merging process, while another type is to improve the opportunity to produce new better search projectiles process. However, both are responsible for getting the best durability rates in search engine. The results of the improvement are has shown that the PTS algorithm provides excellent performance and so on highly competitive compared to other metaheuristic algorithms. Jadallah *et al.* [18] introduces modeling and operation of PV cells. The simulation code is created using MATLAB.

The results shows that an increase in solar radiation and a diode factor led to an increase in the output power of PV module, while measure of cell temperature and saturation current leads to a decrease in power. The IV and P-V dependence curves are provided with a module of 50 branches connected in parallel, each branch with 50 cells connected in series. Modi *et al.* [19] demonstrated a mathematical model of the solar cell based on five parameters current voltage (I-V) and power voltage (P-V) curves are found from the mathematical model that has been developed and analyzed for various operating conditions such as radiation and temperature. In this paper a comparison of the performance features of the advanced solar cell model and the solar cell model with MATLAB is presented. It is evident that the advanced model is accurate enough to be considered in the construction of PV and PV module for continuous analysis. Moreno [20] discussed the importance of detailed separation of solar cells to test the perfect performance of the solar PV array. It shows that the effects are over I-V and P-V curves depending on the internal parameters of cells and external parameters such as irradiance as well temperature. In particular, this article shows evidence of impacts on module transmission capacity when installing resistance Rs. Further, he presented, how temperature can affect the performance of the same members, especially in efficiency. Shahabuddin *et al.* [21] introduce a new metaheuristic optimization technique for the parameters extraction of solar PV cell. The technique named projectile search algorithm is based on the projectile's motion inspired by gravity when projected in the space. The parameters extracted when used in simulation successfully follow the actual characteristic of solar PV cell from France solar cell. Samal *et al.* [22] in her presented research which is originally on designing of PV/wind energy fed to the DC link capacitor of unified power quality controller (UPQC) so as to retain proper voltage across it and operate the UPQC for power quality analysis. The said model is simulated in Matlab and results are verified by using FFT analysis. The proposed PV/wind energy UPQC is design in Matlab simulation for minimization of voltage sag, swell, interruption of voltage, harmonics in load current and compensation of active and reactive power. Shahabuddin *et al.* [23] presented a percentage wise structure of renewable resources including solar energy in a particular place in the world.

4. SOLAR PV MODEL EQUATIONS

The PV model of Figure 3 are given by:

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_{str}} - \left[\boldsymbol{e}^{\frac{\boldsymbol{V+IR_{ser}}}{\boldsymbol{vth}}} - 1\right] - \left[\frac{\mathrm{V+IR_{ser}}}{\mathrm{R_{sht}}}\right] \tag{1}$$

Simulation is done by using MATLAB code for the shaded condition of PV array. Shading is the effect of clouds, buildings, trees on PV array which deteriorate output of PV system. Shading equation can be expressed as:

$$v_{th=}\frac{n_{sc}a_f K_b T_o}{q_e} \tag{2}$$

$$R_{ser\,=}\,R_{ser\,ref\,2}\left[1 + K_{R_{ser}}\left(T_o - T_{refr}\right)\right] + R_{ser\,refr\,1}\left(\frac{G}{G_{refr}}\right)^{\gamma R_{ser}} \tag{3}$$

The (4) and (5) include the irradiance and tempera-ture effects simultaneously into R_{ser} and R_{sht} [24].

$$R_{sht} = R_{sht\,.refr}\left[1 + K_{R_{sht}}\left(T_o - T_{refr}\right)\right]\left(\frac{G}{G_{refr}}\right)^{\gamma R_{sht}} \tag{4}$$

$$a_{f=}\, a_{refr} \tag{5}$$

Diode ideality factor a_f is assumed to be equal to a_{refr}

$$I_{ph=}I_{sct}\left(1+\frac{R_{ser}}{R_{sht}}\right) \tag{6}$$

The (6) is obtainedfrom (1) in the SC condition and represents another wayof expressing I_g dependence with S and T.

$$I_{str=}\frac{I_{ph-}\frac{V_{oct}}{R_{sht}}}{\frac{V_{oct}}{v_{th}}-1} \tag{7}$$

The (7) is obtained from (1) in the SC condition and represents another wayof expressing I_{ph} dependence with S and T.

$$I_{sct}=\left[I_{sct.refr}+\propto_t\left(T_o-T_{refr}\right)\right]\left(\frac{G}{G_{refr}}\right) \tag{8}$$

On the other hand, (8) is obtained from (1) in the OC condition and also represents another way of expressing I_{str} dependence with T. In (4) and (5) include the irradiance and temperature effects simultaneously into Rser and Rsht. At last, according to [25], through the auxiliary expressions:

$$V_{oct=}\, V_{oct.refr}+\beta_t\left(T_o-T_{refr}\right)+K_{V_{oct}}\, v_{th}\ln\left(\frac{G}{G_{refr}}\right) \tag{9}$$

$$V_{oct=}\, V_{oct.refr}+\beta_t\left(T_o-T_{refr}\right)+K_b V_{oct}\, v_{th}\ln\left(\frac{G}{G_{refr}}\right) \tag{10}$$

Where β_t = coefficient of temperature at open circuit voltage, it is desirable to evaluate Isct and Voct values for any climate situation, so that they can then be applied in (4)-(8).

5. SHADING EFFECT

Figures 5 and 6 are the description of simulation results of MATLAB model for three and four panel reepectively which incorporate shading effect. Due to shading various peaks occur which deteriorates the out put power of the PV array. Figure 5 shows partial shading conditions for 3-panels in P-V curve at temperature of 25 °C while Figure 6 shows the partial shading conditions for 4-panels in P-V curve at temperature of 25 °C. Figure 7 shows a MATLAB model of a typical solar PV cell for realizing IV curve of SP 140 PC module from Shell solar for comparision with the IV curve of MATLAB coded model. Comparative analysis is done by obtaining the simulation results in terms of I-V and P-V characteristics from the proposed MATLAB coded simulation model under varying atmospheric conditions for both single and double panel respectively. Comparative values of parameters are given in Tables 1 and 2 respectively. When the two panels are connected in series that is in case of double panel the same case happens as in case of single panel except voltage gets doubled.

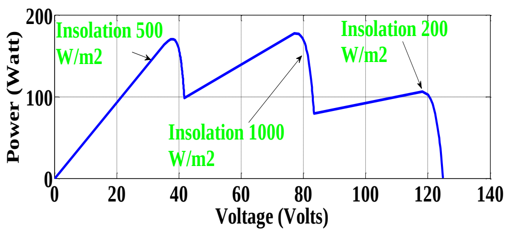

Figure 5. Partial shading conditions for 3-panels in P-V curve at temperature of 25 °C

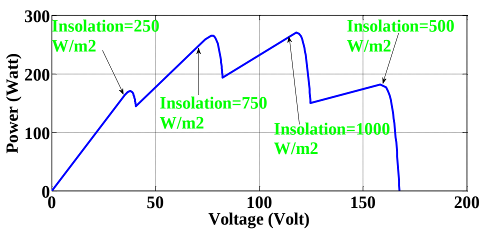

Figure 6. Partial shading conditions for 4-panels in P-V curve at temperature of 25 °C

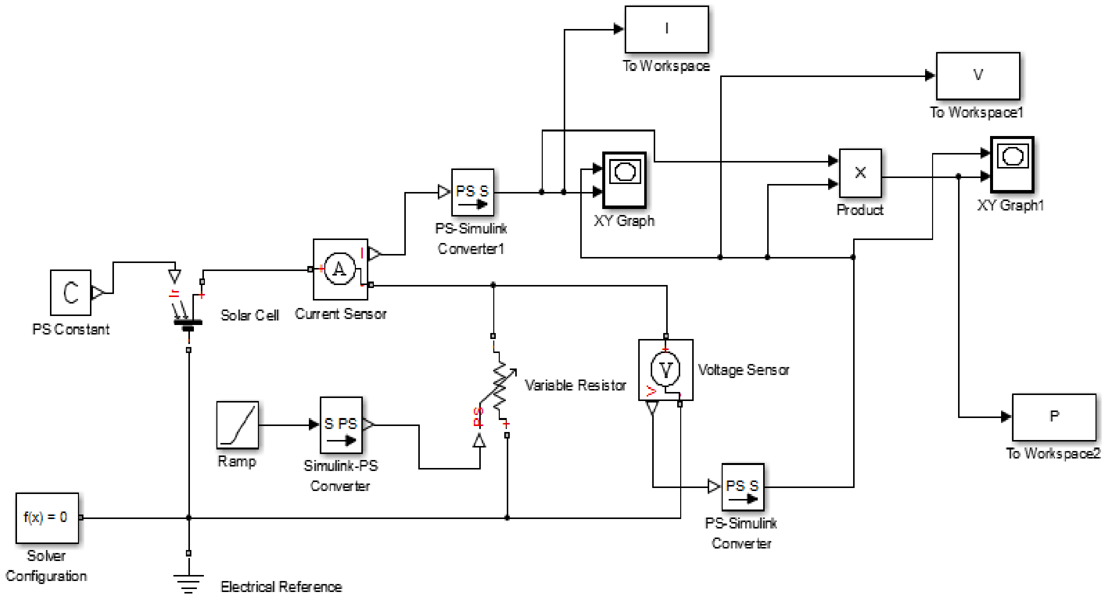

Figure 7. MATLAB model of a typical solar PV cell for realizing IV curve

Table 1. Comparative table for single panel

Irradiance	Isc (Amp.)	Vt (Volt)	Voc (Volt)	Rs (Ω)	Rsh (Ω)	Ig (Amp.)	Isat (Amp.)	F
600W/m^2	2.8200	1.5175	42.0248	0.0012	2.0522e+03	2.8200	2.6289e-12	1.0e+03
800W/m2	3.7600	1.5175	42.4614	0.0011	2.0229e+03	3.7600	2.6333e-12	1.0e+03
1000W/m2	4.7000	1.5175	42.8000	1.00e-03	2.0005e+03	4.7000	2.6361e-12	1.0e+03
Temperature								
25°C	4.7000	1.5175	42.8000	1.00e-03	2.0005e+03	4.7000	2.6361e-12	1.0e+03
35°C	4.7200	1.5684	41.2800	0.0015	4.3410e+04	4.7200	1.7510e-11	1.0e+04
45°C	4.7400	1.6193	39.7600	0.0020	8.4820e+04	4.7400	1.0287e-10	1.0e+04

Table 2. Comparative table for double panel

Irradiance	Isc (Amp.)	Vt (Volt)	Voc (Volt)	Rs (Ω)	Rsh (Ω)	Ig (Amp.)	Isat (Amp.)	F
600W/m2	2.8200	1.5175	84.0496	0.0012	2.0522e+03	2.8200	2.6289e-12	1.0e+03
800W/m2	3.7600	1.5175	84.9228	0.0011	2.0229e+03	3.7600	2.6333e-12	1.0e+03
1000W/m2	4.7000	1.5175	85.6000	1.00e-03	2.0005e+03	4.7000	2.6361e-12	1.0e+03
Temperature								
25°C	4.7000	1.5175	85.6000	1.00e-03	2.0005e+03	4.7000	2.6361e-12	1.0e+03
35°C	4.7200	1.5684	82.5600	0.0015	4.3410e+04	4.7200	1.7510e-11	1.0e+04
45°C	4.7400	1.6193	79.5200	0.0020	8.4820e+04	4.7400	1.0287e-10	1.0e+04

6. COMPARATIVE ANALYSIS

When irradiation is increased from 600 W/m^2 to 800 W/m^2 to 1000 W/m^2 the output voltage that is open circuit voltage (Voc) remains constant and only a slight increase is there, while the short circuit current (Isc) as well as output current (Ig) increases while thermal voltage (Vt) the beauty remains constant throughout the varying irradiation of PV panel. Series resistance (Rs) and shunt resistance (Rsh) also decreases. As the temperature increases from 25°C to 35°C and to 45°C there is no moderate change in the short circuit current (Isc) as well as in the output current (Ig), almost remains constant while and the open circuit voltage (Voc) decreases and the series resistance (Rs) and the shunt resistance (Rsh) are increased. And thermal voltage (Vt) also increased. Due to series connected panels the same short circuit current (Sic) as well as output current (Ig) will flow through both panel while the open circuit voltage (Voc) i.e., output voltage will be doubled from 42.02 volt to 84.04volt.

Effect of shading is shown in Figure 5 & 6 respectively for three and four panels. Temperature is kept constant at 25°C. Figure 8 shows the I-V characteristics of Shell PV cell, compared with the Matlab model. I-V characteristics at temperature of 25°C and irradiation of 1000 W/m^2, which replicates and shows excellent results. Though SP140PC module is of 140W with seventy-two cells combination, here for ease of comparision only one cell's voltage is talen on X-axis. The close replication of the I-V curve indicates the adequate achievement of the MATLAB coded model.

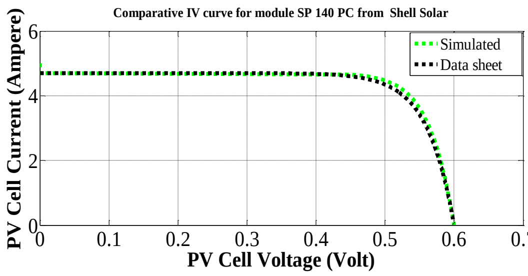

Figure 8. The real solar PV cell I-V plot of a Shell solar cell with the simulated data

7. CONCLUSION

The several advantages of solar PV energy makes it suitable for the future generation of electrical energy though it is dependent on the availability of sun but due to end of conventional energy resources in forthcoming few decades the only option is to replace the conventional energy resources with the solar PV energy for the future generation of electrical energy.In this paper a MATLAB coded solar PV model is developed and the parameters are extracted under varying environmental conditions for single and double panels. Simulation work is carried out in terms of P-V and I-V characteristics under the variations of temperature and irradiations for both single and double panel. Comparative analysis of extracted parameters is also carried out under varying environmental conditions for both single and double panel. The paper successfully implements the MATLAB coded model for simulation of a PV cell from Shell solar. The extracted parameters when used by simulation closely follow the actual IV features of the active Shell solar PV cell. The developed model is accurate enough for the analytical work and for the foundation of an optimized solar PV system. The future work might be carried out for the canalization of the PV system using more panels.

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