A New Approach to Fast Tracking and Low Cost Single Exponential Model Photovoltaic System

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***Abstract*— The work portrayed in this paper furnishes knowledge about advanced solar photovoltaic (PV) conversion system. This PV system is fast and tracks more output power than conventional PV systems. In literature, the PV parameters of a double exponential model were designed with the help of Levenberg-Marquardt algorithm. In this paper, the PV parametric values were taken into consideration and implemented in a single exponential model with curve fitting method. The results of a conventional PV system and it was observed are compared with the implemented PV system and observed that, the implemented PV system tracks 23% excess power than the conventional one. Finally, the PV system is implemented with a series of 2000 interconnected PV cells for higher voltage applications, due to its unfussiness and lower cost. The MATLAB simulated models are presented and discussed.**

***Index Terms*— Curve Fitting Method (CFM), Photovoltaic (PV), Single Exponential Model (SEM).**

I. Introduction

In this millennium renewable energy sources are playing an important role for power generation. A PV system generates DC electricity when sun rays fall on a PV array [1]-[3]. Solar power has an outstanding potential as a renewable energy generation substratum due to surmount solar energy and resulting emission free power generation. These PV systems are functioning based on the principle of photovoltaic effect. With the advent of silicon p-n junctions, the photoelectric current is able to produce power due to inherent voltage drop across the junction. However, such a power generation is well known for the nonlinear relationship between the current and voltage of the photovoltaic cell [4]. It is observed that, there is a unique point at which the photovoltaic cell produces maximum power. At this position, the rate of change of power with respect to the voltage is equal to zero [5]. The PV power generation technology outshines within renewable energies due to its efficiency and minimal cost.

PV cells are connected in series or in parallel to form a PV array. PV cells are connected in series to achieve large output voltages, and connected in parallel to obtain large output currents. For higher PV output, these PV arrays are linked to appear as a PV module [6]. There are several power management issues concerning improvement in the conversion efficiency of a PV array, thus maximizing PV power output. PV array has to be operated at Maximum Power Point (MPP) in order to extract maximum power output. The maximum power of the PV array changes with shading and/or climatic conditions [7], [8]. The PV output current changes with solar irradiation levels, whereas the PV output voltage changes with temperature of the PV array. The conventional single diode PV cell model is implemented, mathematically proved with state space analysis [9]. PV array is simulated and is verified with its characteristic curves at Standard Test Conditions (STC) as well as at different temperatures and irradiation levels. That means keeping one parameter (temperature or irradiation) as constant and the other parameter as changing and thus observed different types of PV characteristic curves.

A new genre of SEMPV cell is acknowledged as efficient along with additional output tracking ability for the same number of PV cells used in conventional model. In order to approach this SEMPV, some of PV parameters has been taken from literature [10], [11] and implemented. The mathematical approach is alike the conventional model. The PV module is checked with larger number of series connected SEMPV cells for higher voltages at STC as well as different irradiations and temperatures.

Section II of this article shows the modeling of a PV cell with simulation results. Section III is devoted to the modeling of a Fast tracking PV device with simulation results. Section IV is dedicated to the comparison and discussion on simulation results and in Section V conclusion is drawn.

II. Modeling of a Single Diode PV Cell

In this paper, single exponential model is preferred to model the PV cell because of simplicity and fewer complications. The equivalent circuit diagram of a single diode PV cell is shown in Fig. 1. From the theory of semiconductors the basic I-V characteristic equation of a PV cell is derived mathematically [1] as follows:

$$I_{ph} - I_0[e^{qV_d/nkT} - 1] = I_L \qquad (1)$$

In the above equation I_{ph} is the photo current, I_0 is diode saturation current, q is charge of the electron, V_d is diode voltage, n is ideality factor, k is Boltzmann's constant, T is absolute temperature and I_L is the Load current.

To represent a practical I-V characteristic PV array, the basic equation (1) requires more parameters. Finally, the open circuit voltage V_{oc} mathematically expressed [9] as:

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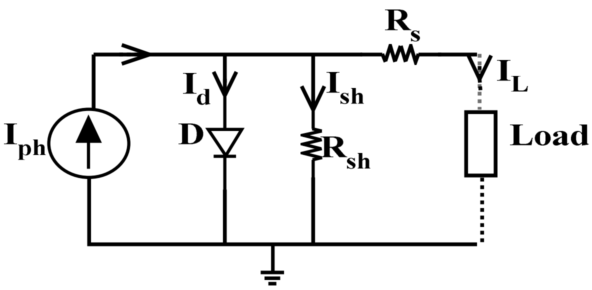


Fig. 1. Equivalent Circuit of a practical PV cell with series and parallel resistances

$$V_{oc} = (nkT/q)\ln\left(\left(I_{ph}/I_0\right)+1\right) \quad (2)$$

V_{oc} is termed as voltage corresponding to the voltage drop across the diode, when the generated current I_L=0.

The final voltage mathematical expression while considering R_{sh} is shown in (3)

$$V_L = \frac{nkT}{q}\left[\ln\left(\frac{I_{ph}-I_L}{I_0}+1\right)-\frac{V_L+I_LR_S}{R_{sh}}\right]-I_LR_S \quad (3)$$

The efficiency calculations of PV systems are required to get the maximum power. The efficiency (η) of the cell is defined [12] as the ratio of peak power to input solar power, given in (3).

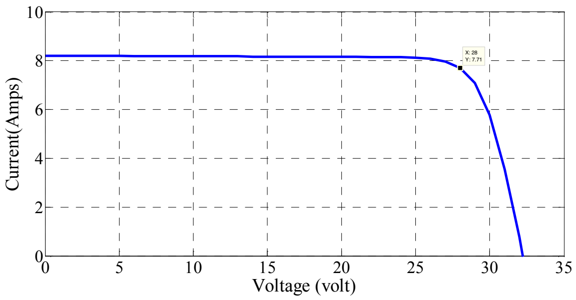
$$\eta = V_{mpp}\, I_{mpp}\,/\,I\,A \quad (4)$$

where I= insolation and A= Area of the cell.

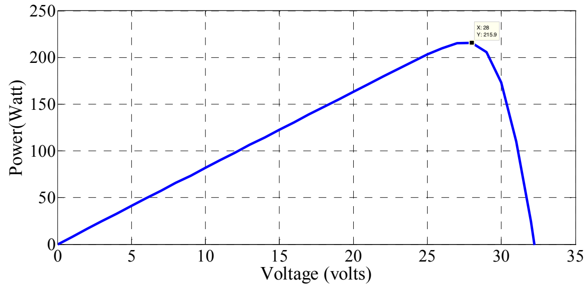
Every PV cell has life anticipation. As time progresses, the quality of the cell reduces [13]-[15]. So, it is necessary to check the quality of the cell whether the performance is in assured level or below level. Calculation of quality is also called as Fill Factor (FF), is described as ratio of the peak power to the product of open circuit voltage and short circuit current, shown below

$$FF = V_{mpp}\,\mathrm{I}_{mpp}\big/V_{oc}\,\mathrm{I}_{sc} \quad (5)$$

The ideal fill factor of a PV panel should be 1 or 100%, but, a good panel has a fill factor in the range of 0.7 to 0.8 and for a bad panel the limit is 0.4, beyond 0.4 FF the panel is of no use [13].The aforementioned safety measures are required to get maximum power from a PV panel. The open circuit voltage increases logarithmically with irradiation, while the short circuit current is a linear function of irradiation. The primary effect with increasing cells temperature is the linear decrease of the open circuit voltage, the short circuit current slightly increases with the cell temperature.



(a)



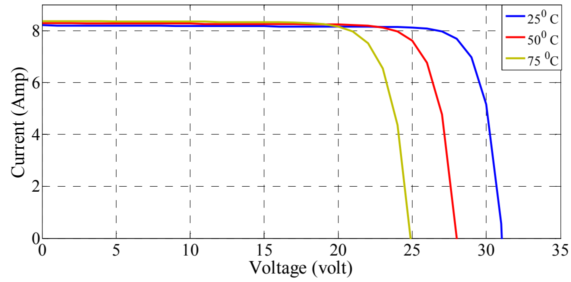
(b)

Fig. 2. A typical (a) I-V curve, (b) P-V curve of a PV system

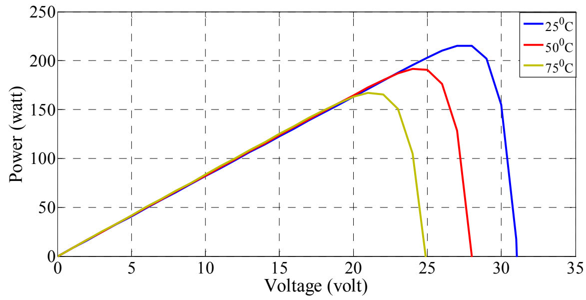
After mathematical modeling of a PV cell the I-V and P-V characteristic curves are shown in Fig. 2 (a) and (b) respectively. These are simulated in MATLAB at standard test conditions (i.e., at 25°C, irradiation at 1000). The climatic conditions are not constant [7], that means changes occurs on weather conditions or due to partial shadings. Because of these non uniform conditions we have to calculate the characteristic curves at different temperatures and irradiation levels. The I-V and P-V characteristic curves of a PV array at different temperatures and irradiation levels are shown in Fig. 3 (a) and (b) and in Fig. 4 (a) and (b) respectively. The model of the PV array was implemented using a MATLAB program. The model parameters are evaluated during execution using the equations listed above. To calculate the current I_L, the program uses typical electrical parameters like I_{sc}, V_{oc}, T and G.

III. Modeling of Fast Tracking SEMPV Cell

The fast tracking SEMPV cell equivalent circuit diagram is same as conventional PV. To design SEMPV, some parameters like n, R_S and R_P are taken from literature[10].

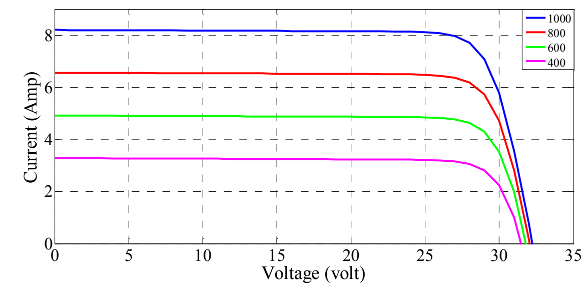


(a)

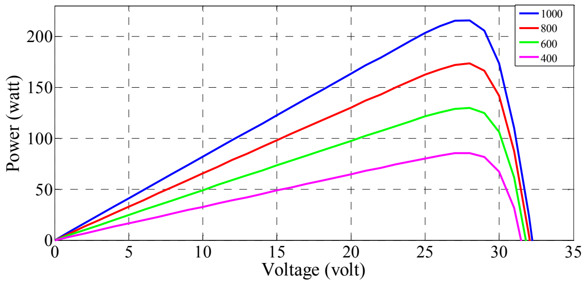


(b)

Fig. 3. Matlab model waveforms of various temperatures and at fixed irradiance (a) I-V and (b) P-V curves of a PV system



(a)



(b)

Fig. 4. Matlab model (a)I-V and (b)P-V characteristic curves at multiple irradiances and fixed temperature of a PV system

The PV parameters [10] is shown in the equation (6)

$$\left.\begin{aligned} n &= K_1 + K_2 T \\ R_S &= K_3 + \frac{K_4}{G} + K_5 T \\ R_P &= K_6 e^{K_7 T} \end{aligned}\right\} \qquad (6)$$

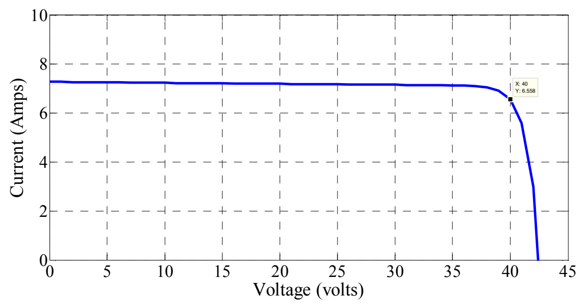
where K_1 to K_7 are constants, these values are mentioned in table I. Keep the diode ideality factor as 2 to approximate the Shockley recombination in the space charge layer. For amorphous cells 'n' is varying with temperature, but characterizing the amorphous cells is more complicated. The value of R_S depends on temperature and its behavior is non linear, where as with irradiance the behavior is unknown that means it is linear. So, to choose 'R_S' the temperature has to be in direct proportion and irradiance in indirect proportion. The R_P value is also dependent on temperature, its behavior is non linear with temperature and linear with irradiance. R_P value is quite larger than R_S. Small changes in R_P will not create much variation on the curve but V_{oc} may vary. The output I-V characteristic equation[9] is as follows:

$$I_L = I_{ph} - I_0\left(e^{(V+IR_S/V_{th}n)} - 1\right) - \frac{V+IR_S}{R_P} \qquad (7)$$

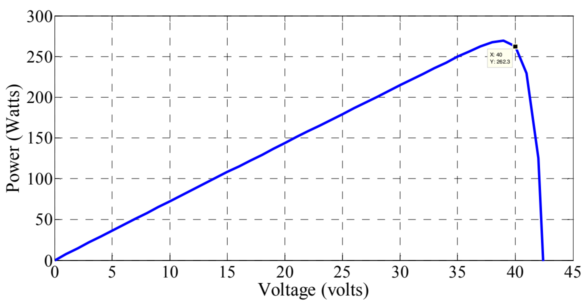
where $V_{th} = (N_S kT/q)$, the threshold voltage of the diode, N_S is number of cells connected in series and 'n' is the diode ideality factor.

The I-V and P-V characteristic curves at STC are drawn from (8) and are shown in Fig. 5. From these characteristic curves we observed that the PV output voltage and power is rapidly escalating than the conventional PV. That means the SEMPV is reaching its MPP fastly and tracking voltage nearly 23% excess. Finally, the PV module is connected with 2000 series and 40 parallel connected cells. For series and parallel combination of cells the equation (7) can be modified as follows:

$$I_L = N_P I_{ph} - N_P I_0\left[e^{\frac{V+IR_S(N_S/N_P)}{N_S V_{th}}} - 1\right] - \frac{V+IR_S(N_S/N_P)}{R_P(N_S/N_P)} \qquad (8)$$

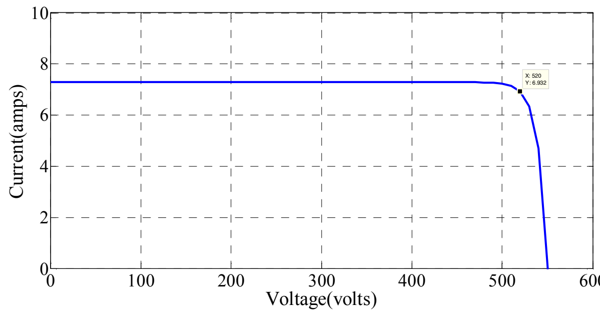


(a)



(b)

Fig. 5. Matlab model of fast tracking PV (a) I-V, (b) P -V characteristic curves



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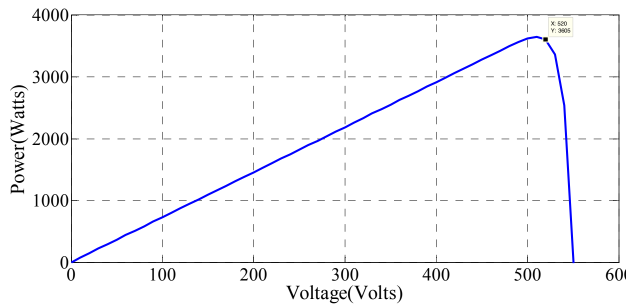


(b)

Fig. 6. An emblematic (a) I-V, (b) P -V characteristic curves of a fast tracking PV with more number of series cells

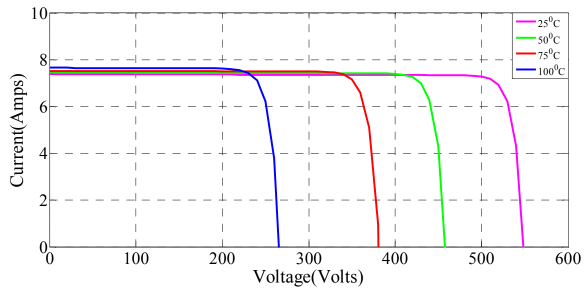
TABLE I
Constants employed in PV model

Variables	Constants	Constants
$A = K_1 + K_2 T$	$K_1 = 2$	$K_2 = 0$
$R_S = K_3 + \frac{K_4}{G} + K_5 T$	$K_3 = 1.47,$ $K_4 = 1.6126e^3$	$K_5 = -4.47e^{-3}$
$R_P = K_6 e^{K_7 T}$	$K_6 = 2.3034e^6$	$K_7 = -2.8122e^{-2}$

TABLE II
Comparison of conventional PV with SEMPV at STC

PV parameters	Conventional PV	SEMPV
V_{OC}	32.9 V	42.5 V
I_{SC}	8.21A	7.28 A
V_{MPP}	28 V	39 V
I_{MPP}	7.71 A	6.91 A
P_{max}	215.9 W	269.7 W

where N_P is the number of parallel connected cells and N_S is the number of series connected cells.



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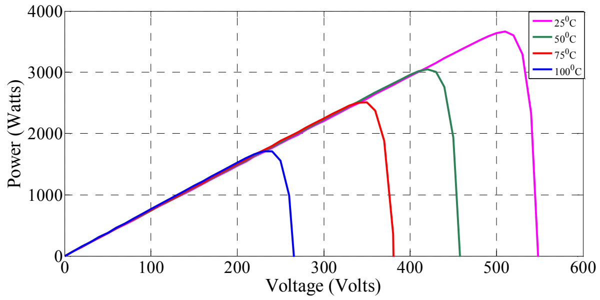

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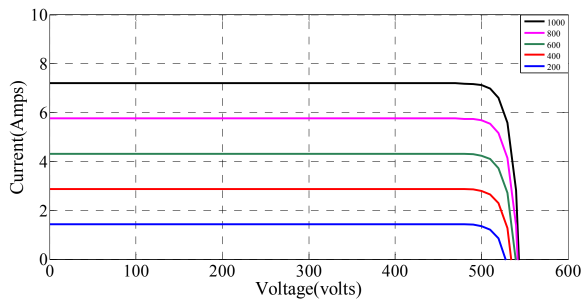

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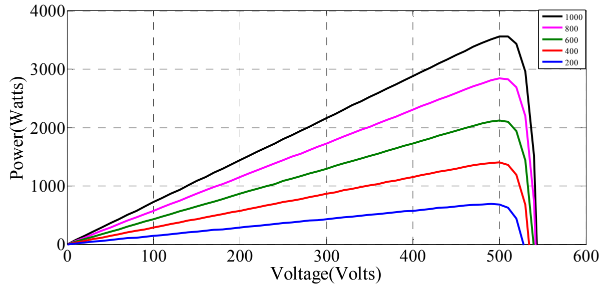

(d)

Fig. 7. Matlab model of fast tracking PV (a) set of I-V curves at constant irradiation and different temperatures (b) set of P-V curves at constant irradiation and different temperatures, (c) set of I-V curves at constant temperature and different irradiations, and (d) set of P-V curves at constant temperature and different irradiations

The characteristic curves of SEMPV are simulated at STC and shown in Fig. 6. Fig. 7 shows all different I-V and P-V characteristic curves at different temperatures and different irradiation levels.

IV. COMPARISON AND DISCUSSION

The conventional PV array is tracking MPP conditions at STC. For better tracking of the MPP conditions, some of the PV parameters have been changed, that has been plotted in I-V and P-V characteristic curves and was observed that 23% more output voltage is gained than the conventional PV. The compared values are listed in table II. The PV module is implemented with 2000 series connected and 40 parallelly connected cells for higher voltage and power applications. The MATLAB implementation results are plotted in Fig. 7 at different temperatures and irradiations.

V. CONCLUSION

In this article, a conventional PV cell with a series and shunt resistance is developed by state space analysis. PV array is connected with series and parallel combinations of PV cells to extract the parameters like open circuit voltage, short circuit current, etc., and plotted the characteristic curves at different temperatures and irradiations. The SEMPV array is connected for fast tracking PV parameters by curve fitting method at STC. By comparing this implementation with conventional PV it has been observed that 23% excess PV output voltage is obtained. Finally, 2000 cells are connected in series for higher voltage applications and operating at MPP is very fast. The I-V and P-V characteristic curves are plotted at different temperatures and irradiation levels.

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