DESIGN OF PHOTOVOLTAIC MODULE TO INVESTIGATE ITS PHYSICAL PARAMETERS

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Abstract: Solar photovoltaic energy is a clean, green source of renewable energy that is essential for addressing any region's power problem. A photovoltaic array has non-linear properties, highly expensive and takes a long time for giving operating curves. Before installing photovoltaic for any purpose or site, the photovoltaic system goes through a crucial phase of analysis, modeling, and simulation that aids in understanding the actual behavior under actual circumstances. This paper emphasizes on the step-by-step modeling and simulation process of the solar panel using in small application. Further investigation of I-V and P-V characteristics are carried out at different operating conditions. This methodology finally allows the photovoltaic system with different physical parameters.

Keywords:
Photovoltaic solar panel, irradiance, ideality factor, I-V curve, P-V curve

Introduction:

With the industrialization and urbanization, energy demand is increasing daily. In order to light up our homes, businesses, and automobiles due to the depletion of fossil fuel supplies, it is necessary to investigate some alternative energy sources [1-2]. The use of traditional energy supplies to meet home and industrial energy demands has a negative impact on the environment, contributing to pollutant growth, acid rain, and global warming. Hence the best and most suitable energy sources to supply the global load demand are solar, wind, tidal, and geothermal energy [3-4]. Since solar energy is plentiful in nature, electric vehicles must make use of it. In addition to better fuel efficiency, the main benefit of these solar-powered electric vehicles is a decrease in carbon dioxide emissions [5]. Mathematical modeling of the photovoltaic (PV) system is providing a deeper understanding of how it operates for the researchers. Literature review proposes that many researchers have advanced functions in the MATLAB environment to calculate the power output for the PV panel [6-7].Other approaches, which combine MATLAB m-file programming with C language programming, are even trickier to comprehend [8]. Various other suggested models, which are constructed in Simulink and based on mathematical equations, demonstrate the impact of temperature and irradiance, however these articles did not current simulations, which are once more challenging for the to be emulated and followed by scholars and readers [9-10]. Specifically when signifying the practise of the solar panel in electric vehicles, the partial shading effect has an energetic role in accomplishing the maximum power output from the equipped solar panel.

A complete step by step equation-based design for the PV solar cell has presented in this paper which is adequate to comprehend the effect of all the physical parameters such as saturation current, ideality factor, series resistance, shunt resistance, and environmental operating conditions such as temperature, irradiance on the I–V and P–V characteristics of the PV module. In this paper, the thorough mathematical model for the PV cell is signified in section 'The mathematical model for PV cell' and the stepwise Simulink circuit is presented in section 'Stepwise Simulink circuit for PV cell'. The discussion of the simulated results is presented in the section 'Simulation results' and the outcomes of this approach are presented in section 'Conclusion'.

Mathematical Model of PV Cell:

Photon energy is converted into the electricity in PV cell unit. Again PV module is formed by connecting the PV cell in series or parallel form generating clean and green energy. This arrangement generates the green and clean energy. The primary circuit for the PV cell is shown in Figure 1. The actual equivalent circuit for the solar cell is shown in Figure 2. This circuit is more

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practical with the addition of series and shunt intrinsic resistances. For modest study, value of the series resistance is minimal, whereas the shunt resistance is substantial.
The output current of PV cell is given in equation (1)

$$I = I_{ph} - I_d - I_{sh} \quad (1)$$

I_{ph} is the photocurrent (A), I_d is the diode current (A) and $I_{sh}$is the shunt current (A) of cell.

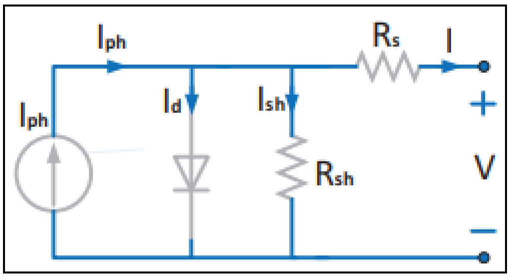

Fig.1 Equivalent circuit of photovoltaic cell
The expression of $I_{ph}, I_{sh}, and\ I_d$ are presented in equation (2), equation (3) and equation (4) respectively.

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times {}^{G}/_{1000} \quad (2)$$

I_{sc} is the short circuit current (A), K_i is the short circuit parameter at 25°C and 1000 ${}^{W}/_{m^2}$, G is the solar irradiance (${}^{W}/_{m^2}$) and T is the ambient temperature.

$$I_{sh} = \left(\frac{V + IR_s}{R_{sh}}\right) \quad (3)$$

$$I_d = I_0 \left[exp\left(\frac{V_d}{V_T}\right) - 1\right] \quad (4)$$

The voltage across the diode (V_d) and thermal voltage (V_T) are given in equation (5) and (6) respectively.

$$V_d = V + IR_s \quad (5)$$

$$V_T = \frac{nkTN_s}{q} \quad (6)$$

where n is the ideality factor of the diode, k is the Boltzmann's constant, q is the electron charge (C), and N_s is the number of cells connecting in series. Putting the values of V_d and V_T in equation (4), the final output current for the solar cell is given in equation (7).

$$I = I_{ph} - I_0 \left[exp\left(\frac{q \times (V + IR_s)}{nkTN_s}\right) - 1\right] I_{sh} \quad (7)$$

Simulink Circuit for PV Cell
The mathematical modelling of solar photovoltaic system is figure up with MATLAB/SIMULINK software. The step by step design of the PV module is discussed in this paper. To implement equation (7) for the final output current of the solar cell, the first step is to model photocurrent then diode current. Reverse saturation current model first design for modelling the saturation current. All the specifications, along with mathematical parameters, for reference solar panel are given in Table 1

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Table1. Parameters for modelling of PV module

Nomenclature	Ratings
Rated power (P_{max})	180 W
Voltage at P_{max}(V_{max})	32.92 V
Current at P_{max}(I_{max})	5.48 A
Open circuit voltage (V_{oc})	39.80 V
Short circuit current (I_{sh})	5.85 A
Series resistance (R_s)	0.221 Ω
Shunt resistance (R_{sh})	415.405 Ω
Short circuit current at cell (K_i)	0.0032 A
Nominal temperature (T_n)	298
Ideality factor (n)	1.3
Bandgap energy (B_{go})	1.1
No. of cell connected in series (N_s)	54
Boltzmann's constant (k)	1.38×10^{-32}J/K
Electron charge (q)	$1.6 \times 10^{-19}C$

Simulation Results:

The complete and comprehensive equation-based method is used to build the circuit in the MATLAB/ Simulink to investigate its physical parameters and operating conditions as discussed in section 'Stepwise Simulink circuit for PV cell', and the simulation results are shown under this section. With the developed model of the PV module, the I–V and P–V characteristics are discussed here.

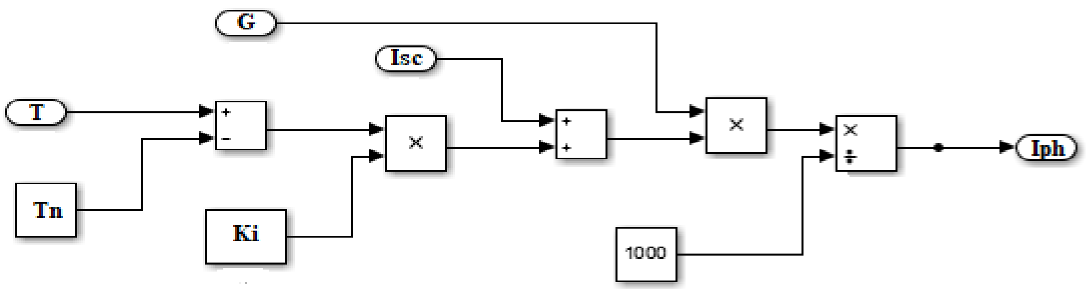

Fig.2 Modeling of photo current

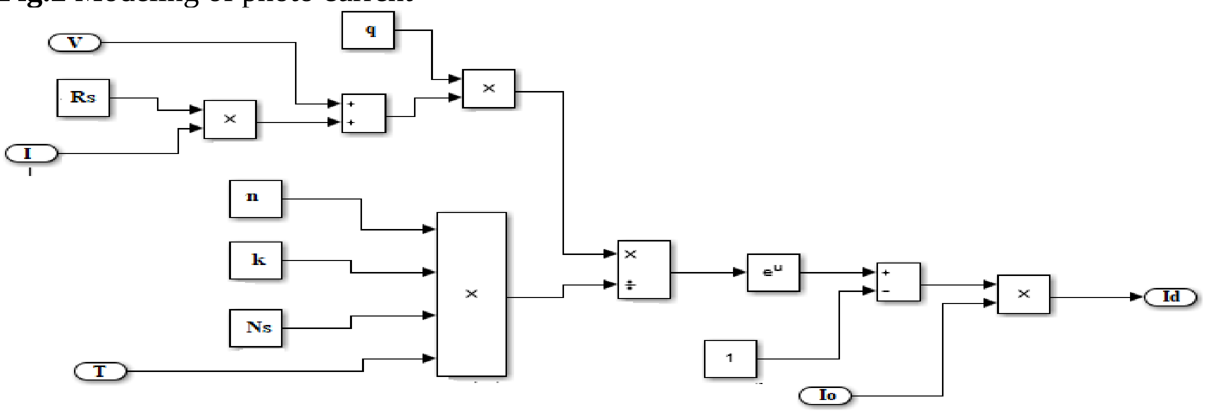

Fig.3 Modeling of diode current

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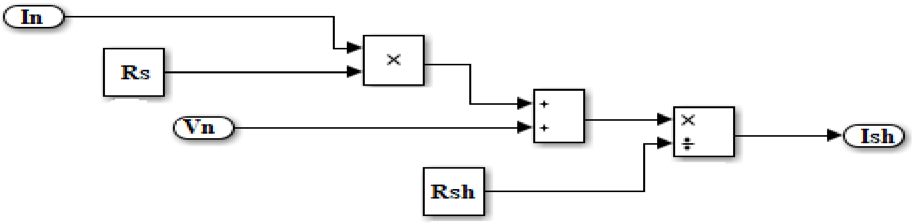

Fig.4 Modeling of shunt current

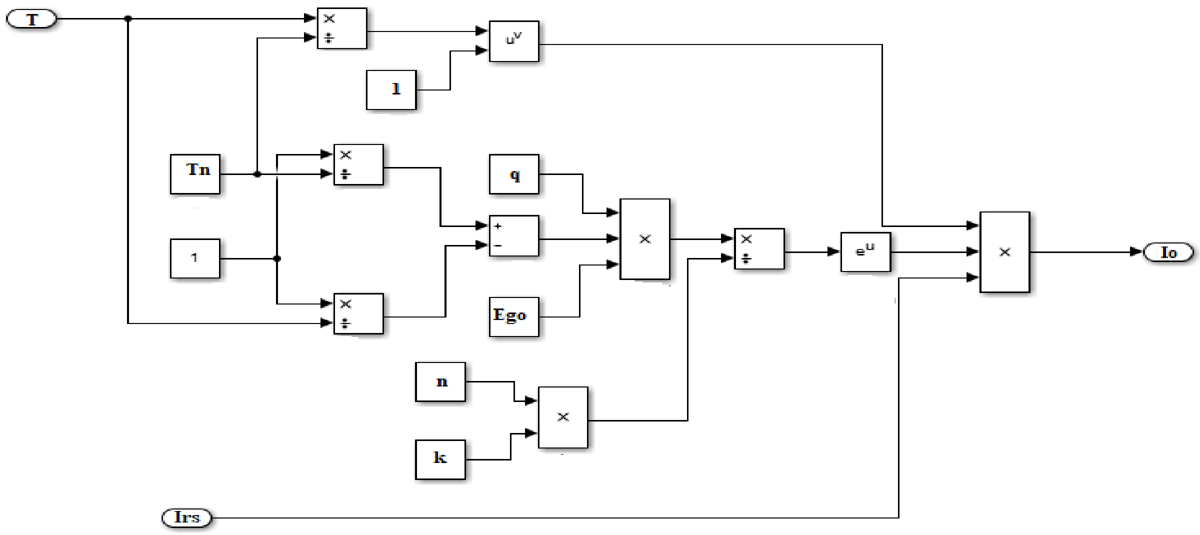

Fig.5 Modeling of saturation current of diode

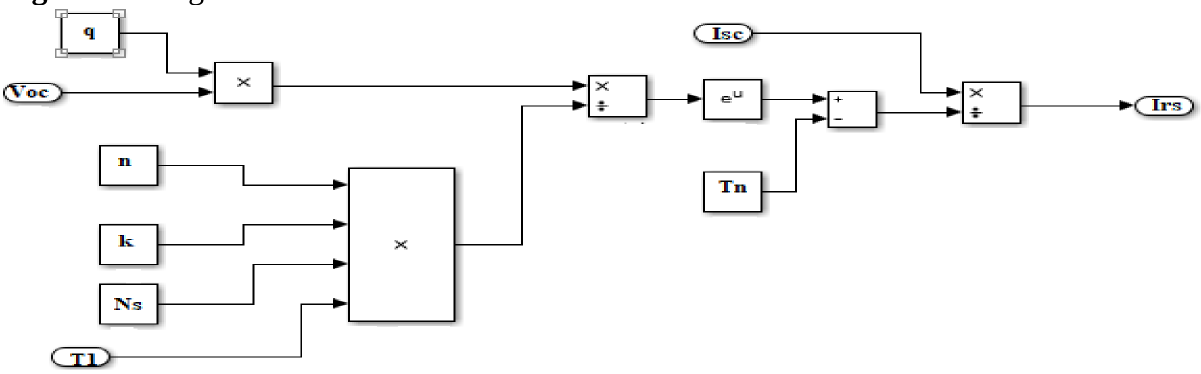

Fig.6 Modeling of reverse saturation current of diode

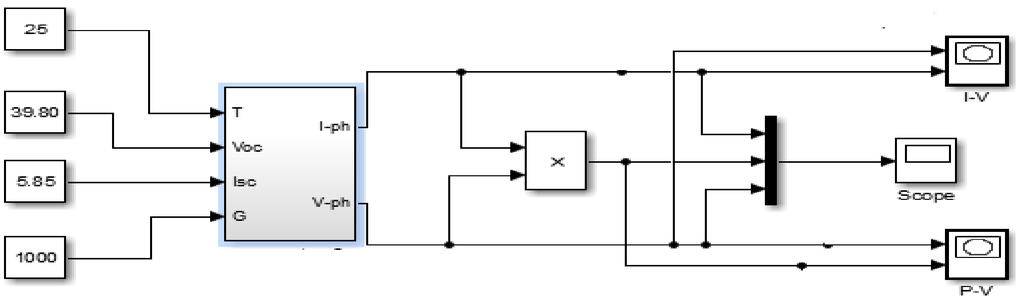

Fig.7 Circuit model of solar photovoltaic cell

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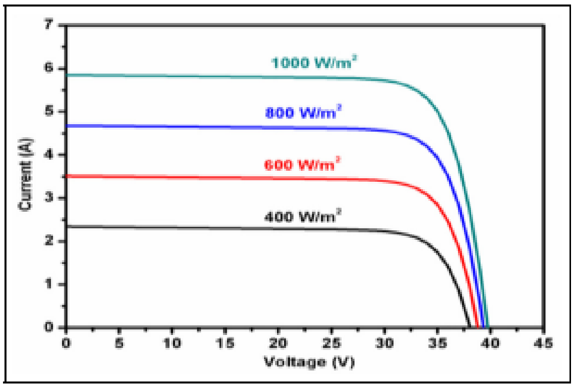

Fig. 8 I–V curve with the varying irradiance at 25° C

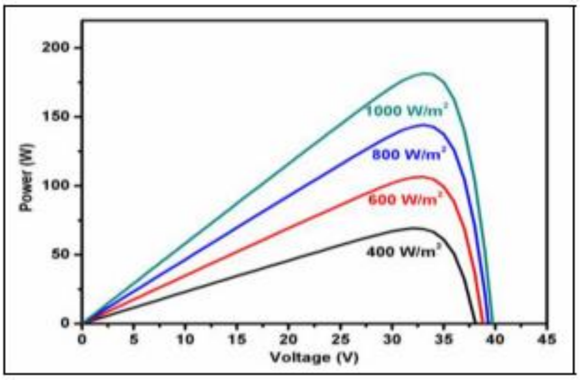

Fig. 9 P–V curve with the varying irradiance at 25° C

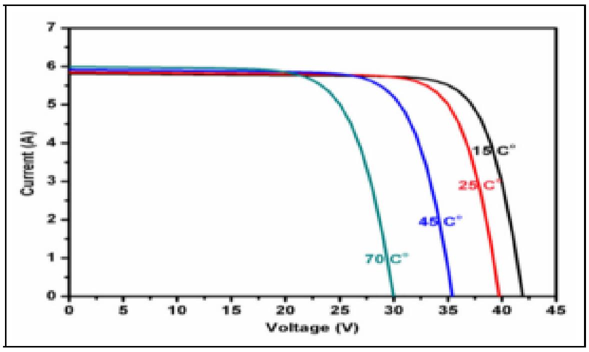

Fig. 10 I–V curve with the varying temperature

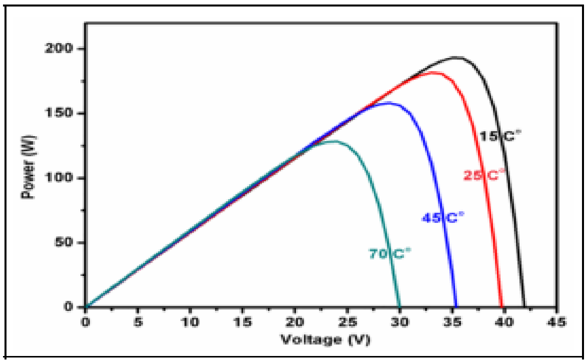

Fig. 11 P–V curve with the varying temperature

Figure 8 shows the I–V characteristics in which the operating temperature keeps constant and varying the irradiance from 400 to 1000 watt/m^2. It shows that by increasing the irradiance from the lower level to high, there is an increase in the output current and the voltage. Figure 9 shows the result of the P–V characteristics of the PV system. As irradiance increases, the power for the PV system rises in the same way and it shows the direct relationship between irradiance and the power. Figure 10 and figure 11 shows the I–V and P-V characteristics of the PV system where the irradiance is kept constant and the temperature is varied from 15 to 70°CIt shows that while increasing the temperature from lower to higher values, there is a slight change in the current but the voltage drastically decreases. In results, the power output decreases as the temperature increases, as shown in Figure 11, and has an inverse relationship with the temperature. Figure 12 and figure 13 shows the P–V and I-V characteristics of the PV module in which the shunt resistance is changing from the higher to the lower value while the temperature and irradiance are kept constant on their optimal values at 25°C and 1000W/m^2, respectively. As the shunt resistance decreases for the higher value such as 415Ω–100Ω, the current and voltage slightly change, which leads to a reduction in the power output. When the shunt resistance decreases to a deficient value such as 10Ω and 5Ω, the current and voltage change noticeably, results in a reduction of the power output as shown in Figure 12. So to maintain the optimal power, shunt resistance should be selected with care.

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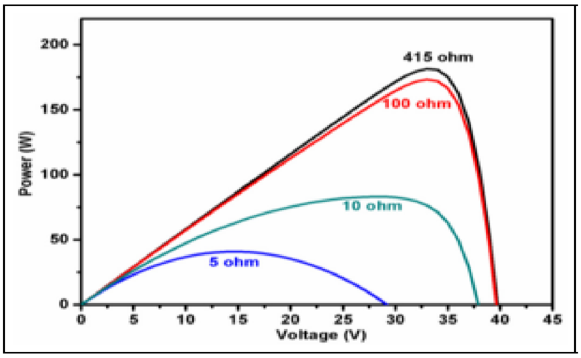

Fig. 12 P-V curve with varying shunt resistance

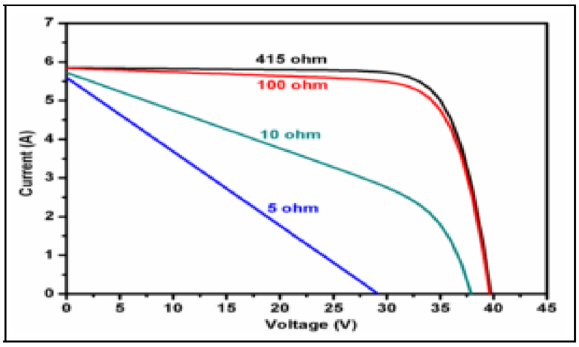

Fig. 13 I-V curve with varying shunt resistance

Conclusion:

In order to assist researchers and readers in modelling the PV solar cell using equations, this paper provides a step-by-step process to comprehend the system's I-V and P-V properties. Prior to choosing a PV panel at any site researchers can use this study for any application. This paper also gives a reliable scheme for checking the PV module's performance under various physical parameters and outside circumstances such as irradiance, temperature, shunt resistance, and saturation. This model is very user-friendly to understand the behaviour of the PV module on several changing conditions. This study focuses on the performance of the chosen flexible solar panel for electric vehicles when there is partial shadowing because, during the day, roughly 50% of the vehicle is partially shaded while it is moving or parked. This study is just the first step toward developing a hybrid system for electric automobiles connecting it with renewable energy generation, such as a source of wind energy.

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