Implementation of Solar PV Module using Simscape MATLAB Tool

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Abstract—*The ever-growing potential threat to human kind Global warming is giving , ever decreasing traditional energy source and ever increasing cost of fossil energy has made alternate energy sources a mainstream research area for decades. The focus and shift to alternate energy sources have the potential to boost economy of any nation. In this paper mathematical modeling of solar PV has been done and results are drawn for constant solar irradiation with variable temperature and vice versa. The paper focuses on a model developed in MatLab/Simulink simscape tool box of (36 Watt) photovoltaic module. An accurate PV module based on mathematical equation that described by solar cell equivalent circuit including a photo current source, a diode, a series resistance and shunt resistance. The model allows the prediction of PV module under different physical parameter that vary with several environmental parameter like solar insolation, temperature, wind speed and shading. The performance of such a system requires a precise knowledge of I-V and P-V characteristics curve. This model can also be used to extract the physical parameter for a given solar PV module as a function of temperature and solar irradiance. Performance of PV module may be improved by analyzing I-V curve. Effect of variation of temperature and solar irradiance is observed in muzaffarpur, Bihar and also observed simulated characteristics. The model simulation results are compared with the datasheet information and they have good agreement.*

Keywords*: photovoltaic module, solar irradiance, V-I characteristics, MatLab/Simulink*

1. INTRODUCTION

A renewable energy system converts the energy present in sunlight, water, wind, geothermal heat, or biomass into a form, which can be used in the form of heat or electricity. In today's climate of growing energy needs to and increasing environmental concern, we must have to think for an alternative to the use of non-renewable and polluting fossil fuels. One of the alternatives is solar energy. Solar energy may be applied in electricity generation, heating water, lighting building or streets, crop drying etc. Solar photo Voltaic (PV) systems convert solar energy directly into electrical energy. Solar power has two big advantages first is renewable source of energy, never going to run out, and second is its effect on environment. In India, more than 300 clear sunny days are observed in various parts. The daily average solar energy incident over India varies from 4-7 kWh/m^2, depending upon location. This may be translated into power generation over 5,000 trillion kWh/year, several times of the total energy consumption of the country in a year. The major component of solar energy utilization is Solar Photovoltaic System (SPV) systems. Its conversion efficiency depends on many factors, such as insolation levels, temperature, and load condition. Power output of PV module is directly proportional to solar radiation. Hence, in order to select the best location to install PV module, the strength of solar radiation need to be considered. Besides that, environmental factors and local climate such as humidity, temperature and wind also need to be considered as it will affect the output power of PV module. These effects are shown clearly in this simulation result where the performances of PV module depend on the amount of solar radiation also the temperature of surrounding. Modeling and simulation of PV module helps in better understanding in terms of the behavior and characteristics. These methods effectively used in predicting the behavior of PV module vary in environmental conditions. There are several methods in modeling PV cell characteristics these are e numerical methods, analytical techniques, artificial intelligence techniques and linearization and Thevenin'sequivalents . As for this paper, analytical methods under standard test condition i,eT$_s$= 25^0 Irradiance = 1000 W/m2 are used where PV cell is modeled as single diode circuit that consists of photocurrent, diode, and series and shunt resistor. By using this method, characteristics of PV cell and module can be determined easily.

2. PV MODULE

Fundamental power conversion unit of a PV generation system is the PV module. It converts light into electricity. The output characteristics of the PV module depend on the solar insulation and the cell temperature. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system application [1]. Any change in the entries, immediately implies change in output, therefore it is important. Modeling this device requires weather data such as

irradiance temperature as an input variable. The output can be voltage, current, power or others. However trace of characteristics I-V, or PV needs these three variables to use an accurate model.

A typical PV module consists of a number of PV cells in series. The conventional technique to model a PV cell is to study the p-n junction physics [2]. A PV cell has a non-linear voltage-current (*V-I*) characteristic which can be modeled using current sources, diode(s) and resistors. Single-diode and double-diode models are widely used to simulate PV characteristics. The single-diode model emulates the PV characteristics fairly and accurately. The manufacturer provides information about the electrical characteristics of PV by specifying certain points in its *V-I* characteristics which are called remarkable points [3]. Voltage current (V-I) curve of a solar PV cell passes through two significant points.

(i) Short circuit Current (I_{sc}). It is the current produced by cell when the positive and negative terminals of the cell are short-circuited, and the voltage between them is zero i.e load resistance is zero.

(ii) Open-circuit voltage (v_{oc}). It is the voltage across the positive and negative terminals under open-circuit condition, and the current is zero i,e load resistance is zero.

In this paper, a simplified PV equivalent circuit with single diode equivalent model is proposed.

The main contribution of this work is the implementation of a generalized PV model in the form of masked block which has a user-friendly icon and dialog in the same way of Matlab/Simulink block libraries

3. MATHEMATICAL MODELING OF SOLAR PV PANEL

Mathematical model of the PV panel can be used to analyze the performance and the characteristics of the solar PV Panel. Physical behavior of a solar cell can be understood by considering equivalent circuit of solar cell that is based on discrete electrical component.
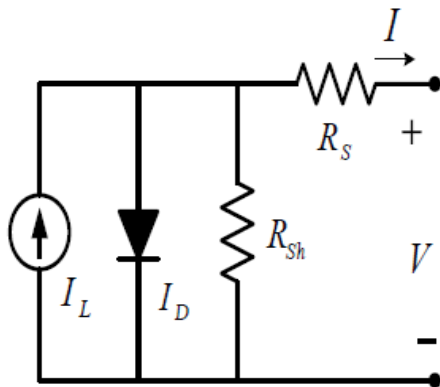
An ideal PV cell is modeled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the figure (1) An equivalent circuit of a solar PV cell (single diode model) includes photo current source I_{ph}, which represent solar photo current, I_D is the diode current, I_{sh} is the shunt current of the cell respectively. Usually R_{sh} is very large so that it does not draw any current and R_s is very small so that there is negligible voltage drop across it. From the equivalent solar PV cell model, the current produced by the cell is equal to current source (I_{ph}), minus the current flows through the diode (I_D), minus current flows through the shunt resistor (I_{sh})

The solar PV cell can be modeled mathematically as given in equation (1) as per the theory of semiconductor and photovoltaic that describes the I-V characteristics of photovoltaic cell. Fig. 2 shows the I-V operating characteristics of a solar cell. A PV array comprises individual cells connected into a unit of suitable power rating. Characteristics of PV array are determined by multiplying individual cell voltage by the number of cells connected in series (Ns) and multiplying the current by number of cells connected in parallel (Np). Three important points are points are open-circuit voltage (Voc), short circuit current (Isc) and Maximum Power Point (MPP).
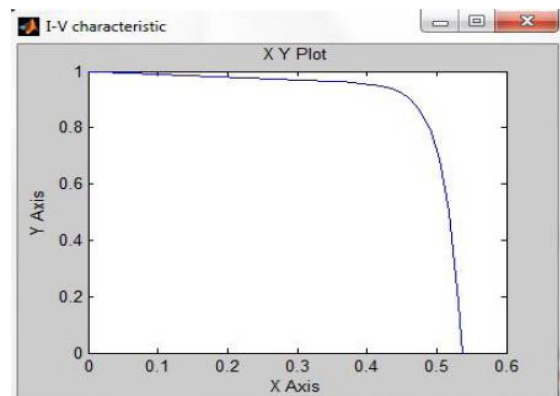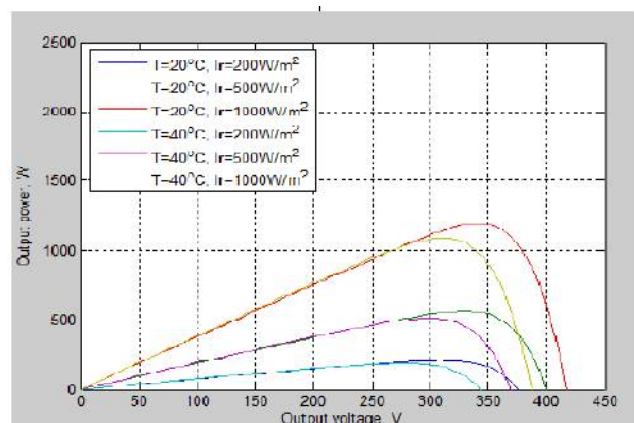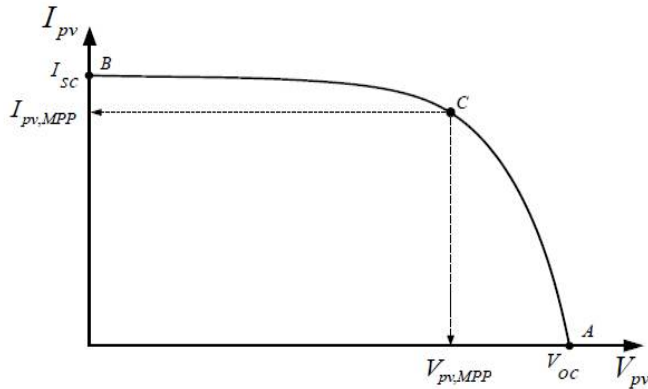

Fig. 1(a) I-V Characteristics

Fig. 1: Equivalent circuit of solar PV cell

Fig. (2) PV cell operating point

Solar cell photo current:

Applying Kirchhoff's current law to the node where the I_{ph}, I_d, R_p and R_{sh} meet, we get

$$I_{ph} = I_d + I_{RP} + I \qquad (1)$$

We get following equation for the photovoltaic current:

$$I = I_{ph} - I_{RP} - I_d \qquad (2)$$

$$I = Iph - Is\left(e^{\left[\frac{q(V+IRS)}{KTA}\right]} - 1\right) \qquad (3)$$

Iph represents the current generated by photovoltaic cells called the photo current and I_S is the saturation current. Constant q (1.6 x 10^{-19}) is electric charge; k (1.38 x 10^{-23}) is Boltzmann constant. Tis the operating temperature of cell and factor Ais a constant which depends on the technology used in photovoltaic cells. In the case of mono crystalline silicon factor Ahas a value of 1.2, in technology based on polycrystalline silicon factor Ahas a value of 1.3.

Current generated by the photovoltaic cells is dependent on the ambient temperature and solar radiation, and can be calculated using the following equation (4):

$$Iph = \lambda (I_{SC} - ki [T - Tr]) \qquad (4)$$

Coefficient $\lambda$is the radiation temperature coefficient and kiis short circuit current temperature coefficient. I_{SC} representsshort circuit current measured under the standard testconditions, where in the case of PV modules the temperature is25 °C and the solar radiation is 1000 W/m2 [4].

Saturation current depends on perating current, defined as:

$$Is = I_{RS}\left(\frac{T}{Tr}\right)^3 e^{\left|qEg\left(\frac{\left(\frac{1}{Tr}-\frac{1}{T}\right)}{KA}\right)\right|} \qquad (5)$$

Where, I_{RS} is the reverse saturation current under standard test conditions and Egstands for the energy band gap, which depends on the semiconductor used in photovoltaic cells.

Reverse saturation current at the reference temperature is calculated by the following equation:

$$I_{RS} = \frac{Isc}{e^{\left[\frac{q(Voc)}{NsKTA}\right]}-1} \qquad (6)$$

$V_{OC}$is the open circuit voltage of photovoltaic module at reference temperature and NSis number of cells connected into series. In the case, when only single cell is modeled, the Ns =1

4. MATHEMATICAL AND SIMULINK MODELING OF PHOTOVOLTAIC ARRAY:

The mathematical model of PV array of Fig. (1) is represented by modifying the equation (3) as:

$$I = N_p I_{ph} - I_s\left(e^{\left[\frac{qV}{KTANs}\right]} - 1\right) \qquad (7)$$

Usually the value of R_{sh} is very larger than Rs, and may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators [5].

Modeling is done in MATLAB SIMULINK. The first step is the creation of equation (4) which requires both the input variables λ and ambient temperature T. After than photocurrent I_{ph} is calculated in the output of the subsystem. Next step is the implementation of saturation current Is equation (5) and I_{RS} equation (6). For each formula separate blocks are made and finally, all are combined to get the resulting current. Solar Irradiance and ambient temperature is the input for the whole model.

Simulation is done on Matlab/Simulink for 36W Tata BP 184459 solar PV module at constant solar radiation intensity and verifying module temperature.

Manufacturing data specification of 36 W solar PV modules (Tata BP 184459) is listed in table 1.

Table 1: Specification of PV module

Model	Tata BP 184459
Maximum power	36W
Open circuit voltage	18V
Short circuit current	2A
Number of cells	36
Dimensions	950x425x35mm
Weight	6 kg
Fill factor	0.85

Table 2: Simulation Parameter

Simulation Parameters	Values
Solar radiation intensity (λ)	800W/m^2
Cell Reference Temperature (Tr)	25^{0}C, 35^{0}C, 40^{0}C, 45^{0}C
Cell Temperature (module operating temp) (T)	40 ^{0}C

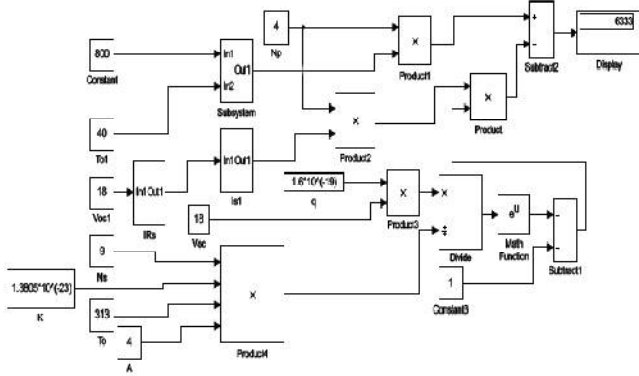| Short circuit temperature co-efficient (Ki)	$0.00023 mA/^0C$
Reverse saturation current (Is or I_{rr})	$21 \times 10^{-10} A$
Boltzmann Constant	$1.38 \times 10^{-23} W/m^2$ -K
Charge on electron	$1.6 \times 10^{-19} C$
Cell saturation current	$0.75 \mu A$
Fill factor	0.85
Area of module (Ae)	$0.40 m^2$
Ideality Factor (A)	4
Band Gap Energy (Eg)	6.5 eV
Number of cells connected in parallel (N_p)	36
Number of cells connected in series (Ns)	9

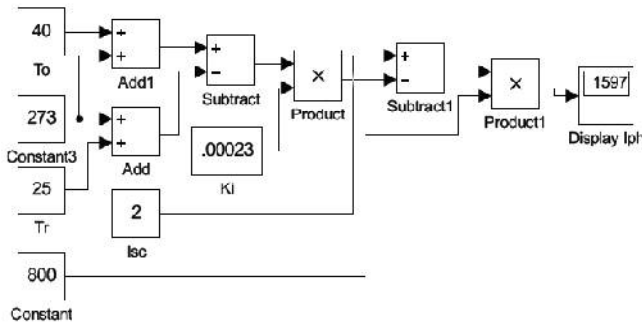**Fig. 3: Detailed view of implementation of equations for resulting module current**
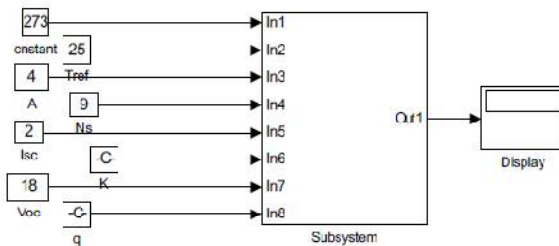

Fig. 4: Calculation of I_{Ph}
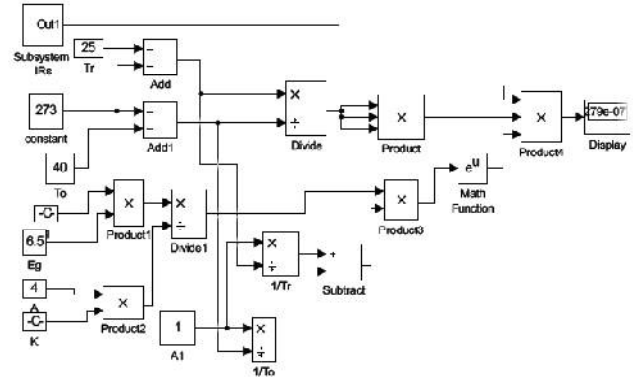

Fig. 5: Calculation of I_{RS}

Fig. 6: Calculation of Is

5. RESULT AND CONCLUSION:

The presented work is detailed modeling and simulation of PV cell and module. It is implemented under MATLAB/ Simulink environment using SimPower System tool box. An accurate PV model was presented and modeled in MATLAB/ Simulink for a 36 watt PV module. Under standard test condition, result has been matched with the parameter specified by manufacturer. When the value of solar radiation is 800W/m^2 and temperature is 25^{0}C, short circuit current is 2A and the open circuit voltage is 18 V confirming a valid model. Theproposed modeling method avoided complexities involved in Parameter identification while achieving comparable accuracy. The method is easy to implement in various simulation platforms for PV power systems.

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