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Modeling and Simulation Based Approach of Photovoltaic System

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ABSTRACT

As the Photovoltaic module exhibits non-linear V-I Characteristics, which are dependent on solar Insolation and environment factors, the development of an accurate power electronic circuit oriented model is essential to simulate and design the photovoltaic integrated system. A circuit based model of photovoltaic array (PV) suitable for simulation studies of solar power system is proposed in this paper. The model is realized using power system block set under MATLAB/SIMULINK. Detailed modelling procedure for the circuit model with numerical values is presented. The simulator is verified by applying the model to 36 W PV modules. The proposed model was found to be better and accurate for any irradiance and temperature variations. The proposed model can be very useful for PV Engineers and expert who requires a simple, fast and accurate PV simulator to design their systems.

KEYWORDS: Photovoltaic module (PV), Mat lab /Simulink, Solar cell model, solar array model, solar

I.INTRODUCTION

The field of Photovoltaic (PV) has experienced a remarkable growth for past two decades in its widespread use from standalone to utility interactive PV systems. The best way to utilize the electric energy produced by the PV array is to deliver it to the AC mains directly, without using battery banks [1]. A recent study in Germany, of 21 PV systems in operation for 10 years, revealed that inverters contributed for 63% of failures, modules 15% and other components 23%, with a failure occurring, on an average, every 4.5 years. [2]

At present, PV BOS research use mathematical functional models for the performance analysis of newly developed systems. These developed systems could not be readily adopted by the field professionals and hence the above Difficulties arise. Hence the need for simplified Simulink modelling of PV module has been long felt. Simple circuit-based PV models have been proposed in Literature [3]-[8]. Although interesting, such methods are impractical, complicated and require high computational effort. In all the above, modelling was limited to simulation of PV module characteristics.

In this paper, the design of PV system using simple circuit model with detailed circuit modeling of PV module is presented. In section II, Equivalent circuit of the PV module & Simulink model for each equation is presented. In section III, complete circuit oriented model is presented.

II. MODELING OF PV MODULE:

Equivalent Circuit: A module consists of a number of solar cells connected in series and parallel to obtain the desired voltage and current. Each solar cell is basically a P-n diode. As sunlight strikes a solar cell, the incident Transmitted light is absorbed within the semiconductor, by using this light energy to excite free electrons from a low energy status to an unoccupied higher energy level.

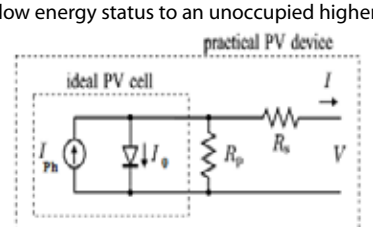


Fig.1 PV cell modelled as diode circuit

When a solar cell is illuminated, excess electron-hole pairs are generated throughout the material, hence the p-n junction is electrically shorted and current flows.

For simplicity, the single diode model of Fig. 1 is studied in this paper. This model offers a good compromise between simplicity and accuracy with the basic structure consisting of a current source and a parallel diode. In Fig. 1, Iph represents the cell photocurrent while Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively.

A. Equations of PV Module

PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays. The following are basic equations from the theory of semiconductors and photovoltaic [15] mathematically describe the I-V characteristic of the photovoltaic cell and module.

Electrical Characteristics Data of SOLKAR 36 W P Moule.

Description	Rating
Rated Power	37.08 Wp
Voltage at Maximum power (Vmp)	16.56 V
Current at Maximum power (Imp)	2.25 A
Open circuit voltage (VOC)	21.24 V
Short circuit current (ISCr)	2.55 A
Total number of cells in series (Ns)	36
Total number of cells in parallel (Np)	1
Note: The electrical specifications are under test conditions of irradiance of 1 kW/m2, spectrum of 1.5 air masses and cell temperature of 25 °C.	

b. Photo Current:

As shown in Fig.1, the module photocurrent Iph of the photovoltaic module depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation.

$$Iph = [Isc + Ki(T - 298)] * \lambda/1000 \quad (1)$$

where Iph [A] is the light-generated current at the nominal condition (25°C and 1000W/m2), Ki is the short-circuit current/ temperature co-efficient at Isc (0.0017A / K), Tk and Tref are the actual and reference temperatures in K, λ [W/m2] is the irradiation on the device surface, and 1000W/m2 is the nominal irradiation. Detailed Simulink model of equation (1) of photocurrent Iph is shown in fig. 2.

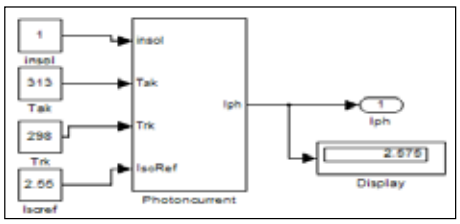


Fig 2. Module Photo current

Module Reverse Saturation Current:
Module reverse saturation current, Irs is given by the equation (2) as follows.

$$Irs = \frac{Iscr}{[\exp(q*Voc/NskAT)-1]} \quad (2)$$

Where q is the electron charge (1.6 × 10-19C),
Voc is the solar module open circuit voltage (21.24V),
Ns is the number of cells connected in series,
K is the Boltzmann constant (1.3805×10-23 J/K), and
A is the Ideality factor (1.6).
Detailed Simulink model of equation (2) is shown in fig. 3.

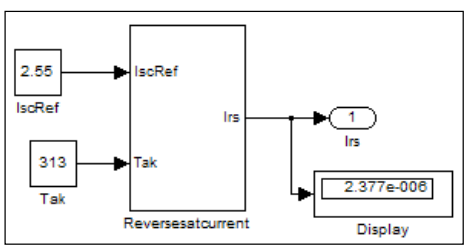


Fig 3. Module reverse saturation current

F. Module Saturation Current I0
The module saturation current I0 that varies with the celltemperature is given by,

$$Io = Irs\left[\frac{T}{Tr}\right]^3 \exp\left[q * Eg0/Bk\left(\frac{1}{Tr} - \frac{1}{T}\right)\right]$$

Where Egg is the band gap energy of the semiconductor (Eg ≈ 1.1 EV for the polycrystalline Si at 250C).

The equation is simulated with model shown in fig. 4.

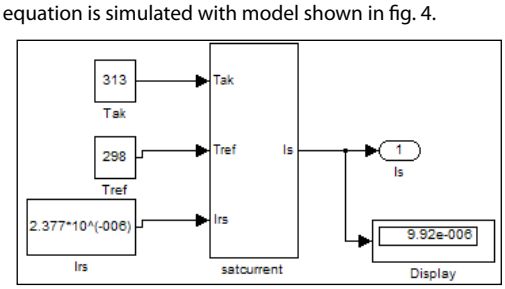


Fig 4. Module Saturation current

The module operating temperature, reference temperature and module reverse saturation current are taken as inputs.

The module saturation current I0 calculated for various temperatures is given in Table 4.

Sr No.	Temperature °c	Module Saturation current
1	25	1.182 * 10 (-006)
2	30	2.456* 10 (-006)
3	40	9.92* 10 (-006)
4	50	3.62* 10 (-006)
5	90	0.003491

G. Module Output Current IPV
The basic equation that describes the current output of PV module I PV of the single-diode model presented in Fig.1 is given by

$$Ipv = Np * Iph - Np * Io\left[\exp\left\{q * \frac{Vpv + Ipv.Rs}{NsAKT}\right\} - 1\right]$$

Where Np and NS are the number of parallel and series connections of cells, respectively, in the given photovoltaic

Module (Np = 1 and Ns = 36), VPV = Voc=21.24V, Rs is the equivalent series resistance of the module and Rsh is the equivalent parallel resistance. The current leakages, the tunnel effect, breakdown by micro plasmas, leaks along surface channels, etc are modelled as a parallel resistance.

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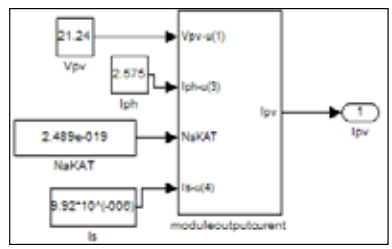


Fig 5 Module output current IPV

MATLAB SIMULINK Model:
All the above four blocks are interconnected to get IPV Simulink Model of PV module. Ipv Simulink Model takes insolation, temperature and VPV as inputs and calculates Ipv. Vpv is varied from 0 to 21.5V. Ipv Simulink Model is simulated with the setup shown in fig.Fig.7.

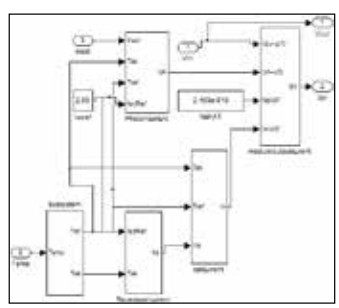


Fig 6: Details of all Interconnection blocks

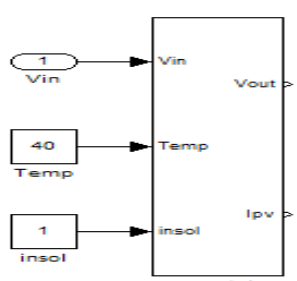


Fig 7: Simulink Model

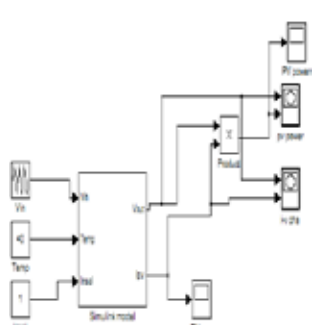


Fig.8 I-V & P-V Charac. Set up of PV Module.

THE SIMULATION RESULTS

The model of the PV module was implemented using a Mat lab Simulink model. The model parameters are evaluated during execution using the equations listed as in the previous section. The PV module chosen for this simulation is SOLKAR, which provides 36W nominal maximum power and has 36 series connected cells. The parameter specification of the module is as shown in Table-1. The model was built in stages as indicated above starting from stage A to the final model. The subsystem contains all the mathematical equations of every stage model block. Figure-9 & 10 shows the I-V& P-V output characteristics of PV module. The optimum operating points changes with the solar insulation, temperature and load conditions

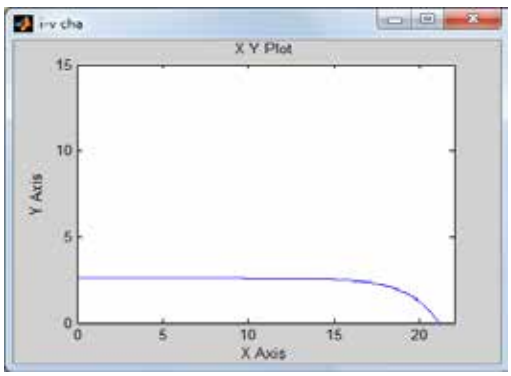


Fig 9 .I-V Characteristics of PV module

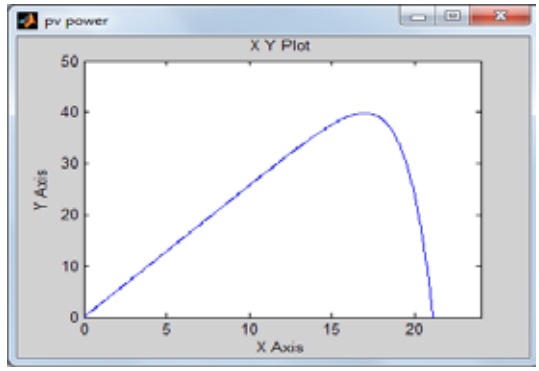


Fig 10.P-V Characteristics of PV module

The voltage input VIN for IPV Simulink model is fed back from the voltage output of the model. A small resistance of 0.221Ω is added to the circuit to aid the charging of capacitor normally added to the current sources.

RESULTS:

After mathematical circuit oriented modelling we have got following results

Photon current Iph: 2.575Amp.
Reverse saturation current IRS: 2.377*10-6
Saturation current: 9.92*10-6
Photovoltaic current Ipv: 2.06Amp.
Photovoltaic voltage Vpv: 21.08V
Photovoltaic power Ppv: 43.42 Watt

CONCLUSION:

A Mat lab/Simulink model for the solar PV cell, module and array was developed and presented based on the Mathematical equations in this paper.

Finally the model can be used to verify the effect of temperature, insolation and try to simulate behavior of photovoltaic system.

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