

**PHOTOVOLTAIC AND PEM FUEL CELL MODELING WITH MATLAB TO  
CONTRIBUTE TOWARDS A GREEN ENERGY POWER GENERATION**Deep P. Thanki<sup>1</sup>, Mr.Hitesh Lade<sup>2</sup><sup>1</sup>M. Tech Student, Surabhi College of Engineering & Technology<sup>2</sup>Electrical Engineering Department, Surabhi College of Engineering & Technology

**Abstract** —The Physical modeling is very little productive so the analysis is done through a mathematical modeling. In this paper numerical model of PV module is done through a single diode PV model. A 36 W PV module planned through MATLAB/Simulink environment. Additionally, composed the SR-12 module PEMFC with 500 W rated power. Diverse attributes of these modules were inspected under various conditions. The principle motivation behind this paper is to utilize this power over generation sources for further analysis of hybrid generation system with renewable energy sources.

**Keywords-** PV module, Solar cell, PEMFC, Mathematical Modeling and MATLAB/Simulink

**I. INTRODUCTION**

Traditional energy sources are not taking care of the energy demand of the world. As the constrained measure of this ordinary sources and compounding worldwide environment world specialist now move towards the renewable energy sources.

Photovoltaic energy is the a standout amongst the most widely recognized energy source among all renewable energy sources. It is all over. It is effectively convert the solar energy in electrical energy with solar cell. It is work on the principal of photovoltaic impact. The yield of PV module relies on upon the solar irradiation and operating temperature. Fuel cell is an electrochemical device that converts the electrical energy directly into electrical energy. It is a fantastic efficient power energy source. It is use as voltage source in grid connected as well as standalone power system. Among all other types of fuel cell PEMFC gives advantages such as low temperature, high power density, fast response and zero emission if it is run through pure hydrogen.

In this paper gives the mathematical modeling of 36 W PV module and PEMFC SR-12 module with rated power 500W. The use of these simple models provides sufficient accuracy to analyze the behavior of Photovoltaic and PEMFC module and have proven to be effective in most cases.

**1.1. Solar Cell**

In PV panel solar cell is the basic part which is made from silicon. Generally a solar cell is a PN junction diode. Made up from two different layers, small amount of impurities added in it. A PV system converts the sunlight into electricity. Number of PV cell is combined to form a PV array. The arrays are group of cells connected in parallel or in series. In fig.1 show the structure of PV cell.

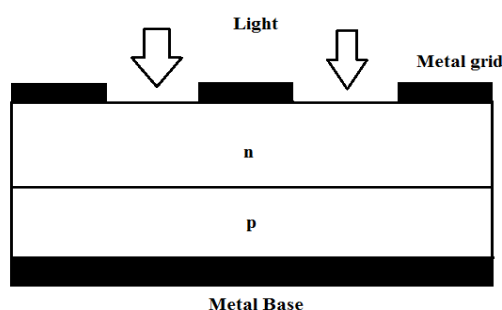
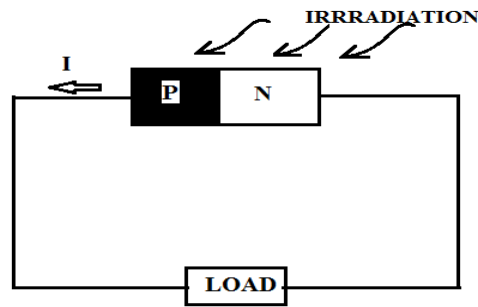


Figure1. Structure of PV Cell [13]

**1.1.1 Working of PV Cell**

The photocell is work on the principal of photoelectric effect. According to which, when energy of sunbeam is receiving by photon particle it hits PV cell. The electrons of the semiconductor get excited and gone to the conductionband from the valence band and become a free to move. Due to the moment of electrons positive and negative terminals are create

and also potential difference create across the two terminals. When external circuit connects between these two terminals, current is flowing through it. In fig.2 show the working of PV cell.

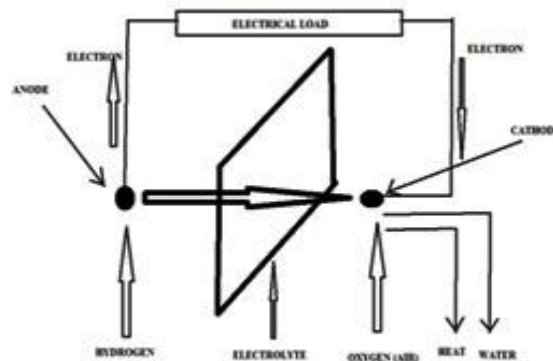


**Figure2. Working of PV cell [13]**

## 1.2 Fuel Cell

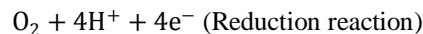
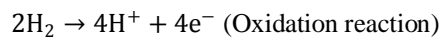
A fuel cell generates the electricity by chemical reaction. Generally, every fuel cell has two electrodes namely anode and cathode. Every reaction takes place at the electrode for producing energy. Every fuel cell has electrolyte which carries the charged particles from one electrode to other. Also there are catalysts, which speed the reaction process. Among all other types of fuel cell PEMFC gives advantages such as low temperature, high power density, fast response and zero emission if it is run through pure hydrogen.

### 1.2.1 Working of Fuel Cell



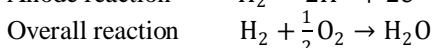
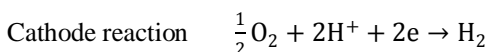
**Figure3. Basic working of fuel cell [14]**

In fig.3 show the basic working of PV cell. By breaking the hydrogen molecules, electrons and positive charge protons are getting free to move. The protons move from the cathode through membrane (electrolyte). The electrons are passing through external circuit to recombine with protons of hydrogen and oxygen molecules to produce water. The actual reaction is done through two half reaction, Oxidation half reaction and reduction half reaction.



### 1.2.2 PEMFC (Polymer Electrolyte Membrane Fuel Cell)

It is also called as proton exchange membrane fuel cell (PEMFC). It is deliver the high power density. It has low weight and volume compared with other fuel cells. In PEMFC, solid polymer as electrolyte porous carbon electrodes containing a platinum or platinum alloy is used as a catalyst. Its operating temperature is very low around 80°c. Due to the less temperature start quickly and less wear on system components.



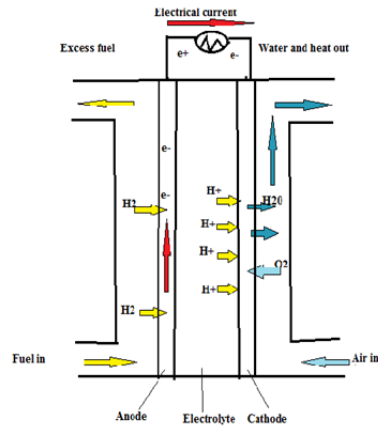


Figure 4. PEM fuel cell [14]

## II. MATHEMATICAL MODELING

### 2.1 Modeling of Solar Cell

General single diode model connected with current source is shown in fig.5.

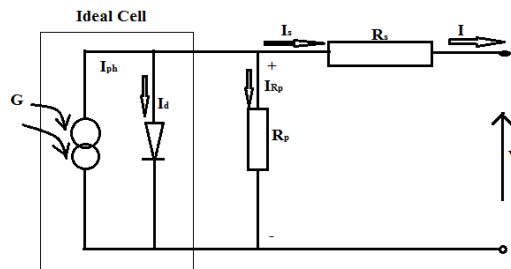


Figure5. Circuit of single PV cell [6]

Applying Kirchhoff's law, [6]

$$I_{ph} = I_d + I_{Rp} + I$$

Where,

$$I_d = \frac{I_{ph}}{\left[ \exp\left(\frac{qV_{oc}}{N_s AkT}\right) - 1 \right]}$$

Photon current,

$$I_{ph} = [I_{scref} + k_i(T_k - T_{ref})] * \frac{\lambda}{100}$$

Modules reverse saturation current,

$$I_{rs} = \frac{I_{sc}}{\left[ \exp\left(\frac{qV_{oc}}{N_s kAT}\right) - 1 \right]}$$

Module saturation current

$$I_{rs} = \left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_g}{Ak} \left\{ \frac{1}{T_r} - \frac{1}{T} \right\}\right]$$

#### Parameter specification:

$I_{ph}$ =light generated current at nominal condition

$K_i$ =Temperature coefficient

$T_k$ & $T_{ref}$ =actual temperature & reference temperature respectively

$q$ =electron charge ( $1.6*10^{-19}$ C)

$V_{oc}$ =solar module open circuit voltage

$N_s$ = number of cells connected in series

$K$ = the Boltzmann constant

$A$ =diode ideality factor

$E_g$ =the band gap energy of semiconductor

### 2.2 Modeling of PEMFC

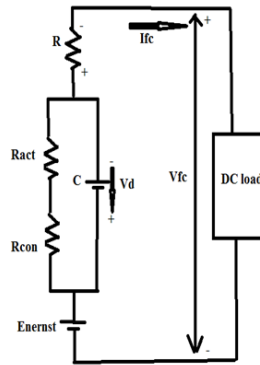


Figure6. Electrical equivalent circuit of PEMFC [7]

The electrical equivalent circuit of the PEM fuel cell is represented in Fig.6. For a single cell the output voltage can be defined by, [7]

$$V_{Fc} = E_{\text{nernst}} - V_{\text{act}} - V_{\text{ohmic}} - V_{\text{con}}$$

For a stack with  $n$  cells connected in series the voltage  $V_s$  can be calculated by:

$$V_s = n * V_{Fc}$$

Where, Cell reversible voltage:

$$E_{\text{nernst}} = 1.229 - (0.85 * 10^{-3}) * (T - 298.15) + (4.31 * 10^{-5}) * T * [\ln(P_{H_2}) + \ln(P_{O_2})]$$

Activation voltage drop:

$$V_{\text{act}} = -[\xi_1 + \xi_2 * T + \xi_3 * T * \ln(C_{O_2}) + \xi_4 * T * \ln(i_{fc})]$$

$$C_{O_2} = \frac{P_{O_2}}{(5.08 * 10^6) * e^{\left(\frac{-498}{T}\right)}}$$

Ohmic Voltage drop:

$$V_{\text{ohmic}} = i_{fc} (R_M + R_C)$$

$$\rho_M = \frac{181.6(1 + 0.03 * \left(\frac{i_{fc}}{A}\right) + 0.062 * \left(\frac{T}{303}\right)^2 * \left(\frac{i_{fc}}{A}\right)^{2.5}}{\left[\psi - 0.634 - 3 * \frac{i_{fc}}{A}\right] * \exp\left[4.18 * \left(T - \frac{303}{T}\right)\right]}$$

$$R_M = \frac{\rho_M * l}{A}$$

Concentration or Mass transport voltage drop:

$$V_{\text{con}} = -B * \ln\left(1 - \frac{J}{J_{\text{max}}}\right)$$

#### Parameter specification:

$P_{H_2}$  &  $P_{O_2}$  = partial pressures of hydrogen and oxygen (atm), respectively;

$T$  = operating temperature;

$T_{\text{ref}}$  = reference temperature;

$I_{fc}$  = cell operating current (A);

$\xi_s$  = parametric coefficients for each cell model;

$C_{O_2}$  = concentration of oxygen in the catalytic interface of the cathode (mol/cm<sup>3</sup>);

$\rho_M$  = specific resistivity of the membrane for the electron flow ( $\Omega - cm$ );

$A$  = Active area (cm<sup>2</sup>);

$l$  = thickness of the membrane (cm);

$R_C$  = resistance to the transfer of protons through the membrane;

$B$  (V) = Parametric coefficient, which depends upon cell and operation state;

$J$  = actual current density of the cell (A/cm<sup>2</sup>);

$J_{\text{max}}$  = maximum current density in the range of 500-1500 (mA/cm<sup>2</sup>).

### III. SIMULATION RESULTS

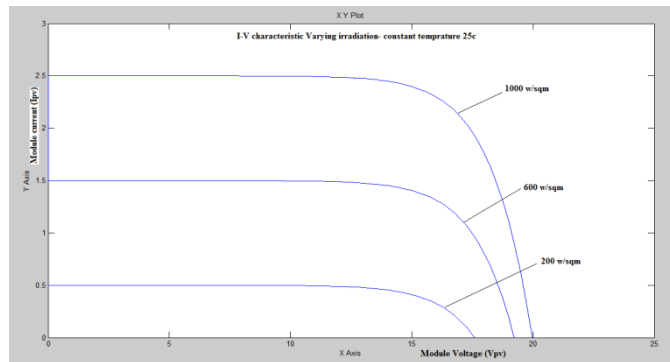
#### 3.1 Simulation Result of PV Module

Table 1 show the data for 36 W PV module, which is taken as reference in this paper.

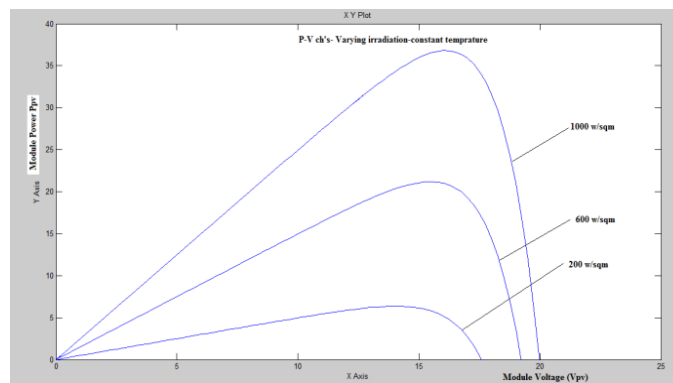
**Table1. Data for 36W solar PV module [6]**

Rated power	37.08W
Voltage at maximum power( $V_{mp}$ )	16.56V
Current at Maximum power ( $I_{mp}$ )	2.25 A
Open circuit voltage ( $V_{oc}$ )	21.24 V
Short circuit current ( $I_{scr}$ )	2.55 A
Total number of cells in series ( $N_s$ )	36
Total number of cells in parallel ( $N_p$ )	1

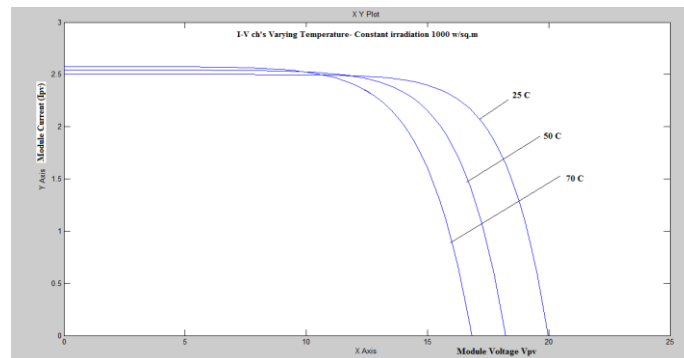
#### 3.1.1 I-V and P-V characteristic of PV module



**Figure 7. I-V characteristic - varying irradiation- Constant temperature 25°C**



**Figure 8. P-V characteristic - varying irradiation- Constant temperature 25oC**



**Figure 9. I-V characteristic Varying Temperature- Constant irradiation 1000 w/sq.m**

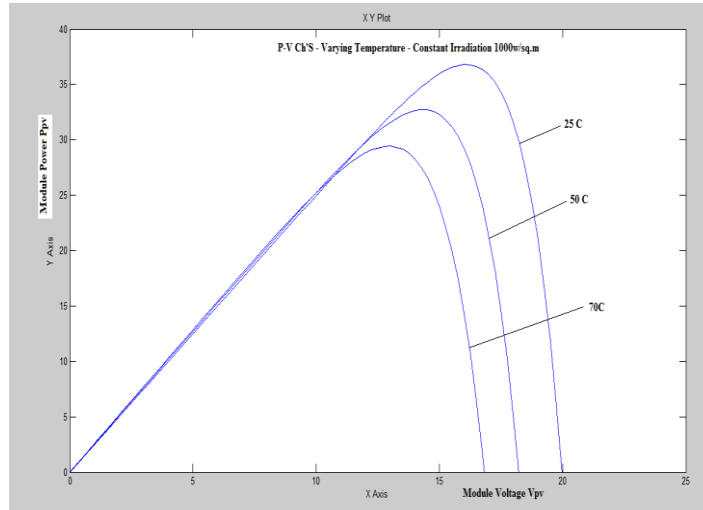


Figure 10. P-V characteristic Varying Temperature- Constant irradiation 1000 w/sq.m

In fig. 7 & 8 shows the V-I and P-V characteristics of the PV module with varying irradiation level (1000, 600, 200 w/sq.m) and constant temperature 25°C. Also, in fig. 9 & 10 shows the characteristics with varying temperature (25, 50, 70°C) and constant irradiation level 1000 w/sq.m.

### 3.2 Simulation result of PEMFC module

Table 2 shows the data for SR-12 modular PEM generator which is used in this paper for designing purpose.

Table-2: Parameters of the SR-12 Modular PEM Generator [7]

N	48	$\xi_1$	-0.948
T	323 K	$\xi$	$0.00286+0.0002\ln A+(4.3 * 10^{-5})\ln C_{H_2}$
A	62.5 cm <sup>2</sup>	$\xi_3$	$7.22 * 10^{-5}$
L	25 $\mu m$	$\xi_4$	$-1.0615 * 10^{-4}$
P <sub>H2</sub>	1.47628 atm	$\psi$	23
P <sub>O2</sub>	0.2095 atm	J <sub>max</sub>	672 mA/cm <sup>2</sup>
B	0.15 V	J <sub>n</sub>	22 mA/cm <sup>2</sup>
R <sub>C</sub>	0.0003 $\Omega$	I <sub>max</sub>	42 A

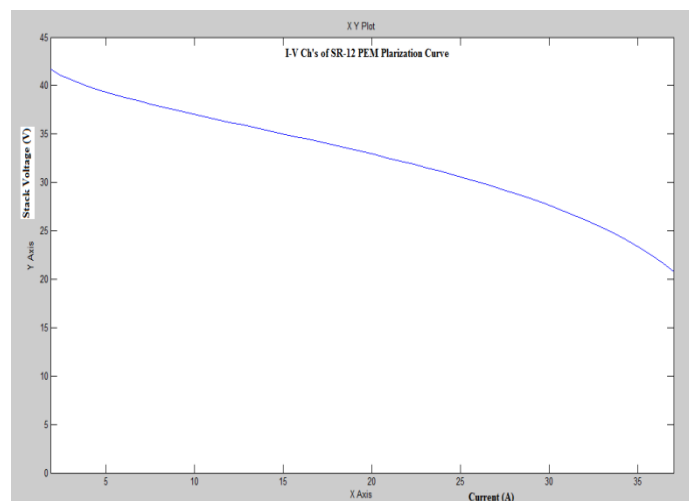
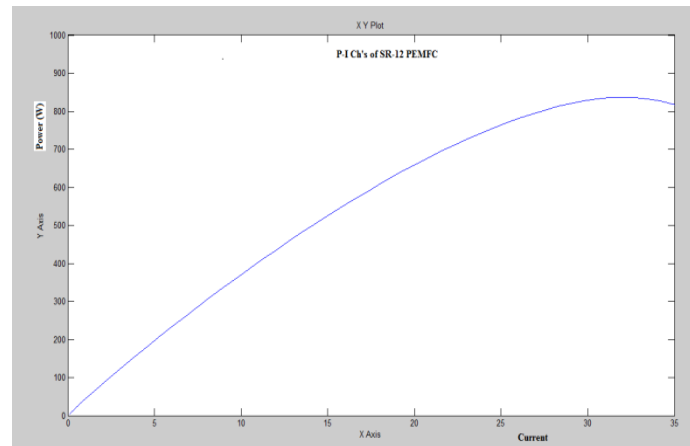


Figure 11. I-V: characteristic of SR-12 PEM polarization curve



**Figure 12. P-I characteristic of SR-12 module**

In fig. 11 & 12 shows the I-V and P-I characteristics of SR-12 PEMFC module. All results are taken through MATLAB/Simulink.

#### **IV. CONCLUSIONS AND FUTURE WORK**

As today increasing the power demand of the world, exhaustible nature of fossil fuels and worsening global environment have created interest in green renewable energy sources. We analyzed here the different characteristics of photovoltaic module with different conditions. Also, examine the different characteristics of fuel cell.

In future we will go towards the design of hybrid system connected to grid as well as standalone system. And we will contribute our work for power management of grid connected renewable hybrid system.

#### **V. REFERENCES**

- [1]. **R. Carbone**, "Grid-Connected Photovoltaic Systems with Energy Storage", IEEE, June 2009, ISBN: 978-1-4244-2544-0.
- [2]. **M. G. Villalva, J. R. Gazoli, E. Ruppert F.** "Modeling and Circuit-Based Simulation of Photovoltaic Array", Brazilian Journal of Power Electronics, Vol. 14, No. 1, pp. 35-45, 2009, ISSN- 1414-8862.
- [3]. **Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho** "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays", IEEE transactions on power electronics, VOL. 24, NO. 5, May 2009, ISSN: 0885-8993.
- [4]. **Alex Dev and S. BerclinJeyaprabha**, "Modeling and Simulation of Photovoltaic Module in MATLAB", International Conference on Applied Mathematics and Theoretical Computer Science, 2013, ISBN: 978-93-82338-35-2.
- [5]. **Ravinder Kumar, R. Muralidharan** "Mathematical Modeling, Simulation and Validation of Photovoltaic Cell", international journal of research in engineering and technology (IJRET), volume 03, 10 Oct.-2014, eISSN: 2319-1163, pISSN- 2321-7308.
- [6]. **Prof. Pandiarajan.N, Dr. Ranganath Muthu**, "Development of power electronic circuit-oriented model of photovoltaic module", International Journal of Advanced Engineering Technology, Vol.II, Issue IV, October-December, 2011, E-ISSN 0976-3945.
- [7]. **JefersonM.Correa, Felix A. Farret, Lucian N. Canha and Marcelo G. Simoes**, "An Electrochemical-Based Fuel-Cell Model Suitable for Electrical Engineering Automation Approach", IEEE transactions on industrial electronics, vol. 51, no. 5, october 2004, 0278-0046.
- [8]. **S. Dharani, R. Seyezhai**, "Development of Simulator and MPPT Algorithm for PEM Fuel Cell", communications on applied electronics, Volume 2, No. 7, August 2015, ISSN: 2394-4714.
- [9]. **A. Derghal, L. khochemane, B. Mahmah**, "Modeling and Validation of Fuel Cell PEMFC", revue des energies renouvelables, Vol. 16, No. 2, 2013, 365-377.

- [10]. **Caisheng Wang and M. Hashem Nehrir**, “Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System”, IEEE Transactions on energy conversion, Vol. 23, No. 3, September 2008, 0885-8969.
- [11]. **AbdrczzakBouharchouhc, El Madjid, TarrakGhcnnam**, “Control and Energy Management of a Grid Connected Hybrid Energy System PV-Wind with Battery Energy Storage for Residential Applications”, Eight International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), IEEE, March 2013, ISBN: 978-1-4673-5269-7.
- [12]. **Sandeep Kumar**,thesis of “modeling and simulation of hybrid Wind/Photovoltaic standalone generation system”, May 2014.
- [13]. **Sanjukta Patel**,thesis of “Modeling and control of a grid connected Wind-PV hybrid generation system”, May 2014.
- [14]. **M.HashemNehrir&Caisheng Wang**, Modeling and Control of Fuel Cells Distributed Generation Application; Wiely-IEEE Press.