Mathematical Modeling of PEMFC and Photovoltaic Module

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Abstract— The Physical modeling is not much efficient so the analysis is done through a Mathematical modeling. In this paper modeling of Photovoltaic cell is done in numerical real life simulation through a single diode Photovoltaic cell. A 36 W PV module designed through MATLAB/Simulink environment. Also, designed the SR-12 module PEMFC with 500 W rated powers. Different characteristics of these modules were examined under different states. Main determination of this research is to use this power generation sources for further analysis of hybrid generation system with renewable energy sources.

IndexTerms— Solar cell, PV module, PEMFC, and MATLAB/Simulink etc…

I. INTRODUCTION

Conventional energy sources are not meeting the energy demand of the world. As the limited amount of this conventional sources and worsening global environment world researcher now move towards the renewable energy sources. Fuel cell is a device which converts in electrical energy by chemical reaction. It is a high quality green 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 merits like huge power density, low-set performing temperature, and rapid response.
Photovoltaic energy is the one of the most common energy source among all renewable energy sources. It is everywhere. It is easily convert the solar energy in electrical energy with solar cell. It is work on the principal of photovoltaic effect. The output of Photovoltaic cell is relying on the sun beam intensity and performing temperature.
In this paper gives the mathematical modeling of 36 W PV module and PEMFC SR-12 module with rated power 500W. By performing the reference model of PEMFC and photovoltaic cell, analyzed the effectiveness and preciseness of the results.

1.1 H_2-Fuel Cell

A H_2 fuel cell is producing the electrical energy through 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 H_2 fuel cell PEMFC gives merits like huge power density, low-set performing temperature, and rapid response.

1.1.1 Working of Fuel Cell

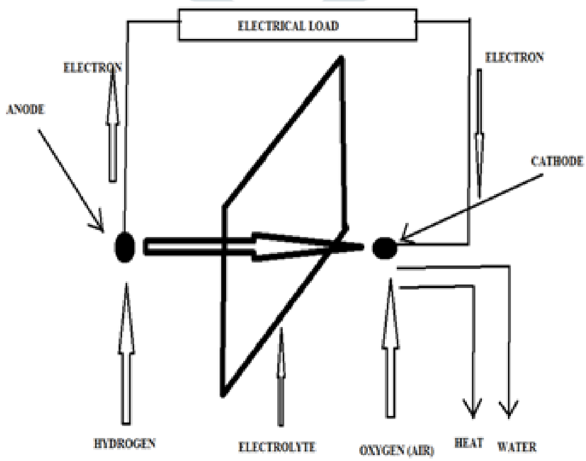

Figure 1: Basic working of fuel cell [14]

In fig.1 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 have been passed with the external electrical circuit to give the outcome of non-polluted water. The actual reaction is given by,

$$2H_{2\,(hydrogen)} \rightarrow 4H^{+} + 4e^{-} \text{ (Oxidation process)}$$

$$O_{2\,(air)} + 4H^{+} + 4e^{-} \rightarrow 2H_{2}o \text{ (Reduction process)}$$

1.1.2 PEMFC

It is known as proton exchange membrane fuel cell (PEMFC). It is deliver the high power density. Due to its lowering weight and volume it widely used. In PEMFC, thick polymer is used as electrolyte, absorptive carbon electrodes containing a platinum or platinum compound is used as a catalyst. Its operating temperature is very low around 80°c. On the reason of lower temperature operate quicker and lesser abrasion on system units.

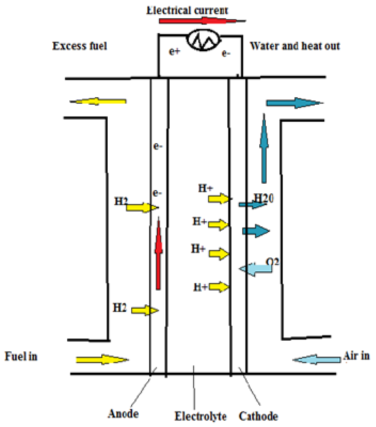

Figure-2: PEM fuel cell [14]

Cathode reaction $\frac{1}{2}O_2 + 2H^{+} + 2e \rightarrow H_2$

Anode reaction $H_2 \rightarrow 2H^{+} + 2e$

Overall reaction $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

1.2 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. 3 show the construction of Photovoltaic cell.

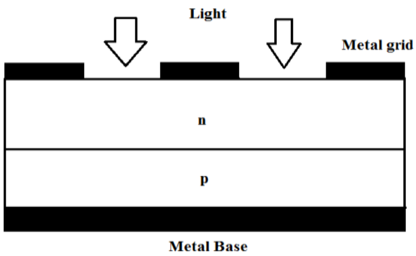

Figure-3: Construction of Photovoltaic cell [13]

1.2.1 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 conduction band 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.4 show the working of PV cell.

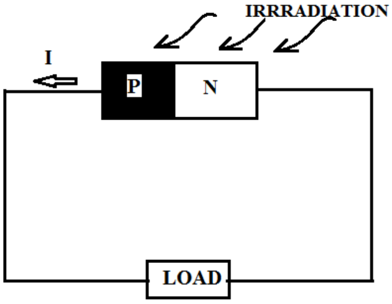

Figure-4: Working of PV cell [13]

2. Mathematical Modeling

2.2 Modeling of PEM fuel cell

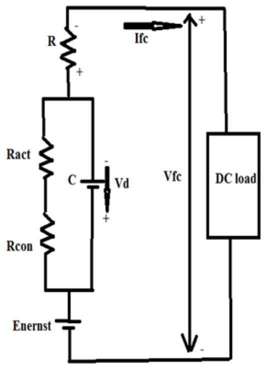

Figure-5: Electrical identical circuit of the PEM fuel cell [7]

The electrical identical circuit of the PEM fuel cell is shown in Fig.5. The outcome voltage of the PEM fuel cell is given as, [7]

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

The stack is containing n number of series cell. The outcome voltage of stack is represent by,

$$V_{stack} = n * V_{Fuel\ cell}$$

Where,

<u>Cell reversible voltage</u>:

$$E_{nernst} = 1.2289 - (0.85 * 10^{-3}) * (T_{opt} - 298.15) + (4.308 * 10^{-5}) * T_{opt} * [\ln(P_{Hydrogen}) + \ln(P_{Oxygen})$$

<u>Activation voltage drop</u>:

$$V_{activation} = -[\xi_1 + \xi_2 * T_{opt} + \xi_3 * T_{opt} * \ln(Co_2) + \xi_4 * T_{opt} * \ln(i_f)]$$

$$C_{O2} = \frac{P_{O2}}{(5.08 * 10^6) * e^{\left(-\frac{498}{T_{opt}}\right)}}$$

<u>Ohmic Voltage drop</u>:

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

$$\rho_M = \frac{181.6\left(1 + 0.03 * \left(\frac{i_f}{A}\right) + 0.062 * \left(\frac{T_{opt}}{303}\right)^2 * \left(\frac{i_f}{A}\right)^{2.5}\right)}{\left[\psi - 0.6339 - 3 * \frac{i_f}{A}\right] * \exp\left[4.18 * \left(T_{opt} - \frac{303}{T_{opt}}\right)\right]}$$

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

Concentration drop of voltage:

$$V_{concentration} = -(B)[\ln\left(1-\frac{J}{J_{max}}\right)]$$

Parameter specification:

P_{H2} = partial pressures of hydrogen molecules (atm.)
P_{O2} = partial pressure of oxygen molecules (atm.)
T_{opt} = operating temperature;
T_{ref} = temperature which is taken to be a reference;
I_f = operating current of cell (A);
ξ_s = parametric constants for each cell;
C_{O2} = concentration of oxygen (mol/cm^3);
ρ_M = specific resistivity of membrane for the electron rate ($\Omega - cm$);
A = Active area (cm^2);
l = Membrane thickness (cm);
R_C = resistance to the transfer of protons by membrane;
B (V) = Parametric constant;
J = cell current density (A/cm^2);
J_{max} = Highest density of current (mA/cm^2).

2.1 Modeling of Solar Cell

General single diode model connected with current source is shown in fig.6.

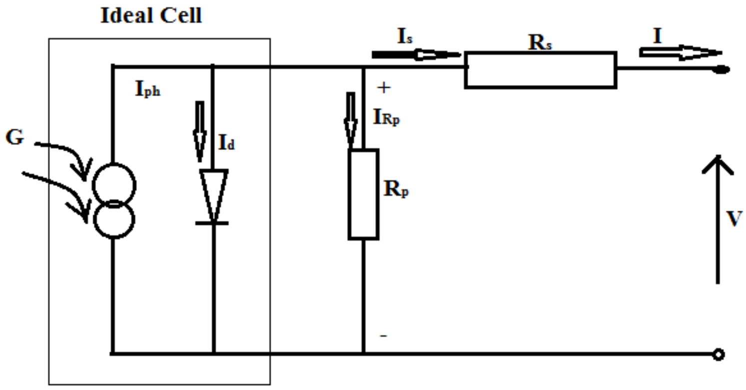

Figure-6: Circuit of single PV cell [6]

Applying Kirchoff'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} = production of current due to the light emission at nominal state
K_i = Temperature coefficient
T_k & T_{ref} = actual temperature & reference temperature respectively
q = charge of each electron (1.6*10^{-19} Coulomb)

Voc = open circuit voltage of photovoltaic module
N_s = No. of photovoltaic cell arrange in series
K = Constant of Boltzmann
A = diode ideality factor
E_g = Band gap energy of semiconductor material

3. Simulation Results

3.2 simulation result of PEMFC module

Table 1 show the data for SR-12 modular PEM generator which is used in this paper for designing purpose.

Table-1: The SR-12 Module PEM fuel cell [7]

N	48	ξ_1	-0.9480
T_{opt}	50° C	ξ_2	0.002860+0.00020*lnA+(4.30 $*$ 10^{-5})ln C_{H2}
A	62.5 cm^2	ξ_3	$7.22 * 10^{-5}$
l	25 μm	ξ_4	$-1.0615 * 10^{-4}$
$P_{hydrogen}$	1.47628 atm	ψ	23
P_{oxygen}	0.2095 atm	J_{max}	672 mA/cm^2
B	0.15 V	J_n	22 mA/cm^2
R_C	0.0003 Ω	I_{max}	42 A

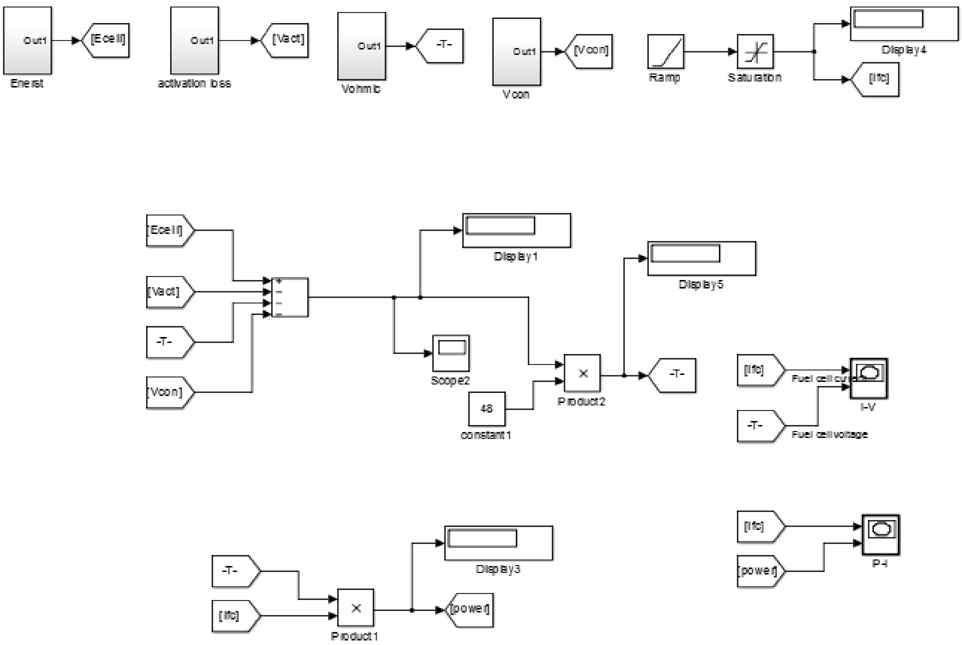

Figure 7: Mathematical modeling of SR-12 module PEMFC

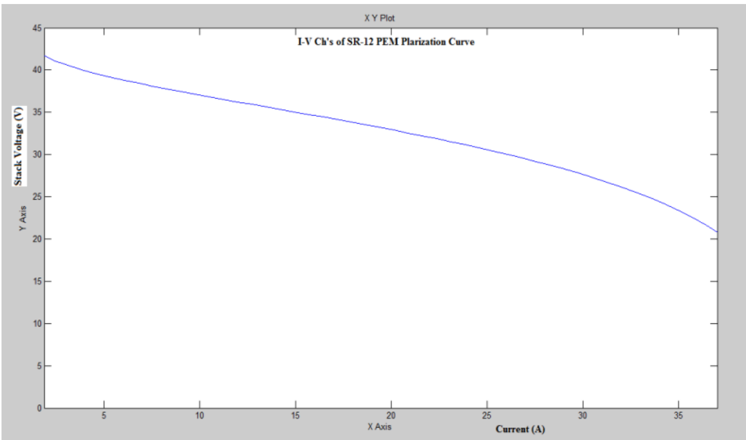

Figure 8 I-V: characteristic of SR-12 PEM polarization curve

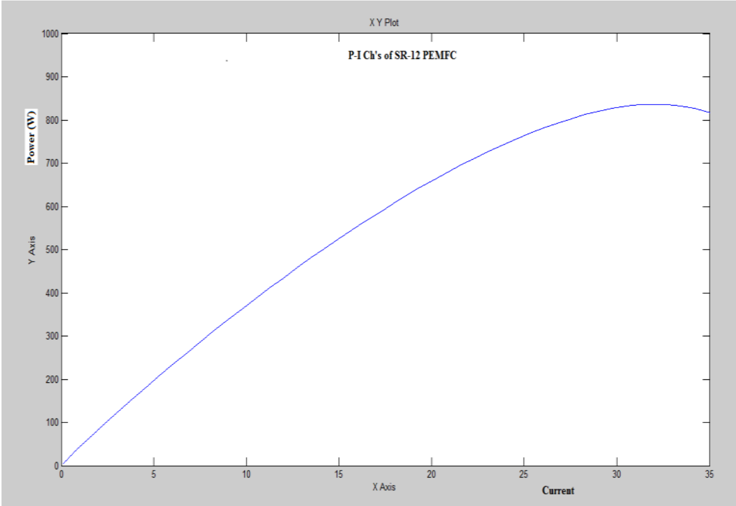

Figure 9: P-I characteristic of SR-12 module

In fig. 7 present the mathematical model of SR-12 PEMFC module. In fig. 8 & 9 present the current - voltage and power - current graphs of SR-12 PEMFC. All results are taken through MATLAB/Simulink.

3.1 Simulation Result of PV Module

Table 2 show the data for 36 W Photovoltaic module, which is consider in this paper.

Table-2: Data for 36W solar PV module [6]

Rated power	37.08W
Voltage at max. power (V_{mp})	16.56V
Current at max. power (I_{mp})	2.25 A
Open circuit voltage (V_{oc})	21.24 V
Short circuit current (I_{scr})	2.55 A
Series solar cell (N_s)	36
Parallel solar cell (N_p)	1

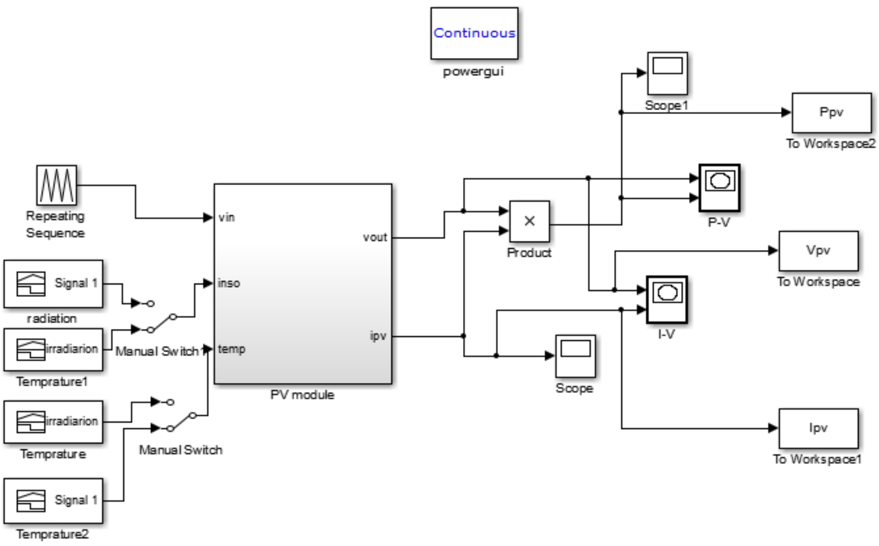

Figure-10: Modeling of PV module

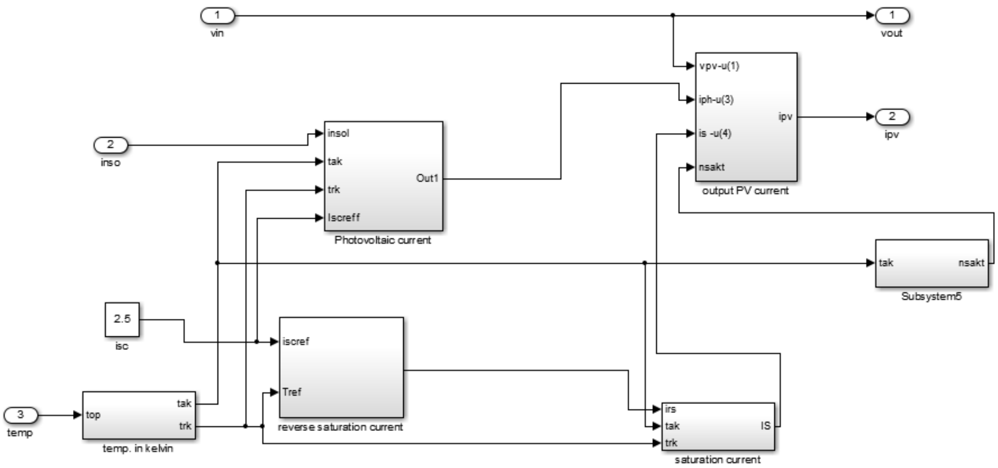

Figure 11: Detail modeling of PV module subsystem

3.1.1 Current - Voltage and Power – Voltage graph of Photovoltaic module

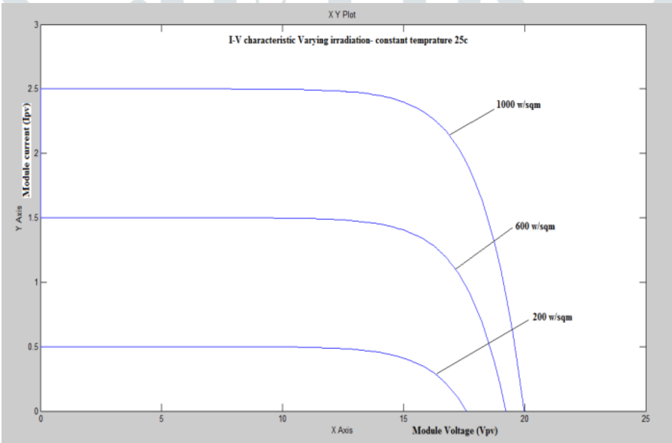

Figure 12: current - voltage graph - vary irradiation- Constant temperature 25°C

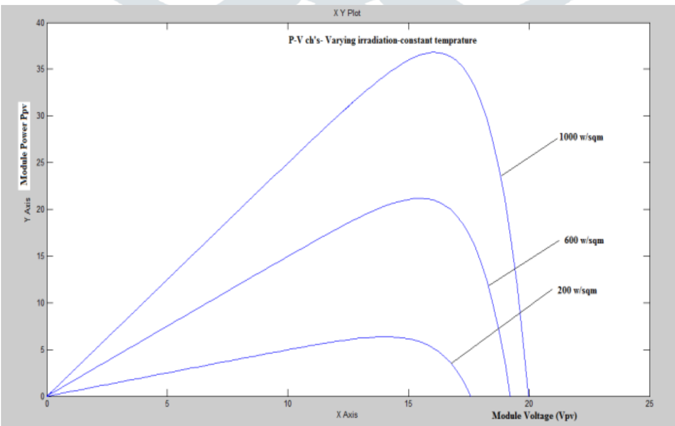

Figure 13: Power - Voltage graph - vary irradiation- Constant temperature 25oC

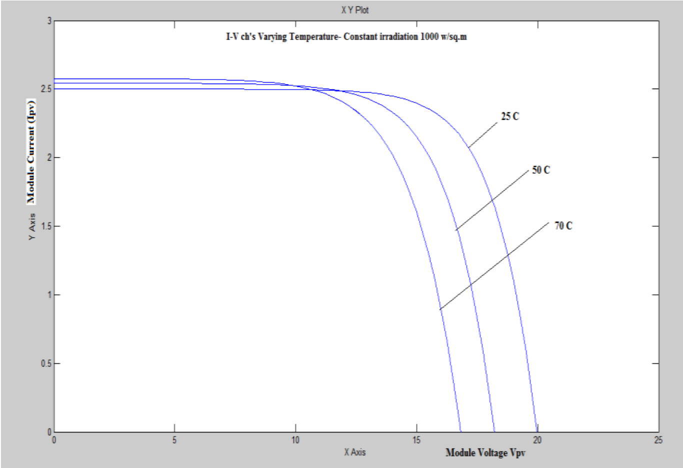

Figure 14: current -voltage graph vary Temperature- Constant irradiation 1000 w/sq.m

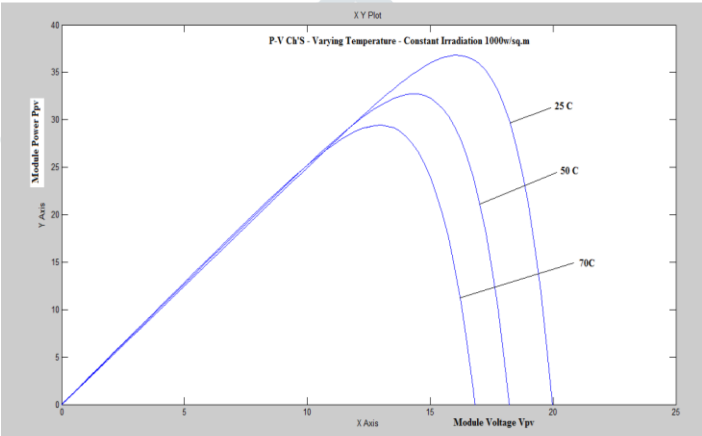

Figure 15: Power - Voltage graph Vary Temperature- Constant irradiation 1000 w/sq.m

In fig. 10 and 11 present the model of PV module and detail modeling of PV module subsystem respectively. In fig. 12 & 13 indicate the current-voltage and power - voltage graphs of the PV module with vary irradiation level (1000, 600, 200 w/sq.m) and constant temperature 25°C. Also, in fig. 14 & 15 shows the characteristics with vary temperature (25, 50, 70°C) and constant irradiation level 1000 w/sq.m.

3. CONCLUSIONS AND FUTURE WORK

As today increasing the power demand of the world, irregularity of non renewable sources and polluted environment have increase interest in 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.

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