Effect of Parameter Variations on Solar PV Module

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Abstract — Solar cells are the devices, which convert the solar radiation into the electrical energy without effecting the environment. To predict the real behavior of solar cells like changes in maximum power, short circuit current and open circuit voltage by changing the temperature and irradiance can be studied by using the MATLAB (simulation model). In this paper, a single diode MATLAB model is used to study the changes in solar PV module by varying temperature and by varying the irradiance.

Keywords— Solar cells, Temperature, Irradiance, Efficiency, MATLAB, Simulation.

I. INTRODUCTION

The continuous use of fossil fuels for industrial purpose leads to huge damage to eco system and living conditions. To sustain our earth, the mankind has to decrease the greenhouse gases like CO2, Methane., by choosing alternatives to fossil fuels. In order to conserve natural living spaces and not to harm the next generation utilization of renewable energy should increase. Among all the renewable energy sources, solar energy is having the large potential and small amount of it is utilizing for various purposes. Photovoltaic Effect converts solar energy to the electrical energy. Widely used applications of PV system are water heaters, street lights, electric vehicles, military and space applications (1,2). Solar panels and modules are works on the principle of Photo voltaic effect, and generates the electric power. These PV modules and panels are largely affected by different weather conditions. In this paper, mainly modeling parameters are explained. By changing the temperature of a simulink PV module, the changes in output parameters are observed.

II. SOLAR CELL AND P-N JUNCTION

A solar cell is a photodiode made by joining the p-type and n-type silicon. To understand how it works is better to know how P-type and N-type silicon works. A brief explanation may be when p-type and n-type silicon are joined this phenomenon is called P-N junction. It can be observed in the figures 3.6 shown below.

The p-type has an excess of holes but few electrons and the n-type has many electrons but few holes. When the two different semiconductors are joined, and the light is switched on as it has been showed before the electrons in the n-type flow to the p-type semiconductor, and meanwhile the holes flow from the p-type to the n-type. An electric field is built up to stop this flow created and therefore a voltage will be built in. Since this electric field is not large enough to stop the flow of electrons and holes a current is produced.

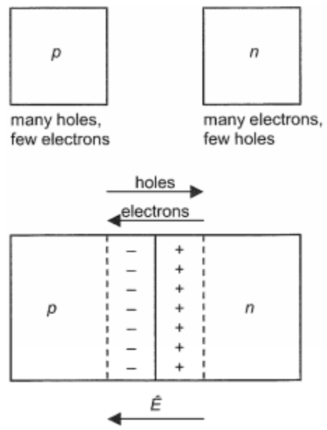

Figure 1 P-N Junction of Different Part of The Semiconductor

A PV cell is an electronic device that converts sunlight into direct current electricity through the PV effect. In order for this energy conversion to be possible, silicon-based semiconductors are widely-used to form a p-n junction in the PV cell. This junction is created by connecting n-type and p-type semiconductors, which are usually produced through ‘doping’: doping is a technique used to vary the number of electrons and holes in semiconductors so as to modify their electrical properties through the addition of impurities. Through the connection, excess electrons diffuse to the p-type semiconductor from the n-type semiconductor, and conversely excess holes diffuse to the n-type semiconductor from the p-type semiconductor, such a movement creating a positively charged area at the n-type side and a negatively charged area at the p-type side, hence forming an electric field at the junction. When the photovoltaic cell is illuminated, electrons in the semiconductor material will be knocked loose from their atoms when light photons hit the cell, assuming that the energy of these photons is greater than the energy band gap of the material, multiple electron-hole pairs will be formed and electrons will start to flow through the material and the external circuit in the direction dictated by the electric field at the junction. After completing all the traveling, the electrons will then return and recombine with the holes back in the semiconductor to close the circuit, and therefore direct current electricity is generated as the result. On the other hand, an inverter can be used to convert direct current into alternating current if required.

III. MODELLING OF SOLAR CELL

In general, there are three main types of equivalent circuit commonly used for SDM: the ideal single-diode model (ISDM), the simplified single-diode model (SSDM), and the regular single-diode model (SDM), as shown in Figure 4.1. The ISDM is the least complex among all three models because it only requires three parameters to set up its IV characteristic equation, but it does not always promise good simulation results, especially in practical situations. The SDM is a more popular option in the industry, as it provides better accuracy. However, with the addition of the parameters from the shunt and series resistors, as opposed to the ISDM, this model requires solving five nonlinear equations in order to set up its I-V characteristic equation, thus requiring the use of a non-linear numerical solver which adds complexity to the system and leads to longer computation times. The SSDM is an alternative approach to reduce the complexity of the SDM by eliminating the shunt resistance, but the model will then have less accurate simulation results against some environmental changes, such as temperature variations, and it will still require a non-linear numerical solver for the remaining four parameters. The ideal 1-D solar cell model is represented by a constant current source and a diode. The photonic current, IPH, is the amount of current produced by the electron-hole pairs generated by the impinging sunlight. This phenomenon is called photovoltaic effect. IPH depends on the intensity of the incident solar light, characteristics of the solar panel, and the ambient temperature. Using the SDM, as an example, based on the equivalent circuit from Figure 2, the I-V characteristics of a single PV cell can be derived as follows:

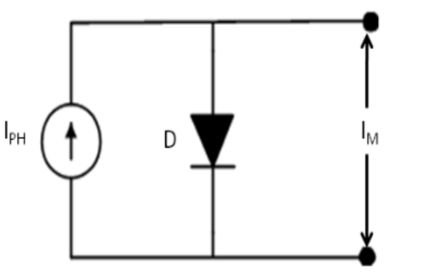

Figure 2. 1-D Ideal model for a Solar cell

Using Kirchhoff's Current Law:

$$I = I_{ph} - I_D - I_{sh} \quad (4.1)$$

where I is the output current, I_{ph} is the photocurrent, I_D is the diode current, I_{sh} is the shunt current. Using Kirchhoff's Voltage Law and Ohm's law:

$$V_D = V + I \times R_s \quad (4.2)$$

where V_D is the diode voltage, V is the output voltage, Rs is the series resistor. Using Ohm's Law, it may be seen that:

$$V_D = I_{sh} \times R_{sh} \quad (4.3)$$

where R_{sh} is the shunt resistor. Substituting Eq. (2.3) into Eq. (2.2), we have

$$I_{sh} = \frac{V_D}{R_{sh}} = \frac{V + IR_s}{R_{sh}} \quad (4.4)$$

From the Shockley's diode equation, we have

$$I_D = I_s \left[e^{\left(\frac{V_D}{nV_T}\right)} - 1 \right] \quad (4.5)$$

where I_s is the diode reverse saturation current, n is the emission coefficient/ideality factor, and V_T is the thermal voltage. The thermal voltage can be expressed as:

$$V_T = \frac{k_B T}{q} \quad (4.6)$$

where k_B is the Boltzmann's constant, T is the temperature of the PV cell, and q is the magnitude of the electron charge constant. I-V characteristics equation for a single PV cell using the SDM is expressed as:

$$I = I_{ph} - I_s \left[e^{\left(\frac{V_D}{nV_T}\right)} - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (4.7)$$

IV. RESULTS AND DISCUSSIONS

A. Simulation of PV Cell

Fig. 3 shows PV cell model based on the equations derived in chapter-4. For simplicity analysis has been done with insolation 1000W/m^2.

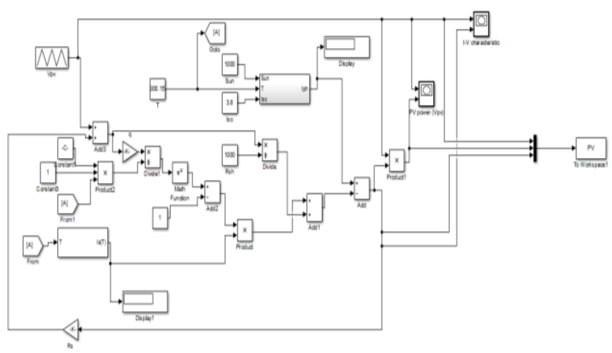

Fig. 3 Simulation model of PV Cell

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Fig. 4 and fig. 5 shows PV and I-V characteristics respectively.

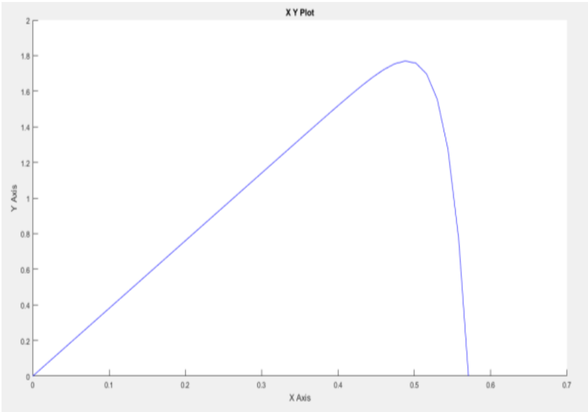


Fig. 4 P-V characteristics of PV Cell

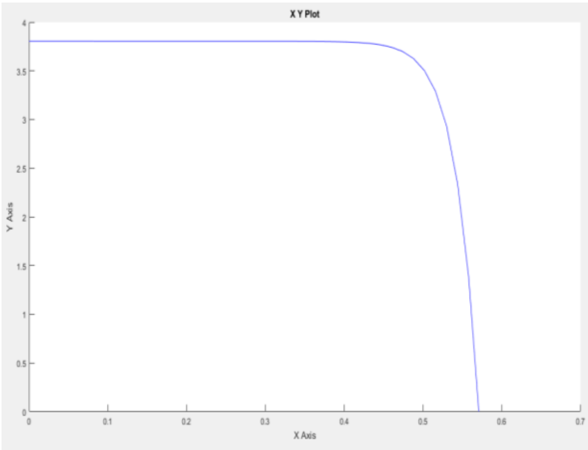
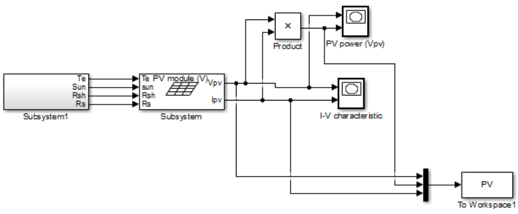


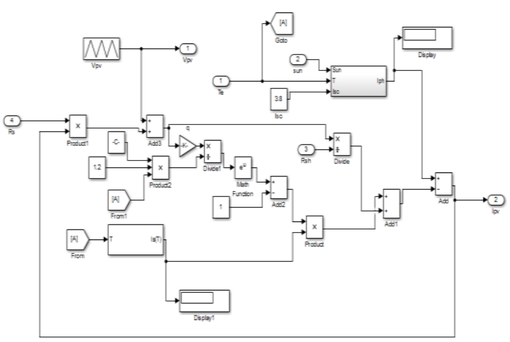
Fig. 5 I-V characteristics of PV Cell

B. *Simulation of PV Module*

Fig. 6 (a) and (b) shows PV module model based on the equations derived in earlier section



(a)



(b)

Fig. 6 (a) Simulation model of PV module (b) subsystem configuration

Fig. 7 and fig. 8 shows PV and I-V characteristics of PV module respectively.

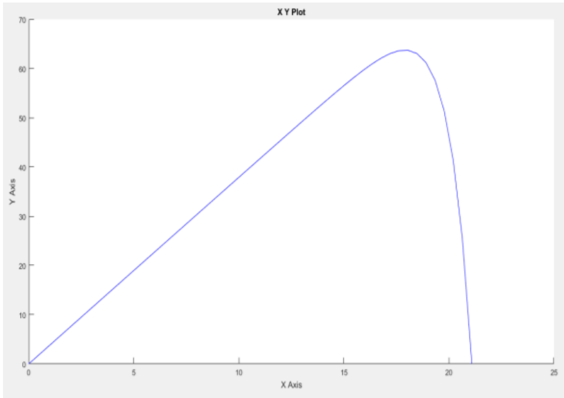


Fig. 7 P-V characteristics of PV module

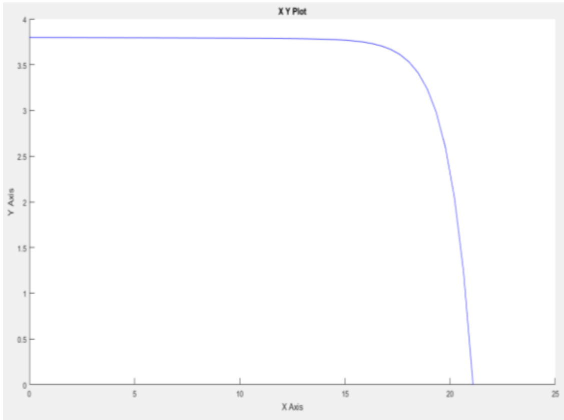


Fig. 8 I-V characteristics of PV module

C. *Simulation of PV Array*

PV array is combination of different PV modules either in series or parallel. As the output of PV cell is very less so to achieve desired output series and parallel combinations of PV module is necessary. Fig. 9 shows PV array model.

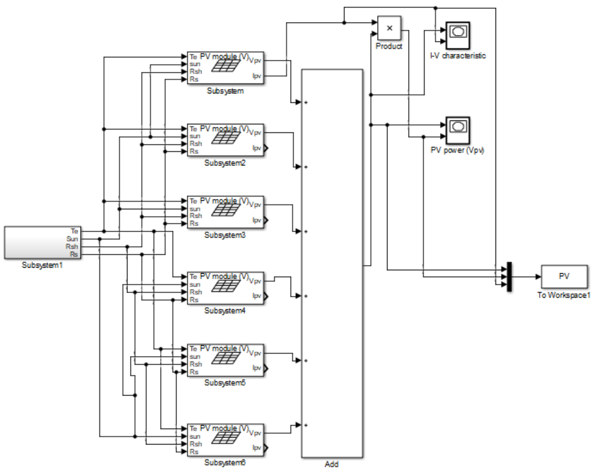


Fig. 9 Simulation model of PV Array

Fig. 10 and fig. 11 shows P-V and I-V characteristics of PV Array respectively.

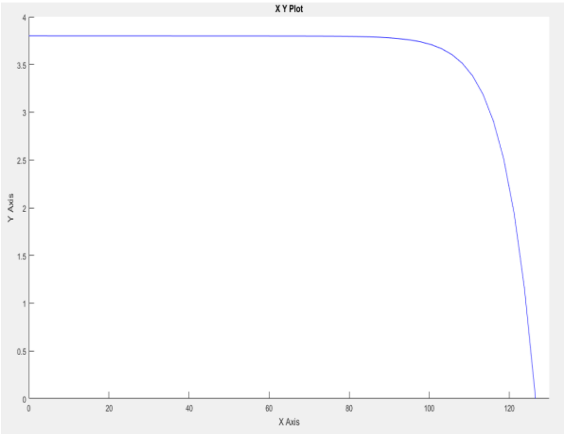


Fig. 10 I-V characteristics of PV Array

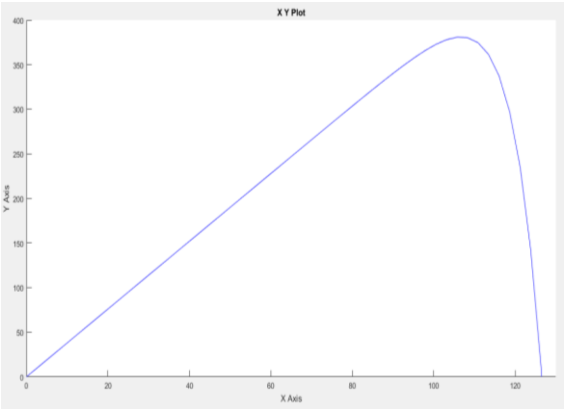


Fig. 11 P-V characteristics of PV Array

D. *Simulation of PV Array for Effect of Variation of R_s*

R_S does not affect a solar cell at open-circuit voltage because the overall current flow through the solar cell is zero. But, the effect of RS is clearly seen near the short-circuit conditions. Fig. 5.10 shows the simulation model for variation of series resistance on PV array.

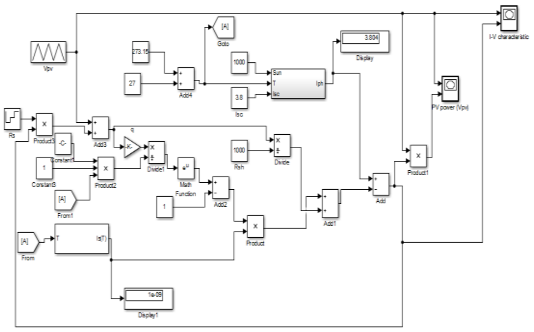


Fig. 12 Simulation model of PV array for effect of variation of series resistance

From Fig. 13 and 14, it can be seen that with the increase in series resistance Rs the open-circuit voltage remains the same, but both the short-circuit current and fill factor reduce significantly. In practice, the value of the lumped series resistance Rs is kept quite low to prevent this drastic degradation in performance.

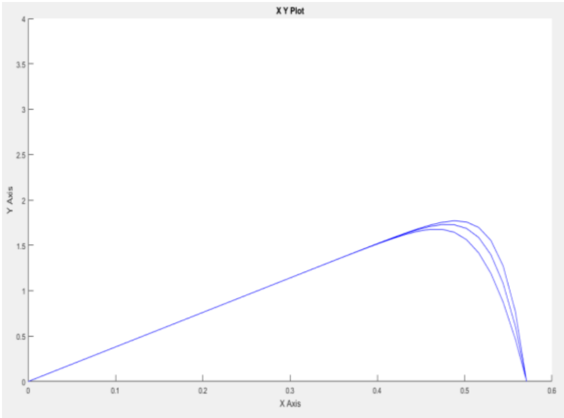


Fig. 13 P-V characteristics for effect of varying R_s

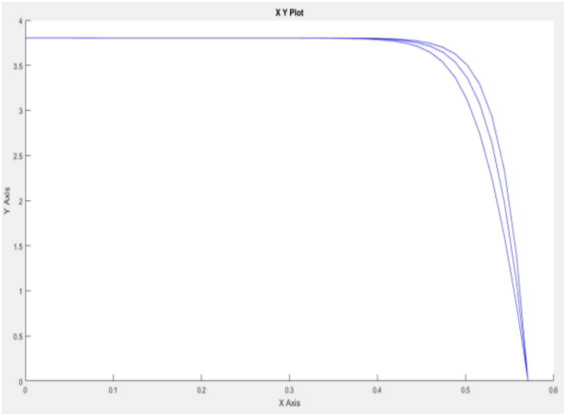


Fig. 14 I-V characteristics for effect of varying R_s

E. *Simulation of PV Array for Effect of Variation of R_{sh}*

Shunt resistance must be good enough to obtain the maximum power output of a PV cell. Shunt resistance is used to measure high currents and it is connected in parallelly. With the increase of shunt resistance power-voltage (P-V) increases and it increases maximum power output also.

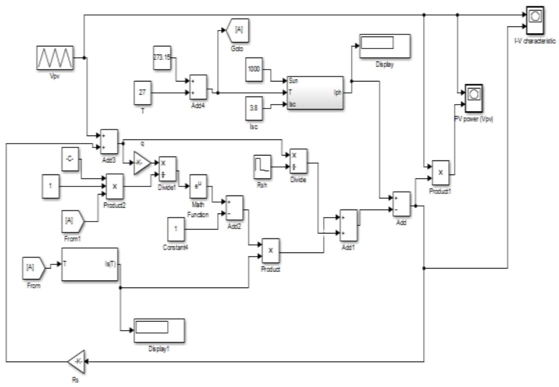


Fig. 15 Simulation model of PV array for effect of variation of shunt resistance

But the infinity value for shunt gives the best output. With the decrease of shunt resistances power output also decreases. As the shunt resistance is reduced it reduces the overall output resistance. Thus the voltage drop across it and the parallel diode in the solar cell model decreases. This causes reduction in the output voltage across the load. The *I-V* curves deteriorate with decrease in shunt resistance R_{SH}. Fig. 15 shows the simulation model for variation of shunt resistance on PV array.

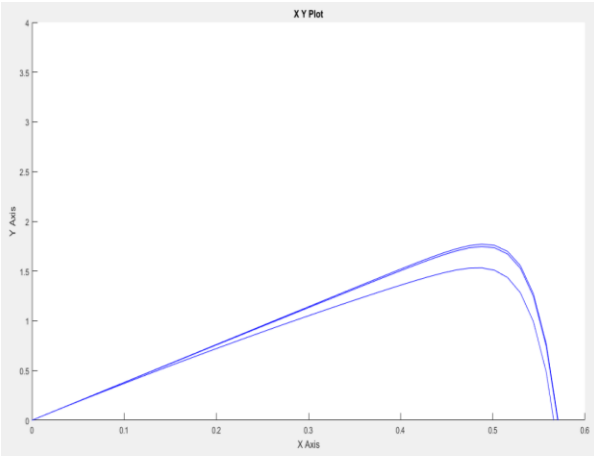


Fig. 16 P-V characteristics for effect of varying R_{sh}

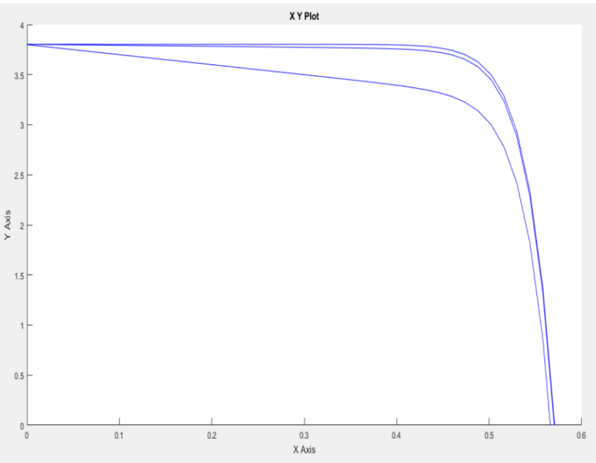


Fig. 17 I-V characteristics for effect of varying R_{sh}

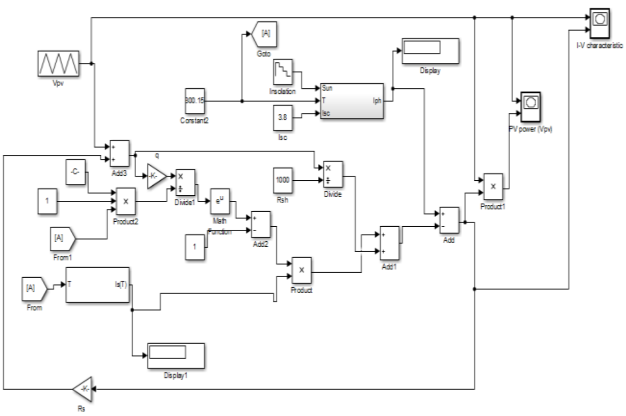


Fig. 18 Simulation model for effect of varying solar radiation

Figure 16 and 17 shows the P-V and I–V curves with varying shunt resistance Rs. From the figure, it can be seen that the value of open-circuit current remains same, but short-circuit current and fill factor reduce with the increase in shunt resistance.

F. Simulation of PV Array For Effect of Solar Radiation

The simulation varies the strength of the solar irradiation. It is expected that both the output current and voltage will increase with stronger solar irradiation. Fig. 18 shows the simulation model for effect of varying solar radiation.

The change of solar irradiation affects the degree of input photon energy thus changing both the voltage and current outputs of the solar module. The influence on current is significantly larger than that of the voltage, this being due to the fact that the current is more greatly affected by the change as demonstrated by the practical direct proportionality in the photocurrent equation, whereas the voltage is only related to the current with a small short-circuit temperature coefficient. Figure 19 and 20 shows the P-V and I–V curves with varying shunt resistance Rs.

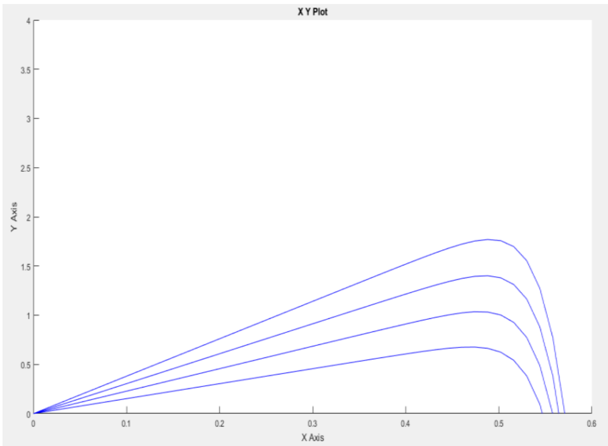


Fig. 19 P-V characteristics for effect of varying solar radiation

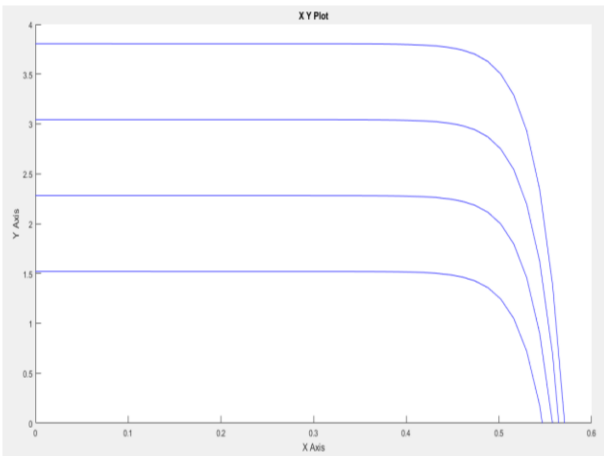


Fig. 20 I-V characteristics for effect of varying solar radiation

G. Simulation of PV Array for Effect of Varying Temperature

The simulation varies the PV cell temperature. It is expected that the voltage will decrease with higher temperature and the corresponding current will increase slightly. Fig. 21 shows the simulation model for effect of varying temperature on PV array.

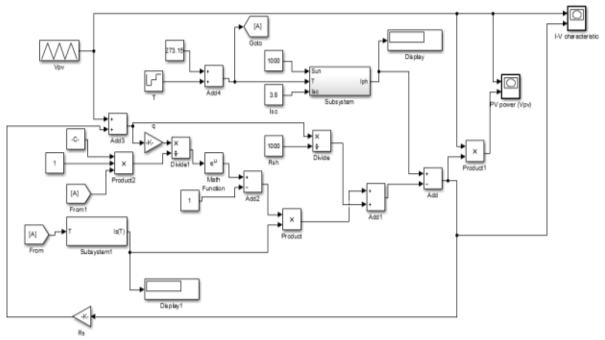


Fig. 21 Simulation model for effect of varying temperature

Since the PV cell is made of semiconductors that temperature change will alter its excitation energy band-gap. Hence, increasing the operating temperature will increase the energy of the electrons in the cell which means a decreasing band gap as lower energy will be required to break the chemical bonds, causing a lower open-circuit voltage. The increase in the temperature also causes a weak increase in the current, this being due to the shifting of the irradiation spectrum under different temperature. Though the effect is minor, the change in irradiation alters the current correspondingly similar to the previous section as demonstrated by the photocurrent equation. Fig. 22 and 23 shows the P-V and I-V characteristics for effect of variation of temperature.

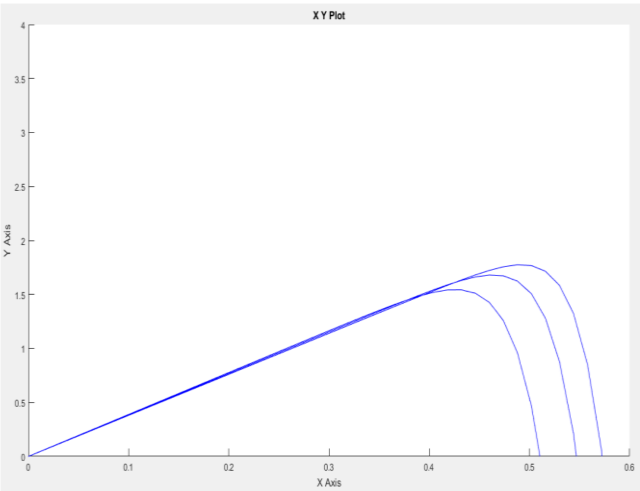


Fig. 22 P-V characteristics for effect of varying temperature

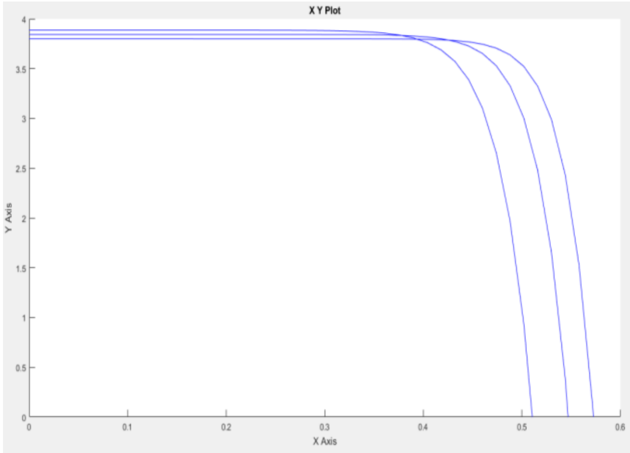


Fig. 23 I-V characteristics for effect of varying temperature

H. Simulation of PV Array for Effect of Varying I_s

Fig. 24 shows the PV array simulation model for effect of varying I_s. As seen in Fig 5, reducing the diode saturation current increased the open circuit voltage and the maximum power point delivered by the solar cell.

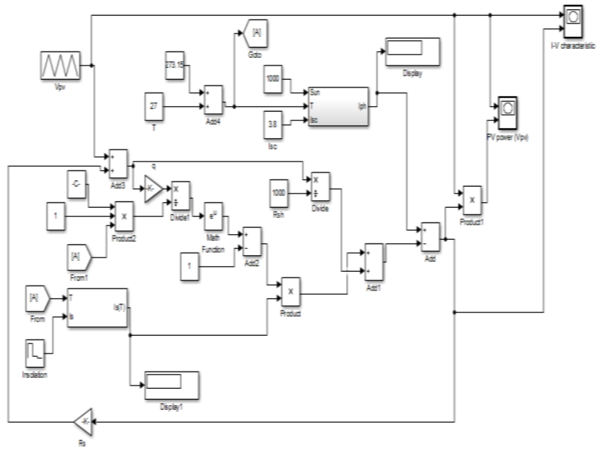


Fig. 24 Simulation model for effect of varying I_s

Fig. 25 and 26 shows the P-V and I-V characteristics for effect of variation of I_s.

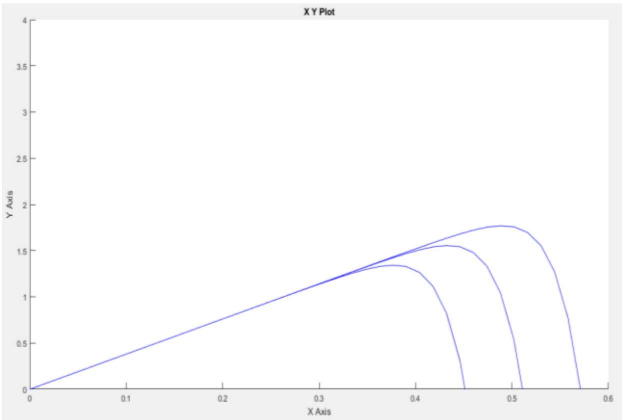


Fig. 25 P-V characteristics for effect of varying I_s

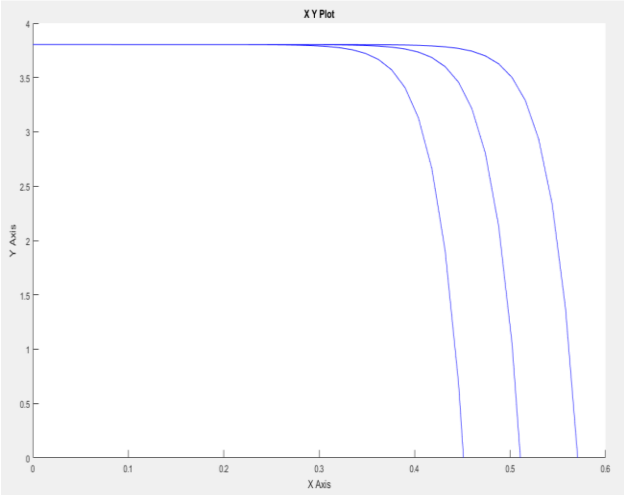


Fig. 26 P-V characteristics for effect of varying I_s

V. CONCLUSION

This work is based on a MATLAB/SIMULINK simulation by using the fundamental circuit equations of a solar photovoltaic cell. The characterization of the solar photovoltaic cell by using different parameters and it shows the great effects of the parameter's variation. From the developed work and as expected it is possible to conclude that the PV cell presents different behaviors depending on the internal and external parameters. For practical purposes the power delivered by a photovoltaic system always should be the highest it can be. This being the case, the most interesting operating point along the I-V curve is the maximum power point. This thesis focus on the effect of various parameters like solar insolation, temperature, series resistance, shunt resistance etc. As the temperature increases maximum power, open circuit voltage decreases and short circuit current increases ultimately efficiency decreases. This is because of increased intrinsic recombination. By the increase of heat energy, band gap of semiconductor decreases the open circuit voltage which is a function of band gap, decreases faster than the increase in the short circuit current so it leads to the decrease in the efficiency. The negative temperature coefficient of Silicon material reveals that as the temperature increases, the maximum power output decreases. As the irradiance increases, the number of photons incidenting on the module produces maximum power and leads to increase in the efficiency. By analyzing effect of different parameters on solar PV it has been revealed that the designer can select the best suitable parameters for system and good efficiency can be achieved.

REFERENCES

[1]. Deepak Verma, Savita nema, A.M Shandhiya, Soubhagya K. Dash "Maximum Power point tracking techniques:Recaptulation in solar photovoltaic systems." Elsevier journal of Renewable energy Reviews – 54 (2016)1018-1034.

[2]. R.K Nema ,Savita and Gayatri Agoihotri, "Computer Simulation based study of photovoltaic cells/Modules and their experimental verification, International journal of recants trends in engineering ,vol 1,No 3,may 2009.

[3]. Rajesh Kumar Nema*, Savita Nema and Gayatri Agnihotri, "Design, development and simulation of PC-based scheme for characterization of solar photo voltaic modules", *Int. J. Power Electronics, Vol. 2, No. 3, 2010.*

[4]. Deepak Verma n, Savita Nem a,A.M. Shandilya ,Soubhagya K.Dash, Maximum power point tracking (MPPT) techniques: Recapitulation in solar photovoltaic systems ,renewable and Sustainable Energy Reviews 54 (2016) 1018–103.

[5]. Savita Nema, R. K. Nema, and Gayatri Agnihotri "Inverter topologies and control structure in photo voltaic applications: A review," Journal Of Renewable And Sustainable Energy 3, 012701 _2011.

[6]. Deepak Verma†, S. Nema‡ and A. M. Shandilya "A Different Approach to Design Non -Isolated. DC–DC Converters for Maximum Power Point Tracking in Solar Photovoltaic Systems", Journal of Circuits, Systems, and Computers Vol. 2 5, No. 8 (2016) 1630004.

[7]. Savita Nema, R.K .Nema, Gayatri Agnihotri," .Ramani, Dr. A. Krishnan, "Matlab / simulink based study of photo voltaic cells / modules / array and their experimental verification," *Volume 1, Issue 3, 2010 pp.487-500* .

[8]. Xuan Hieu Nguyen1* and Minh Phuong Nguyen2. "Modulation and Low" Mathematical modeling of photovoltaic cell/module/arrays with tags in Matlab/Simulink", Nguyen and Nguyen *Environ Syst Res (2015) 4:24.*

[9]. Chauhan Anurag, Saini RP. A review on Integrated Renewable Energy System based power generation for stand-alone applications: configurations, storage options sizing methodologies and control .Renew Sustain Energy Rev 2014;38:120–99

[10]. Singh Solanki Chetan. Solar photo voltaics: fundamentals, technologies and applications. New Delhi: PHI Learning Pvt. Ltd.; 2011

[11]. Nema Savita, Nema RK, Agnihotri Gayatri .MATLAB/Simulink based study of photo voltaic cell s/modules /array and their experimental verification. Int. Journal of Energy Environ 2010;1(3):47–500. [14]

[12]. Nema RK, NemaSavita, Agnihotri Gayatri. Computer simulation based study of photo voltaic cells/modules and their experimental verification. International journal of RecentTrendsEng2009;1(3):151–6. [15]

[13]. Nema RK, Nema Savita, Agnihotri Gayatri. Design, development and simulation of PC-based scheme for characterisation of solar photo voltaic modules. Int JPowerElectron 2010;2(3):304–25.

[14]. NemaRK, SavitaNema, GayatriAgnihotri. Determination of IV characteristics of solar photovoltaic module by computer

ISSN: 2395-2946

controlled loading .In: Proceed- dings of the15 th international photovoltaics cience &e ngineering conference (PVSEC- 15);2005. [17].

[15]. PradhanR, SubudhiB .As teepest- descent based maximum power point tracking technique for a photovoltaic power system. In: Proceedings of the 2nd international conference on control and embedded systems (ICPCES). 2012.1:6;p.19–17.

[16]. J. P. Benner and L. Kazmerski, "Photovoltaic's gaining greater visibility" IEEE Spectrum, vol. 29,pp. 34-42, sept. 1999.

[17]. Wang Peng, ZhuHaipeng, Shen Weixiang, ChooFook Hoong, LohPohChiang, Tan Kuan Khoon. A novel approach of maximizing energy harvesting in photo voltaic systems based on bi section search theorem. In:Proceedings of the Twenty-Fifth Annual IEEE Conference and Exposition (APEC) on Applied Power Electronics.2010.p.2143–48.