A DISSERTATION

ON

Mathematical modeling of Solar photovoltaic system using Matlab/Simulink

Submitted In Partial Fulfilment of the Requirement for the Award of the Degree in

M.Tech

In

Renewable Energy Technology

Submitted By

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2020-2022

Declaration

This is certified that M.tech dissertation on **"Mathematical modelling of Solar photovoltaic system using Matlab/Simulink"** is submitted by me (Harshit Singh) for the partial fulfilment of the requirements for the award of the degree of Master of Technology in Renewable Technology in the department of Electronics and communication Engineering, Faculty of Engineering , in the Integral University, Lucknow, UP (India). This comprises original study based on the research articles and other authentic resources from the wed and due acknowledgement have been made in the text to the materials used. I hereby further declare that in case of any legal dispute in relation to may research work, I will be solely responsible. Also, any part of this work has not been presented or published anywhere for the award of degree.

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This is to certify that the thesis titled **“Mathematical modelling of Solar photovoltaic system using Matlab/Simulink”** has been carried out by **Harshit Singh** under my supervision and guidance in partial fulfilment of the requirements for the award of degree of **“Master of Technology”** in Renewable Energy Technology at department of Electronics and Communication Engineering, Integral University, Lucknow, India.

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This is to certify that Mr. Harshit Singh has studied in **"Mathematical modelling of Solar photovoltaic system using Matlab/Simulink, taking references from the Solar Photovoltaic plant installed in Integral University Lucknow"**. This study was the integral part of his field work as per the M.Tech syllabus.

The field work conducted successfully.

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ABSTRACT

Renewable energy is considered as next alternative to fossil fuels and nowadays, it attracts much attention in agriculture and environmental protection. Application of solar photovoltaic system is drying and dehydration of products, heating, irrigation, greenhouse and power generation etc. Temperature and sun radiation varies nonlinearly. Power generation varies with reference to radiation and temperature in photo-voltaic (PV) system. PV characteristic is nonlinear and PV cell is the basic unit for electricity generation. To get the characteristic response of PV, it aimed to develop a solar cell/panel model and array on a platform like MATLAB. In this thesis, step by step procedure has been defined for modelling solar cell, module, and array models of the photovoltaic system. The PV array characteristic are simulated for different irradiance ($200W/m^2$,$400W/m^2$,$600W/m^2$,$800W/m^2$,$1000W/m^2$) and temperature variation (5°C, 10°C, 15°C, 20°C, 25°C). The output characteristic of the reference model matches with simulated results. The output reduced when the solar irradiation reduced from 1000 to 200 W/m^2. As the reference temperature increased, the output voltage increase, whereas the output current increases slightly. This model would be useful for check the effect of different parameters like series resistance, shunt resistance etc. It would also be useful for investigating the working parameters like temperature & radiation condition and different series and parallel combinations of panels. This modelling is useful in investigating the performance of solar arrays in different applications of solar power generation, as well as modelling provides a major role in the mounting of PV panels.

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SYMBOLS AND ABBREVIATIONS

n	Diode ideality factor
T_i	operating temperature
E_{g0}	band gap energy
K_i	Solar cell temperature coefficient
R_{sh}	Shunt resistance
R_s	Series resistance
T	module temperature (k).
I_{ph}	Light generated current of a PV cell
I_r	solar irradiance
I_D	Diode current
I_C & V_C	Supplied current and terminal voltages respectively.
I_o	Diode reverse saturation current
I_{rs}	Module reverse saturation current
I_{sc}	Short-circuit current of a PV cell
J	Moment of inertia of the system in kg-m^2
K	Boltzmann's constant
L_a	Self inductance of the armature winding
P_{max}	Maximum power output of a PV panel
P_{Array}	Output power of the PV array
Q	Charge of an electron
R_a	Armature resistance
R_s	Module resistance
V_T	Thermal voltage
N_P	Number of module in parallel
N_S	Number of module in series

CHAPTER 1
INTRODUCTION

So as to realize the influence of the solar energy the project starts to describe the energy situation nowadays. Energy is an issue that touches every person on the planet. At present in the world, especially in industrialized and emergent countries, energy has become vital for all the human beings. Accordingly the energy demand has been increasing dramatically in the last years.

Because of the greenhouse effect, environmental impact and the increasing cost of the fossil fuel-based energy sources, much more energy usage from renewable sources and more efficient utilization of conventional sources is becoming to be indispensable. The World Resource Institute estimates that 61.4% of global greenhouse emissions come from energy consumption. Thereby a solution that reduces these pollutants should include investment in the fields of renewable sources and energy efficiency in order to allow energy to play its role in the economy without endangering the environment. [1]

The increasing of the electricity price and the increasing of the environmental impact the world is suffering, solar energy may be considerably accepted one of the key solutions.

Solar energy is radiant light and heat coming from the solar radiation. It is a renewable source since the methods used to transform the solar energy into electricity don’t produce any smoke or pollutants. However since the power generated by this source comes from the sunlight, it cannot be used during the night, and even during some days when the weather is completely cloudy, rainy, snowy or another natural factors. Solar energy can mainly be divided in two mainly sources; it can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications. The research has been focused on photovoltaics within the solar energy.

Solar photovoltaic modules are manufactured by semiconductor materials and they turn the radiant energy coming from the sun into direct current and therefore, electricity. The competitiveness of this field is increasing; in 2013, for the first time in more than a decade, solar was over all other renewable energy technologies in the sense of new generating capacity installed with an increase of 29 percent compared with 2012. [2] .Worldwide total PV installations represented 1.8 GW in 2000 and 71.1 GW in 2011 with a growth rate of 44%. [3].

This has led to a situation where the electricity from solar panels costs as much or is even cheaper than electricity purchased from the grid is within reach.

Nonetheless, solar power generation has still some problems as follows: the conversion efficiency of solar cells is lower, and the output power of photovoltaic (PV) array has great relationship with irradiation and temperature.[4]

Regardless the problems described above, one of the most important and critical problems on the photovoltaics field is the shadowing effect. Shaded conditions is sometimes inevitable because some parts of the photovoltaic system receives less intensity of sunlight due to several factors such as clouds, the time of the day, the season of the year or even shadows from neighboring objects.[5]

1.1 THE SUN AND ITS RADIATION

The sun is a hot atmosphere of gas heated by nuclear fusion reactions at its centre. Its diameter is about 1.39×10^9 m and is, on the average 1.5×10^{11} m from the earth. As seen from the earth, the sun rotates on its axis about once every 4 weeks. However it does not rotate as a solid body; the equator takes about 27 days and the Polar Regions take about 30 days for each rotation. [7]

The energy produced in the interior of the solar sphere at temperatures of many millions of degrees must be transferred out to the surface and then be radiated into space. A succession of radiative and convective processes occur with successive emission, absorption and reradiation. In the subchapter below the different types of radiation that reaches the Earth's surface will be described.

1.2 COMPONENTS OF RADIATION

Solar radiation incident on the atmosphere from the direction of the sun is the solar extraterrestrial beam radiation. This radiation passing through the earth's atmosphere is attenuated, or reduced, by about 30%. Beneath the atmosphere, at the Earth's surface, the radiation that will be observable are:

- **Beam Radiation:** The solar radiation received from the sun without having beenscattered by the atmosphere.

- **Diffuse Radiation:** The solar radiation received from the sun after its direction hasbeen changed by scattering by the atmosphere.[7]

Therefore, the total sum of the beam and the diffuse solar radiation on a surface is called Total Solar Radiation. The components of the solar radiation can be observed in the figure below:

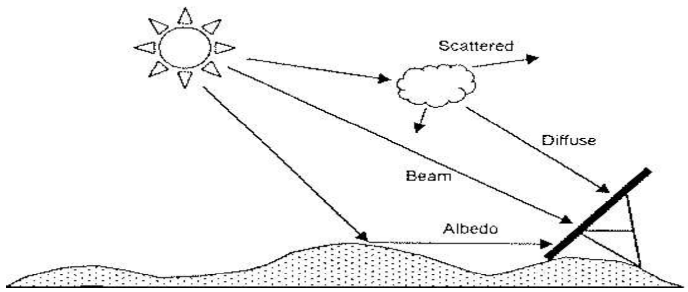


FIGURE 1.1 Solar Radiation [8]

1.3 SEMICONDUCTORS

Solar cells are manufactured from semiconductor materials. This type of materials acts as insulators at low temperatures but as conductors when energy or heat is available. So far, most solar cells are made by silicon-based, since this is the most mature technology. However, other materials are under active investigation and may supersede silicon in the long term. [6]
The electrical properties of semiconductors can be explained using two different theories:

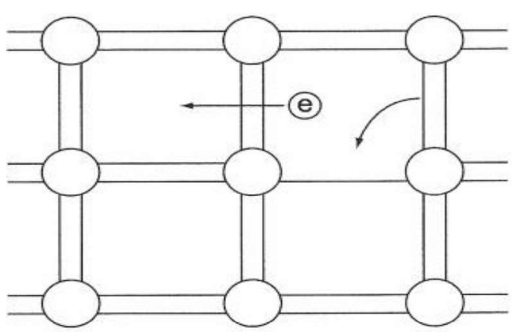


FIGURE1.2: Schematic representation of covalent bonds in a silicon crystal lattice [6]

- At low temperatures, the bonds joining the silicon atoms are intact, so the silicon acts as an insulator. However, at higher temperatures, some of these bonds are broken and two processes can be taken place; electrons from the broken bond are able to move, and the ones from the neighboring bonds can also move to the broken bond, allowing the broken bond to propagate as if it had a positive charge. This phenomenon is called the bond model.

- **The band model:** The electrons in covalent bonds have energies corresponding to those in the valence band. In the conduction band the electrons are free. The minimum energy needed to release an electron from a covalent bond to the conduction band it's called the forbidden gap. The holes remaining conduct in the opposite direction in the valence band, as described for the band model.

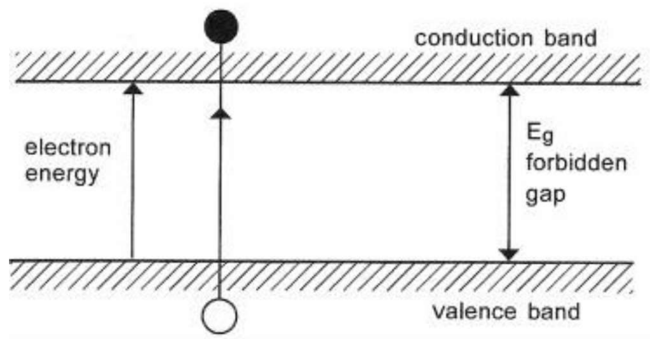


FIGURE 1.3 Schematic of the energy bands for electrons in a solid [6]

1.4 SEMICONDUCTOR TYPES

There are three mainly types of semiconductor materials used for solar cells; crystalline, multicrystalline and amorphous semiconductors. The research of these material is focused on silicon matter.

- Crystalline silicon. In this case the atoms are arranged in a regular pattern. Since the careful and slow manufacturing processes, this material is the most expensive one.
- Multicrystalline or polycrystalline silicon. Regions of crystalline Si separated by 'grain boundaries', where bounding is irregular. It is cheaper to produce since the techniques are less critical.

- Amorphous silicon. It can be produced more cheaply than polysilicon, since there is no long- range order in the structural arrangement of the atoms, resulting in areas within the material containing unsatisfied bonds.

1.5 ABSORPTION OF LIGHT

When the light drops into semiconductor material, photons with energy Eph greater than the forbidden gap, Eg, interact with electrons in covalent bonds, using up their energy to break bonds and create electron-hole pairs, which can then circulate independently. The next figure shows how electron wanders off due to the energy of the photons. It will explained in the next part how solar cells produces a voltage and a current flows through a solar cell.

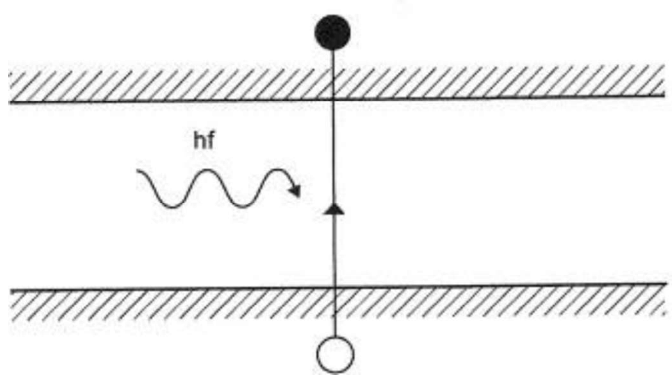


FIGURE1.4: The creation of electron- hole pairs when illuminated with light of energ y E_{ph} $=E_{hf}$ where Eph >Eeg [6]

1.6 SOLAR CELLS AND P-N JUNCTIONS

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 below 1.5.

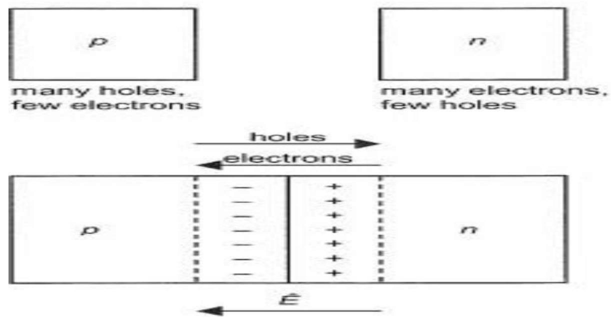


FIGURE1.5 P-N junction of different part of the semiconductor [6]

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, andmeanwhile 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.

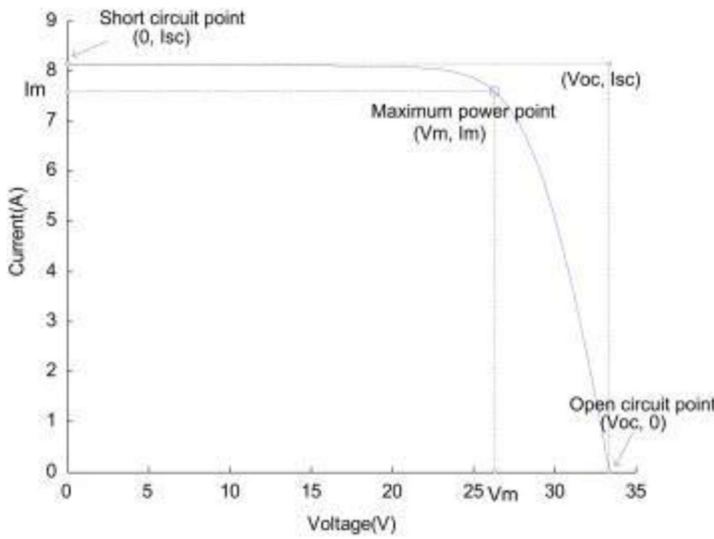
1.7 BEHAVIOUR OF SOLAR CELLS

When the light is falling on a solar cell, it behaves as the following formula (1.1), obtained from the Ideal Diode Law [6]:

$$I_L = I_2 - I_o\left[exp\left(\frac{qV}{aKT}\right) - 1\right] \qquad (1.1)$$

Where I_L is the light-generated current, I_2 is the current,I_0 is the current when no light is falling on the cell: it increases as T increases, and it increases as material quality increases, q is the charge on an electron k is Boltzmann's constant, T is absolute temperature, a is the ideality factor (between 1 and 2). It increases as the current decreases.

The characteristic curve represent all of the combinations of current and voltage at which the module or cell can be operated or loaded. Normally simple in shape, these curves actually provide the most complete measure of the health and capacity of a PV module or array, providing much more information than traditional electrical test methods [9]



F IGURE1.6 Characteristic I-V curves of a solar c el l [10]

Here two different parameters have to be introduced:

- **Short circuit current Isc :** Is the maximum current, given when voltage is 0.
- **Open circuit voltage Voc:** Is the maximum voltage, given at zero current.

There is also a relevant point, MPP is the maximum power point, therefore the point where the product of Vmp*Imp is at its maximum value.

Another important parameter is the fill factor (FF) is the ratio between Pmax and Isc*Voc. It gives an information about the quality of the solar cell, if it increases so do the quality of the solar cell.

1.8 PARASITIC RESISTANCES

However this curve describes the case of an ideal solar cell. An ideal solar cell is modeled by a current source, representing the photo-generated current IL, in parallel with a diode, representing the p–n junction of a solar cell. In a real solar cell, there exist other effects. Two of these extrinsic effects include:

- current leaks proportional to the terminal voltage of a solar cell characterized by a parallel resistance Rsh

- losses of semiconductor itself and of the metal contacts with the semiconductor characterized by a series resistance Rs [11]

The electrical disposition of those resistances as well as the model of a solar cell can be observed in the following image:

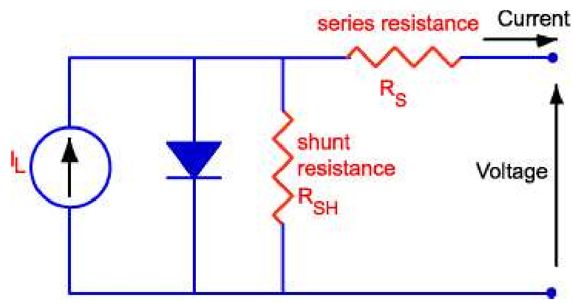


Figure1.7 Different parasitic resistance in a solar cell [6]

So, the formula including the impact of the parasitic resistances is: [12]

$$I_L = I_2 - I_o\left[exp\left(\frac{qV}{aKT}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (1.2)$$

1.9 Solar photovoltaic (PV) energy conversion (Photovoltaic effect) :

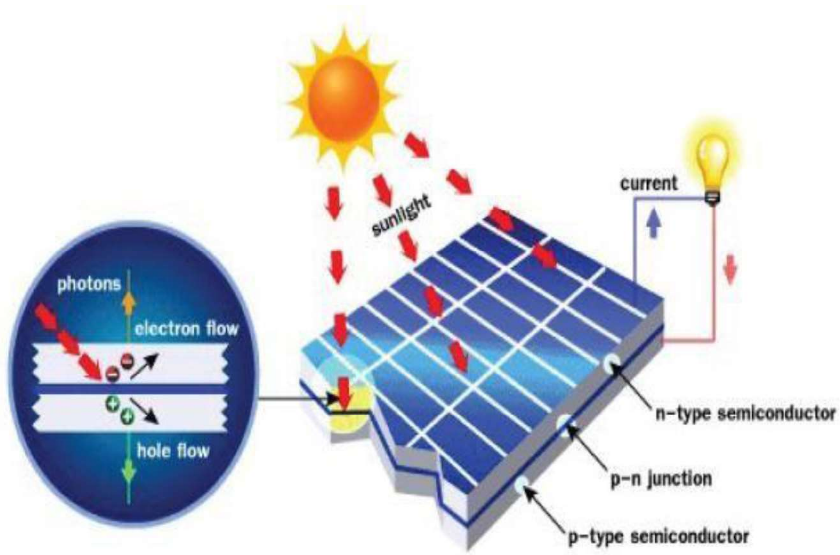


Figure1.8 Photovoltaic effect

A solar cell is nothing but a PN junction diode under light illumination. Sun light can be converted into electricity due to photovoltaic effect. Sun light composed of photons (packets of energy). These photons contain various amount of energy corresponding to different wave lengths of light. When photons strike a solar cell they may be reflected or absorbed or pass through the cell. When solar radiation is absorbed in PN junction diode, electron-hole pairs (EHP) are generated.

- Electron hole pair (EHP) generated in depletion layer:

Electrons of EHP will be repealed towards N side because of electric field and holes ofEHP will be repealed towards P side because of electric field.

- Electron hole pair (EHP) generated in quasi neutral region:

In this region, the electron and holes of EHP will wander around in the region randomly.There is no electric force to guide them in any direction.

- Minority carriers of P and N regions:

The minority carrier near the depletion region will also get direction by electric field.

In this way there will be increase of positive charge at P side and increase of negative charge at N side. This build up of positive and negative charge causes a potential difference to appear across the PN junction due to light falling on it. This generation of photo voltage is known as photovoltaic effect.

1.9.1 Performance analysis of photovoltaic (PV) cell

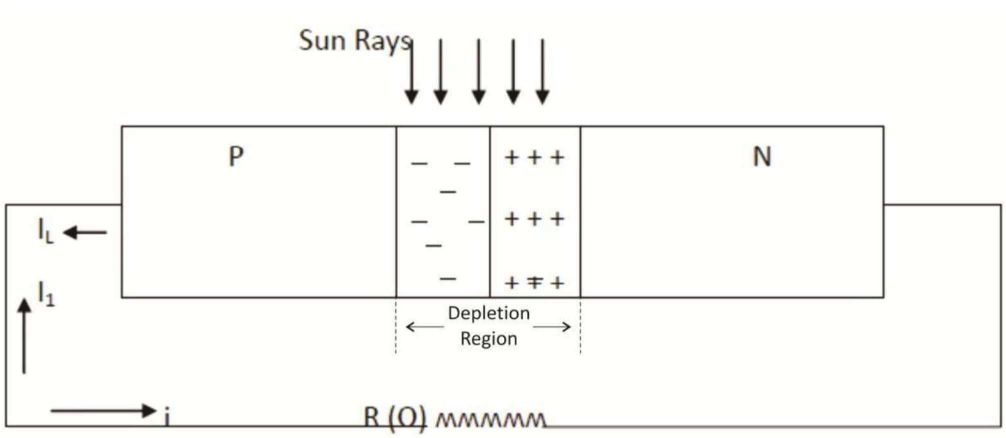


Fig. 1.9 Photovoltaic cell performance

Consider a PN junction with resistive load as shown in figure. When solar cell is illuminated, electron hole pair is generated in the depletion region. This electron hole pair when separated from each other across junction then a current (I_L) flows in external circuit by photovoltaic effect.

This photo current (I_L) produces a voltage drop across resistive load and this voltage will forward bias the PN junction.

1.9.2 Efficiency of solar cell

- Conversion efficiency of solar cell is defined as the ratio of output power to incident optical power. For maximum power output,

$$\%\eta = \frac{P_m}{P_{in}} \times 100 \qquad (1.3)$$

$$\%\eta = \frac{V_m I_m}{I.A} \times 100 \qquad (1.4)$$

Where, Pm-maximum power(watt), Pin-input power(Watt), Vm-maximum voltage(Volt),Im-maximum current(Amp), I- solar intensity(watt/m2), A- area(m^2)

- **Fill Factor (FF)**

It is the ratio of maximum power to the product of Voc and Isc

$$FF = \frac{V_m I_m}{V_{OC} I_{SC}} \qquad (1.5)$$

- **Limitation of solar cell :**

There are several factors that limit the efficiency of solar cells, these are:

1.Photons with energy below the band gap energy, cannot generate electron hole pair so there energy is not converted into useful output. These electron generate only heat and reduces the electrical efficiency of solar cell.

2. Photons with energy above the band gap energy, only a fraction of energy is used for generating free electrons for conduction. Remaining energy will produce heat and reduce electrical efficiency of solar cells.
3. When sun light fall on solar cell, some part of it is reflected back, some part is absorbed and some part is transmitted, only absorbed solar light is converted into electricity so its efficiency is poor.

- **Solar cell material :**

The solar cells are made of various materials. Silicon is the most commonly used material for solar cells. The electrical properties of silicon depend on the type and amount of dopants. Phosphorous and boron are most widely used doner and accepter dopant respectively.
The choice of material depends upon the energy gap, efficiency and cost. In order to reduce the cost, the level of efficiency should be high. The cost can be reduced by using thin film technology. A variety of compound semiconductor are to be used to manufacture thin film solar cell. These materials are CdS, CdTe, InP, GaAs, ZnTe, AlSb (Aluminium Antimonide).

Table 1.1 Energy Gap of some materials

Material	Energy Gap (ev)
Si	1.1
CdTe	1.44
CdS	2.42
GaAs	1.40
InP	1.27
ZnTe	2.2
AlSb	1.63

According to types of crystal, the solar cells are of three types First is mono crystalline silicon cells (Maximum efficiency= 24%)
Second is poly crystalline silicon cells (Maximum efficiency= 17.8%)Third is amorphous silicon cell (Maximum efficiency= 13%)

1.10 Solar Cells, Solar Modules and Solar Array

Solar cell is basic unit of solar electricity generator. It is made up of semiconductor material. When sun light falls on solar cells, it produces electricity by photovoltaic effect. One solar cell produces 0.5 Volt DC voltages.

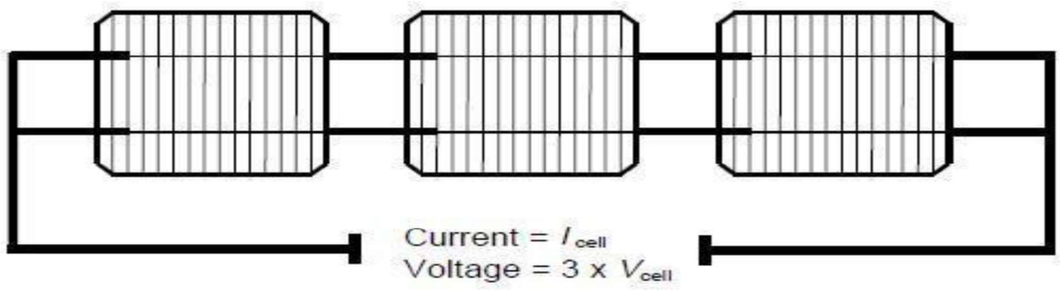


Figure 1.10 Series connection of three solar cells

When solar cells are connected in series to produce high voltage, it is called as solar module. The number of solar cells in solar module is determined by the required voltage. Generally solar modules are made to produce output voltage of 18 Volt DC voltage

(Voltage of one solar cell) × (Number of solar cells) = Output of solar module (1.6)

By using this formula, we can say that 36 solar cells of 0.5 Volt each will be required for producing 18 Volt output voltage module. These 36 solar cells will be connected in series as shown in the figure 1.10.

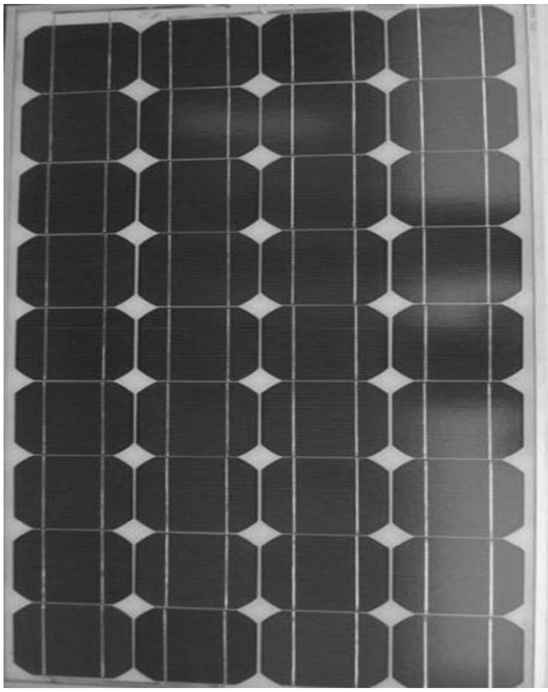


Figure1.11(a) Opaque PV Module

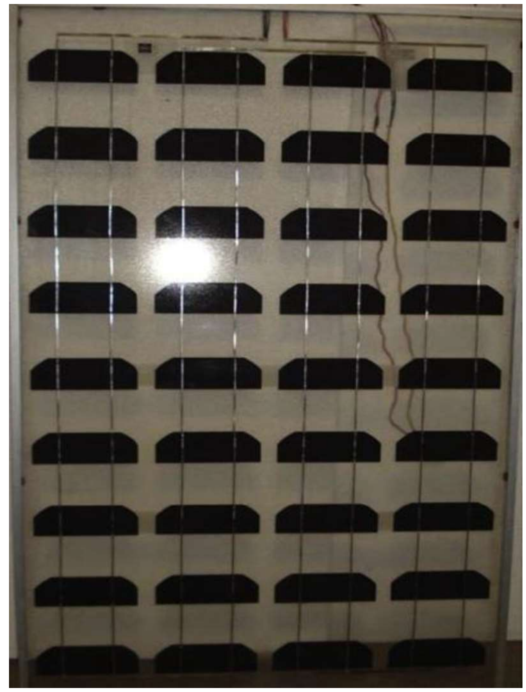


Figure1.11(b) Semitransparent PV Module

Solar modules are of two types namely Opaque module and Semitransparent module. In opaque modules, front side is transparent glass cover and back side is insulating tedler material which is not transparent.

In semitransparent type module, both the front and back side is transparent glass cover (ethyle vinyl acetate).

Packing factor (PF) is defined as the ratio of area covered by solar cell to the area of PV module. In case of rectangular solar cells, packing factor is 1.

Area covered by solar cell = Area of PV module × Packing Factor (1.7)

Non packing factor area (Area between two solar cells) = (1 - PF) × Module Area (1.8)

The efficiency of semitransparent module is higher than opaque module because in semitransparent PV module only un-used solar energy by cell is responsible for raising the cell temperature and energy received by space between two solar cells is transmitted outside so it is not responsible for increment in temperature ie. Top heat loss and bottom heat loss is more in semitransparent PV module.

While in case of opaque module, energy received by space between two solar cells is reflected back so it also responsible for increment in temperature ie. Top heat loss and bottom heat loss is less in opaque PV module.

From semitransparent PV module, we get electrical energy, space heating and illumination while from opaque PV module, we get electrical energy and space heating only.

When sun rays falls on PV module, heat s transferred inside by convection. To regulate this heat, we have to provide force movement of air from top to bottom. For this, use a DC fan.When solar modules are electrically connected in series or parallel, the arrangement is called solar array / solar generator. For series connection of two solar modules, the plus terminal of one module is connected to the minus terminal of second module. When two modules are connected in series then total output voltage will be 24 Volt.

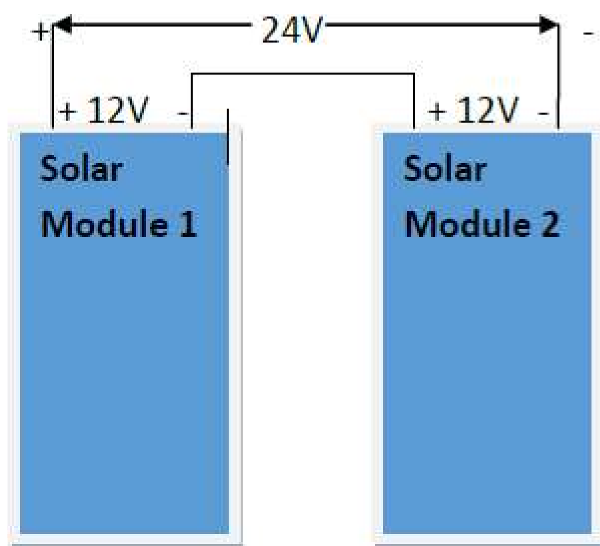


Figure 1.12 Series connection of two PV Modules to form a PV array

For increasing output current and power, a number of modules are connected in parallel. The modules which are being connected in parallel, they must have same output voltage.

$$\text{No. of modules connected in parallel (Np)} = \frac{\text{Operating current of Solar Array}}{\text{Current of solar Module}}$$

$$\text{No. of modules connected in series (Ns)} = \frac{\text{Operating current of Solar Array}}{\text{Voltage of solar Module}}$$

Total no. of modules in solar generator= Ns × Np

CHAPTER 2
LITERATURE SURVEY

2.1 Literature Review:

A function in Matlab environment has been developed to calculate the current output from data of voltage, solar irradiation and temperature in the study of (Walker 2001) and (Gonzalez-Longatt 2005). Here, the effect of temperature, solar irradiation, and diode quality factor and series resistance is evaluated. A difficulty of this method is to require readers programming skills so it is not easy to follow. Another method which is the combination between Matlab m-file and C-language programming is even more difficult to clarify (Gow and Manning 1999). Among other authors, a proposed model is based on solar cell and array's mathematical equations and built with common blocks in Simulink environment in (Salmi et al. 2012), (Panwar and Saini 2012), (Savita Nema and Agnihotri 2010), and (Sudeepika and Khan 2014). In these studies, the effect of environmental conditions (solar insolation and temperature), and physical parameters (diode's quality factor, series resistance Rs, shunt resistance Rsh, and saturation current, etc.) is investigated. One disadvantage of these papers is lack of presenting simulation procedure so it causes difficulties for readers to follow and simulate by themselves later. This disadvantage is filled in by (Jena et al. 2014), (Pandiarajan and Muthu 2011). A step-by-step procedure for simulating PV module with subsystem blocks with user-friendly icons and dialog in the same approach with Tarak Salmi and Savita Nema is developed by Jena, Pandiarajan and Muthu et al. However, the biggest gap of the studies mentioned above is shortage of considering the effect of partially shading condition on solar PV panel's operation. In other researches, authors used empirical data and Lookup Table or Curve Fitting Tool (CFtool) to build P–V and I–V characteristics of solar module (Banu and Istrate 2012). The disadvantage of this method is that it is quite challenging or even unable to collect sufficient data if no experimental system be available so that modeling curves cannot be built and modeled. From the work of (Ibbini et al. 2014) and (Venkateswarlu and Raju 2013), a solar cell block which has already been built in Simscape/Simulink environment is employed. With this block, the input parameters such as short circuit current, open circuit voltage, etc. is provided by manufacturers. The negative point of this approach is that some parameters including saturation current, temperature, and so on cannot be evaluated. Solar model developed with Tag tools in Simulink environment is recorded in the research of (Varshney and Tariq 2014), (Mohammed 2011), etc. In these papers, only two aspects (solar irradiation and temperature) are investigated without providing step-by-step simulation procedure.

1. Banu I-V, Istrate M (2012): This paper presents a method of modeling and simulation of photovoltaic arrays in MATLAB /Simulink using solar cell block from Sim Electronics library. The method is used to determine the characteristic of a particular photovoltaic cell panel and to study the influence of different values of solar radiation at different temperatures concerning performance of photovoltaic cells. This model it can be used for build a photovoltaic circuit model for any photovoltaic array. All modules which form the photovoltaic system model are individually modeled and validated in Simulink.

2. Gonzalez-Longatt FM (2005): This paper define a circuit-based simulation model for a PV cell in order to allow estimate the electrical behavior of the cell with respect changes on environmental parameter of temperature and irradiance. An accurate PV module electrical model is presented based on the Shockley diode equation. The general model was implemented on Matlab scrip file, and accepts irradiance and temperature as variable parameters and outputs the I-V characteristic. A particular typical 60W solar panel was used for model evaluation, and results was compare with points taken directly from the manufacturer's published curves and show excellent correspondence to the model.

3. **Jena C, Das A, Paniigrahi CK, Basu M (2014):** This paper presents a unique step-by-step procedure for the simulation of photovoltaic modules with Matlab/ Simulink. The objective is to design & simulate a controller for the unlimited solar power drawn from the sun & produce a higher voltage o/p through the d.c. to d.c. (Buck-boost) converter .One-diode equivalent circuit is employed in order to investigate I-V and P-V characteristics of a typical 36W solar module. The proposed module is designed with different icons, dialogue box like simulink block libraries. This PV module is interfaced to the buck boost converter and the performance has been studied by the matlab simulink.

4. **Mohammed, S. S. (2011) :** This paper presents modeling of Photovoltaic (PV) module using MATLAB/Simulink. The model is developed based on the mathematical model of the PV module. Two particular PV modules are selected for the analysis of developed model. The essential parameters required for modeling the system are taken from datasheets. I-V and P-V characteristics curves are obtained for the selected modules with the output power of 60W and 64W from simulation and compared with the curves provided by the datasheet. The results obtained from the simulation model are well matched with the datasheet information.

5. **Salmi et. al.(2012):** This paper focuses on a MATLAB/SIMULINK model of a photovoltaic cell. This model is based on mathematical equations and is described through an equivalent circuit including a photocurrent source, a diode, a series resistor and a shunt resistor. The developed model allows the prediction of PV cell behaviour under different physical and environmental parameters. The model can also be used to extract the physical parameters for a given solar PV cell as a function of temperature and solar radiation. In addition, this study outlines the working principle of PV module as well as PV array. In order to validate the developed model, an experimental test bench was built and the obtained results exhibited a good agreement with the simulation ones.

6. **Sudeepika P, Khan GMG (2014):** The physical modeling of the system is not that much efficient so the analysis is done through the mathematical modeling approach. In this paper mathematical analysis is done for the single diode model. Single diode model is employed to investigate the I-V and P-V characteristics of 46 W module . The effect of irradiation and temperature is also considered. The analysis is done in MATLAB/SIMULINK environment. This mathematical analysis approach is a very flexible to change the parameters of the system.

7. **Kadeval, H. N., & Patel, V. K. (2021):** This paper attracts much attention in agriculture and environmental protection. Application of solar photovoltaic system is drying and dehydration of products, heating, irrigation, greenhouse and power generation etc. Temperature and sun radiation varies nonlinearly. Power generation varies with reference to radiation and temperature in photo-voltaic (PV) system. PV characteristic is nonlinear and PV cell is the basic unit for electricity generation. To get the characteristic response of PV, it aimed to develop a solar cell/panel model and array on a platform like MATLAB. In this research paper, step by step procedure has been defined for modelling solar cell, panel, and array models of the photovoltaic system. Kyocera solar KC-200GT 200W solar panel is used as a refer-ence model for further modelling. The PV array characteristic are simulated for different irradiance(200W/m2,400 W/m2 ,600 W/m2 ,800W/m2 ,1000W/m2)and temperature variation(25°C, 35°C, 45°C, 55°C, 75°C). The output characteristic of the reference model matches with simulated results. The output reduced when the solar irradiation reduced from 1000 to 200 W/m2. As the temperature

increased, the output voltage decreases, whereas the output current increases slightly. This model would be useful for investigating the effect of different parameters like series resistance, shunt resistance, thermal voltage, solar cell temperature coefficient of short circuit current etc. It would also be useful for investigating the working parameters like temperature & radiation condition and different series and parallel combinations of panels. This modelling is useful in investigating the performance of solar arrays in different applications of solar power generation, as well as modelling provides a major role in the mounting of PV panels.

8. Hysa, A. (2019): This paper the described by non-linear outputs characteristics in current-voltage and power-voltage. This outputs is affected by various effects such as; series resistance (R_S), shunt resistance (R_{sh}), solar irradiance and temperature. In this paper the effect of variation of parameters has been studied such as series resistance (R_S) and shunt resistance (R_{sh}) of the diode in the photovoltaic cell and these effects could be seen in the Current-Voltage (I-V) and Power-Voltage (P-V) characteristic curves. In this paper also has been studied the effect of variation of the environmental parameters such as solar irradiance and temperature. Results show that a higher temperature at constant solar irradiance produces a decrease power. So the voltage and the photovoltaic cell output power tend to decrease at higher temperatures, but there is no noticeable effect on the photovoltaic cell current. Thus, it is important to keep the cell temperature as low as possible, because higher temperatures have negative effect on output power of photovoltaic cell. On the other hand, the effect of solar irradiance on photovoltaic cell, it reveals that higher solar irradiance gives higher current and higher power. Shunt resistance has significant effect on the operating characteristic curves of PV cells as low power output is recorded if the value of shunt resistance varies from 0.07 ohms to 1700 ohms. Finally, I have presented power-voltage characteristic curves and current voltage characteristic curves of photovoltaic cell for different solar irradiance in Shkoder, Tirana and Vlore.

CHAPTER 3

METHODOLOGY

The equivalent circuit of a PV cell is shown in Fig.3.1. The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis (Pandiarajan and Muthu 2011). Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems. The equivalent circuit for PV array is shown in Fig. 3.2. The voltage–current characteristic equation of a solar cell is provided as (Tu and Su 2008; Salmi et al. 2012): Module photo-current Iph: Here, Iph: photo-current (A); Isc: short circuit current (A) ; Ki: short-circuit current of cell at 25 °C and 1000 W/m^2;T: operating temperature (K); Ir: solar irradiation (W/m^2).Module reverse saturation current Irs:Here, q: electron charge, = 1.6 × 10−19C; Voc: open circuit voltage (V); Ns: number of cells connected in series; n: the ideality factor of the diode; k: Boltzmann's constant, = 1.3805 × 10−23 J/K.

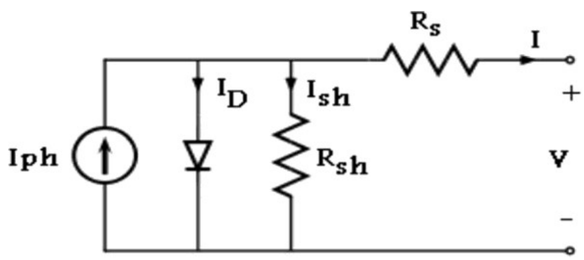


Figure3.1 PV cell equivalent circuit [19]

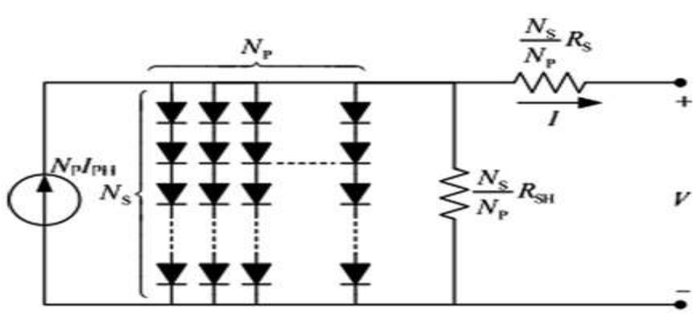


Figure3.2 Equivalent circuit of solar array[22]

The module saturation current I_0 varies with the cell temperature, which is given by:

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q\times E_{g0}}{nk}\left(\frac{1}{T}-\frac{1}{T_r}\right)\right] \quad (3.1)$$

$$I = N_p \times I_{ph} - N_p \times I_0 \times \left[exp\frac{\frac{V}{N_S}+I\times R_S/N_p}{n\times V_t} - 1\right] - I_{sh} \quad (3.2)$$

with

$$V_t = \frac{K\times T}{q} \quad (3.3)$$

and

$$I_{sh} = \frac{V\times N_S/N_p + I\times R_S}{R_{sh}} \quad (3.4)$$

Here: Np: number of PV modules connected in parallel; Rs: series resistance (Ω); Rsh: shunt resistance (Ω);Vt: diode thermal voltage (V).

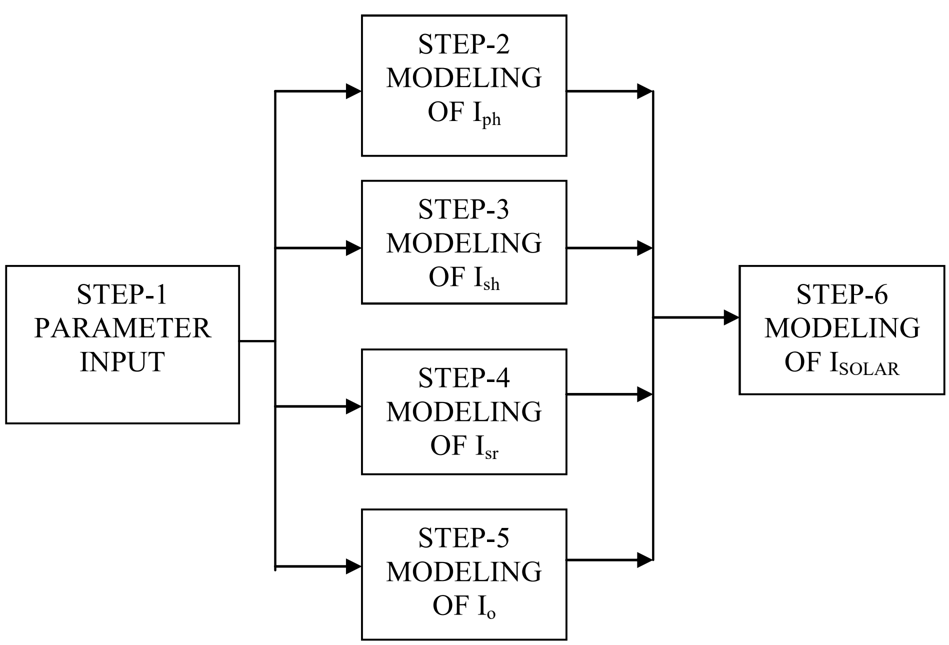


Figure 3.3: Solar Cell modeling block

- **Reference model**

The 400 W solar power array is taken as the reference module for simulation and the detailed parameters of array is given in Table 3.1.

Table 3.1 Electrical characteristics data of DS-400W PV array

NAME	Value
Rated power (Vmp)	400W
Voltage at maximum power (Vmp)	18V
Current at maximum power (Imp)	5.55A
Open circuit voltage (V_{OC})	21.6V
Short circuit current (I_{SC})	6.11A
Total number of cells in parallel (N_P)	36
Maximum system voltage	1
Range of operation temperature	1000

- Step by step procedure for modeling of photovoltaic arrays with tags:

A mathematical model of PV array including fundamental components of diode, current source, series resistor and parallel resistor is modeled with Tags in Simulink environment (http://mathwork.com). The simulation of solar module is based on equations given in the section above and done in the following steps.

Step 1: Provide input parameters for modeling: Tr is reference temperature = 298.15 °K; n is ideality factor = 1.2; k is Boltzmann constant = 1.3805×10^{-23} J/K; q is electron charge = 1.6×10^{-19}; I_{sc} is PV module short circuit current at 25 °C and 1000 W/m^2 = 6.11 A; Voc is PV module open circuit voltage at 25 °C and 1000 W/m^2 = 0.6 V; E_{g0} is the band gap energy for silicon = 1.1 eV. Rs is series resistor, normally the value of this one is very small = 0.008Ω; R_{sh} is shunt resistor, the value of this is so large = 1000 Ω .

Step 2 : Modelling of I_{ph}(Module photocurrent):Module photon-current is given in Eq. (3.5) and modeled as Figure.3.4 (I_{r0} = 1000 W/m^2). Initially, in system block, degree Celsius temperature(operating temperature) was converted into degree Kelvin and then given to subsystem. As per Eq.3.5, I_{ph} was photocurrent and modelled in MATLAB as shown below where its subsystem was also shown and all parameters were defined say I_{ph} (photo current), I_{sc} (short circuit current of module), K_i (Solar cell temperature coefficient of the short-circuit current (in °K or °C), T_i (operating temperature), Ir (solar irradiance). Modeling was shown in Figure.3.4.

$$I_{Ph} = [I_{sc} + K_i(T_i - 273)] \times I_r/1000 \quad (3.5)$$

Step 3: Modelling of I_{sh} (Module shunt saturation current): Module shunt saturation current was modeled in MATLAB as shown in Figure.3.7.As per Eq.3.6, where and value were given for panel and array modeling and V was open circuit volt-age so it was same as Voc say 21.6 V and R_S and R_{sh} represent the series and parallel resistances of the cell.

Modeling was very simple just using adder, multiplier and divider blocks its shows in equation(3.6)

$$I_{sh} = \frac{V\left(\frac{N_P}{N_S}\right)+I*R_S}{R_{sh}} \quad (3.6)$$

Step 4: Modeling of I_{rs} (Module reverse saturation current): Module reverse saturation current was modelled in MATLAB as shown in Figure3.5 as per Eq.3.7 where different constants are taken as k: Boltzmann's constant 1.380658x10^{-23} J/K q: electron charge 1.60217733x10^{-19}°C etc.

$$I_{rs} = I_{sc}/\left[\exp\left(\frac{qV_{oc}}{N_s knT}\right) - 1\right] \quad (3.7)$$

Step 5: Modeling of Io (Module saturation current): Modeling of module saturation current was modeled in MATLAB as shown in Figure.3.6 .

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q\times E_{g0}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] (3.8)$$

Modelling of saturation current was done as per Eq.3.8, whose parameters were Irs: Module reverse saturation current; T_R: Solar cell absolute reference temperature at STC, in K; T: absolute operating temperature of solar cell, in K; q:Electron charge, 1.60217733e^{-19} Cb; k Boltzmann's constant; 1.3806503×10^{-23} J/K and the ideality factor Modified.

Step 6 : Modelling of I(Module output current):

The modelling of module output current is given in Figure 3.8.Complete simulation model with step 1 to step 5 .Step 1 to step 4 was done and combine together in step 5 as per Eq.3.9 complete block schematic is shown in Figure 3.8. The solar PV array includes six modules and each module has 36 solar cells connected in series. Therefore, the proposed model of solar PV array is given in Figure. 3.11.

$$I = N_P * I_{Ph} - N_P * I_o * \left[exp\left(\frac{\frac{V}{N_S}+I\times R_S/N_p}{n\times V_t}\right) - 1\right] - I_{sh} (3.9)$$

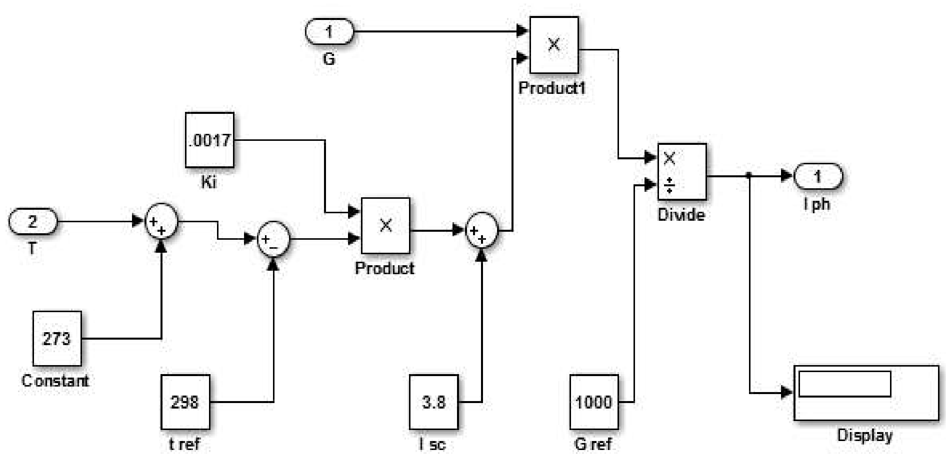


Figure 3.4. Modeled circuit for Eq. (3.5)

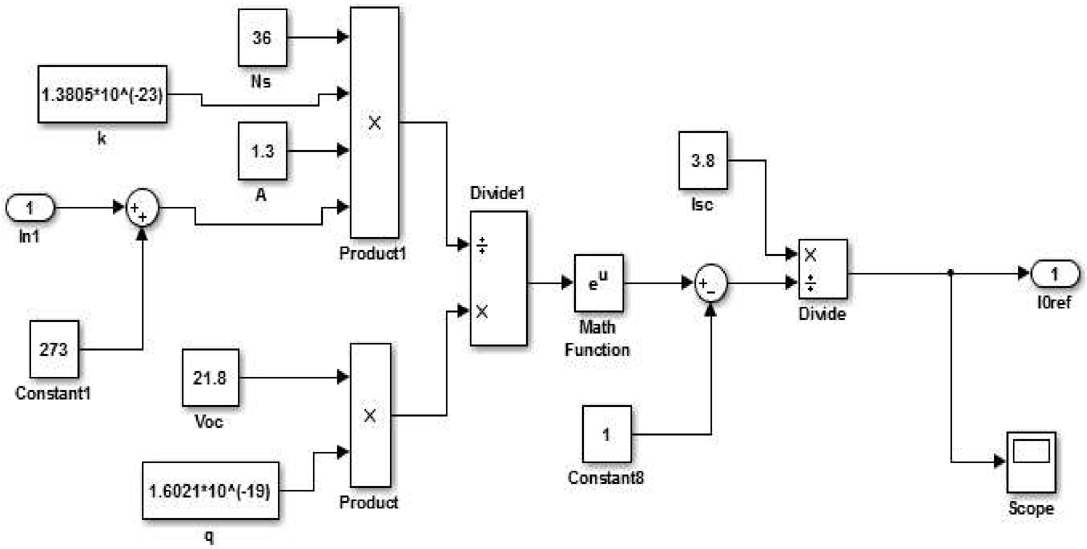


Figure 3.5. Modeled circuit for Eq. (3.7)

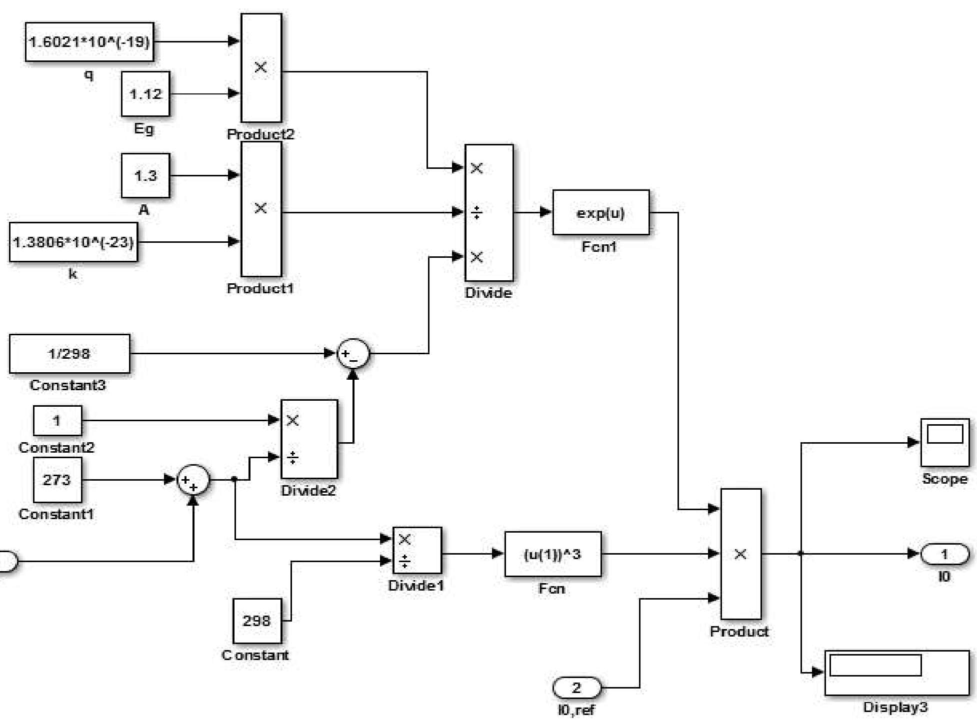


Figure 3.6 . Modeled circuit for Eq. (3.8)

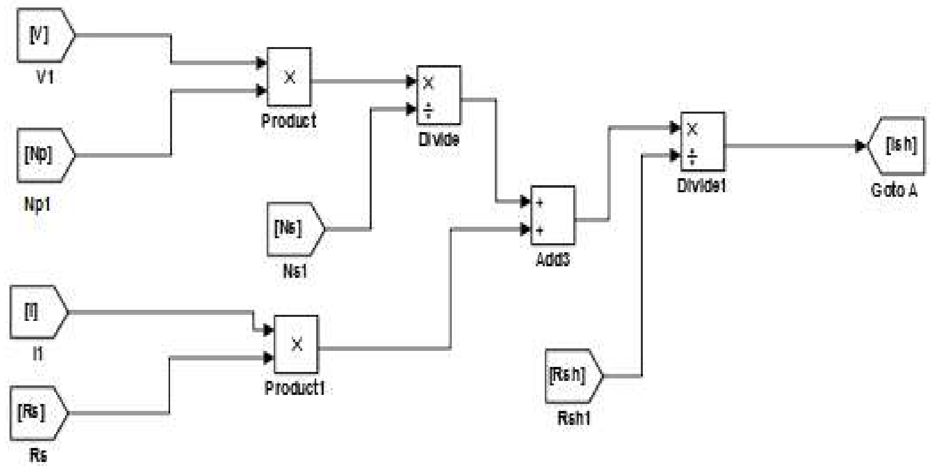


Figure 3.7. Modeled circuit for Eq. (3.6)

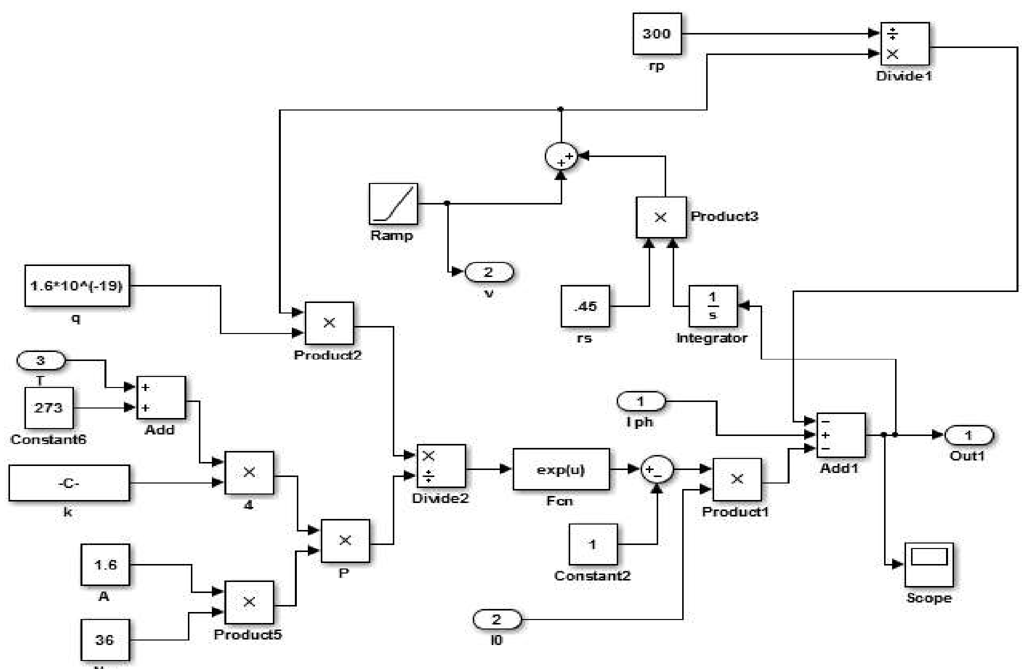


Figure 3.8. Modeled circuit for Eq. (3.9)

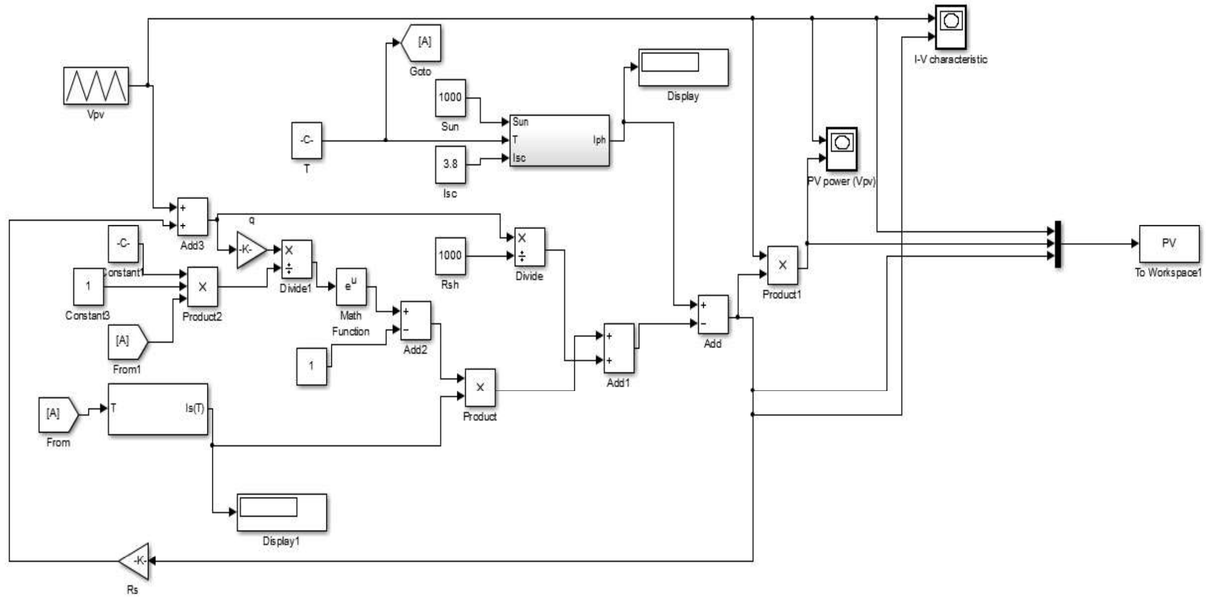


Figure 3.9: Simulation model of solar PV cell

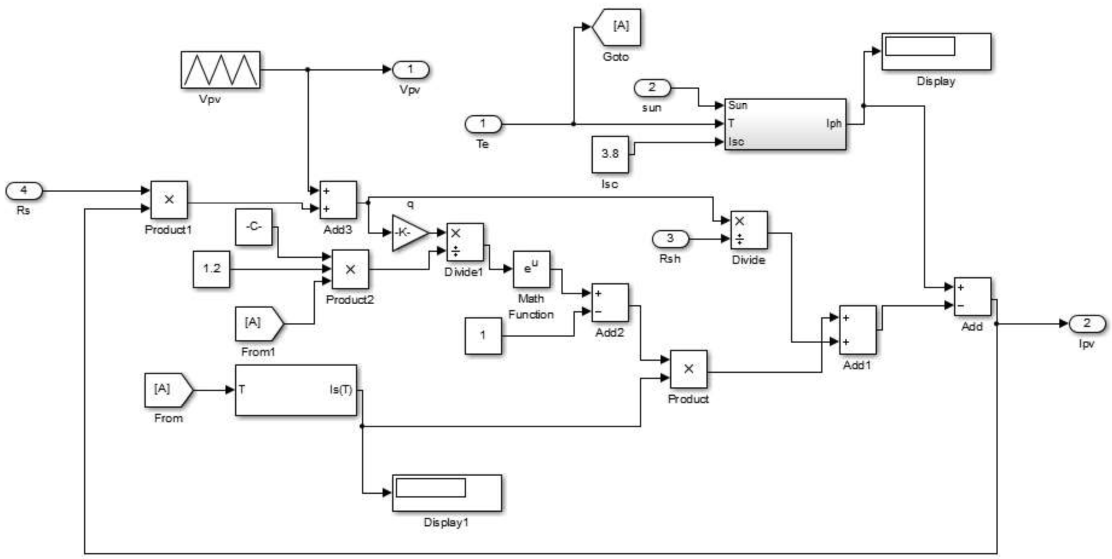


Figure 3.10: Simulation model of solar PV module

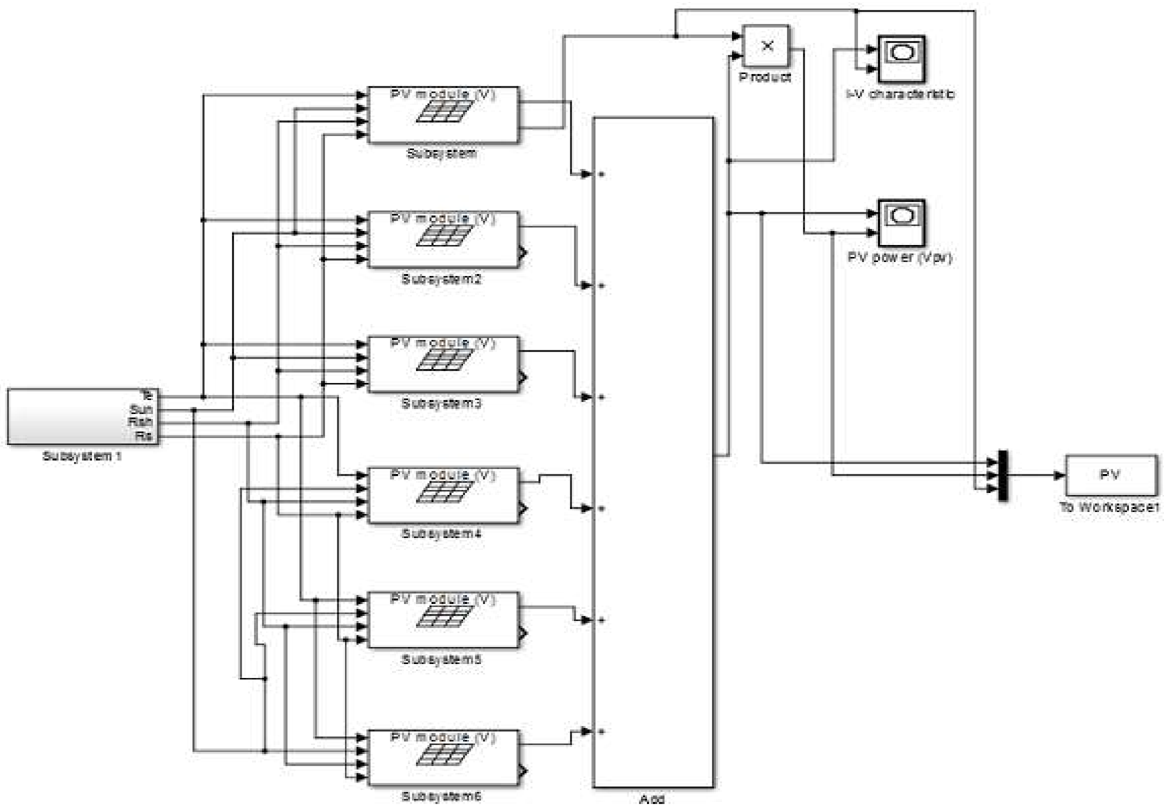


Figure 3.11: Simulation model of solar PV Array

CHAPTER-4
RESULTS AND DISCUSSION

(i) I–V and P–V characteristics for the PV array under variable temperature and fix irradiation are obtained as in Figure.4.1 and Figure.4.2. Here reference temperature variations are 5°C, 10°C, 15°C 20°C, 25°C at 1000W/m^2 irradiance. Here, the reference temperature varies from then output current increases as well as output power increases.

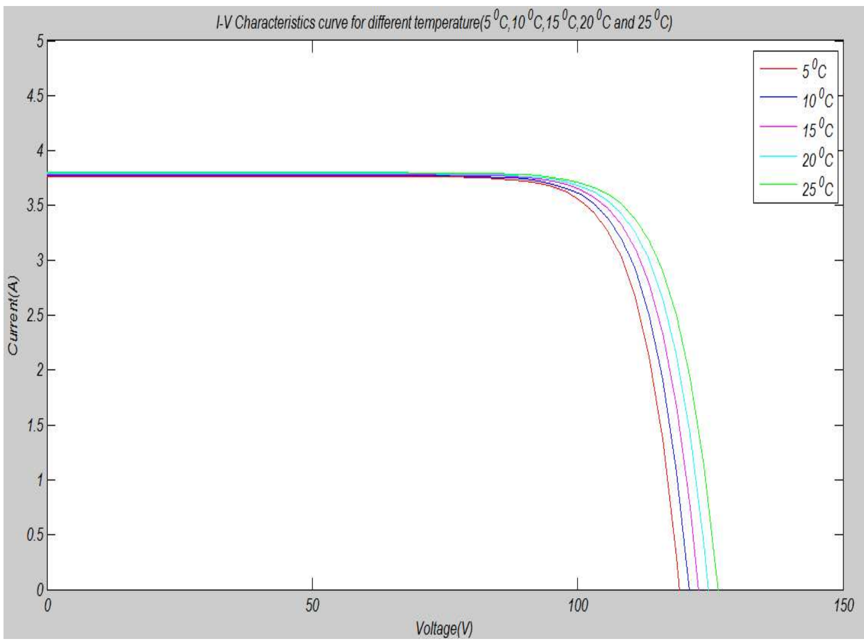


Figure 4.1 I-V characteristic of solar PV system Modelling with different reference Temperature

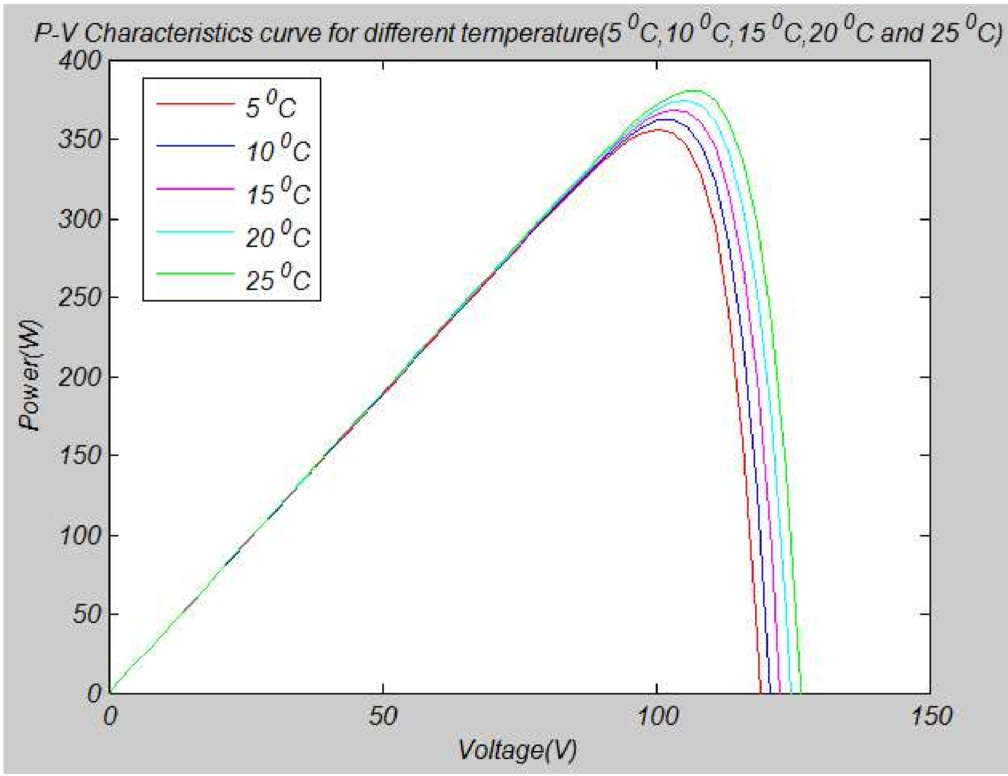


Figure 4.2 P-V characteristic of solar PV system Modelling with different reference Temperature

(ii) I–V and P–V characteristics for PV array under varying irradiation of 200W/m^2, 400W/m^2, 600W/m^2, 800W/m^2, 1000W/m^2 with constant temperature say 25°C are given in Figure4.3 and Figure 4.4. When the irradiation increases, the current and voltage output increase. This results in rise in power output in this operating condition.

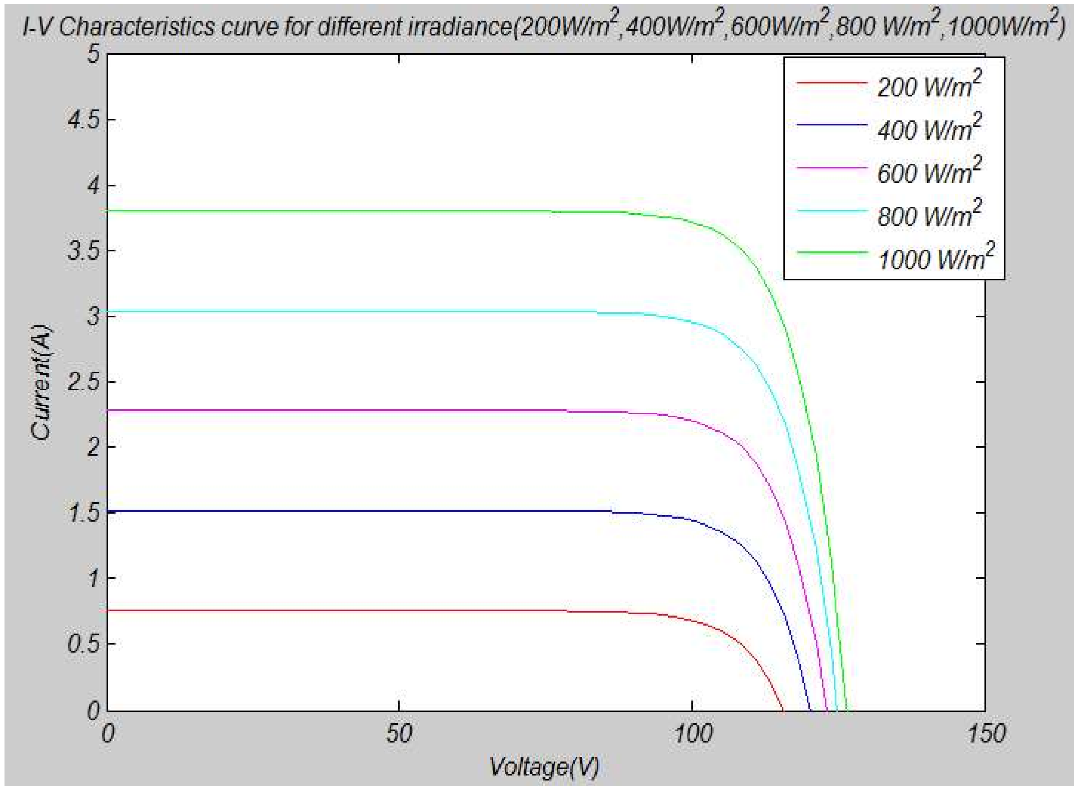


Figure 4.3 I-V characteristic of solar PV system Modelling with different irradiance.

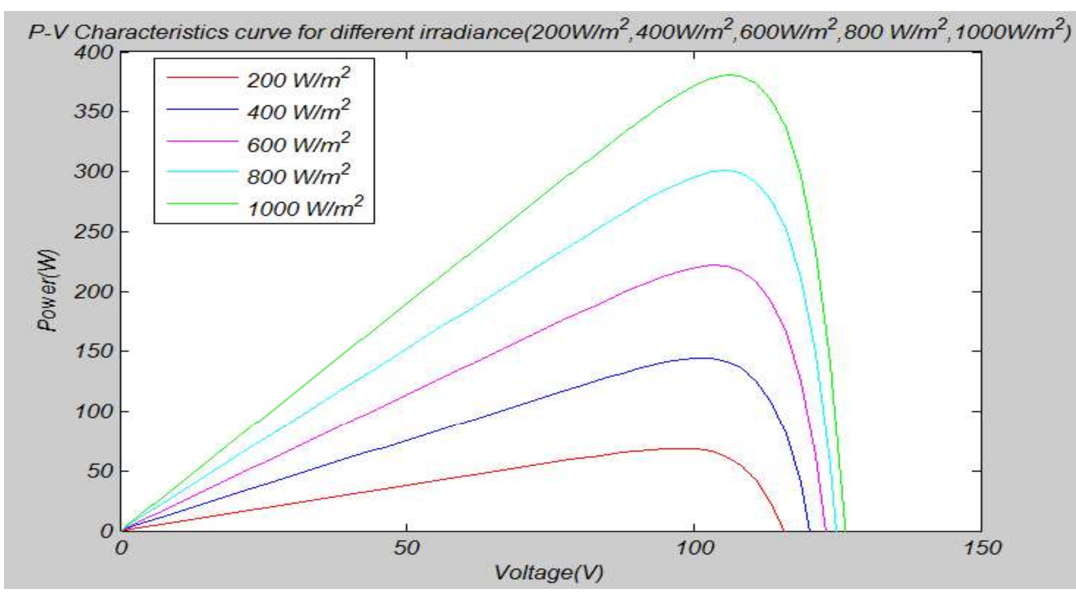


Figure 4.4 P-V characteristics of solar PV system Modelling with different irradiance

(iii) I-V and P-V characteristics for different series resistance are shown in Figure 4.5 & Figure 4.6.When increase the series resistance then output power decreases.

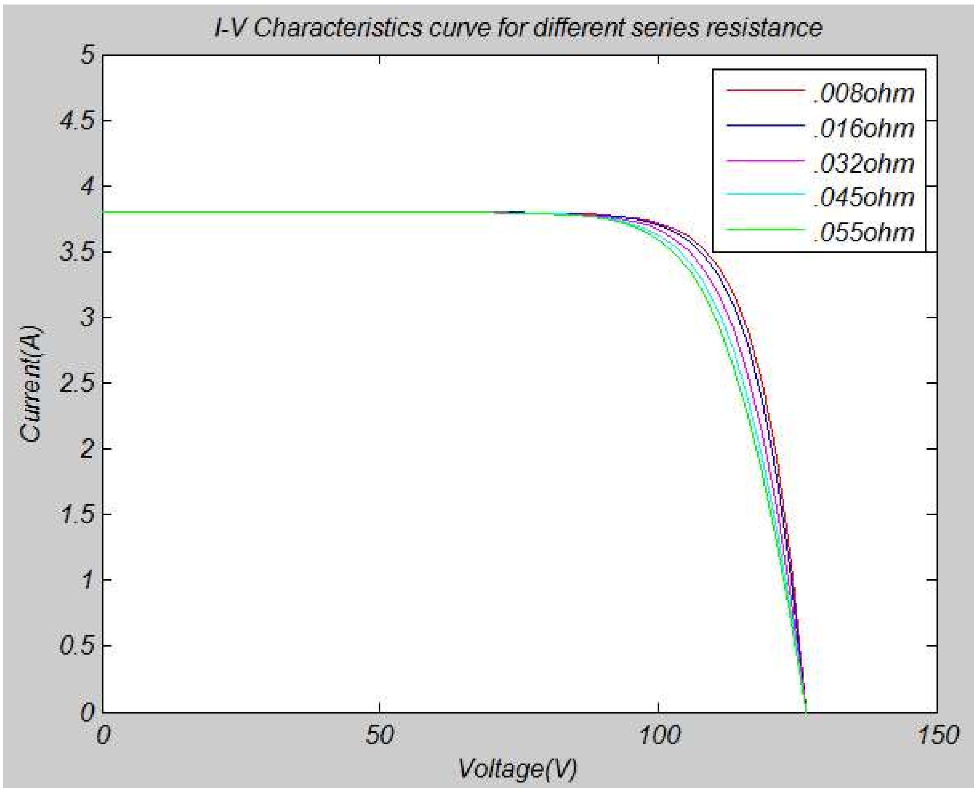


Figure 4.5 I-V characteristics of solar PV system Modelling with different series resistance

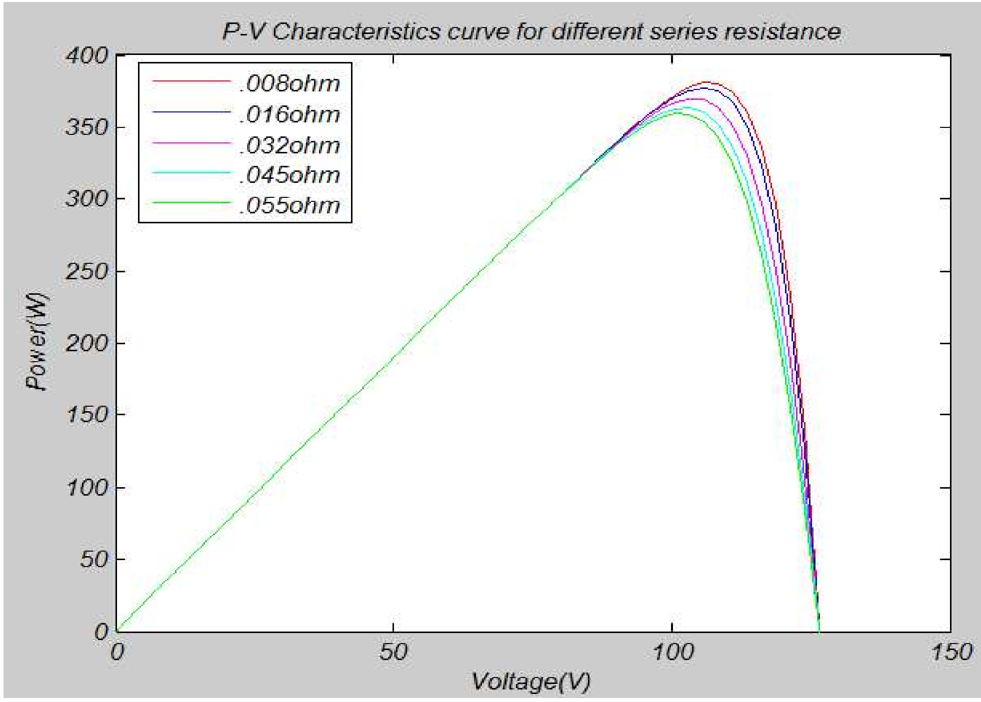


Figure 4.6 P-V characteristics of solar PV system Modelling with different series resistance

(iv) I-V and P-V characteristics for different shunt resistance are shown in Figure 4.7& Figure 4.8.When we increase the shunt resistance there is no effect come out in the output current and power. P–V characteristics under varying shunt/parallel resistance R_{sh}, constant temperature and irradiation are shown in Figure 4.9.When R_{sh} varies between 1000 and 1 Ω, the current output, voltage and output power decreases.

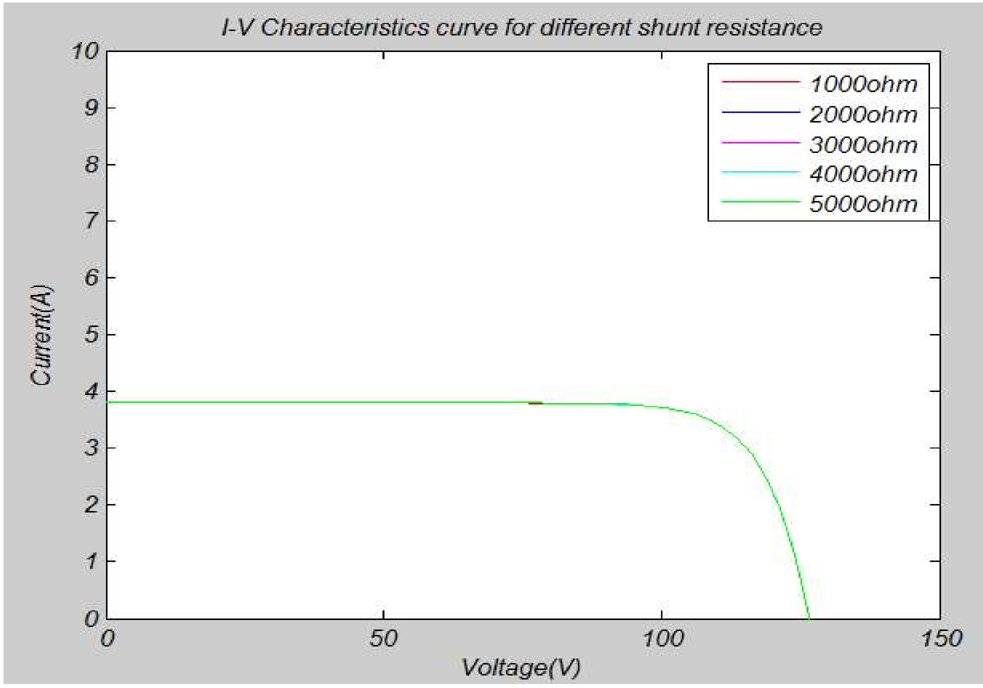


Figure 4.7 I-V characteristics of solar PV system Modelling with different shunt resistance.

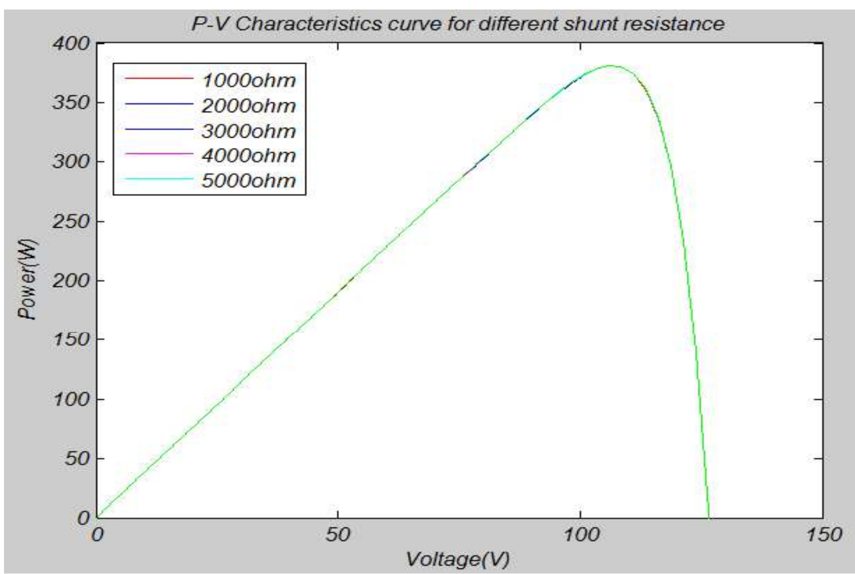


Figure 4.8 P-V characteristics of solar PV system Modelling with different shunt resistance

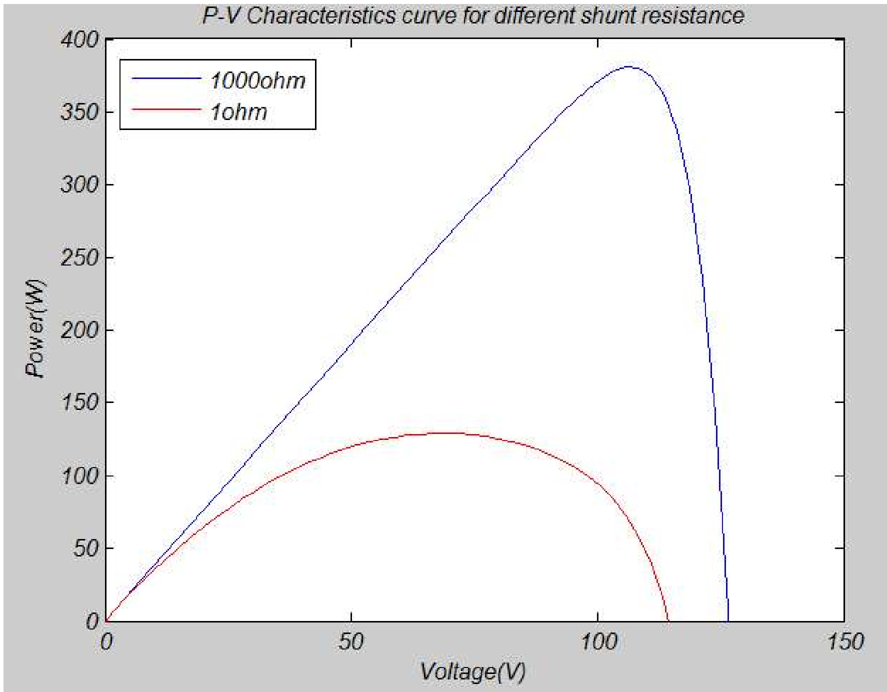


Figure 4.9 P-V characteristics of solar PV system Modelling with 1000ohm and 1ohm shunt resistance

This MATLAB/Simulink model is a dynamic model for any solar array modelling. This modelling helps to understand the the I-V and P-V operating principles and tool for predicting the behaviour of PV array under any variable environmental condition as well as variable parameters like series resistance, shunt resistance, ideality factor, operating temperature etc.

CHAPTER-5

CONCLUSION

Stepwise procedure for modelling solar array in MATLAB with user-friendly stimulation tool is shown in each step, which will help further modelling the solar system and I-V & P-V characteristic. So that any system behaviour can be predicted for any number of cell, panel, or array under any variable of environmental condition like temperature, irradiance, series resistance, shunt resistance, etc. The present model is the dynamic model for further modelling solar PV systems using the maximum power point tracking technique and its performance analysis for power generation application in a solar PV system.

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ANNEXURE-01

Mathematical Modeling of Solar Photovoltaic System Using Matlab/Simulink

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[1, 2, 3] Integral University, Lucknow, U.P.

Abstract- *Renewable energy is considered as next alternative to fossil fuels and nowadays, it attracts much attention in agriculture and environmental protection. Application of solar photovoltaic system is drying and dehydration of products, heating, irrigation, greenhouse and power generation etc. Temperature and sun radiation varies nonlinearly. Power generation varies with reference to radiation and temperature in photo-voltaic (PV) system. PV characteristic is nonlinear and PV cell is the basic unit for electricity generation. To get the characteristic response of PV, it aimed to develop a solar cell/panel model and array on a platform like MATLAB. In this paper, step by step procedure has been defined for modelling solar cell, module, and array models of the photovoltaic system. The PV array characteristic are simulated for different irradiance and temperature variation. The output characteristic of the reference model matches with simulated results. The output reduced when the solar irradiation reduced from 1000 to 200 W/m2. As the reference temperature increased, the output voltage increase, whereas the output current increases slightly. This model would be useful for check the effect of different parameters like series resistance, shunt resistance etc. It would also be useful for investigating the working parameters like temperature & radiation condition and different series and parallel combinations of panels. This modelling is useful in investigating the performance of solar arrays in different applications of solar power generation, as well as modelling provides a major role in the mounting of PV panels*

Keywords- Photovoltaic system, MATLAB, irradiance, solar arrays.

I. INTRODUCTION

So as to realize the influence of the solar energy the project starts to describe the energy situation nowadays. Energy is an issue that touches every person on the planet. At present in the world, especially in industrialized and emergent countries, energy has become vital for all the human beings. Accordingly the energy demand has been increasing dramatically in the last years.

Because of the greenhouse effect, environmental impact and the increasing cost of the fossil fuel-based energy sources, much more energy usage from renewable sources and more efficient utilization of conventional sources is becoming to be indispensable. The World Resource Institute estimates that 61.4% of global greenhouse emissions come from energy consumption. Thereby a solution that reduces these pollutants should include investment in the fields of renewable sources and energy efficiency in order to allow energy to play its role in the economy without endangering the environment. [1]
The increasing of the electricity price and the increasing of the environmental impact the world is suffering, solar energy may be considerably accepted one of the key solutions.

Solar energy is radiant light and heat coming from the solar radiation. It is a renewable source since the methods used to transform the solar energy into electricity don't produce any smoke or pollutants. However since the power generated by this source comes from the sunlight, it cannot be used during the night, and even during some days when the weather is completely cloudy, rainy, snowy or another natural factors. Solar energy can mainly be divided in two mainly sources; it can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications. The research has been focused on photovoltaics within the solar energy.

Solar photovoltaic modules are manufactured by semiconductor materials and they turn the radiant energy coming from the sun into direct current and therefore, electricity. The competitiveness of this field is increasing; in 2013, for the first time in more than a decade, solar was over all other renewable energy technologies in the sense of new generating capacity installed with an increase of 29 percent compared with 2012. [2] .Worldwide total PV installations represented 1.8 GW in 2000 and 71.1 GW in 2011 with a growth rate of 44%. [3].

This has led to a situation where the electricity from solar panels costs as much or is even cheaper than electricity purchased from the grid is within reach.

Nonetheless, solar power generation has still some problems as follows: the conversion efficiency of solar cells is lower, and the output power of photovoltaic (PV) array has great relationship with irradiation and temperature.[4]
Regardless the problems described above, one of the most important and critical problems on the photovoltaics field is the shadowing effect. Shaded conditions is sometimes inevitable because some parts of the photovoltaic system receives less intensity of sunlight due to several factors such as clouds, the time of the day, the season of the year or even shadows from neighbouring objects.[5] When the light is falling on a solar cell, it behaves as the following formula (1.1), obtained from the Ideal Diode Law [6]:

$$I_L = I_2 - I_o\left[exp\left(\frac{qV}{aKT}\right) - 1\right] \quad (1.1)$$

Where IL is the light-generated current, I_2 is the current,I_0 is the current when no light is falling on the cell: it increases as T increases, and it increases as material quality increases, q is the charge on an electron k is Boltzmann's constant, T is absolute temperature, a is the ideality factor (between 1 and 2). It increases as the current decreases.

The characteristic curve represent all of the combinations of current and voltage at which the module or cell can be operated or loaded. Normally simple in shape, these curves actually provide the most complete measure of the health and capacity of a PV module or array, providing much more information than traditional electrical test methods [9]

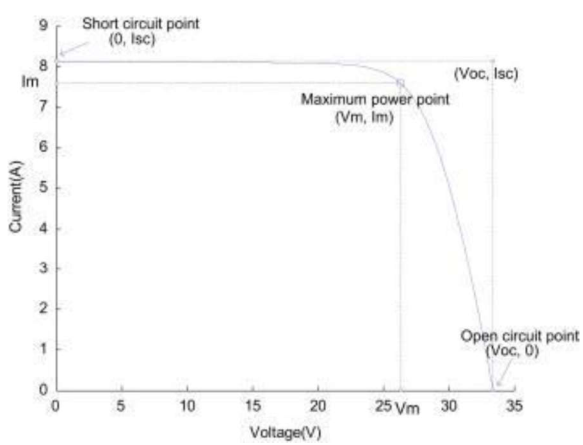

Fig. 1. Characteristic I-V curves of a solar c el l [10]

Here two different parameters have to be introduced:

- **Short circuit current Isc :** Is the maximum current, given when voltage is 0.
- **Open circuit voltage Voc:** Is the maximum voltage, given at zero current.

There is also a relevant point, MPP is the maximum power point, therefore the point where the product of Vmp*Imp is at its maximum value.

Another important parameter is the fill factor (FF) is the ratio between Pmax and Isc*Voc. It gives an information about the quality of the solar cell, if it increases so do the quality of the solar cell.

II. METHODOLOGY

The equivalent circuit of a PV cell is shown in Fig.2. The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis (Pandiarajan and Muthu 2011). Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems. The equivalent circuit for PV array is shown in Fig. 3. The voltage–current characteristic equation of a solar cell is provided as (Tu and Su 2008; Salmi et al. 2012): Module photo-current Iph: Here, Iph: photo-current (A); Isc: short circuit current (A) ; Ki: short-circuit current of cell at 25 °C and 1000 W/m^2;T: operating temperature (K); Ir: solar irradiation (W/m^2).Module reverse saturation current Irs:Here, q: electron charge, = 1.6 × 10−19C; Voc: open circuit voltage (V); Ns: number of cells connected in series; n: the ideality factor of the diode; k: Boltzmann's constant, = 1.3805 × 10−23 J/K.

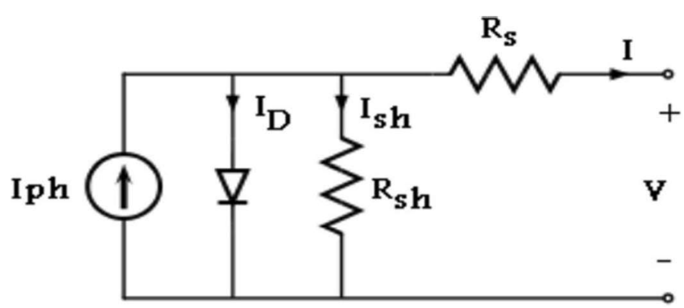

Fig. 2. PV cell equivalent circuit [19]

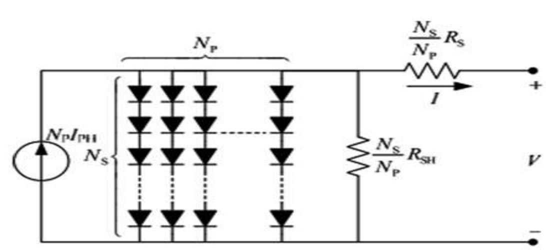

Fig. 3. Equivalent circuit of solar array[22]

The module saturation current I_0 varies with the cell temperature, which is given by:

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q \times E_{g0}}{nk}\left(\frac{1}{T}-\frac{1}{T_r}\right)\right] \quad (2.1)$$

$$I = N_p \times I_{ph} - N_p \times I_0 \times \left[exp\frac{\frac{V}{N_S}+I \times R_S/N_p}{n \times V_t} - 1\right] - I_{sh} \quad (2.2)$$

with

$$V_{t=}\frac{K \times T}{q} \quad (2.3)$$

and

$$I_{sh} = \frac{V \times N_S/N_p + I \times R_S}{R_{sh}} \quad (2.4)$$

Here: Np: number of PV modules connected in parallel; Rs: series resistance (Ω); Rsh: shunt resistance (Ω);Vt: diode thermal voltage (V).

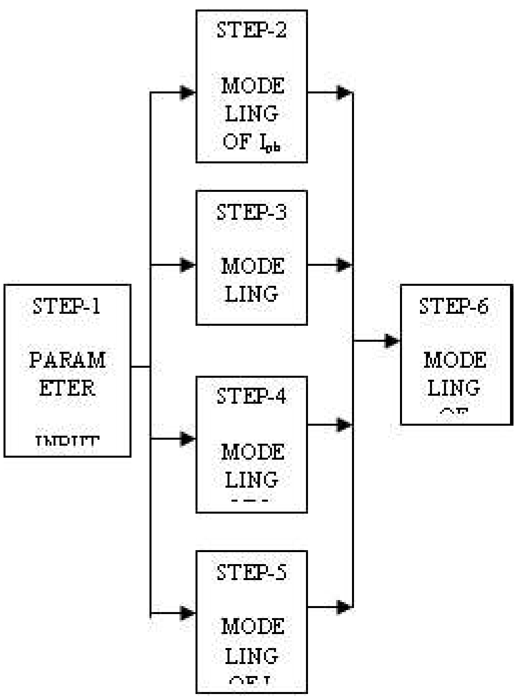

Fig. 4:Solar Cell modeling block

Reference model

The 400 W solar power array is taken as the reference module for simulation and the detailed parameters of array is given in Table 1.

Table 1 Electrical characteristics data of DS-400W PV array

NAME	Value
Rated power (Vmp)	400W
Voltage at maximum power (Vmp)	18V
Current at maximum power (Imp)	5.55A
Open circuit voltage (V_{OC})	21.6V
Short circuit current (I_{SC})	6.11A
Total number of cells in parallel (N_p)	36
Maximum system voltage	1
Range of operation temperature	1000

Step by step procedure for modeling of photovoltaic arrays with tags:

A mathematical model of PV array including fundamental components of diode, current source, series resistor and parallel resistor is modeled with Tags in Simulink environment (http://mathwork.com). The simulation of solar module is based on equations given in the section above and done in the following steps.

Step 1: Provide input parameters for modeling: Tr is reference temperature = 298.15 °K; n is ideality factor = 1.2; k is Boltzmann constant = 1.3805×10^{-23} J/K; q is electron charge = 1.6×10^{-19}; I_{sc} is PV module short circuit current at 25 °C and 1000 W/m^2 = 6.11 A; Voc is PV module open circuit voltage at 25 °C and 1000 W/m^2 = 0.6 V; E_{g0} is the band gap energy for silicon = 1.1 eV. Rs is series resistor, normally the value of this one is very small = 0.008Ω; R_{sh} is shunt resistor, the value of this is so large = 1000 Ω .

Step 2 : Modelling of I_{ph}(Module photocurrent):Module photon-current is given in Eq. (2.5) and modeled as Fig.5 (I_{r0} = 1000 W/m^2). Initially, in system block, degree Celsius temperature(operating temperature) was converted into degree Kelvin and then given to subsystem. As per Eq.2.5, I_{ph} was photocurrent and modelled in MATLAB as shown below where its subsystem was also shown and all parameters were defined say I_{ph} (photo current), I_{sc} (short circuit current of module), K_i (Solar cell temperature coefficient of the short-circuit current (in °K or °C), T_i (operating temperature), Ir (solar irradiance). Modeling was shown in Fig.3.4.

$$I_{Ph} = [I_{sc} + K_i(T_i - 273)] \times I_r/1000 \quad (2.5)$$

Step 3: Modelling of I_{sh} (Module shunt saturation current): Module shunt saturation current was modeled in MATLAB as shown in Fig. 6. .As per Eq.2.6, where and value were given for panel and array modeling and V was open

circuit volt-age so it was same as Voc say 21.6 V and R_S and R_{sh} represent the series and parallel resistances of the cell.
Modeling was very simple just using adder, multiplier and divider blocks its shows in equation (2.6)

$$I_{sh} = \frac{V\left(\frac{N_P}{N_S}\right)+I*R_S}{R_{sh}} \tag{2.6}$$

Step 4: Modeling of I_{rs} (Module reverse saturation current): Module reverse saturation current was modelled in MATLAB as shown in Fig. 6 as per Eq.2.7 where different constants are taken as k: Boltzmann's constant $1.380658\text{x}10^{-23}$ J/K q: electron charge $1.60217733\text{x}10^{-19}$C etc.

$$I_{rs} = I_{sc}/\left[\exp\left(\frac{qV_{oc}}{N_s knT}\right)-1\right] \tag{2.7}$$

Step 5: Modeling of Io (Module saturation current): Modeling of module saturation current was modeled in MATLAB as shown in Fig.7 .

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q\times E_{g0}}{nk}\left(\frac{1}{T}-\frac{1}{T_r}\right)\right] \tag{2.8}$$

Modelling of saturation current was done as per Eq.3.8, whose parameters were Irs: Module reverse saturation current; T_R: Solar cell absolute reference temperature at STC, in K; T: absolute operating temperature of solar cell, in K; q:Electron charge, $1.60217733e^{-19}$ Cb; k Boltzmann's constant; 1.3806503×10^{-23} J/K and the ideality factor Modified.

Step 6 : Modelling of I(Module output current):

The modelling of module output current is given in Fig. 9.Complete simulation model with step 1 to step 5 .Step 1 to step 4 was done and combine together in step 5 as per Eq.2.9 complete block schematic is shown in Fig. 3.8. The solar PV array includes six modules and each module has 36 solar cells connected in series. Therefore, the proposed model of solar PV array is given in Fig. 3.11.

$$I = N_p * I_{Ph} - N_p * I_o * \left[exp\left(\frac{\frac{V}{N_s}+I\times R_S/N_p}{n\times V_t}\right)-1\right] - I_{sh} \tag{2.9}$$

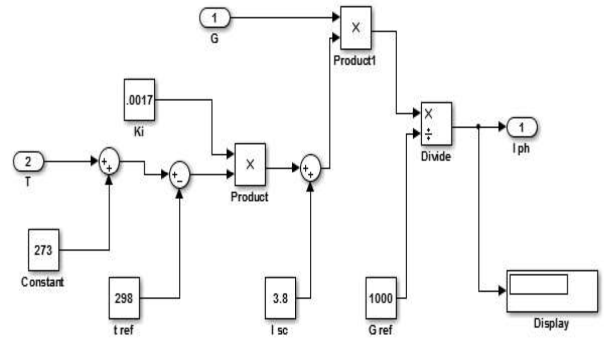

Fig. 5 Modeled circuit for Eq. (2.5)

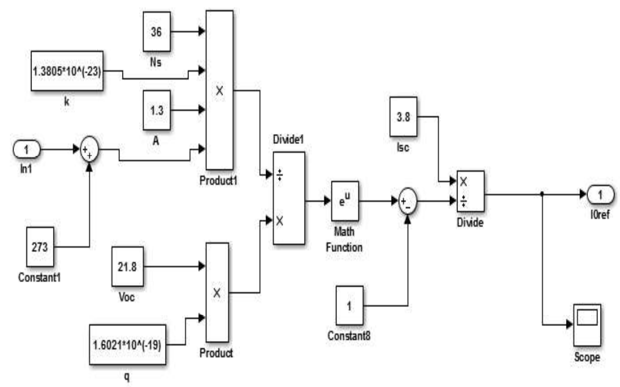

Fig. 6 Modeled circuit for Eq. (2.7)

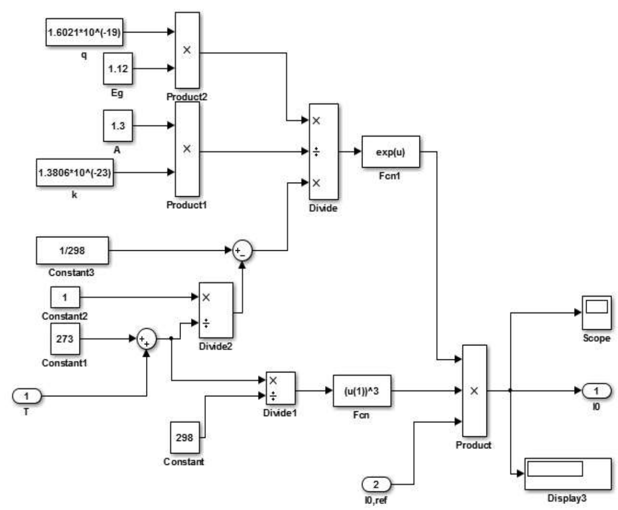

Fig. 7 Modeled circuit for Eq. (2.8)

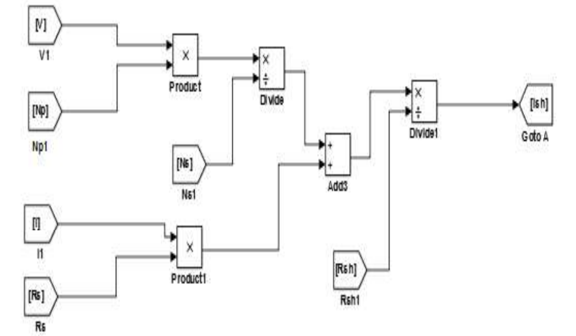

Fig. 8 Modeled circuit for Eq. (2.6)

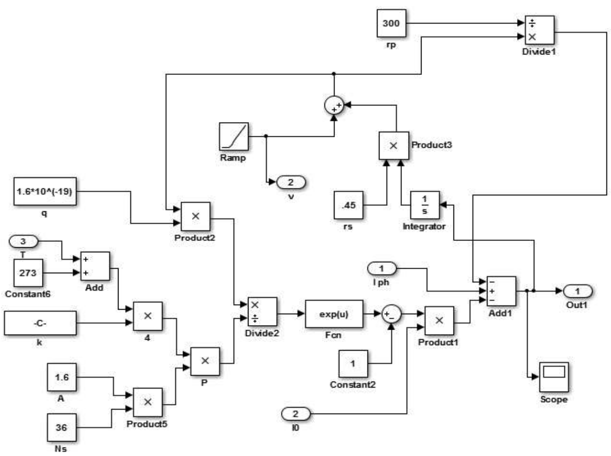

Fig. 9 Modeled circuit for Eq. (2.9)

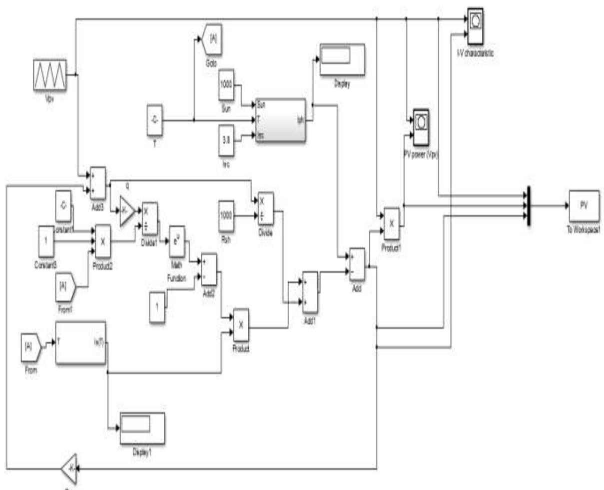

Fig. 10. Simulation model of solar PV cell

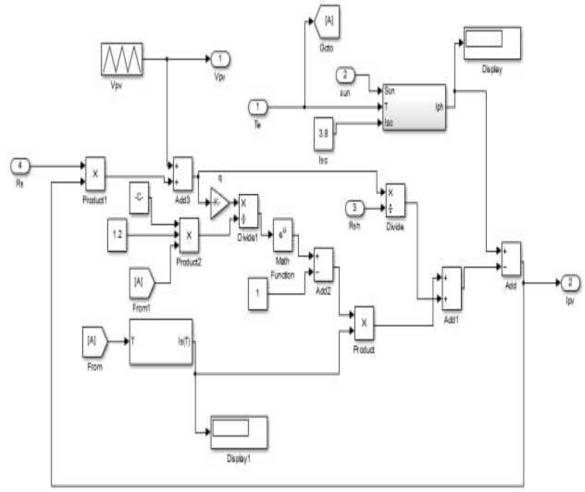

Fig. 11 Simulation model of solar PV module

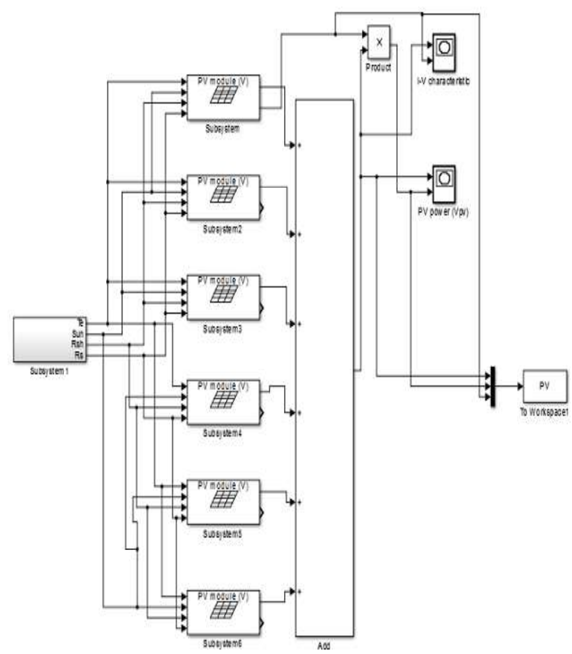

Fig. 12 Simulation model of solar PV Array

III. RESULTS AND DISCUSSION

(i) I–V and P–V characteristics for the PV array under variable temperature and fix irradiation are obtained as in Fig.13 and Fig.14. Here reference temperature variations are 5°C, 10°C, 15°C 20°C, 25°C at 1000W/m^2 irradiance. Here, the reference temperature varies from then output current increases as well as output power increases.

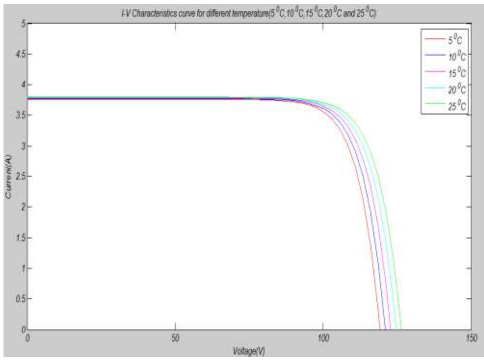

Fig. 13 I-V characteristic of solar PV system Modelling with different reference Temperature

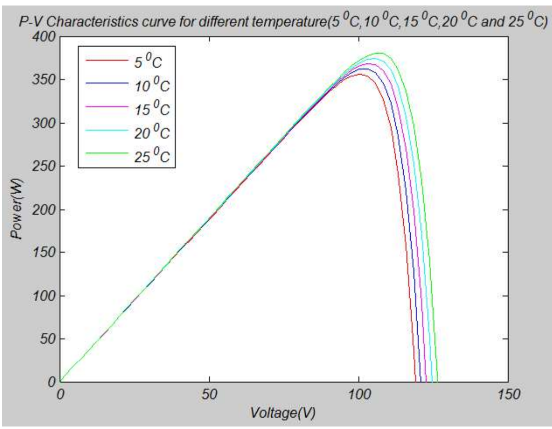

Fig. 14 P-V characteristic of solar PV system Modelling with different reference Temperature

(ii) I–V and P–V characteristics for PV array under varying irradiation of 200W/m^2, 400W/m^2, 600W/m^2, 800W/m^2, 1000W/m^2 with constant temperature say 25°C are given in Fig. 15 and Fig. 16. When the irradiation increases, the current and voltage output increase. This results in rise in power output in this operating condition.

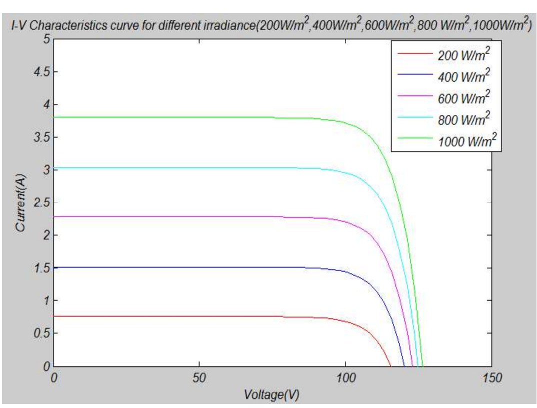

Fig. 15 I-V characteristic of solar PV system Modelling with different irradiance**.**

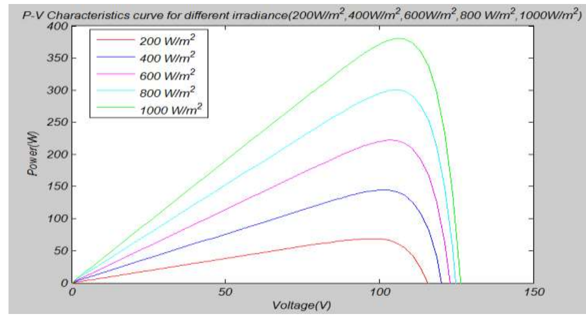

Fig. 16 P-V characteristics of solar PV system Modelling with different irradiance

(iii) I-V and P-V characteristics for different series resistance are shown in Fig. 17 & Fig. 18.When increase the series resistance then output power decreases.

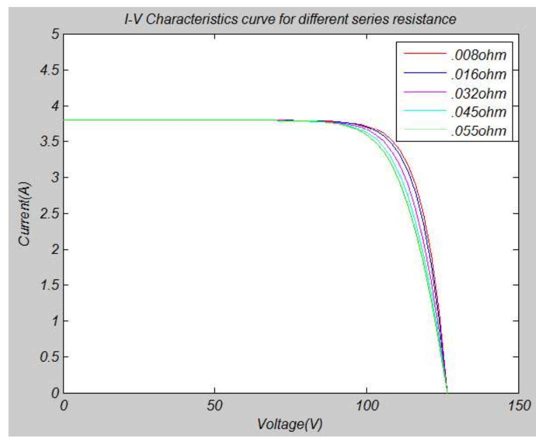

Fig. 17 I-V characteristics of solar PV system Modelling with different series resistance

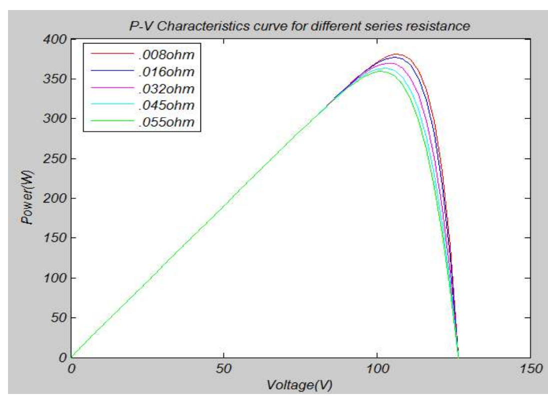

Fig. 18 P-V characteristics of solar PV system Modelling with different series resistance

(iv) I-V and P-V characteristics for different shunt resistance are shown in Fig. 19 & Fig. 20.When we increase the shunt resistance there is no effect come out in the output current and power. P–V characteristics under varying shunt/parallel resistance R_{sh}, constant temperature and irradiation are shown in Fig. 19.When R_{sh} varies between 1000 and 1 Ω, the current output, voltage and output power decreases.

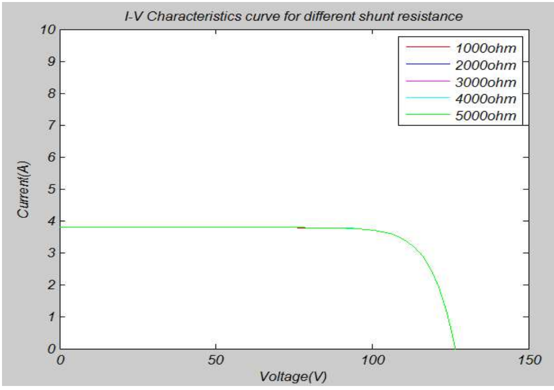

Fig. 19 I-V characteristics of solar PV system Modelling with different shunt resistance**.**

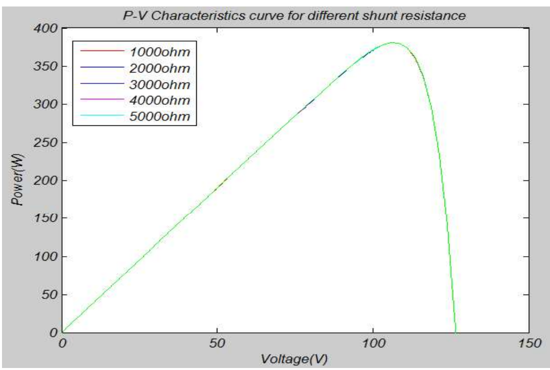

Fig. 20 P-V characteristics of solar PV system Modelling with different shunt resistance

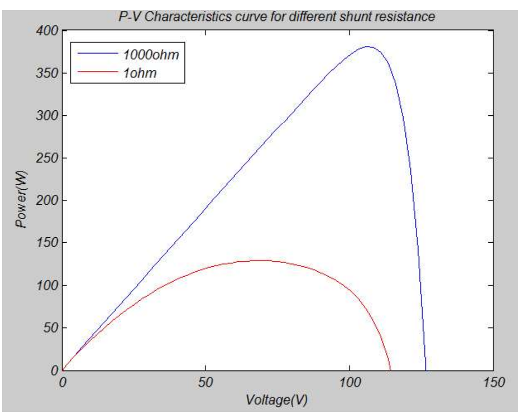

Fig. 21 P-V characteristics of solar PV system Modelling with 1000ohm and 1ohm shunt resistance

This MATLAB/Simulink model is a dynamic model for any solar array modelling. This modelling helps to understand the the I-V and P-V operating principles and tool for predicting the behaviour of PV array under any variable environmental condition as well as variable parameters like series resistance, shunt resistance, ideality factor, operating temperature etc.

IV. CONCLUSION

Stepwise procedure for modelling solar array in MATLAB with user-friendly stimulation tool is shown in each step, which will help further modelling the solar system and I-V & P-V characteristic. So that any system behaviour can be predicted for any number of cell, panel, or array under any variable of environmental condition like temperature, irradiance, series re-sistance, shunt resistance, etc. The present model is the dynamic model for further modelling solar PV systems using the maximum power point tracking technique and its performance analysis for power generation application in a solar PV system.

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