Different parameter analysis of PV cell

A dissertation submitted in partial fulfillment of the requirement for the award of the degree of

MASTER OF TECHNOLOGY

In

RENEWABLE ENGINEERING TECHNOLOGY

By

AMAN KHURANA

(2K15/RET/01)

Under the Guidance of

Mr. P.V. Ram Kumar

Associate Professor

DEPARTMENTNT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGY UNIVERSITY

BAWANA ROAD, DELHI – 110042

Certificate

This is to certify that the dissertation entitled on **"Different parameter analysis of PV cell"** submitted to Delhi Technological University (formerly Delhi College of Engineering) by **Mr. Aman Khurana (2K15/RET/01)** in the partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Renewable Energy Technology (Mechanical Department)** is a bona fide record of the candidate's own work carried out under the supervision of **Mr P.V. Ram Kumar** The information and data enclosed in this thesis is original and has not been submitted elsewhere for honoring any other degree.

Signature of the Supervisor	***Signature of the HOD***
Mr. P.V. Ram	**Dr R.S. Mishra**
(Associate Professor)	(Head of Department)
Department of Mechanical Engineering Engineering	Department of Mechanical
Delhi Technological University	Delhi Technological University
Delhi - 110042	Delhi - 110042

Candidate Declaration

I hereby declare that the work which is being presented in this thesis entitled **"Different parameter analysis of PV cell"** is my own work carried out under the guidance of **Mr. P.V. Ram Kumar**, Associate Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi.

I further declare that the matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

Date: **Aman khurana**

Place: Delhi **Roll No. -2K15/RET/01**

Acknowledgement

With a great pleasure I would like to express my first and sincere gratitude to my supervisor **Mr P.V. Ram Kumar** for his continuous support, patience, motivating ideas, enthusiasm and immense knowledge. His guidance always enlightens and helped me to shape my work.

Besides my Supervisor, I would like to express my deep gratitude and respect to **Dr R.S. Mishra**, Head, Department of Mechanical Engineering , Delhi Technological University, Delhi for his encouragement, insightful comments and valuable suggestions during the course.

I wish to express my heart full thanks to my friend **Manish Poonia and Rahul Malowa** for their goodwill and support that helped me a lot in successful completion of this project. I also wish to express my heart full thanks to the classmates as well as staff at Department of Applied Physics, Delhi Technological University, Delhi for their goodwill and support that helped me a lot in successful completion of this project.

Finally, I want to thank my parents, brother and friends for always believing in my abilities and for always showering their invaluable love and support.

Aman Khurana
M. Tech.(RET)
2K15/RET/01

TABLE OF CONTENTS

INDEX

LIST OF FIGURES

LIST OF TABLES

Abstract

Today energy is the main concern for any country. It is one of the main factors for growth and development. Sources of light and fuel are changed time to time. First it was made by wood or animal dung or waste plants. Later they got replaced by non renewable sources of energy coal, water & nuclear energy. These types of sources are very limited. So use of renewable sources becomes essential.

There is a huge scope of solar energy. Earlier generation cost of solar cell is very high. But now it is utterly down because of many factors. These are recent market trends, regulatory pressures, consumer incentives, and rapid technological advancement. Stand alone system reduces the transmission cost. Solar power is generated by various mean like solar thermal power plant, Photovoltaic system etc but PV cell is more economic and efficient cell.

By Seeing the current development and future scope of PV cell study of this system becomes interesting. In this project PV cell behaviour with different parameters were studied. Parameters are insolation, temperature, series resistance,shunt resistance, reverse saturation current of diode .First I-V and P-V characteristics then change in Maximum power with variation of these parameters is analyzed and variation in the voltage for maximum power is also observed. All simulation work was done in MATLAB. Codes used in this simulation work are also attached in this report.

Chapter 1
Introduction

A Photovoltaic cell converts light energy into electricity. Solar modules or solar panel are made up of solar cell. Cell resistance is not constant. It varies with photon intensity. Series connection improves the voltage rating and parallel connection improves the current rating.

1.1 Working of PV cell

When photon hits the atom, electrons excite from its normal state. Excited electron has 2 options. Either it dissipates the energy as heat and return to its orbital or travel through the cell until it reaches an electrode and current flows. Cell has 2 parts. One part is p type material and other one is n type material. When photon energy emits on the cell, holes and electrons generation take place which constitutes a current. Current produced from cell is Direct current (DC).Now a inverter is connected further which converts DC into AC.

1.2 Material

Generally solar cell's names are same as of its material. Some cells are designed so that they are compatible to work in space. It could be single junction material or multi junction material depends on no of layer used.

There are three sorts of cell. PV cells can be characterized into to start with, second and third generation cells. wafer based cell made up of crystalline silicon .Another is thin film cell mainly used for large generation. The third era of sun powered cells incorporates various thin-film advances frequently portrayed as rising photovoltaic—the vast majority of them have not yet been financially connected are still in the exploration or improvement stage

1.3 Current development

For best execution, earthly PV frameworks plan to amplify the time they confront the sun. Sun oriented trackers accomplish this by moving PV panels to take after the sun. The expansion can be by as much as 20% in winter and by as much as half in summer. Static mounted frameworks can be streamlined by examination of the sun way. Boards are regularly set to scope tilt, a point equivalent to the scope, however execution can be enhanced by altering the plot for summer or winter. For the most part, as with other semiconductor gadgets, temperatures above room temperature lessen the performance of photovoltaic.

Various sunlight based panels may likewise be mounted vertically over each other in a tower, if the zenith distance of the Sun is more prominent than zero, and the tower can be turned evenly all in all and each panel also around a level pivot. In such a tower the boards can take after the Sun precisely. Such a device might be described as a ladder mounted on a turntable circle. On the off chance that the peak separation of the Sun achieves zero, the "ladder" might be turned toward the north or the south to stay away from a sunlight based panel creating a shadow on a lower sun oriented board. Establishments might be ground-mounted (and infrequently incorporated with cultivating and brushing) or incorporated with the rooftop or dividers of a (building-coordinated photovoltaic).[1]

1.4 Application of solar cell

Solar cell applications are vast. This can be used as standalone system as well as in hybrid mode. In hybrid mode solar energy is also used to heap up the water which can be further used for generation or for other purpose. By this type of arrangement we can get direct electricity from solar energy or through first converting it into thermal energy and then into electricity. So the overall efficiency of system get improved.

1.4.1 Rooftop and building integrated system

Figure 1 rooftop PV panel

This type of system shown in figure 1 is called rooftop and building oriented system. if a open gap is provided to circulate the air then PV panel can provide passive cooling i.e. It can be used for cooling in day time.[4] Also PV cell on rooftop stores heat during night. Generation from rooftop PV system is not so high.

1.4.2 Concentrator photovoltaic

In this type of PV system solar energy is concentrated through mirrors. Mirror angles are put in such a way so that they can concentrate on a line or on a point.[5] Sometimes automatic tracking system also used for improving the efficiency. This type of scheme is used in large power generation or in thermal solar power generation.[6]

1.4.3 PV & thermal hybrid

This type of system are frameworks that change over sunlight based radiation into heat and electrical vitality. These frameworks consolidate a solar cell, which changes over daylight into power, with a sunlight based collector, which catches the rest of the vitality and expels squander heat from the PV module.[7] This type of system are more efficient.

1.4.4 Rural electrification

LED lights are great initiative by government of India to get rid of kerosene lamp.. Cuba is the country which is giving sun powered energy to ranges that are off grid. Nonetheless, in 1995 sun powered provincial zap ventures had been observed to be hard to maintain because of ominous financial matters, absence of specialized help, and a heritage of ulterior thought processes of north-to-south innovation exchange.[8]

1.4.5 Standalone systems

Many gadgets use the PV cell for charging. This idea has replaced battery which was used earlier. Many other standalone systems are used in the area which are not in the reach of grid supply.[9] Cell life are quite high so it becomes a better option to use PV cell instead of battery.

1.4.6 Spacecraft application

Sun oriented boards on rocket are generally the sole wellspring of energy to run the sensors, dynamic warming and cooling, and interchanges. A battery stores this vitality for utilize when the solar cell are in shadow.[10]To expand the power produced per kilogram, these panels utilize high-cost, high-effectiveness, and close-stuffed rectangular multi-intersection PV cells made of gallium arsenide (GaAs) and other semiconductor materials.

Chapter 2
Literature review

2.1 What is solar cell

Photovoltaic is the process of converting sunlight directly into electricity using solar cells. Today it is a rapidly growing and increasingly important renewable alternative to conventional fossil fuel electricity generation, but compared to other electricity generating technologies, it is a relative newcomer, with the first practical photovoltaic devices demonstrated in the 1950s. Research and development of photovoltaic received its first major boost from the space industry in the 1960s which required a power supply separate from "grid" power for satellite applications. These space solar cells were several thousand times more expensive than they are today and the perceived need for an electricity generation method apart from grid power was still a decade away, but solar cells became an interesting scientific variation to the rapidly expanding silicon transistor development with several potentially specialized niche markets. It took the oil crisis in the 1970s to focus world attention on the desirability of alternate energy sources for terrestrial use, which in turn promoted the investigation of photovoltaic as a means of generating terrestrial power. Although the oil crisis proved short-lived and the financial incentive to develop solar cells abated, solar cells had entered the arena as a power generating technology. Their application and advantage to the "remote" power supply area was quickly recognized and prompted the development of terrestrial photovoltaic industry. Small scale transportable]applications (such as calculators and watches) were utilized and remote power applications began to benefit from photovoltaic.[11]

2.2 Current-voltage and Power -voltage curve

A model of PV module with moderate complexity that includes the temperature independence of the photocurrent source, the saturation current of the diode, and a series resistance is considered based on the Shockley diode equation. Solar Cell I-V Characteristics Curves are basically a graphical representation of the operation of a solar cell or module summarizing the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible current times voltage equals power, so we can create solar cell P-V curves representing the power versus the voltage for a photovoltaic device.[12]

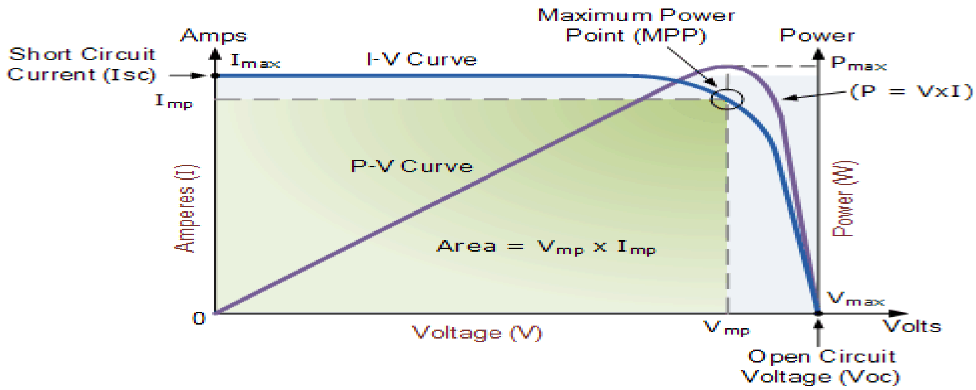


Figure 2 I-V & P-V curve

2.3 Parameters who impact the characteristics

- Insolation level
- Temperature
- Series resistance
- Shunt resistance
- Diode reverse saturation current

The fundamental equation of PV cell is used to study the model and to analyze and best fit observation data. The model can be used in measuring and understanding the behaviour of photovoltaic cells for certain changes in PV cell parameters. A numerical method is used to analyze the parameters sensitivity of the model to achieve the expected results to understand the deviation of changes in different parameters situation at various conditions respectively. The ideal parameters are used to study the models behaviour. It is also compared the behaviour of current-voltage and power-voltage by comparing with produced maximum power point though it is a challenge to optimize the output with real time simulation. All simulation work was done in MATLAB.[13]

2.4 Use of Maximum Power Point Tracking

Function of a MPPT is analogous to the transmission in a car. When the transmission is in the wrong gear, the wheels do not receive maximum power. That's because the engine is running either slower or faster than its ideal speed range. The purpose of the transmission is to couple the engine to the wheels, in a way that lets the engine run in a favorable speed range in spite of varying acceleration and terrain.

Now we need to understand that how MPPT works. The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery.

MPPT is most effective under these conditions:

- Cold weather, cloudy or hazy days: Normally, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.
- When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers.

A MPPT **solar charge controller** is the charge controller embedded with MPPT algorithm to maximize the amount of current going into the battery from PV module. MPPT is DC to DC converter which operates by taking DC input from PV module, changing it to AC and converting it back to a different DC voltage and current to exactly match the PV module to the battery.[14]

Examples of DC to DC converter are

- **Boost converter** is power converter which DC input voltage is less than DC output voltage. That means PV input voltage is less than the battery voltage in system.
- **Buck converter** is power converter which DC input voltage is greater than DC output voltage. That means PV input voltage is greater than the battery voltage in system.

MPPT algorithm can be applied to both of them depending on system design. Normally, for battery system voltage is equal or less than 48 V, buck converter is useful. On the other hand, if battery system voltage is greater than 48 V, boost converter should be chosen .In this report we defined how our parameters affect the Maximum power and the corresponding voltage i.e. Maximum Power point. [15]

Chapter 3
Mathematical model

The model of the general PV module which comprises of a photodiode current, a diode, a parallel resistor which is significance of leakage current and an resistor connected in series expressing internal resistance stream, is appeared in figure 2.[16]

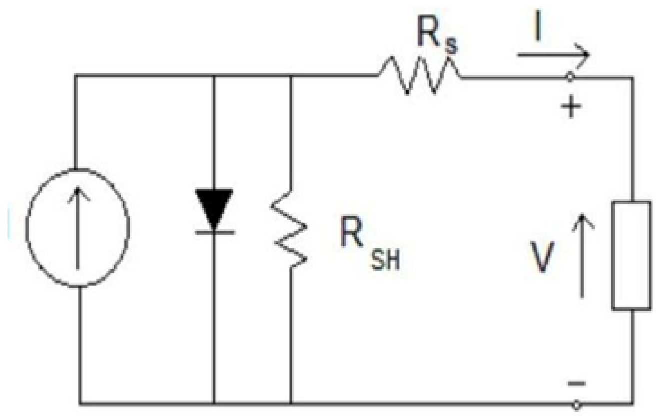


Figure 3 model of PV Cell

PV cell output current is given by

$$I = I_{ph} - I_s\left(e^{\left\{\frac{q(V+IR_s)}{k*Tc*\eta}\right\}} - 1\right) - \frac{V + IR_s}{R_{sh}}$$

Where

I_{ph} = photocurrent of PV cell,
I_s= saturation current of PV cell in dark,
q = value of charge of an electron= 1.602 x 10^{-19}C

k = Boltzmann's constant = 1.38 x 10^{-38}J/K
T_c= Working temperature of PV cell
A = an ideal factor here we are taking 1.498
R_{sh} = a shunt resistance we are taking 0.3 Ω
R_s = a series resistance we are taking 60Ω

Table 1 Parameters taken for mathematical modeling

The photocurrent of cell is given by

$$I_{ph} = [I_{sc} + K_i(T_c - T_{ref})] * G$$

Where

I_{sc} = short-circuit current of PV cell

K_i is known as temperature coefficient for current. For silicon cell 1.38* e^{-23}

T_{ref}= the cell's reference temperature

G = the solar radiation level in kW/m^2

On the other hand, the cell's saturation current varies with the cell temperature, which is described as

$$I_s = I_{rs}(\frac{T_c}{T_{ref}})^3 e^{[\frac{qEg\left(\frac{1}{T_{ref}}-\frac{1}{T_c}\right)}{k\eta}]}$$

Where,

I_{rs} = the cell's reverse saturation current,

Eg = Energy barrier between the conduction and valence band

I-V curve for PV cell is shown in figure 3 and power curve is shown in figure 4.

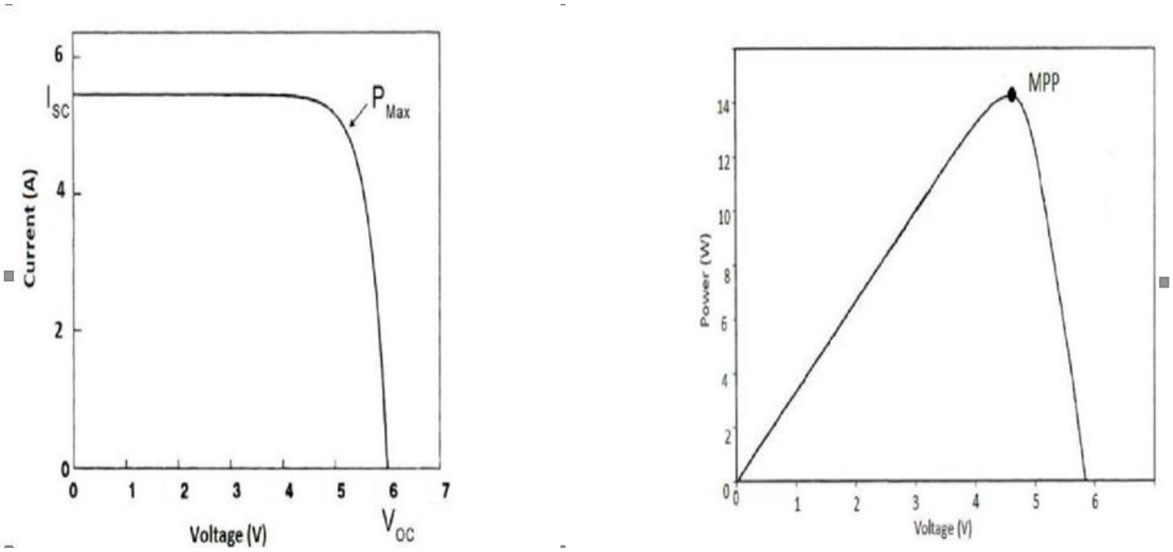


Figure 4 I-V & P-V curve of PV cell

Chapter 4
Analysis with different parameters

We are going to analyze I-V & P-V characteristics of solar cell with the variation of different parameters. I-V & P-V characteristics of PV cell are given by mathematical model which is described in last chapter.

4.1 Impact of change in solar irradiance

With the increament of solar radiation there is increment of current-voltage (I-V) graph and its most extreme point moreover. The effect on the power-voltage graph is that while there is increment of solar radiations there is increment of PV graph .Constants utilized for getting the outcomes in MATLAB are

Reference value for short circuit current (Iscref) =2.55mA
Reference value for ambient Temperature (TrKref)=25^{o}**C**
Reference value for insolation (Gref)=1
Reference value for open circuit voltage (Vocref)=0.59

Table 2 Reference values used in simulation

```
1.Function [Vpv,Id,Ppv]= Insolation(ins,Tac)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
%voltage temperature coefficient
Ki=3.18e-3;
%Current temperature coefficient
k = 1.381e-23;
q = 1.602e-19;
```

```
Rs=0.0001
Rsh=10000;
G = ins/1000;
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
      Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
      Vpv(i+1)=Vpv(i)+0.015;
if Id(i+1)<0
    Id(i+1)=0;
end
end
Ppv=Vpv.*Id;
End
```

2. [V1,I1,P1]=Insolation(1000,25)

```
[V2,I2,P2]=Insolation(1200,25)
[V3,I3,P3]=Insolation(1400,25)
[V4,I4,P4]=Insolation(1600,25)
subplot(2,1,1)
plot(V1,I1,'r',V2,I2,'g',V3,I3,'b',V4,I4,'y')
legend('1000 W/m2','1200 W/m2','1400 W/m2','1600 W/m2')
title('I-V characteristics')
xlabel('Voltage (V)');
ylabel('current (I)');
```

```
subplot(2,1,2)
plot(V1,P1,'r',V2,P2,'g',V3,P3,'b',V4,P4,'y')
title('P-V characteristics')
legend('1000 W/m2','1200 W/m2','1400 W/m2','1600 W/m2')
xlabel('Voltage (V)')
ylabel('power (P)')
```

As we increase the insolation level I-V & P-V curve increases i.e. current and power level increases for the same voltage output. By increasing the insolation level short circuit current (Isc) and open circuit voltage (Voc) increases. With insolation level of 1000W/m^2,1200 W/m^2,1400 W/m^2,1600 W/m^2 different curves are[17]

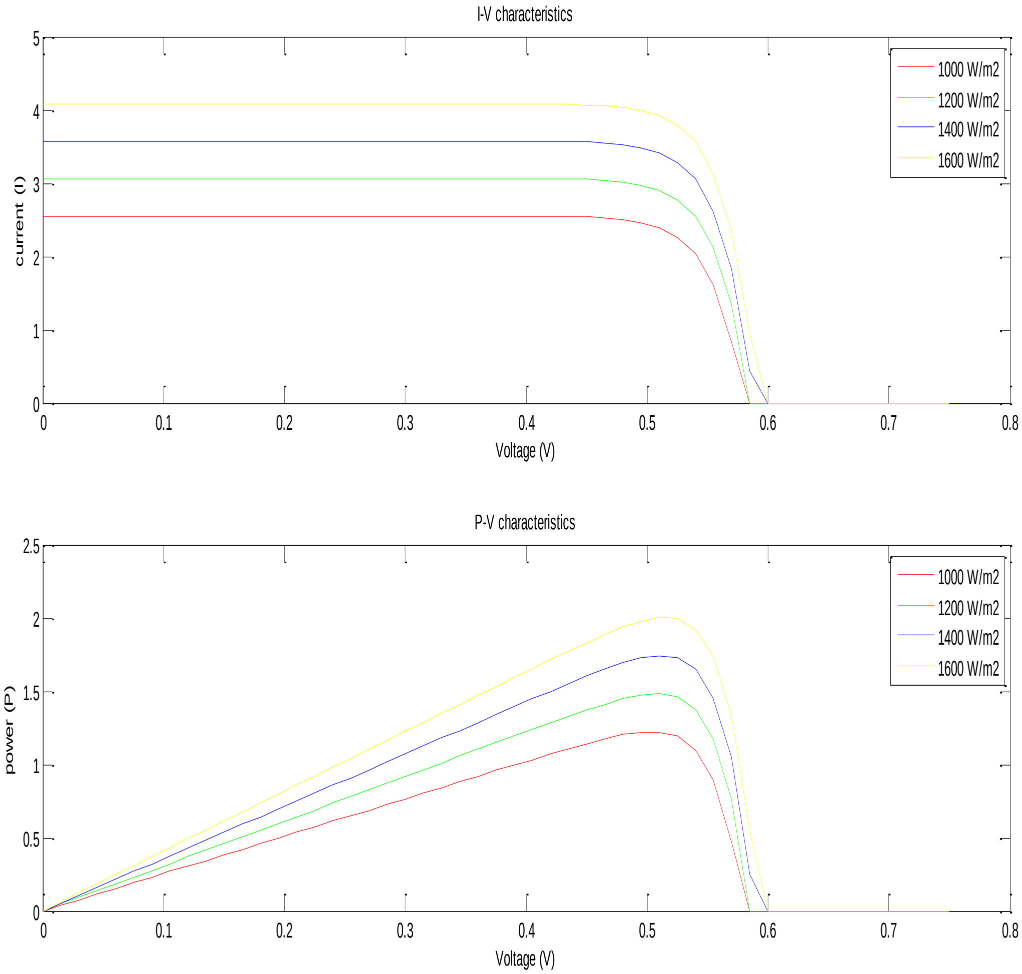


Fig 5 I-V & P-V characteristics with different insolation level

4.2 Impact of change in cell Temperature

Same reference values are used as for getting the effect of different solar irradiance level i.e. same value of Iscref, TrKref, Gref etc. By increasing temperature Voc decreases and Isc increases.

```
1.function[Vpv,Id,Ppv]=TEMPERATURE(ins,Tac)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
Ki=3.18e-3;
k = 1.381e-23;
q = 1.602e-19;
nref=1.498;
TaK = Tac + 273.15;
n = nref*(TaK/TrKref);
Ns=36;
Vtref = nref * k * TrKref/q;
Vt = Vtref*(TaK/TrKref)
Rs=0.0001
Rsh=10000;
G = ins/1000;
Iscref=2.55;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
    Id(i+1)=Iph-(Io*(exp((Vpv(i))/Vt)-1));
    Vpv(i+1)=Vpv(i)+0.015;
```

```
if Id(i+1)<0
   Id(i+1)=0;
end
end
Ppv=Vpv.*Id;
End
```

```
2 [V1,I1,P1]=TEMPERATURE(1000,25)
[V2, I2,P2]=TEMPERATURE (1000,26)
[V3, I3,P3]=TEMPERATURE (1000,27)
[V4, I4,P4]=TEMPERATURE (1000,28)
subplot(2,1,1)
plot(V1,I1,'r',V2,I2,'g',V3,I3,'b',V4,I4,'y')
legend('25 C','26 C','27 C','28 C')
title('I-V characteristics')
xlabel('Voltage (V)');
ylabel('current (I)');
subplot(2,1,2)
plot(V1,P1,'r',V2,P2,'g',V3,P3,'b',V4,P4,'y')
title('P-V characteristics')
legend('25 C','26 C','27 C','28 C')
xlabel('Voltage (V)')
ylabel('power (P)')
```

If we increase the cell temperature then there is increase in Isc and decrease in Voc.For Different temperature value of 25^oC,26^oC,27^oC,28^oC curves are

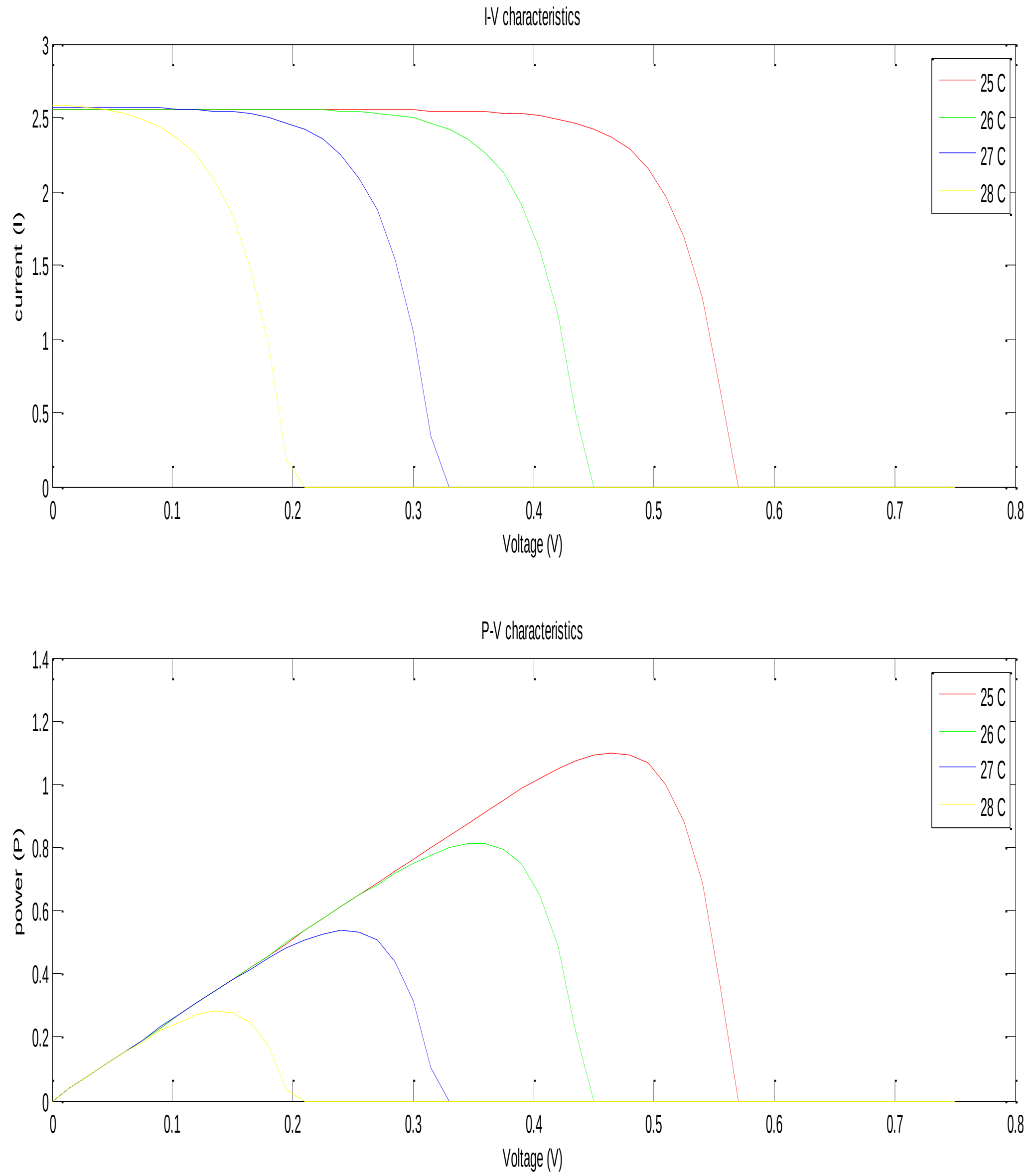


Fig 6 I-V & P-V characteristics with different temperature

4.3Impact of change in Series Resistance (Rs)

Although effect of series resistance is not so significant . With variation of series resistance short circuit current changes slightly and open current voltage remains same .By increasing value of series resistance current-voltage curve and power voltage curve decrease.

```
function[Vpv,Id,Ppv]= Resistance(Rs)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
% Nominal array open circuit voltage
Kv = -0.123;
% Volage/ temperature coefficient
Ki=3.18e-3;
% Current temp coeff
ins = 1000;
Tac =25;
k = 1.381e-23;
% Boltzmann's constant
q = 1.602e-19;
% Electron charge
Rsh=10000;
G = ins/1000;
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
```

```
for i=1:50;
      Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
      Vpv(i+1)=Vpv(i)+0.015;
if Id(i+1)<0
    Id(i+1)=0;
end
end
Ppv=Vpv.*Id;
end
```

```
2.[V1,I1,P1]=Resistance(0.01)
[V2,I2,P2]=Resistance (0.02)
[V3,I3,P3]=Resistance (0.03)
[V4,I4,P4]=Resistance (0.04)
subplot(2,1,1)
plot(V1,I1,'r',V2,I2,'g',V3,I3,'b',V4,I4,'y')
legend('0.01 ohm','0.02 ohm','0.03 ohm','0.04 ohm')
title('I-V characteristics')
xlabel('Voltage (V)');
ylabel('current (I)');
subplot(2,1,2)
plot(V1,P1,'r',V2,P2,'g',V3,P3,'b',V4,P4,'y')
title('P-V characteristics')
legend('0.01 ohm','0.02 ohm','0.03 ohm','0.04 ohm')
xlabel('Voltage (V)')
ylabel('power (P)')
```

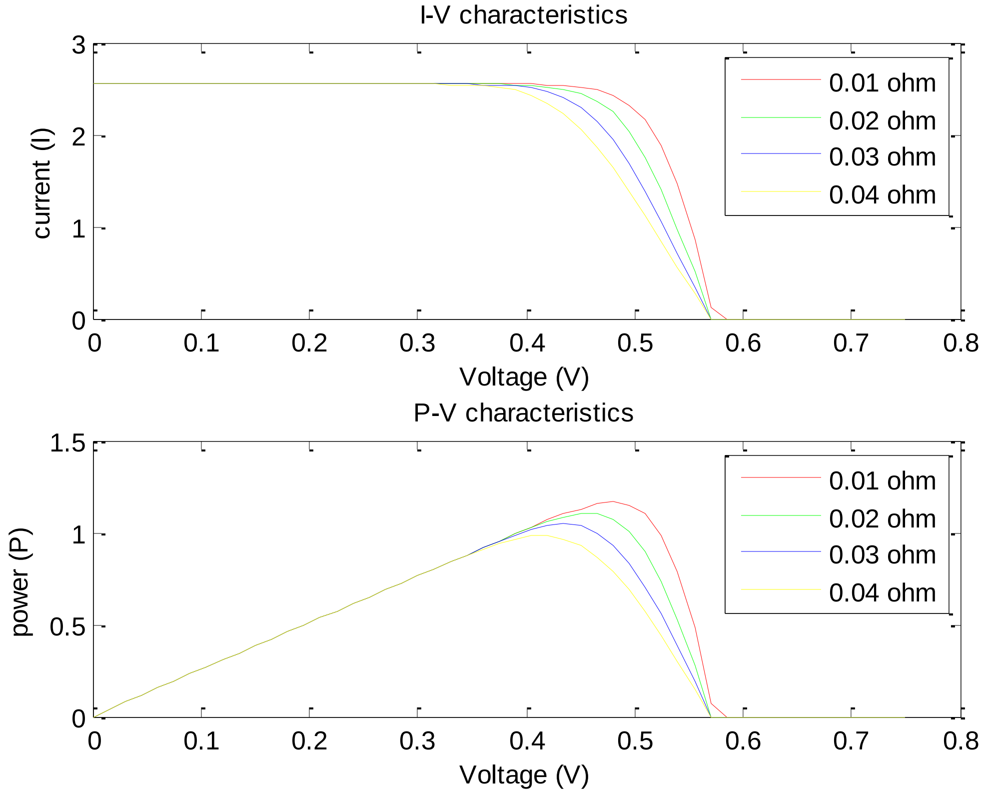


Fig 7 I-V & P-V characteristics with different series resistance

We can observe that there is not so significant effect of varying series resistance. There are change in curves but not in open circuit voltage and short circuit current. So peak power changes and voltage at which peak power is observed also changes.

4.4 Impact of change in Shunt Resistance (Rsh)

For the different voltage and current output shunt resistance can be calculated. Formula for getting this resistance is

$$R_{sh} = \frac{(V + R_S I)}{\left[I_{ph} - I_S \left(\exp\left(\frac{qV + qR_S I}{NKT} \right) - 1 \right) I \right]}$$

Shunt resistance has little impact on current-voltage curve. With the increase of shunt resistance, short circuit current remains almost same but open circuit voltage increases.

```
1)function[Vpv,Id,Ppv]= Shunt(Rsh)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
Ki=3.18e-3;
ins = 1000;
Tac =25;
k = 1.381e-23;
q = 1.602e-19;
Rs=0.0001
G = ins/1000;
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
```

```
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
    Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
    Vpv(i+1)=Vpv(i)+0.015;
if Id(i+1)<0
   Id(i+1)=0;
end
end
Ppv=Vpv.*Id;
end
```

2) [V1,I1,P1]=Shunt(1)

```
[V2,I2,P2]=Shunt(4)
[V3,I3,P3]=Shunt(5000)
subplot(2,1,1)
plot(V1,I1,'r',V2,I2,'g',V3,I3,'b')
legend('1 ohm','4 ohm','5000 ohm')
title('I-V characteristics')
xlabel('Voltage (V)');
ylabel('current (I)');
subplot(2,1,2)
plot(V1,P1,'r',V2,P2,'g',V3,P3,'b')
title('P-V characteristics')
legend('1 ohm','4 ohm','5000 ohm')
xlabel('Voltage (V)')
ylabel('power (P)')
```

Observation are taken on different value of shunt resistance of 1ohm, 4 ohm, 5000 ohm .As we can see in the graph by varying series resistance Isc remains same and Voc changes but variation of Voc is also not so much significant.[18]

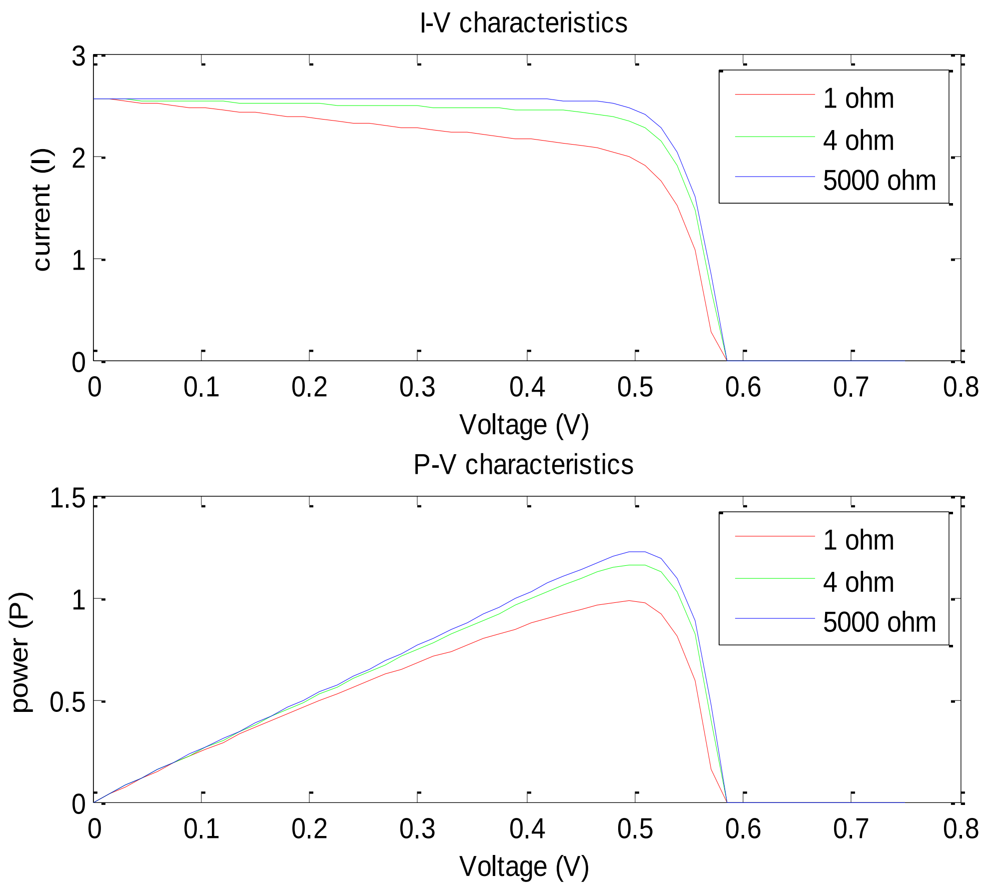


Fig 8 I-V & P-V curve with different shunt resistance

4.5 Impact of change in Diode Reverse Saturation Current (Is)

Diode reverse saturation current is the maximum current that can flow in the reverse bias condition. With the increase of diode Is,Voc decreases and Isc remains almost same.

```
1.function[Vpv,Id,Ppv]= saturationCURRENT(Io)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
Ki=3.18e-3;
ins = 1000;
Tac =25;
k = 1.381e-23;
q = 1.602e-19;
Rs=0.0001
Rsh=10000;
G = ins/1000;
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
%Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
    Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
    Vpv(i+1)=Vpv(i)+0.015;
if Id(i+1)<0
```

```
    Id(i+1)=0;
end
end
Ppv=Vpv.*Id;
end
```

2. [V1,I1,P1]=saturationCURRENT(1e-9)

```
[V2,I2,P2]=saturationCURRENT(20e-9)
[V3,I3,P3]=saturationCURRENT(100e-9)
subplot(2,1,1)
plot(V1,I1,'r',V2,I2,'g',V3,I3,'b')
legend('1nA','20nA','100nA')
title('I-V characteristics')
xlabel('Voltage (V)');
ylabel('current (I)');
subplot(2,1,2)
plot(V1,P1,'r',V2,P2,'g',V3,P3,'b')
title('P-V characteristics')
legend('1nA','20nA','100nA')
xlabel('Voltage (V)')
ylabel('power (P)')
```

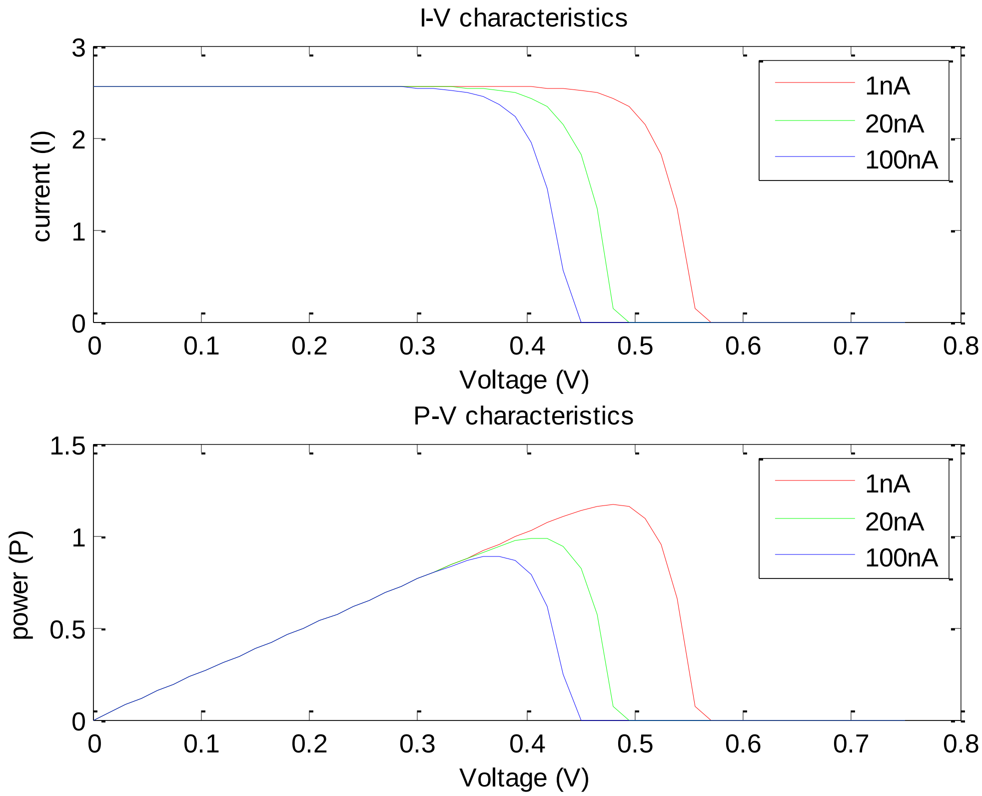


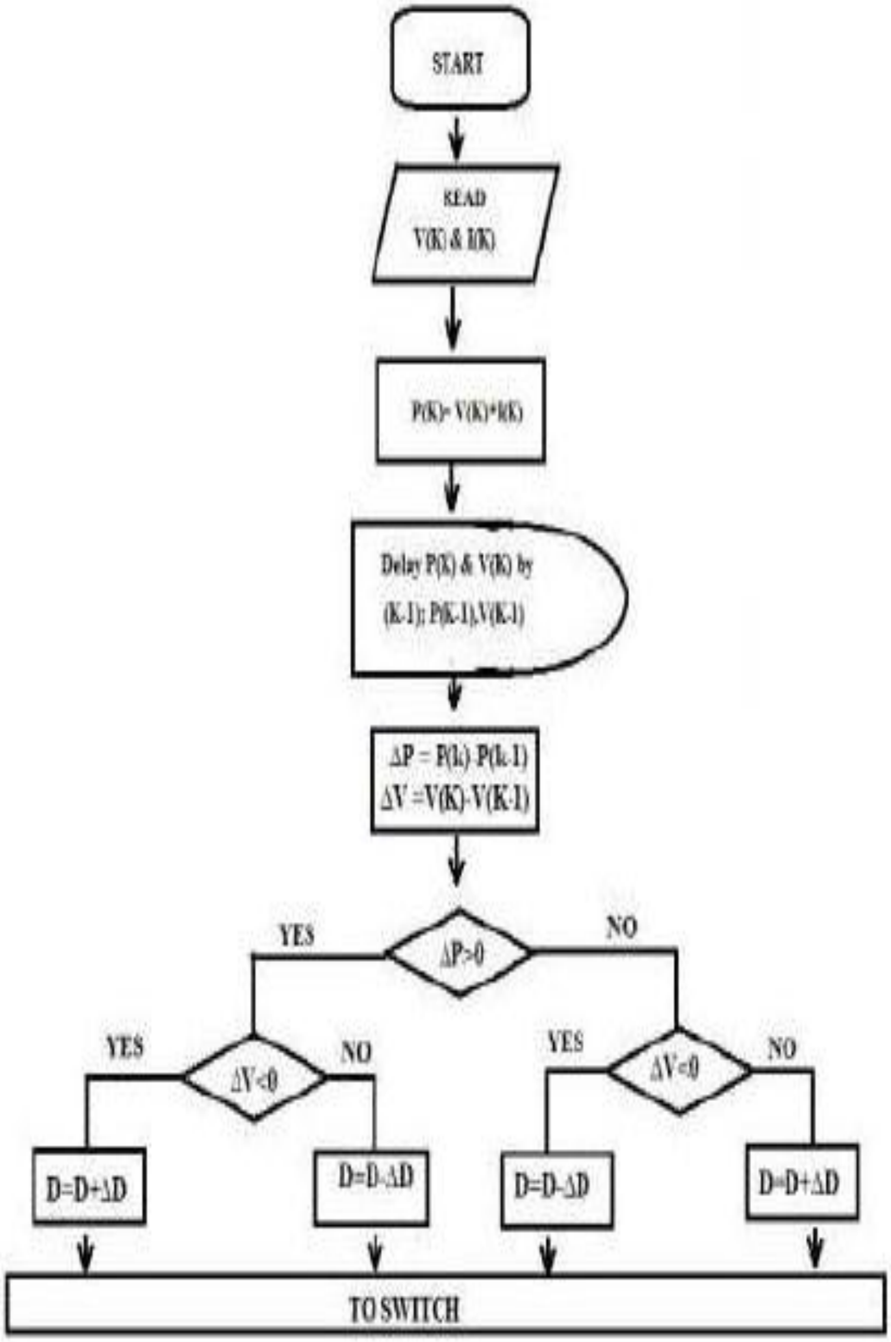
Fig 9 I-V & P-V curve with different Is

Observation are taken on 3 different value of 1nA, 20nA and 100nA.As we can see maximum power point increases with increasing value of diode reverse saturation current.

CHAPTER 5
MPPT (MAXIMUM POWER POINT TRACKING)

Perturb and observe is utilized here. The P&O calculation is additionally called "hill-climbing", while the two names allude to a similar calculation relying upon how it is executed.P&O comprise of an annoyance on the obligation cycle of the power converter and P&O a bother in the working voltage of the DC connect between the PV exhibit and the power converter.On account of the P&O algorithm, irritate the obligation cycle of the power converter infers changing the voltage of the DC connect between the PV exhibit and the power converter, so both name allude to a similar procedure.The indication of the last irritation and the indication of the last augmentation in the power are utilized to choose what the following annoyance ought to be on the left of the Maximum power point increasing the voltage increase the power while on the right decrement in the voltage increases the power.

On the off chance that there is addition in the power, the bother ought to be kept a similar way and if the power diminishes, at that point the following annoyance ought to be the other way. In view of these certainties, the calculation is actualized. The procedure is repeated until the MPP is come to.[19] At that point the working point sways around the MPP. A plan of the calculation is appeared in Figure


START
READ
V(K) & I(K)
P(K)= V(K)*I(K)
Delay P(K) & V(K) by
(K-1); P(K-1),V(K-1)
ΔP = P(k)-P(k-1)
ΔV =V(K)-V(K-1)
ΔP>0
YES
NO
ΔV<0
YES
NO
ΔV<0
YES
NO
D=D+ΔD
D=D-ΔD
D=D-ΔD
D=D+ΔD
TO SWITCH

5.1 Effect of insolation:-

As we increase the insolation level Maximum power of the solar cell also increases .As we increase the insolation level, Voltage at which maximum power is observed shifts towards the right. For the simulation series resistance of 0.1 mΩ and shunt resistance of 10000Ω are taken.

```
1)function[Vpv,Ppv]= MPPT(ins,Tac)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
Ki=3.18e-3;
%ins = 1100;
%Tac =25;
k = 1.381e-23;
q = 1.602e-19;
Rs=0.0001
Rsh=10000;
G = ins/1000;
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
    Vpv(i+1)=Vpv(i)+0.015
```

```
if Id(i+1)<0
   Id(i+1)=0;
end
end
Ppv=Vpv.*Id
End
```

```
2.function [Vmax,Pmax]=FMP(in,Ta)
i=2;
V(1)=0;
[V,P]=MPPT(in,Ta);
V(2)=V(1)+0.015;
DP=P(2)-P(1);
while DP>0.001
if DP>0
   if V(i+1)>V(i)
   V(i+1)=V(i)+0.015;
   else
      V(i+1)=V(i)-0.015;
   end
   else
   if V(i+1)>V(i)
   V(i+1)=V(i)-0.015;
   else
      V(i+1)=V(i)+0.015;
   end
end
DP=P(i+1)-P(i);
i=i+1;
end
if P(i)>P(i-1)
   Vmax=V(i)
```

```
   Pmax=P(i)
else
   Vmax=V(i-1)
   Pmax=P(i-1)
end
```

```
3.[V1,P1]=FMP(1000,26);
[V2,P2]=FMP(3000,26);
[V3,P3]=FMP(4000,26);
[V4,P4]=FMP(8000,26);
disp('With increasing value of insolation  MAX voltage is ')
disp(V1)
disp(V2)
disp(V3)
disp(V4)
disp('With increasing value of insolation  MAX power is ')
disp(P1)
disp(P2)
disp(P3)
disp(P4)
```

For observing the Maximum power and Maximum voltage variation different value of insolation level 1000,3000,4000,8000 W/m^2 are taken. There is significant difference in maximum power with variation of insolation level but difference in maximum voltage is not so significant and as we know both of these two increase with increasing insolation level.[20]

```
With increasing value of insolation  MAX voltage is
    0.3900

    0.4050

    0.4200

    0.4350

With increasing value of insolation  MAX power is
    0.9279

    2.9736

    4.0416

    8.4005
```

5.2 Effect of temperature

```
[V1,P1]=FMP(1100,26);
[V2,P2]=FMP(1100,28);
[V3,P3]=FMP(1100,30);
disp('With increasing value of Temperature  MAX voltage is ')
disp(V1)
disp(V2)
disp(V3)
disp('With increasing value of Temperature  MAX power is ')
disp(P1)
disp(P2)
disp(P3)
```

As we increase the temperature Maximum power decreases and Maximum voltage also decreases. For different value of 26^{o}C,28^{o}C and 30^{o}C observation are taken and insolation level of 1100W/m^2 kept same.

```
With increasing value of Temperature  MAX voltage is
    0.3900

    0.1650

    0.0150

With increasing value of Temperature  MAX power is
    1.0275

    0.3977

    0.0396
```

5.3 Effect of series resistance

By increasing the value of series resistance, there are decrease in Maximum power and Maximum voltage.

```
1 function[Vpv,Ppv]= MPPT2(Rs,Rsh)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
Ki=3.18e-3;
ins = 1100;
Tac =25;
k = 1.381e-23;
q = 1.602e-19;
G = ins/1000;
Rs=0.00001
Rsh=10000
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
Io=(Iscref+Ki*(TaK-TrKref))/exp(((Vocref+Kv*(TaK-TrKref))/Vt)-1)
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
    Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
    Vpv(i+1)=Vpv(i)+0.015
if Id(i+1)<0
   Id(i+1)=0;
```

```
end
end
Ppv=Vpv.*Id
end

2function [Vmax,Pmax]=FMP2(Rs,Rsh)
i=2;
V(1)=0;
[V,P]=MPPT2(Rs,Rsh);
V(2)=V(1)+0.015;
DP=P(2)-P(1);
while DP>0.001
if DP>0
    if V(i+1)>V(i)
    V(i+1)=V(i)+0.015;
    else
        V(i+1)=V(i)-0.015;
    end
    else
    if V(i+1)>V(i)
    V(i+1)=V(i)-0.015;
    else
        V(i+1)=V(i)+0.015;
    end
end
DP=P(i+1)-P(i);
i=i+1;
end
if P(i)>P(i-1)
    Vmax=V(i)
    Pmax=P(i)
```

```
else
   Vmax=V(i-1)
   Pmax=P(i-1)
End
```

```
3 [V1,P1]=FMP2(0.000002,10000);
[V2,P2]=FMP2(0.000004,10000);
[V3,P3]=FMP2(0.000006,10000);
disp('With increasing value of resistance  MAX voltage is ')
disp(V1)
disp(V2)
disp(V3)
disp('With increasing value of resistance  MAX power is ')
disp(P1)
disp(P2)
disp(P3)
```

Different value of series resistance of 2 µΩ, 4 µΩ,6 µΩ are taken for the shunt resistance of 10000Ω.As we can see from the results Maximum power and Maximum voltage decrease as we increase the series resistance.

```
With increasing value of resistance  MAX voltage is
    0.5100


    0.5100


    0.3900

With increasing value of resistance  MAX power is
    1.3514


    1.3479


    0.9949
```

5.4 Effect of shunt resistance

As we increase the shunt resistance there is increase of Maximum voltage and Maximum power and as we know value of shunt resistance is generally very high so there is not so significant difference in Maximum voltage and Maximum power values.

```
[V1,P1]=FMP2(0.001,10);
[V2,P2]=FMP2(0.001,500);
[V3,P3]=FMP2(0.001,3000000);
disp('With increasing value of resistance  MAX voltage is ')
disp(V1)
disp(V2)
disp(V3)
disp('With increasing value of resistance  MAX power is ')
disp(P1)
disp(P2)
disp(P3)
```

Results are

```
With increasing value of resistance  MAX voltage is
    0.4950

    0.5100

    0.5100

With increasing value of resistance  MAX power is
    1.3176

    1.3419

    1.3424
```

5.5 Effect of saturation current

```
function[Vpv,Ppv]= MPPT3(Io)
Iscref = 2.55;
TrKref = 273.15 + 25;
Gref = 1;
Vocref = 0.59;
Kv = -0.123;
Ki=3.18e-3;
ins = 1100;
Tac =25;
k = 1.381e-23;
q = 1.602e-19;
G = ins/1000;
Rs=0.00001
Rsh=10000
Iscref=2.55;
TaK = Tac + 273.15;
Isc=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref));
Vt = 0.025*(TaK/TrKref);
Iph=(Iscref*(1+Ki*(TaK-TrKref))*(G/Gref))
Vpv(1)=0;
Id(1)=Isc;
for i=1:50;
    Id(i+1)=Iph-(Io*(exp((Vpv(i)+Id(i)*Rs)/Vt)-1))-(Vpv(i)+Id(i)*Rs)/Rsh;
    Vpv(i+1)=Vpv(i)+0.015
if Id(i+1)<0
   Id(i+1)=0;
end
end
Ppv=Vpv.*Id
end
```

```
2. function [Vmax,Pmax]=FMP3(Io)
i=2;
V(1)=0;
[V,P]=MPPT3(Io);
V(2)=V(1)+0.015;
DP=P(2)-P(1);
while DP>0.001
if DP>0
    if V(i+1)>V(i)
    V(i+1)=V(i)+0.015;
    else
        V(i+1)=V(i)-0.015;
    end
    else
    if V(i+1)>V(i)
    V(i+1)=V(i)-0.015;
    else
        V(i+1)=V(i)+0.015;
    end
end
DP=P(i+1)-P(i);
i=i+1;
end
if P(i)>P(i-1)
    Vmax=V(i)
    Pmax=P(i)
else
    Vmax=V(i-1)
    Pmax=P(i-1)
end
```

```
3. [V1,P1]=FMP3(1e-9);
[V2,P2]=FMP3(20e-9);
[V3,P3]=FMP3(100e-9);
disp('With increasing value of Temperature  MAX voltage is ')
disp(V1)
disp(V2)
disp(V3)
disp('With increasing value of Temperature  MAX power is ')
disp(P1)
disp(P2)
disp(P3)
```

```
With increasing value of Temperature  MAX voltage is
    0.4800

    0.4050

    0.3750

With increasing value of Temperature  MAX power is
    1.2889

    1.0877

    0.9845
```

As saturation current increases Maximum voltage and Maximum power decrease. Series resistance of 10 μΩ and shunt resistance of 10000Ω are taken for the resul

Chapter 6
Conclusion and future scope

In this project variation in I-V & P-V curve with change in different parameters are observed. Significance of these variation is mainly given by short circuit current (Isc) ,open circuit voltage (Voc),Maximum power and the voltage at which maximum power is observed i.e. Maximum power point. As we can see Isc Voc and maximum power increase with increasing insolation level. [21]Voltage at maximum power also shifts towards the right with increasing insolation. With increase in temperature level Isc increases and Voc decreases so Maximum power decreases and Maximum power shifts towards the left. With variation of series resistance there is no such significant change in Current voltage (I-V) & power voltage (P-V) curve Although Maximum power and that point decreases. Effect of shunt resistance is not so significant. Increment in Rsh tends to increase in Voc but Isc remains same. On the other hand increment in Is tends to decrease in Voc. In this case Isc also remains constant

This work was done considering uniform illumination throughout the cell. So work on behavior of cell in the non uniform illumination stays left. In that case heating of cell at different point of cell will vary, So cell output will differ from its usual behavior. For mathematical study under that condition we need to require a constant so that we can normalize the shape.

References

1. Vick, B.D., Clark, R.N. (2005). Effect of panel temperature on a Solar-PV AC water pumping system, pp. 159–164 in: Proceedings of the International Solar Energy Society (ISES) 2005 Solar Water Congress: Bringing water to the World, 8–12 August 2005, Orlando, Florida.

2. Building Integrated Photovoltaic, Wisconsin Public Service Corporation, accessed: 23 March 2007. Archived 2 February 2007 at the Wayback Machine.

3. Solar panels keep buildings cool *University of California, San Diego*. Retrieved 19 May 2015.

4. Global Market Outlook for Photovoltaics 2014–2018" *(PDF).EPIA–European Photovoltaic Industry Association. p. 45.* Archived *from the original on 12 June 2014 Retrieved 19 May 2015.*

5. Mojiri, A.; Taylor, R.; Thomsen, E.; Rosengarten, G. (2013*). "*Spectral beam splitting for efficient conversion of solar energy—A review". Renewable and Sustainable Energy Reviews. 28: 654–663. doi:10.1016/j.rser.2013.08.026.

6. *Pathak, M. J. M.; Sanders, P. G.; Pearce, J. M. (2014). "Optimizing limited solar roof access by exergy analysis of solar thermal, photovoltaic, and hybrid photovoltaic thermal systems". Applied Energy.* ***120****: 115–124.* *doi:10.1016/j.apenergy.2014.01.041*.

7. Off grid solutions for remote poor. ebono.org. (26 February 2008).

8. Barclay, Eliza (31 July 2003). Rural Cuba Basks in the Sun. is lamonline.net.

9. Brebbia, C. A. Boundary element methods in engineering. New York, NY, USA:: Springer, 1982.

10. Allen, George Cyril. *The industrial development of Birmingham and the Black Country, 1860-1914*. Diss. University of Birmingham, 1928.

11. Christie, M. A., and M. J. Blunt. "Tenth SPE comparative solution project: A comparison of upscaling techniques." *SPE Reservoir Simulation Symposium*. Society of Petroleum Engineers, 2001.

12. Hamed, Basil M., and Mohammed S. El-Moghany. "Fuzzy controller design using FPGA for photovoltaic maximum power point tracking." *International Journal of Advanced Research in Artificial Intelligence* 1.3 (2012): 14-21...

13. Chowdhury, Suman, et al. "Performance parameter analysis of grid connected building integrated photovoltaic application in Bangladesh." *Informatics, Electronics & Vision (ICIEV), 2012 International Conference on*. IEEE, 2012

14. How 3D Printers Are Boosting Off-The-Grid, Underdeveloped Communities – MotherBoard, Nov. 2014

15. *King, Debbie L.; Babasola, Adegboyega; Rozario, Joseph; Pearce, Joshua M. (2014). " Mobile Open-Source Solar-Powered 3-D Printers for Distributed Manufacturing in Off-Grid Communities". Challenges in Sustainability. **2**. doi:10.12924/cis2014.02010018*

16. Erickson, Jon D.; Chapman, Duane (1995). "Photovoltaic Technology: Markets, Economics, and Development"World Development. 23 (7): 1129–1141. doi:10.1016/0305-750x(95)00033-9.

17. Xing, Y., Han, P., Wang, S., Liang, P., Lou, S., Zhang, Y., ... & Mi, Y. (2015). A review of concentrator silicon solar cells. *Renewable and Sustainable Energy Reviews*, *51*, 1697-1708.

18. Nguyen, X. H., & Nguyen, M. P. (2015). Mathematical modeling of photovoltaic cell/module/arrays with tags in Matlab/Simulink. *Environmental Systems Research*, *4*(1), 24.

19. Bellia, H., Youcef, R., & Fatima, M. (2014). A detailed modeling of photovoltaic module using MATLAB. *NRIAG Journal of Astronomy and Geophysics*, *3*(1), 53-61.

20. Gupta, A. K., Chauhan, N. S., & Saxena, R. (2016, February). Real time IV and PV curve tracer using LabVIEW. In *Innovation and Challenges in Cyber Security (ICICCS-INBUSH), 2016 International Conference on* (pp. 265-269). IEEE.

21. Altas, I. H., & Sharaf, A. M. (2007, May). A photovoltaic array simulation model for matlab-simulink GUI environment. In *Clean Electrical Power, 2007. ICCEP'07. International Conference on* (pp. 341-345). IEEE.