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Performance Evaluation of SOLAR PV CELL under Different Solar Irradiation

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Abstract: ***Sun powered vitality has been utilized by human race since long times utilizing a heaps of innovations. A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. For PV cells, a more slender semiconductor sheet is uniquely made to structure an electric field, positive extremity on one side and negative on other. At the point when photons strike a sun powered cell, electrons are accumulated detached from iotas the semiconductor material. In the event that current conduits are appended to the both the sides, structuring a current exchanging circuit, the electrons move to manifestation of a current i.e., power for fulfilling different power needs. The overall performance of solar cell varies with varying Irradiance and Temperature .With the change in the time of the day the power received from the Sun by the PV panel changes. This paper gives an idea about how the solar cell performance changes with the change in above mentioned factors and compares the solar radiation of two regions Faridabad and Chennai. The results are simulated in MATLAB.***

Keywords: MATLAB, Voltage open circuit, Solar cell, Fill factor

1. Introduction

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current. However a photovoltaic cell is different from a photodiode. In a photodiode light falls on N channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased. A complex relationship between voltage and current is exhibited by the P-N junction in the solar cell. The voltage and current both being a function of the light falling on the cell, there exists a complex relationship between insolation (sunlight) and output power. The photovoltaic effect was discovered by Alexander-Edmond Becquerel in 1839[1].

Solar cells capture slow-moving low energy electrons. These effects are saturated and cause a fixed energy loss under bright light condition. However, on an overcast day i.e. at lower insolation levels these mechanisms show an increasing percentage of the total power being generated. Too much insolation causes saturation of cells, and the number of free electrons or their mobility decreases greatly. For an example in case of silicon the holes left by the photoelectrons neutralizes taking some time, and in this time these absorb a photoelectron from another atom inside the cell. This causes maximum as well as minimum production rates.

The photovoltaic (PV) effect is the direct conversion of light into electricity in solar cells. When solar cells are exposed to sunlight, electrons excite from the valence band to the conduction band creating charged particles called holes. In one PV cell, the upper or n-type layer is crystalline silicon doped with phosphorus with 5 valence electrons while the lower or p-type layer is doped with boron, which has 3 valence electrons. By bringing N and P type silicon (semiconductors) together, a p-n junction serves for creating an electric field within the solar cells, which is able to separate electrons and hole and if the incident photon is energetic enough to dislodge a valance electron, the electron

will jump to the conduction band and initiate a current coming out from the solar cells through the contacts. Figure 1 shows this process.

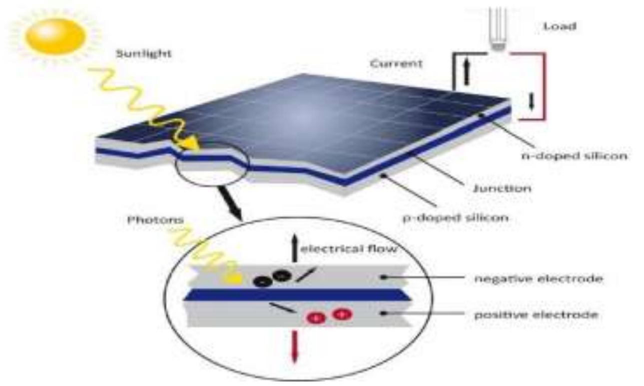


Figure 1: SOLAR cell working

The entire solar cell working is based on solar irradiation and working temperature. In this paper, compare two solar radiation amounts falling on different cities in India and further conclusions about efficiency and working of solar cells in different regions are analyzed. We have emphasized here on solar irradiation because we want to see the impact of intensity on the efficiency of solar cell.

2. Literature Survey

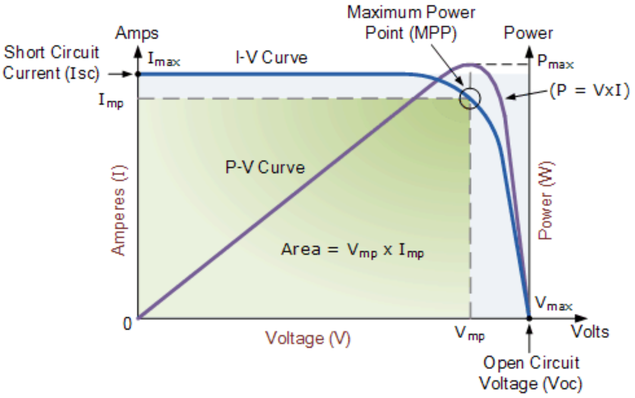
2.1 I-V characteristics of solar cell

The current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a solar cell is the product of current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level. With the solar cell open-circuited that is not connected to any load the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells open circuit voltage, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells short circuit current, or Isc.

The span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between were the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and Vmp. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the "maximum power point" or MPP. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

The maximum power point (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: Vmp ≅ (0.8–0.90)Voc and Imp ≅ (0.85–0.95) Isc. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.



2.2 Solar Array Parameters

2.1.1 V_{OC} = open-circuit voltage

This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition). This value is much higher than Vmp which relates to the operation of the PV array which is fixed by the load. This value depends upon the number of PV panels connected together in series.[6]

2.1.2 I_{SC} = short-circuit current

The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). This value is much higher than Imp which relates to the normal operating circuit current.

2.1.3 MPP = maximum power point

This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where MPP = Imp x Vmp. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp).

2.1.4 FF = fill factor

The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions and the product of the open-circuit voltage times the short-circuit current, (Voc x Isc) This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8.

2.1.5 Percentage efficiency

The efficiency of a photovoltaic array is the ratio between the maximum electrical power that the array can produce compared to the amount of solar irradiance hitting the array [2]. The efficiency of a typical solar array is normally low at around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film) being used.

2.1.6 Solar Irradiance /(solar radiation) :

It is measured perpendicular to the incoming sunlight. It is a measure of the solar power over all wavelengths per unit area incident on the Earth's

2.1.7 Absorption of light:

When the energy of a photon is equal to or greater than the band gap of the any material, the photon is absorbed by the material and by gaining energy electron jump from valance band to conduction band.

Case1:Eph < EG Photon with energy Eph less than the band gap energy EG interact weakly with the semiconductor, passing through it as if it were transparent.

Case 2: Eph = EG it have enough energy to create an electron hole pair and are efficiently absorbed.

Case3: Eph > EG Photons with energy much greater than the band gap are strongly absorbed. However, for photovoltaic applications, the photon energy greater than the band gap is wasted .Bandgap (EG) vary according to material for silicon bandgap is 1.1ev and for germanium 2ev.

2.1.8 Absorption Coefficient:

The absorption coefficient determines how far into a material light of a particular wavelength can penetrate before it is absorbed. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will appear transparent to that wavelength. The absorption coefficient depends on the material and also on the wavelength of light which is being absorbed. Semiconductor materials have a sharp edge in their absorption coefficient, since light which has energy below the band gap does not have sufficient energy to excite an electron into the conduction band from the valence band.

2.1.9 Generation rate:

The generation of an electron-hole pair can be calculated at any location within the solar cell at any wavelength of light or for the entire standard solar spectrum when light fall on semiconductor. Generation is the greatest at the surface of the material, where the majority of the light is absorbed. The generation rate gives the number of electrons generated at each point in the device due to the absorption of photons. Generation is an important parameter in solar cell operation as it lead to production of current.

The probability of absorbing a photon depends on the likelihood of having a photon and an electron interact in such a way as to move from one energy band to another. For photons which have an energy very close to that of the band gap, the absorption is relatively low since only those electrons directly at the valence band edge can interact with the photon to cause absorption. As the photon energy increases, not just the electrons already having energy close to that of the band gap can interact with the photon. Therefore, a larger number of electrons can interact with the photon and result in the photon being absorbed.

The absorption coefficient, α, is related to the extinction coefficient, k, by the following formula:

$$\alpha = \frac{4\pi k}{\lambda}$$

where λ is the wavlength. If λ is in nm, multiply by 10^7 to get the absorption coefficient in the the units of cm^{-1}

The performance of a solar cell is measured in terms of its conversion efficiency at converting sunlight into electricity, i.e. the efficiency of a PV device is defined in terms of the power produced from the incident photons.

Visible light waves may vary between 400 and 700 nanometres, although the sun's spectrum also includes shorter ultraviolet waves and longer waves of infrared. The silicon atoms in a photovoltaic cell absorb energy from light wavelengths that lie in range of the visible spectrum. Light causes the charges to move, producing an electric current. As solar radiation has a great effect on efficiency of the solar cell and other parameters. The intensity of photons falling on comparatively hotter place will be more therefor more current in induced in cell.

Energy is inversely proportional to wavelength given by- $E=hc/\lambda$ where λ =wavelength, h=Plank's constant, c=velocity of light If energy of incident light is more then wavelength is less due to which the light get absorbed in the top most region of solar cell and generate more electron hole pair and hence after the separation of hole pairs as electron jump from valance band to conduction band it leads to generating of electricity.

In this paper, we compare two solar radiation amounts falling on different cities in India (Faridabad and Chennai) and further conclusions about efficiency and working of solar cells in different regions are analyzed. [3]

Faridabad has average solar intensity of 523w/cm2 and Chennai has higher one with 577w/cm2. Therefore, the V-I characteristics and maximum power point and efficiency of solar cells operating in Chennai is higher.

2.3 MATLAB Code

```
%solar intensity Tamil - 5.77KW/sqm and Faridabad - 5.23KW/sqm%
close all;
clear all;
clc ;
T=310;
Tr1=40;
Tr =298;
S=[577 523];
ki=0.00002;
Iscr=3.5;
Irr=0.000021;
k=1.38065*10^(-23);
q=1.6022*10^(-19);
VT=25;
n=1.2;
A=2.15;
Eg=1.21;
Rs=0.0001;
Rsh=1000;
 V0=[0:1:200];
for i=1:2
Iph=(Iscr+ki*(T-Tr))*((S(i))/100);
Irs=Irr*((T/Tr)^3)*exp(q*Eg/(k*A)*((1/Tr)-(1/T)));
I0=Iph-Irs*(exp (V0)/(VT*A)-1);
P0 = V0.*I0;
figure (1)
plot (V0,I0);
axis ([0 20 0 50]);
grid on
hold on;
figure (2)
plot (V0,P0);
axis ([0 20 0 400]);
hold on;
grid on
figure (3)
plot (V0,I0,V0,P0,'-s','MarkerSize',10,...
   'MarkerEdgeColor','red');
axis ([0 20 0 400]);
hold on;
grid on
figure (4)
end
```

2.4 Simulation Results

2.4.1 I-V Characteristics

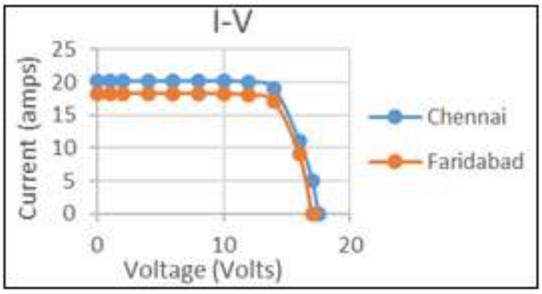


Figure 1: I-V characteristics. Voc of Chennai is larger than Faridabad. Isc (Chennai) = 20.1 amp and (Faridabad) =18.7 amp.

2.4.2 P-V Characteristics

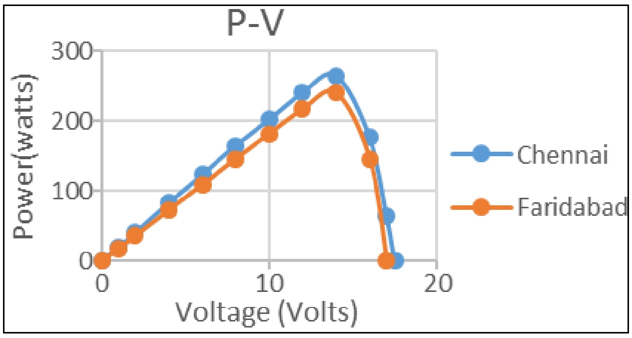


Figure 2: P-V characteristics. MPP of Chennai is larger than Faridabad. Maximum power of Chennai = 265 watts and Faridabad is 239 watts at 14.2 and 14 volts respectively.

2.5 Tables

Table 1: Comparison of parameters

Parameters	Chennai	Faridabad
Voc	17.5	17.2
Isc	20.2	18.32
Vm	14.2	14
Im	18.96	17.07
Pmax	265	239
FF	0.76	0.75
Efficiency	51%	49%

3. Conclusion

We have observed in MATLAB simulations that under greater intensity of light in Chennai region, solar cells have comparatively more efficiency than one operating in Faridabad. The more effective conversion of falling photons into electricity via solar cells is possible in Chennai. Further this model is operated under no losses.

We can utilize the proposed models for different converters and their control studies. The same model can further used to study MPPT algorithms under variant conditions.

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Author Profile

Divya Nagpal, is a post graduate student in YMCA University Haryana. Her area of interests are control systems, power control and renewable energy.