

Pulse Width Modulation based inverter for standalone solar PV cell application”

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Abstract:

As the power demand is going on increasing day-by-day, it is responsible for our engineers to make it available as per the demand. Many of the power generating plant are using non-renewable sources as their primary source. But these may become extinct at any time and before facing the situation we have to choose an alternative to avoid the power crisis. One of the best alternatives is choosing non-conventional sources like solar energy, Wind Energy, Tidal energy, Bio-mass energy etc as the primary sources for power generation in power stations. The power from these sources is several times greater than the one, which we are using at the present. Out of these energy sources, the best one which suits for our country is the solar energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW, which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus if we convert this to other forms of energy, it may be one of the most promising of the non-conventional energy resources. This paper defines a 5-parameter based simulation model for PV cells under partial shading conditions in order to allow estimate the characteristics of the cells so that proper conclusions regarding steps and measures need to be taken to increase solar cell efficiency and thus solar energy capitalization can

be proposed for studies. Environmental issues with concerns on global warming, green house effects, depletion of natural reserves like fossil fuels, natural gas, coal, etc. is motivating research to invest in technologies that can harvest energy from renewable energy sources like wind, solar, tidal waves, etc. Of these, the solar energy with irradiance levels of up to 1kW/m^2 is abundant and photovoltaic power is a prime candidate for electrical energy generation. The first step is the absorption of solar radiation within the semiconductor. In the second step, transformation to electrical energy is made by generating current and voltage by the incident solar radiation on the solar cells that produces electrons-hole pairs. Several such solar cells are connected in different configurations depending on the current/voltage requirements to form Modules. The solar photovoltaic (SPV) based system have increasing roles in electric power technologies and pollution-free electric supplies. A great deal of research has been conducted in this field over the last few decades. SPV panel is a power source having non-linear internal resistance. The panel output power varies with temperature and insulation. This reviews the generalized mathematical modeling and simulation of Solar Photovoltaic System. One-diode equivalent circuit is employed in order to

investigate I-V, P-I and P-V characteristics Single phase standalonen inverter using MATLAB/Simulink.+

Keywords: standalone inverter; Maximum power point tracker (MPPT); Total harmonic distortion; photovoltaic system

1.Introduction

Growing demand for electrical energy, soaring prices of fossil fuels with increased concern about degrading environment have generated enormous amount of interest in the utilization of renewable energy sources such as sun.power generation from photovoltaic (pv)cell has seen rapid groeth in the past few years leading to extensive research on using solar energy. A PV system has the following advantages:

1. Low maintenance cost
2. Absences of moving or rotating parts and hence no wear and tear
3. Almost no environmental impact

The PV system has significant potential commercially both off grid and grid connected ranging form very small applications to megawatts of power in SPV power plants.Despite its rapid growth in past few years,there are several challenges that hinder the commercial use of PV system. These include high installation cost of power generation systems and low energy conversion-efficiency .The I-V chareacteristiic of a PV cell is non – linear with maximum power available at the knee point. A PV system is generally operasted in afashion to extract maximum power from the PV source .Maximum power-point tracking(MPPT) is generally employed,which requires

power electroniucs converters such as dc-dc converter or dc-ac inverter and some control algorithms in oirdere to optimize the utilization of PV systems.The objectives of MPPT is to extract maximum power generated byb the PV system under varyibng condition of temperature and solar insolation . a major challenges in solar PV based system is to tackle the non-linear current-voltage(I-V)charecteristics of PV cell,leading to the tracking of a unique maximum power point(MPP) on its power-voltage(P-V) charecteristics curve. Generally,the PV panels are connected in series(to enhancethe PV array voltage)and parallel (to enhance the PV current) so as tomeet the load power demand.Since PV module has non-linear charecteristics, it is necessary to model it for the design and simulation of PV system applications.

The stand-alone system is used in off-grid application with battery storage. Its control algorithm must have an ability of bidirectional operation, which is battery charging and converting dc into ac The electrical power supplied by a solar PV cell depends on many extrinsic factors, such as temperature and insolation level.The peak value of panel power increases with insolation and decreases with ambient temperature. The complex volt-ampere characteristic of the PV panel requires the use of harvesting techniques which is called maximum power point tracking (MPPT). With the help of duty ratio control of a dc-to-dc converter, the solar PV panel voltage is kept at the maximum power point (MPPT) of the solar PV panel, irrespective of the variation of temperature and insolation. Thus the solar PV panel delivers the maximum

power. However, the values of both panel voltage and current vary corresponding to the variation of insolation and temperature. These values also correspond to a particular load resistance, which is equal to V/I as specified by ohm's law. The power (P) is given by $P=V*I$. A PV cell has an exponential relationship between current and voltage, and MPP occurs at the knee of the curve

2. PV SYSTEM COMPONENTS

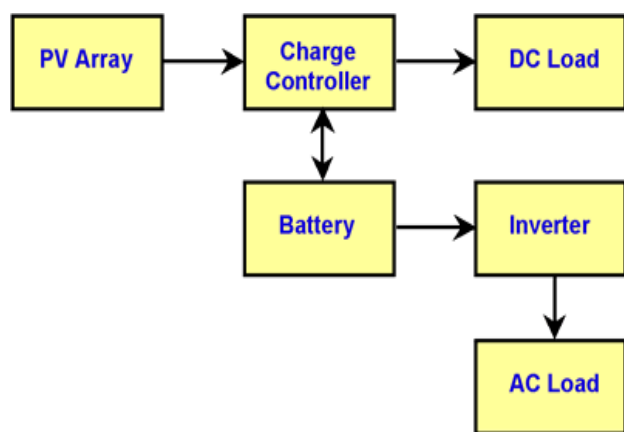


Fig 1. PV MODULE MATHEMATICAL MODELLING

3. SOLAR PV CELL/ARRAY

A solar panel cell basically is a p-n semiconductor junction. When exposed to the light, a DC current is generated (fig. 1.2.1). The smallest unit is a cell which when combined in a string i.e. either in series or parallel, form a module which, further, in a bigger number forms an array. The generated current varies linearly with the solar irradiance. The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode. The solar cells are connected in series and parallel to create a solar array.

Fig. shows I-V and P-V characteristics of a typical PV cell.

where $P/dV=0$. At this point the characteristic resistance of the PV cell becomes equal to the load resistance.

MPPT utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

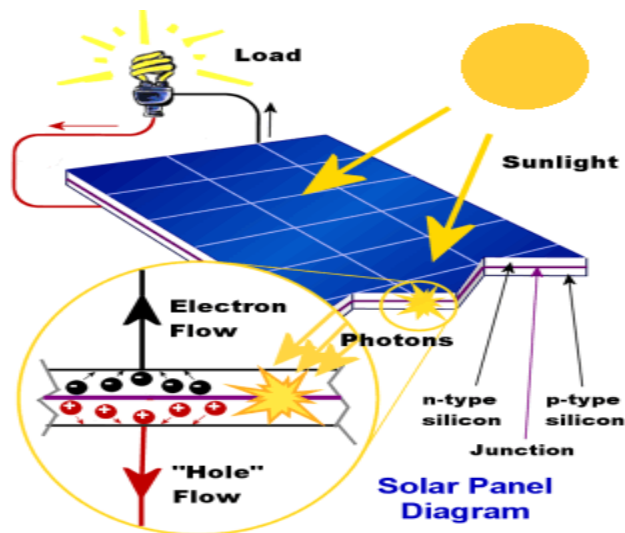


Figure 2: Working of a simple PV system.

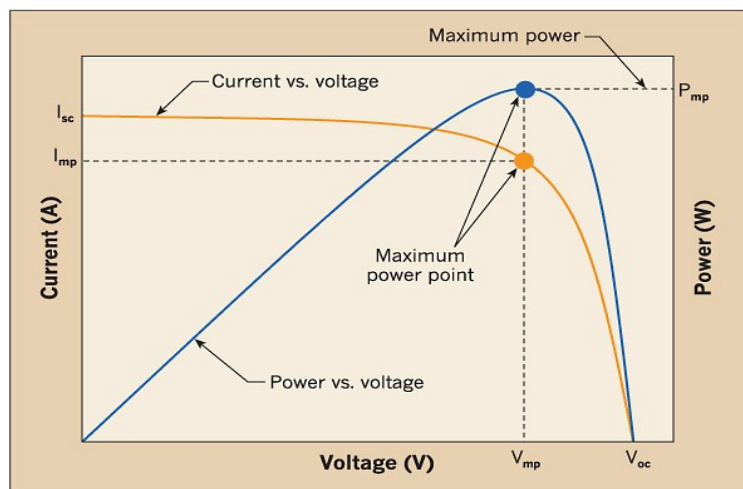


Figure 3 : I-V and P-V characteristics of a PV cell.

4. SOLAR CELL

A Solar cell (also called a Photo-Voltaic cell) is an electrical device that converts the electrical energy of light directly into electricity as in figure 2 . A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the PN junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load. Regardless of size, a typical silicon PV cell produces about 0.5-0.6 volt DC under open circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions, a typical commercial PV cell with a surface area of 1.580*0.800 square metres will produce about 170W peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 67W.

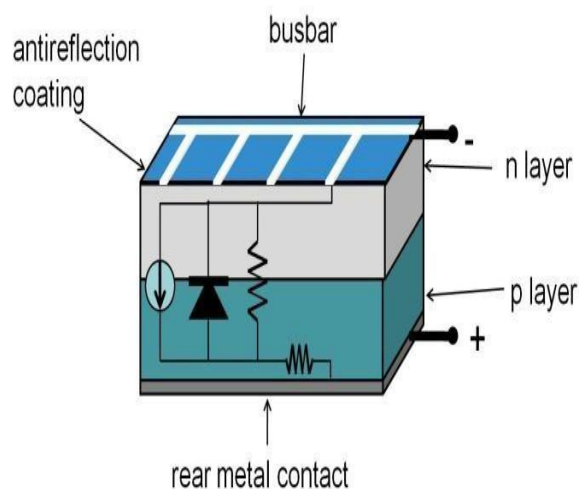


Figure 4. PV module configurations in a PV plant

5 . 5-PARAMETER BASED MODEL OF A SOLAR PV CELL

A solar cell model is represented by a constant current source and a diode as shown in Figure 5. The light generated current, I_L , is the amount of current produced by the electron-hole pairs generated by the impinging sunlight. This phenomenon is called photovoltaic effect. I_L depends on the intensity of the incident solar light, characteristics of the solar panel, and the ambient temperature. The most important electrical characteristics of a PV cell module/array are [3]:

- a) Short Circuit current (I_{SC}): Usually this is associated with the light generated current I_L and is considered the same for normal levels of solar irradiance. It increases slightly with increasing temperature. It is directly proportional to the incident optical power.
- b) Open circuit voltage (V_{OC}): It is logarithmically dependent on the solar irradiance. With the increase in temperature there is an increase in saturation current and results in reduction of the open circuit voltage.

The behavior of photovoltaic (PV) cells can be modeled with an equivalent circuit shown in Figure 5. This circuit includes a series resistance, R_S and a diode in parallel with a shunt resistance, R_{SH} . The letter "V" represents the voltage at the load. This circuit can be used for an individual cell, for a module consisting of several cells, or for an array consisting of several modules.

For the typical silicon solar cell used in the design here:

Open circuit voltage (V_{OC}) = 0.57 V

Short Circuit current (I_{SC}) = 0.76 A (Depends on the area of the solar cell)

Series resistance occurs due to:

a) Movement of current through the emitter and base of the solar cell

b) Contact resistance between the metal contact and silicon

c) Resistance of the top and the rear metal contacts.

Shunt resistance mostly arises due to:

a) Manufacturing defects, rather than poor solar cell design.

b) Leakage of current through the cell, around the edges of the device and between contacts of different polarity.

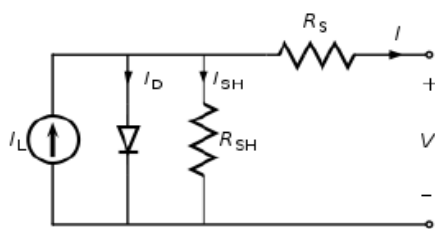


Figure 5: Equivalent circuit representing the 5-Parameter model

Application of Kirchoff's Current Law (Equation (3.1)) on the equivalent circuit[5] results in the current flowing to the load.

$$I = I_L - I_D - I_{SH} \dots (1)$$

The shape of the current-voltage (I-V) curve changes as the operating conditions (cell temperature, T_C and effective irradiance, G_{eff}) change, therefore it is expected that the value of the parameters describing the curve will change as well. Figure 3.1. 2 shows how the shape of the I-V curve changes by changes in the operating conditions.

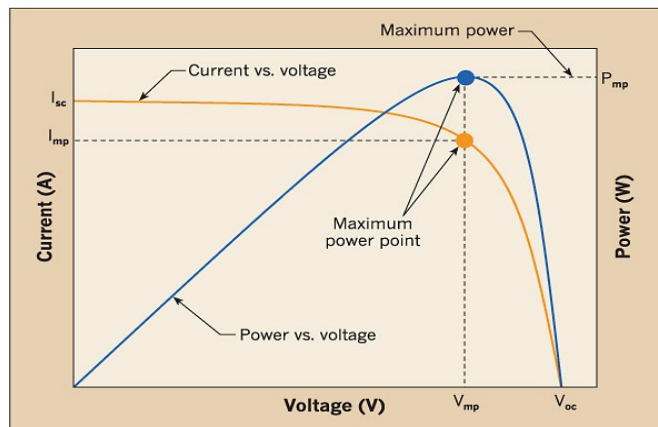


Figure 6 : I-V and P-V characteristics of a PV cell

If the diode current and the current through the shunt resistance (I_D and I_{SH} , respectively) are expanded, Equation (2) is obtained. Equation (3) is used to calculate the power (P).

$$I = I_L - I_0 \left[e^{\frac{V+IR_S}{a}} - 1 \right] - \frac{V+IR_S}{R_{SH}} \dots (2)$$

$$P = IV \dots (3)$$

The five parameters (from which the 5-Parameter model obtains its name) are a, I_L, I_0, R_S and R_{Sh} , where

a : ideality factor

I_L : light current

I_0 : diode reverse-saturation current

R_S : series resistance

R_{Sh} : shunt resistance

The shape of the current-voltage (I-V) curve changes as the operating conditions (cell temperature, T_C , effective irradiance, G_{eff} , and incidence angle, θ) change, therefore it is expected that the value of the parameters describing the curve will change as well. It is observed that if the five parameters (a, I_0, I_L, R_S and R_{Sh}) that correspond to a specific cell temperature and irradiance are known, the 5-Parameter model is excellent at predicting the shape of the I-V curve.

6. CALCULATION OF REFERENCE PARAMETERS AT SRC

To calculate the five reference parameters (a_{ref} , $I_{0,ref}$, $I_{L,ref}$, $R_{s,ref}$, and $R_{sh,ref}$), five pieces of information are needed at reference conditions (usually Standard Rated Conditions, SRC, where $T_c=25$ °C and $G_{eff}=1000$ W/m²). The pieces of information are the short circuit current (I_{sc0}), open circuit voltage (V_{oc0}), current and voltage at the maximum power point (I_{mp0} and V_{mp0} , respectively), and the slope of the I-V curve at the short circuit point. The subscript “0” indicates at reference conditions. This information is usually provided by the manufacturer.

To find the reference parameters it is important to know the meaning of each piece of information[2]:

At short circuit current: $I=I_{sc0}$, $V=0$

At open circuit voltage: $I=0$, $V=V_{oc0}$

At the maximum power point: $I=I_{mp0}$, $V=V_{mp0}$

At the maximum power point: $dP/dV_{mp}=0$

At short circuit: $dI_{sc}/dV= -1/R_{sh,ref}$

Having these five pieces of information, Equation (2) can be rewritten as Equation (4). Substituting the known information results in Equations (5) to (9).

$$I = I_{L,ref} - I_{0,ref} \left[e^{\frac{V+I.R_{s,ref}}{a_{ref}}} - 1 \right] - \frac{V+I.R_{s,ref}}{R_{sh,ref}} \dots \quad (4)$$

$$I_{sc} = I_{L,ref} - I_{0,ref} \left[e^{\frac{I_{sc0}.R_{s,ref}}{a_{ref}}} - 1 \right] - \frac{I_{sc0}.R_{s,ref}}{R_{sh,ref}} \dots \quad (5)$$

$$0 = I_{L,ref} - I_{0,ref} \left[e^{\frac{V_{oc}}{a_{ref}}} - 1 \right] - \frac{V_{oc}}{R_{sh,ref}} \dots \quad (6)$$

$$I_{mp0} = I_{L,ref} - I_{0,ref} \left[e^{\frac{V_{mp0}+I_{mp0}.R_{s,ref}}{a_{ref}}} - 1 \right] - \frac{V_{mp0}+I_{mp0}.R_{s,ref}}{R_{sh,ref}} \dots \quad (7)$$

$$\frac{d(IV)}{dV} = 0 \dots \quad (8)$$

$$\frac{dI}{dV_{sc}} = -\frac{1}{R_{sh,ref}} \dots \quad (9)$$

The five reference parameters (a_{ref} , $I_{0,ref}$, $I_{L,ref}$, $R_{s,ref}$, and $R_{sh,ref}$) can be obtained by simultaneously solving Equations (5) through (9). Using Gauss Siedel method these equations are solved and following values are obtained:

$$a_{ref} = 0.0392 \text{ eV}$$

$$I_{0,ref} = 0.3223 * 10^{-6} \text{ A}$$

$$I_{L,ref} = 0.7630 \text{ A}$$

$$R_{s,ref} = 0.03684 \text{ } \Omega$$

$$R_{sh,ref} = 10 \text{ } \Omega$$

7. SIMULATION OF A SOLAR CELL MODEL:

By varying environmental parameters i.e. insolation (G_{eff}) and temperature (TC), which are in W/m² and Kelvin respectively in the developed model for PV cell (Figure 3), we get different behaviors of I-V and P-V curves. Following observations are made.

a) Varying temperature (T_c)

By varying values of T_c different curves are obtained for the developed PV cell model.

I-V characteristics: I-V characteristics are shown in the figure 4. With variation in T_c , the I_{sc} does not change however different values of

Voc are observed. As we can see with increasing Tc, Voc increases Geff being constant.

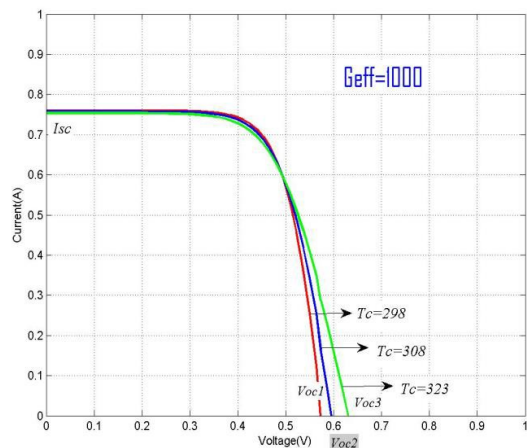


Figure 4: variation of I-V curve with respect to Tc

P-V characteristics:

Different PV curves are obtained by varying Tc, as shown in figure 5. It is observed that for a single cell, output voltage Voc is directly proportional to the temperature Tc.

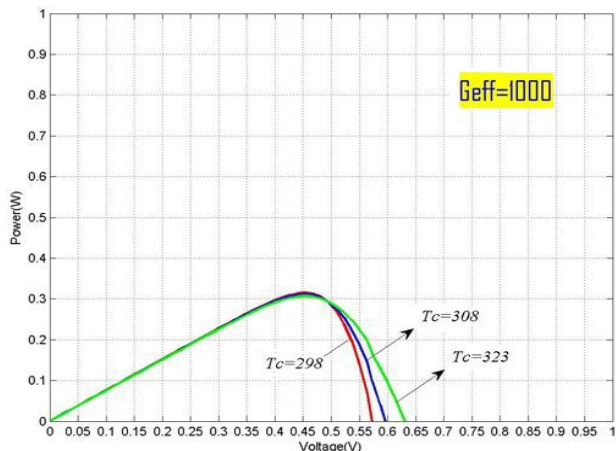


Figure 5: Variation of P-V curve with respect to Tc

CONCLUSION

The 5-Parameter model presented in this paper is a user interactive model which accepts data and shows corresponding behavior on SIMULINK platform to predict the output for specified cell

parameters under different operating conditions. The model requires an easy one time calculation of the five parameters.

APPENDIX

C program to evaluate the reference parameters

```
#include<stdio.h>
#include<math.h>
#include<conio.h>
void main()
{
clrscr();
int i;
float
ion=0.0000003221,ilo=0.7613,ao=0.0352,rso=0.
0364,rsho=9.70;
float
rs,a,il,rsh,io,c,d,e,z,po,ko,xo,x1,rs=rso,aop=ao,r
shp=rsho,ilp=ilo,iop;
iop=ion;
io=ion;
a=ao;
rs=rso;
rsh=rsho;
il=ilo;
float
imp=0.69119,vmp=0.45,isc=0.7606,voc=0.5728;
for(i=1;i<=5;i++)
{
c=exp(isc*rs/a);
rs=(rsh/isc)*(il-isc+io*(1-c));
z=log((il/io)-(voc/(rsh*io))+1);
a=voc/z;
po=imp*rs;
ko=(vmp+po)/a;
d=exp(ko);
il=imp+((vmp+imp*rs)/rsh)+(io*d);
xo=(vmp+imp*rs)/a;
x1=exp(xo);
rsh=(rs*imp-vmp*imp)/((io*x1*(vmp-
imp*rs)/a)-imp);
e=exp(isc*rs/a);
io=a*rs/(rsh*(rsh-rs)*e);
if(fabs(rs-rso)>0.001)
rso=rs;
else
```

```

rsp=rs;
if(fabs(a-ao)>0.01)
ao=a;
else
aop=a;
if(fabs(il-ilo)>0.001)
ilo=il;
else
ilp=il;
if(fabs(rsh-rsho)>0.001)
rsho=rsh;
else
rshp=rsh;
if(fabs(io-ion)>10(-7))
ion=io;
else
iop=io;
}
printf("c= %f\n",c);
printf("z= %f\n",z);
printf("po= %f\n",po);
printf("ko= %f\n",ko);
printf("d= %f\n",d);
printf("x1= %f\n",x1);
printf("rs= %f\n a= %f\n il= %f\n rsh=%f\n
io=%f\n",rsp,aop,ilp,rshp,iop);
getch();
}

```

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