Mathematical Modelling of Grid Connected Photovoltaic System using MATLAB/SIMULINK and Hardware Implementation

Smitanjali Rout
M.Tech Student
Department of EEE, CUTM, Jatani

ABSTRACT

This paper represents the implementation of a PV Model using MATLAB/Simulink software and also its hardware implementation. The PV system can be PV cell, module, and array for most reliable Use on simulation based circuit. The proposed model is designed PV system from the mathematical equations of Photo current and photovoltaic voltage by using user-friendly icon and dialogue box from simulink block Libraries. That makes the mathematical PV model properly simulated and analyzed with power electronics interference and maximum power point Tracking control system. By considering the effect of sunlight irradiance and cell temperature, the output current, voltage and power characteristics of PV model are simulated and optimized using the proposed model. This emphasized the dynamics behavior of PV system to be easily simulated, analyzed, and optimized.

Keyword

Mathematical model of photovoltaic cell; photovoltaic module; array; boost converter; mppt algorithm; pwm; single phase inverter; three phase inverter; MATLAB/simulink; gate pulse using 555 timer; voltage doubler circuit in hardware.

1. INTRODUCTION

Now a day's people are more concerned about the application of the renewable energy source, like wind, tidal, biomass, ocean and solar radiation (photovoltaic) because of the raising oil prices, fossil fuel deficit, global warming and negative impact of environment. Among all the renewable energy sources the energy through photovoltaic (PV) can be most effective because it's the most essential, sustainable source. Photovoltaic system can directly converts sunlight to direct current means it converts the solar radiation (irradiance) to DC electricity without environment impact. In photovoltaic system the main two inputs are solar irradiation and temperature, which are available free of cost .Temperature and irradiance are variable in nature. Solar irradiations are more sustainable in nature and unique[4-5-6]. Its a pollution free system. We are seeing the demand of photovoltaic

system; this is getting more important because of growing population condition in the worldwide. So the electricity demand will also increase as per the population ratio as it's a 21st century our need are more than our want,PV system, being semiconductor device, its statiand don't have moving parts, so its operation and maintenance cost are little high among all the renewable energy resourceThough for current era the efficiency of the photovoltaic system is low, but there are many researched are going on(pipeline) to improve efficiency and reduces its cost and its size.The output characteristics of PV module depend upon the solar irradiation, cell temperature. Though PV module has nonlinear characteristics because PV module is a semiconductor device, so it necessary to design and simulation of maximum power point tracking (MPPT) for

application of PV system. As we know PV system produces DC output (voltage, current),its output we can use directly or can be stored in battery as it's a DC source.PV system is of two types i.e. stand alone system or grid connected system. For the grid connected system the DC voltage obtained the PV panel will be connected to the converters i.e buck converter, boost converer,buck-boost converter,then the output of the converters connected to the inverter that can be single-phase inverter or three-phase inverter for the optimized results[7-8-9].The main contribution of this paper is implementation of PV model in MATLAB/simulink, which is user-friendly. From the photocurrent equation, the mathematical model of PV cell, module, array can be designed in MATLAB/simulink in Section II.Threre are various methods are available in MPPT control like P&O algorithmic method, Fuzzy logic methods, Neural network method etc, among all P&O method is chosen because of its implementation is easy and gives effective results discussed in Section III. Modeling and implementation of boost converter and inverter are discussed in Section IV, Simulation results and experimental verification discussed in Section (V-VI), and finally briefly conclusions are future development are drawn in Section VII

2. PHOTOVOLTAIC MODEL

Solar cell is basically a p-n junction semiconductor device which is fabricated in thin wafer. Sunlight is nothing, but it's a form of electromagnetic radiation, According to Einstein law E=hv, the electromagnetic radiation of sunlight can be directly converted into direct electricity, through the effect of photovoltaic [10-11]. Irradiation is the rate of flow of solar intensity per unit area. When the PV system will be exposed to the sunlight, the generated photons contain energy which is greater than the band-gap energy (abt 0.5-0.7v) of the semiconductors are absorbed and some electron-hole pairs are created[1-2-3] i.e. proportional to the incident solar irradiation. Photovoltaic system is directly proportional to the solar spectrum/insolation.I_V and P_V characteristics of pv system is nonlinear, because of variation of solar irradiance intensity and temperature of cell.

2.1 Solar Cell

it's a p-n junction semiconductor device,

2.2 Solar module

No. of cells can be connected in series and parallel to give raise solar module,

2.3 Solar array

No. of solar modules connected in series and parallel to comprise the solar array according the demands.

Fig.1 shows the equivalent circuit diagram of photovoltaic cell, to simulate the demanded array, the parameters of cell should be properly multiplied with the cells
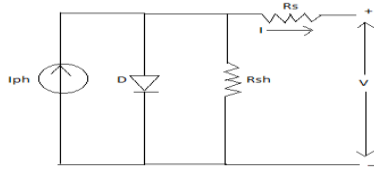
Fig.1: Equivalent circuit of PV cell

The model equations are given for solar cell from(1) to (6)

$$I = Iph - Id - Ish \qquad (1)$$

$$Iph = [Is + Ki(Tc - Tref)]\lambda \qquad (2)$$

$$Id = Is[\exp(V + IRs)/(kTcA) - 1] \qquad (3)$$

$$Ish = (V + IRs)/Rsh \qquad (4)$$

$$Is = Irs\left(\frac{Tc}{Tref}\right)^3 \exp\left[qEg\left(\frac{1}{Tref} - \frac{1}{Tc}\right)\right] \qquad (5)$$

$$Irs = Isc/[\exp(qVoc/NskATc) - 1] \qquad (6)$$

Where;

I: Output current of PV array

Iph: Photo current

Id: Diode current

Ish: Shunt current

Ki: Cell short circuit current temp. Coefficient

Tc: Working temperature
Tref: Reference temperature
Is: Cell saturation dark current
 Q: Charge (1.6e-19C)
A: Ideal factor
Voc: Open circuit voltage
V: PV voltage
Rs: Series resistance
Rsh: Shunt resistance
K: Boltzmann's constant (1.38e-23 J/K)
Ns: Number of cell in series
Np: Number of cell in parallel
Eg: Band gap energy

2.4 Cell saturation dark current (Is)
It is the current developed when the cell faces low intensity, dark saturation current differentiate one diode to another, it measure the recombination in the device, the diode which has lager recombination will have a larger saturation dark current

2.5 Ideal factor (A)
It measures how closely the diode follows the ideal diode equation.

2.6 Series resistance (Rs)
 In solar cells its value is very low, in ideal condition it's neglected, If Rs will be high then current will decreases and losses increases. It has mainly three impacts, i.e. the current movement through emitter and base, it's the contact resistance between the metal contact and silicon, and the resistance of the top and rear metal contacts.

2.7 Shunt Resistance (Rsh)
It has high value, because to reduce leakage current, power loss will be caused by presence of Rsh, by providing an alternative current path for the leakage current. It will be severed at low intensity levels.

2.8 Bypass diode
This diode affects the solar cell only reverse bias condition, it eliminates the destructive effect of hot-spot, and it is connected antiparallel to the solar cell.

2.9 Parasitic Resistance
The main impact of parasitic resistance is to reduce the fill factor. The resistive effect of solar cell can be reduced the efficiency of the solar cell by dissipating power in the Rs, Rsh resistance.

2.10   Efficiency
It is the fraction of incident power which will be converted to electricity.

2.11   Fill factor
Fill factor will determine the quality of the solar cell.

2.12   Tendem cells
It can be either individual cell or reconnected in series, the current in the solar cell is the difference between the leakage current and forward bias current.

2.13   Effect of Temperature
The increased temperature mostly affect the open circuit voltage (Voc).When the temperature will be increased, then the band gap of semiconductor will be reduced , so less amount of energy will be required to break the bond. The Voc will be decreased as the temperature will increase because of the temperature dependence on cell dark saturation current increases slightly with temperature

2.14   Effect of intensity
As the intensity of the solar irradiation will be increased then the short circuit current will increase sharply, as the current is directly proportional to the intensity level and the open circuit voltage slightly increase.

3.   MPPT
As we already discussed the inputs of solar cell are solar irradiation and cell temperature, Which are variable in nature, so the output DC voltage and current also be varied respectively, for this effect the losses will be more in the cells, so to reduce the losses in the system we are developing maximum power point tracking system (MPPT), which will track the maximum power at the moment from the P_V curve, so that disturbance will be reduced, as a result the losses will be decreased. The damaged of the grid will be reduced .As the output will be more stable and consistency, the efficient will be increased. There are more than 19th methods are available for the MPPT, among them I used P&O method for my proposed work,[10-11] it is easy in implementation and reliable and gives effective results.

3.1 Perturbation observation (P&O) method:
By using controller in PV system the output of the PV array will be changed with a smaller step in each control cycle. The mode can be increased or decreased as per the system operation, but in P&O method the step size is fixed. It can sense both voltage and current, it can be analog or digital, it is

a true MPPT, its convergence speed varies. Both the output voltage and output current of pv array can be control object, for this process is called "perturbation";then, next maximum point will be occurred by comparing the output power of PV array of the cycles before and after the perturbation[12-13].

In this method to select the present point it will be compared with the previous point. If the output power will be increased, "perturbation" will be continued to work the direction in the previous cycles, if else the output power is decreased, "perturbation" will be changed the direction. In this process, the actual operating point of PV array can be moved closer to the maximum power point, back and forth process occurs to reach the steady state , it is most effectively applicable in a small area.P&O methods flow chart is given bellow;

Fig.2: Flowchart of P&O Algorithm

4. IMPLEMENTATIO AND SIMULATION OF MODEL

4.1 Boost Converter Model

The boost converter[14] with inverter interfaces PV panel and the load. The designed equations for the Boost converter are given from equations (7) to (10)

The voltage ratio of the Boost converter is given as,

$$\frac{Vo}{Vg} = \frac{1}{1-D} \qquad (7)$$

The duty ratio of the Boost converter is given as

$$D = 1 - \frac{Vg}{Vo} \qquad (8)$$

Where;
Vg: Input voltage
Vo: Output voltage
 D: Duty cycle

In fig.5 the simulation model of boost converter is given. The inductor and capacitor is designed based on the following given equations for the continuous operation's of converter,

$$L = \frac{Vg * D}{f * \Delta IL} \qquad (9)$$

$$C = \frac{D}{f} \times Ro \times (\frac{\Delta Vo}{V}) \qquad (10)$$

The designed parameters used in simulation are

L= 1.74 mH, C= 1.174*10^-4F, R=308 Ω ,

Fz= 100kHz

4.2 Pulse width modulation (PWM)

In the PWM technique the square wave from pulse generator will be converted to triangular wave by changing the frequency of the pulse generator and this triangular wave form is compared with the sine wave, In PWM the carrier frequency is compared with the modulated frequency to get desired pulse for the system[16].

4.3 Inverter

The output voltage we obtained from the PV system is DC voltage ,which is given to the boost converter to increase the voltage level, now after boosting we will give the boost voltage to single- phase and three-phase inverter circuit to get the AC voltage for our application. The inverter circuits are modulated through PWM technique [15].
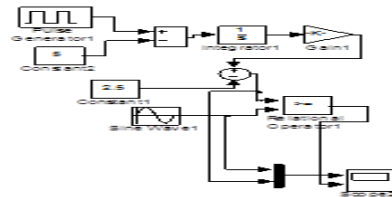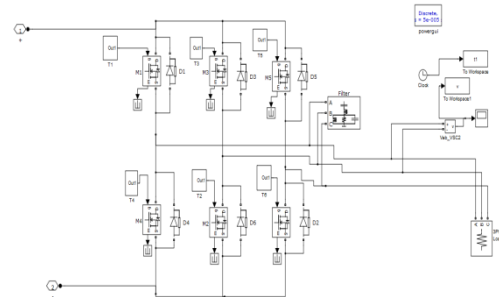

Fig.3: Simulink block generating the gate signal

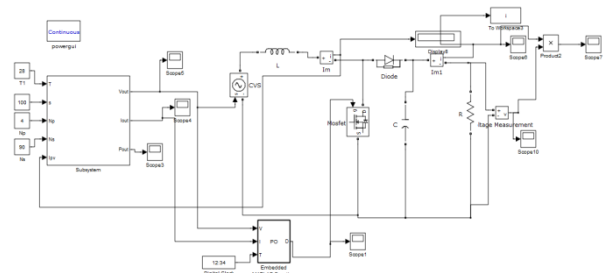**Fig4Simulink block three-phase inverter**

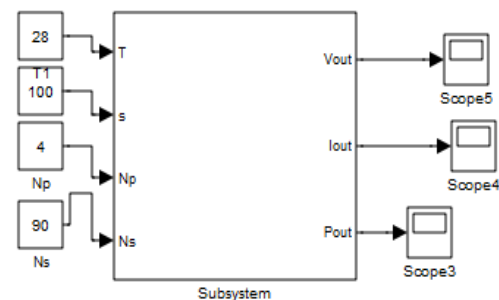**Fig.5: Simulation model of PV array with mppt and boost converter**

Fig.6Simulink block of the photovoltaic array
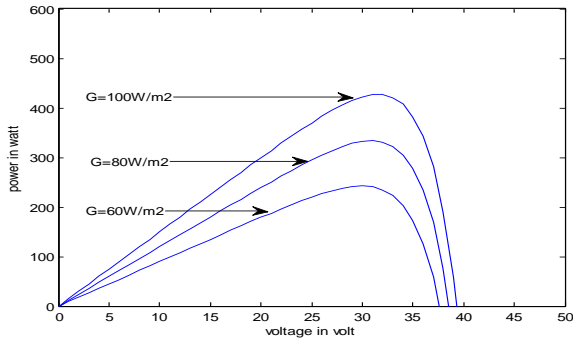
5. RESULTS

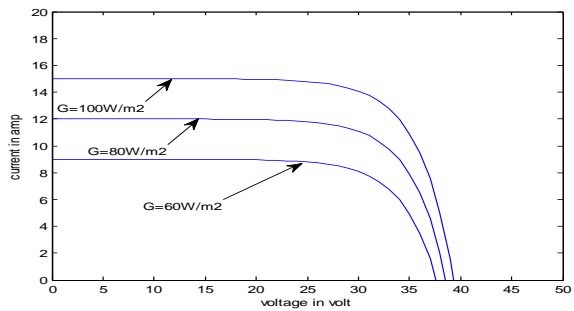**Fig.7:P_V curve of varying irradiance at constant temperature 28°c**

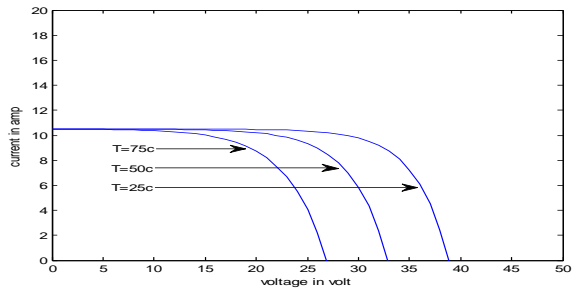**Fig.8: I_V curve of varying irradiance at constant temperature 28°c**

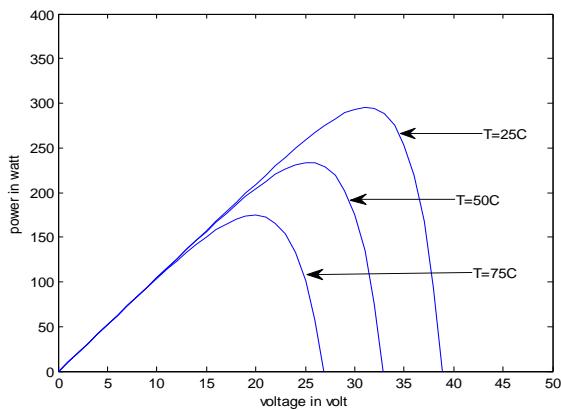**Fig.9: I_V curve of varying temperature at constant irradiance 1000W/m2**

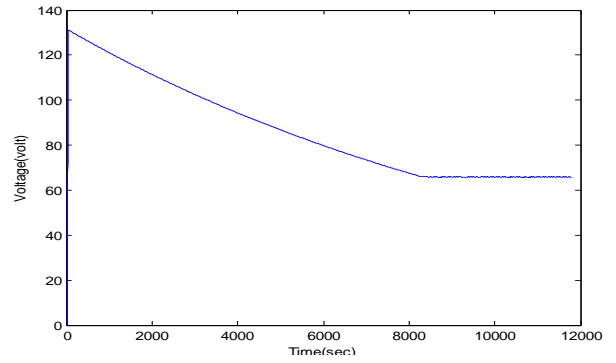**Fig.10:P_V curve of varying temperature at constant irradiance 1000w/m2**

Fig.11: Output voltage from boost converter

Fig.12:Output voltage from three phase inverter

TABLE I. Characteristics of the PA

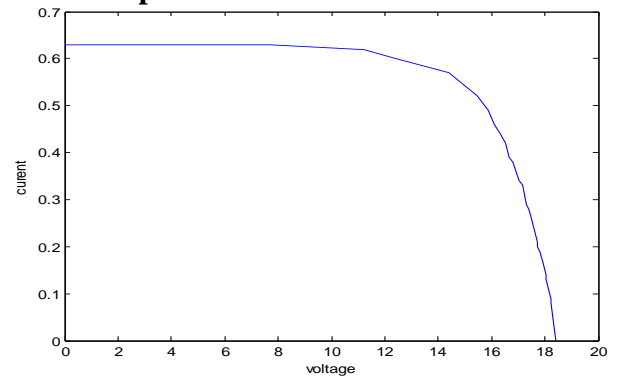| PARAMETER	VALUES
Peak power	500 watt
Np	4
Ns	90
Isr	3.75A
Tr	301K
Ki	0.00021A/K
Irr	0.000023A
A	2.13

5.2 Experimental Verification

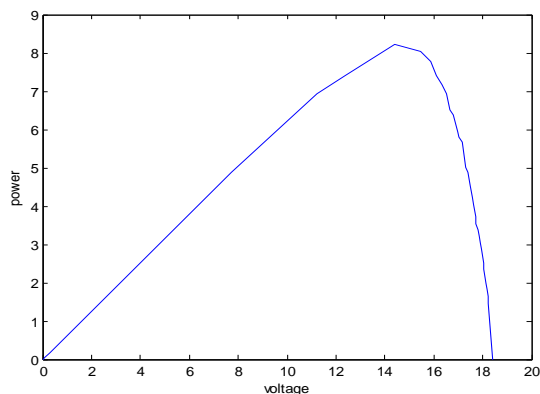**Fig.13: I_V characteristics from experiment**

Fig.14: P_V characteristics from experiment

The waveforms obtained by varying the solar isolation and temperatures which are fed into the PV array model have been plotted as shown above; I-V and P_V curves obtained at 301K for various irradiance levels , we observed that by increasing the solar radiation at constant temperature the voltage and current output from PV array also increases .Hence at higher isolation we can get our required level voltage P-V curves obtained at 280C for various irradiance levels , we observed that by increasing the solar isolation level, the power output from PV array increases. I-V curves obtained at an irradiance of 100 mW /cm2 for various temperatures. we observed that by increasing the temperature level at constant irradiance, the voltage output from PV array decreases but current output increases slightly with respect to voltage and, hence the power output from PV array decreases.

5.1 Hardware Implimentation

To implements the circuit in hardware we need the parameters which are given in the Table no.II.In this paper we used the high pass capacitor instead of MPPT, By using high pass capacitor the DC output voltage can be made ripple free ,this ripple free output voltage will be given to the L555 timer circuit to make the DC voltage into pulse of DC voltage ,to boost the DC output voltage then it will be given to the voltage boost circuit which is made up of by arranging capacitors and diodes. Then this boosted voltage will be given through step up transformer. The circuit diagram of hardware implementation is given on the fig no.15.The result obtained from the experiment is given in the Table.III.

Table.Ii: Datasheet For Hardware

Parameters	Code	Quantity	Values
555 timer	NE555	1	-
Diode	1N4001	2	-
Capacitor	104	1	0.01nf
Capacitor	-	3	2.2 µf,63v
Resister	Brown,black, red	1	10 k ohm
Potentiometer	E02	1	1M

Fig.15: Hardware implementation

Table.Iii: Result From Hardware Circuit

Input voltage(V)	Output Voltage(V)
6.59	13.2
2.9	5.4
7.2	13.9
4.8	10.7
5.3	11.2

6   CONCLUSION

Designed and Simulation model of Photovoltaic cell from mathematical is established in this paper ,and the output I_V and P_V characteristics of the cell is studied and analyzed by taking different conditions , i.e. by varying temperature or by varying irradiance. Then the common P&O algorithm for MPPT control is described and a MPPT control photovoltaic system is built and simulated in the MATLAB/Simulink. Then designed a boost converter and the parameters are designed according to the input supply and finally the boosted dc output voltage is given to the load through designed three-phase inverter circuit, which is modulated by designed PWM modulation technique, Finally this circuit is implemented in hardware for our application.

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