Design and Modeling of Generalized Photovoltaic System with a Half-Bridge Converter

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Abstract— Due to energy crisis renewable energy has become an important part of power generation systems. Among the renewable energy sources photovoltaic energy is the most important energy resource as it is clean, pollution free and inexhaustible. Photovoltaic system produces direct current through photo voltaic effect. The PV output varies depending on solar irradiation and temperature. In order to step up the voltage, a DC-DC converter is used. To obtain high efficiency, it is desirable to operate the PV at maximum power point. For extracting the maximum power, maximum power point tracker (MPPT) with perturb & observe (P & O) algorithm is used. By this P & O, the array voltage or current is periodically perturbed and PV output power is compared with previous perturbation cycle to control the duty cycle of the DC-DC converter. This paper focuses on modeling of PV with MPPT. The entire system is designed and modeled using MATLAB/SIMULINK and simulation results are presented.

Key words: DC-DC Converter, MPPT, PV, P & O Control Algorithm

I. INTRODUCTION

Due to increasing energy demands, rising oil prices, fossil fuel deficiency, global warming and high population the use of the renewable energy sources have gained interest. Day by day the need for energy is increasing. Among the various renewable energy sources, photovoltaic systems have become most relevant because of ubiquity, abundance and the sustainability of solar radiant energy. Regardless of the intermittency of sunlight, solar energy is widely available and it is completely free of cost. Solar cellsgenerate direct current when exposed to sunlight, without any negative environmental impacts. PV system, being composed of semiconductor devices, is quiet in operation and free of moving parts. One of the major disadvantages of the PV system is its high initial cost and low efficiency. But compared to fossil fuels, solar energy provides potentially long term benefits without any CO2 emission [1].

The output power of a PV module depends on the solar insolation and cell temperature. The amount of photovoltaic power generated varies with changing environmental conditions such as temperature and irradiation .When the output power of photovoltaic module change, the overall efficiency of PV also vary. With the dynamic variations, the output energy of PV is varied from time to time. In order to avoid the dynamic variations when connected to a variable load and to ensure the maximum power generation, a power converter, which is generally a dc-dc converter, is used. By inserting this power converter between the PV array and the load, the impedance of the system is dynamically changedwith the help of an implemented control algorithm [2]. The converter helps to regulate the output voltage from the system.

Due to the nonlinear behavior of voltage and current output of the PV cell, the power output obtained is varying. In order to obtain unique maximum power point (MPP) at particular weather condition, a suitable control algorithm can be used. This maximum power point changes with varying environmental condition such as temperature and irradiation. For the P-V and I-V curves of a PV system, the point at which it should operate to extract maximum power can be determined. One of the control algorithms that is easy to implement with very simple control and less cost is the Perturb and Observe (P & O) method. It operates periodically decrementing and incrementing the terminal voltage or current of each PV cell. This measured voltage or current is then compared with PV output power from the previous perturbation cycle [3].

This paper presents the modeling and simulation of PV system with MPPT using a DC-DC converter. The converter is a half bridge converter whose duty cycle is controlled by using P & O algorithm. The coming sections deal with modeling of PV array along with MPPT algorithm followed by the design of DC-DC half bridge converter. Simulink model and the results obtained are presented.

II. MODELING OF PV ARRAY

Solar cell is basically a p-n junction made from two different layers of silicon. It converts solar irradiation into direct electric current through the phenomenon photovoltaic effect. When sunlight in the form of electromagnetic radiation falls on the surface of semiconductor device it will emit photons that contain large energy, which allows the electrons to flow through the material to produce electricity. The basic equation of an ideal PV cell is given by,

$$I = Ipv,cell - Io,cell\,[\frac{\exp(qV/AKT)}{Id} - 1] \quad …………(1)$$

Ipv, cell-current generated by the incident light
Io, cell – reverse saturation current of the diode
q – electron charge 1.602*10^-9c
K – Boltzmann's constants, 1.381*10^-23J/K
T – temperature in Kelvin
A – diode identity constant
V – voltage across PV cell
I – output current of ideal PV module

The equivalent circuit of PV cell can be represented with a single diode model as in fig.1.

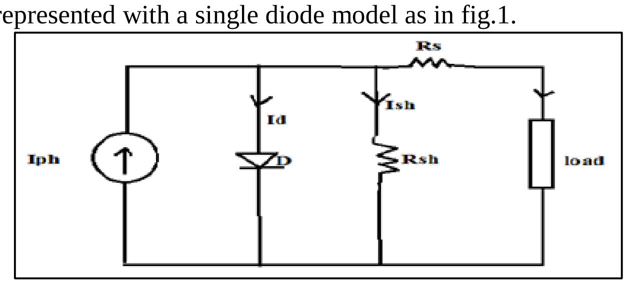


Fig. 1: Model of a PV cell

The single diode model contains a current source in parallel with a diode D. The current thorough the diode D is Id and diode is connected parallel to the resistor Rsh.

Two resisters are connected in this figure. One is connected in parallel to the current source and the other is connected in series to the current source. The series resister Rs determines the internal resistance of the cell. And the value of the parallel resister Rsh controls the leakage current from the cell to the ground [4].

The modeling of PV module is mainly based on the mathematical equation of solar cell which is given by the equation 2.

$$I = Ipv - Io[\exp\{(q(V + I * Rs / Ns * AKT)] - 1\}) - V + I * Rs / Rp \quad ....(2)$$

The generated current (Ipv) depends on solar radiation and this is also a fact that these factors are also influenced by the temperature; the Ipv is given by the equation,

$$Ipv = [Isc + Ki (T - Tref) * G / Gn] \quad ....(3)$$

PV module reverse saturation current at reference temperature at normal condition is by the equation,

$$Irs = Isc(n) / [\exp(q * Voc / Ns * AKTr) - 1] \quad ....(4)$$

Module saturation current is Io and is given by the equation,

$$Io = Irs [T / Tref \}^\wedge 3 * \exp[qEg / AK (1/Tref - 1/T)] \quad ....(5)$$

For a single diode ,the output current of PV module is given by,

$$I = Np * Ipv - Io * Np [\exp[q(V + I * Rs / Ns * AKT) - 1] \quad ...(6)$$

Ns-no of cells connected in series
Np-no of cells connected in parallel

Modeling is done at reference temperature of 25^{0}C and at different irradiation like 1000w/m^2, 600w/m^2, 200w/m^2 and uses a 1kW PV panel.

III. DESIGN OF DC-DC CONVERTER

DC-DC converter is used for regulating the output voltage of the photovoltaic system to a required level. This is because the output voltage produced by the PV system is low. So conveniently increasing the voltage for a particular application commonly DC-DC boost converter is used. Here a half bridge boost converter is used. The duty cycle of the DC-DC converter is determined and controlled by MPPT algorithm.

The inductor value is determined by the equation

$$L = [\frac{Vo(1-D)^2 * D}{2}] * f_s * I_o \quad .... (7)$$

V0= DC output voltage
D= duty ratio
F_s= switching frequency of converter
Io= average output current

The capacitance value of the DC-DC converter can be calculated as,

$$C = \frac{Vo * D}{R * \Delta Vo * f_s} \quad .... (8)$$

Where ΔVo is the maximum peak to peak ripple in output voltage, which is commonly taken as 1%.

Switching frequency is mainly depends upon the switching losses, cost of the switch and efficiency of converter. Hence it is desired to select 10 KHz as switching frequency.

IV. MAXIMUM POWER POINT TRACKING ALGORITHM

In this paper P & O control algorithm is taken as MPPT technique. This technique compares the power of the previous step with the power of the present step. This P & O method has a very simple structure and has fewer measured parameters. It operates by periodically incrementing or decrementing the PV voltage and comparing PV output power with that of previous perturbation cycle. If the power is increasing perturbation is still followed in that particular direction as of earlier, in the next cycle also. Otherwise occurred, then perturbation will continue in the reverse direction. The flowchart for the control algorithm is represented in the figure. This cyclic process is continued still attains the maximum power point [8]. The algorithm is shown in fig.2.

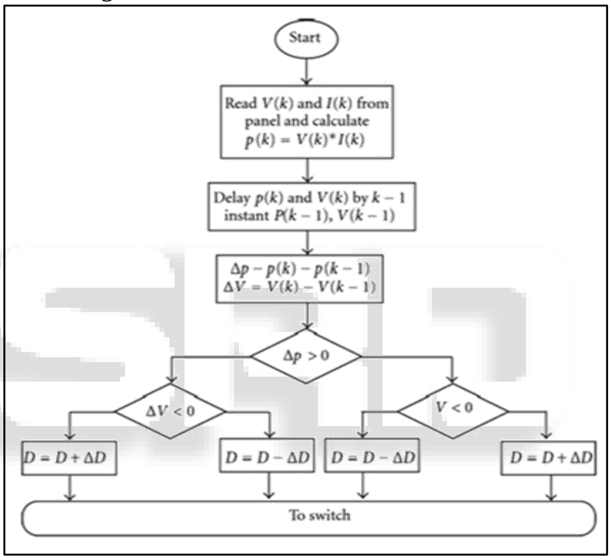


Fig. 2: P & O Algorithm

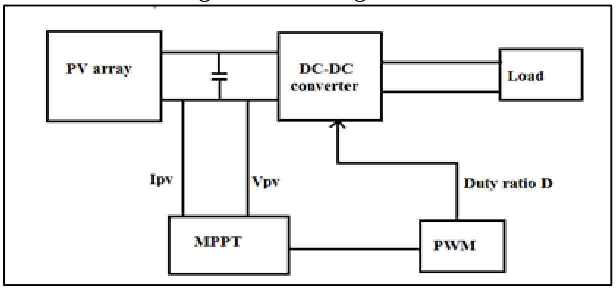


Fig. 3: System layout

V. SIMULATION RESULTS

The simulation system is shown as block diagram in fig.3.The modeling and analysis of the photovoltaic module is realized with MATLAB/SIMULINK. Fig.4 shows SIMULINK model for PV array. The input for the PV model is temperature and insolation or irradiation. The PV contains 100 series cells and three parallel cells in order to get high voltage and current. The PV array is of 1kW power. The different simulation results are shown below.Fig.5 shows the input irradiation level to the system.

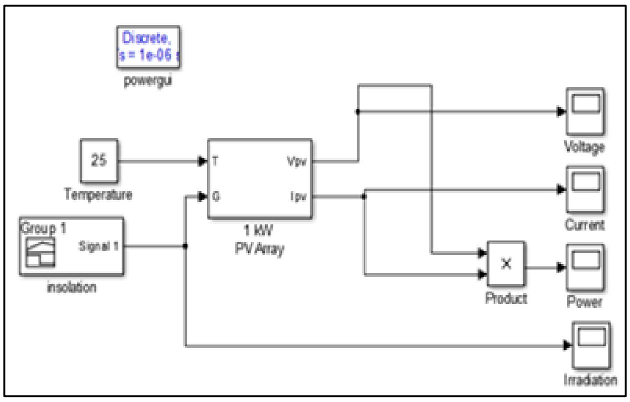


Fig. 4: Simulink model of PV array

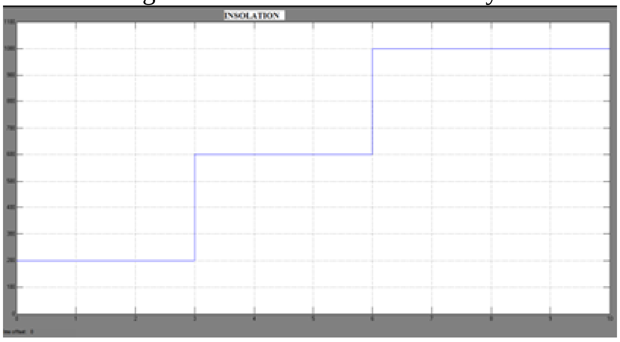
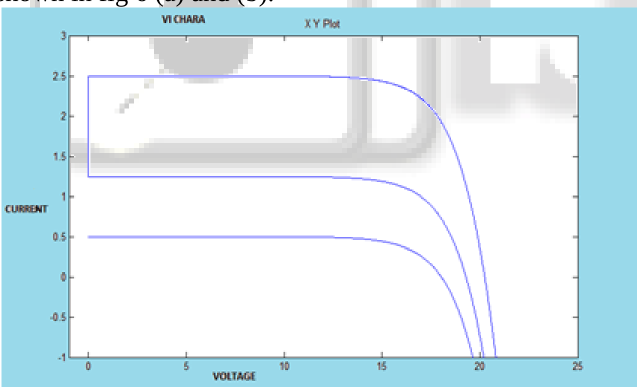


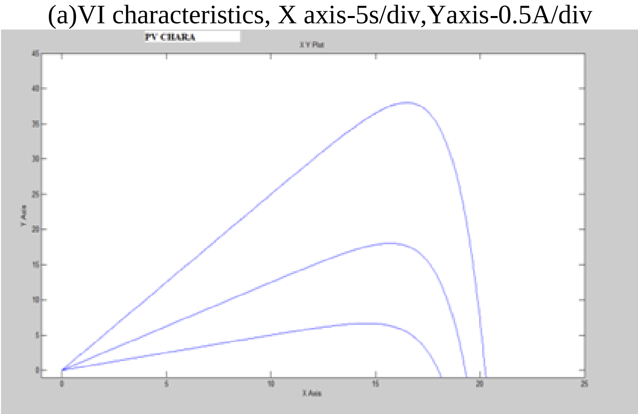
Fig. 5: PV insolation Level
Xaxis:1s/div,Yaxis100w/m^2/div

The irradiation levels changed from 200w/m^2 to 1000w/m^2.Clearly the given irradiation levels are 200w/m^2,600w/m^2,1000w/m^2.

The V-I and P-V characteristics of the array is shown in fig 6 (a) and (b).

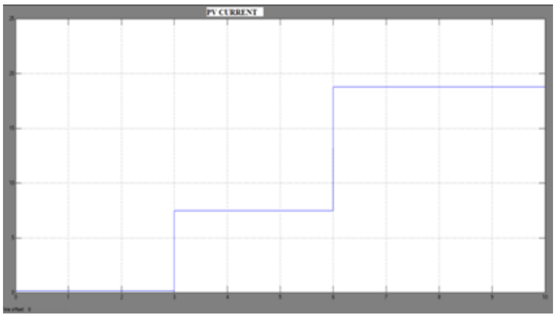


(a)VI characteristics, X axis-5s/div,Yaxis-0.5A/div

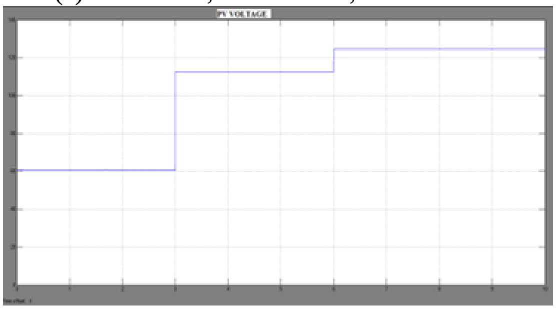


(b)PV characteristics, Xaxis-5W/div,Yaxis-5A/div

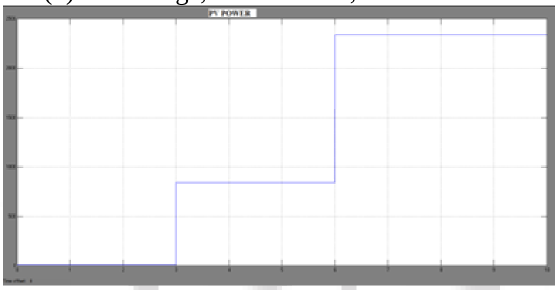
Fig. 6: VI and PV characteristics of the solar array for different irradiation levels



(a) PV current,Xaxis-1s/div,Yaxis-5A/div



(b) PV voltage, Xaxis-1s/div,Yaxis-20V/div



(c) PV power, X axix-1s/div,Yaxis-500W/div

Fig. 7: Current, Voltage and Power output of the PV array

The output current, voltage and power from the PV array is shown in fig.7. The Simulink model of the half bridge dc-dc converter is shown in fig.8.

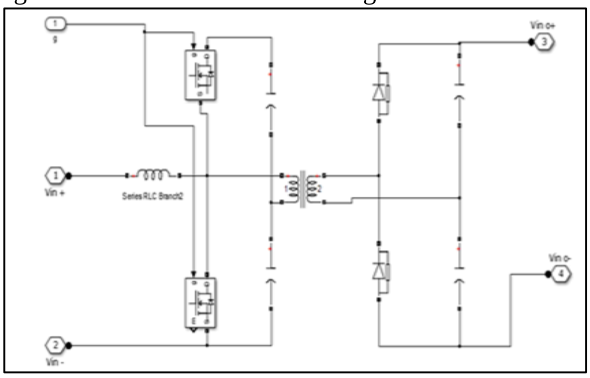


Fig. 8: Half Bridge DC-DC Converter

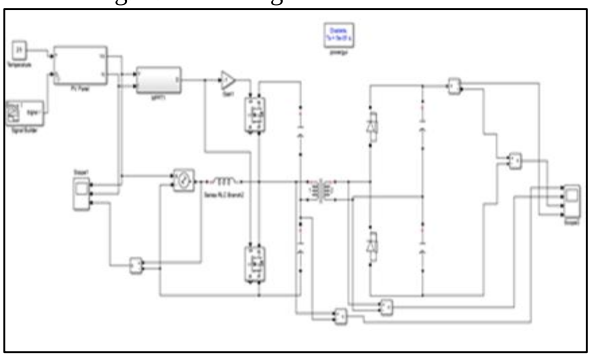


Fig. 9: Simulation model of the PV array with MPPT and Converter

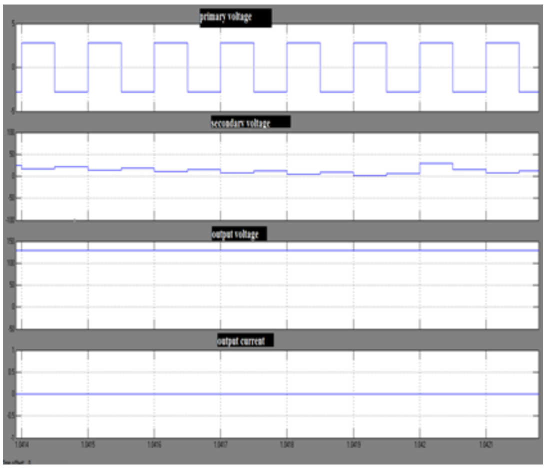


Fig. 10: Waveforms of the converter,X axis-.0001s/div

- Transformer Primary voltage,Y axis-5V/div
- Transformer Secondary voltage,Yaxis-50V/div
- Output voltage,Yaxis-50W/div
- Output Current,Yaxis-0.5A/div

The complete simulation model in MATLAB/Simulink with the PV array and the dc-dc converter is shown in fig.9 and the waveforms obtained from the converter are shown in fig.10.

VI. Conclusion

The mathematical modeling and simulation of the Photovoltaic system with MPPT and boost converter is done. The model is designed for 1kw power with variable irradiation and constant temperature. P &O algorithm of MPPT is used to produce pulses for DC-DC half bridge converter. The simulation is analyzed and it is seen that by increasing the solar irradiation, the PV current, PV voltage and PV power get increased. But by increasing the temperature power and voltage get reduced. From the model, it is also observed that by increasing the series resistances Rs, power get reduced. But power is increased by increasing the diode ideality factor. The system can be used for various solar applications such as pumps or for supplying household equipment.

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