Modelling and Simulation of Perturb and Observe Algorithm on Solar PV System using Different Converters in MATLAB/Simulink

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Abstract—**This paper deals with implementation of Perturb and Observe algorithm on a Photovoltaic System using different converters in MATLAB/SIMULINK. The model of Photovoltaic System is based on mathematical equations. The Perturb and observe algorithm is the Maximum Point Tracking Technique (MPPT) which applied on the developed Photovoltaic system in order to operate it at its maximum power point. The Perturb and Observe algorithm controls the duty ratio of converters for varying the load according to the maximum power point tracking. The converters that are used in this paper are DC-DC buck and DC-DC boost converters. Hence the DC voltage generated by the Photovoltaic System can be increased or decreased accordingly using the appropriate converter.**

Keywords—Modelling; Photovoltaic Panel; MPPT; DC-DC Boost Converter; DC-DC Buck Converter

I. INTRODUCTION

The demand of inexhaustible energy has experienced a noticeable rise in recent times because of the exhaustion of exhaustible sources used for power generation and increasing awareness of its detrimental effects over the environment. This demand has been bolstered by advancement in research and innovative technology which has been introduced until now to help in the productive utilization of these inexhaustible resources and it is estimated that renewable sources might contribute about 20%–50% to the energy consumption up to the end of the 21st century. [1]

There are two main kinds of sources for electrical power production. One of them is exhaustible and the other is inexhaustible. Today; to generate most of electrical power conventional sources like coal; gas; nuclear power are used. Some of conventional sources are polluting the environment while generating electricity. And nuclear energy is not much preferable because of its harmful radiation effect on the mankind. After a period of time; these conventional sources will not be sufficient enough to fulfil the requirements of the mankind. So the focus has shifted towards non-conventional energy sources like solar; wind; tidal; etc and some of the electrical power is being generated by them.With the continuous reduction in the cost of PV power generation and the further intensification of energy crisis; PV power generation technology obtains more and more application.[1]

II. PHOTOVOLTAIC CELL MODELLING

A Simulink model of a photovoltaic cell in Simulink is obtained based on mathematical equations. This model is then further simulated to obtain a Photovoltaic array model. In order to obtain the desired power solar cells are connected in parallel and series. A group of photovoltaic cells is known photovoltaic module and a group of photovoltaic modules is known photovoltaic array. The Photovoltaic cell can be interpreted as an electrical circuit as shown in figure 1 below.

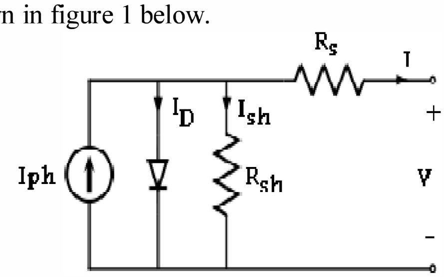

Fig. 1: Equivalent Circuit Diagram [16]

The mathematical modelling of photovoltaic array can be described as:

$$I = Iph - Io\left(\exp\left(q(V + IRs)/_{NKT}\right) - 1\right) - \frac{(V+IRs)}{Rsh} \quad (1)$$

Where:
I-Output current in amperes
Iph-Photocurrent in amperes
Io-Reverse saturation current in amperes
V-Voltage in volt
Rs-Series resistance in ohms
T-Temperature in Kelvin
Rsh-Shunt Resistance in ohms
N-Ideality factor
q-Charge of electron in coulombs

The photocurrent is obtained as described by the following equation:

$$Iph = \frac{Ir}{Irref}(Iphref + \mu sc * (Tc - Tcref)) \quad (2)$$

Where:
Ir-Irradiance in W/m^2

Irref-Irradiance at STC=1000W/m^2
Tcref-Cell temperature at STC= 25+273K
Tc-Cell temperature
µsc-coefficient temperature of short circuit current in A/K
Iphref-Photocurrent at STC in amperes

III. PV MODULE

The Solar Photovoltaic Module chosen to be simulated in Matlab/ Simulink is Vikram Solar Model: Eldora 40. It consists of 36 cells which are connected in series to produce a total power of 40 watt. The electrical characteristics of the solar photovoltaic module at 25^{o}C and 1000W/m^2 is as given in the Table 1 below.

TABLE 1: ELECTRICAL CHARACTERISTICS OF PV MODULE

Characteristics	Values
Maximum Power (Pmax)	40W
Voltage at Maximum Power (Vm)	17.40V
Current at Maximum Power (Im)	2.30A
Open Circuit Voltage (Voc)	22.25V
Short Circuit Current (Isc)	2.53A
No. of cells in Series (Ns)	36
No. of cells in Parallel (Np)	1

The Figure 2 shows the Simulink model for the above described solar photovoltaic module. It is obtained through mathematical equations. There are two inputs to the solar photovoltaic module i.e. temperature and irradiance.

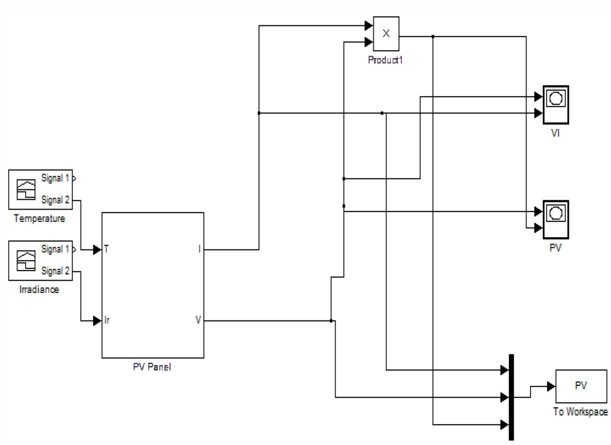

Fig. 2: Simulation Model of PV Module

The Power *vs.* Voltage characteristics and Voltage Vs Current characteristics of the solar photovoltaic module is shown in the figures 3 and 4 respectively. The Power and Current are at Y-axis while Voltage is at X-Axis. The characteristics obtained are for 1000W/m^2 irradiance and 25^{o}C of temperature. It can be seen that the maximum power obtained is 40W and the module has an open circuit voltage of 22.25V and short circuit current of 2.53A.

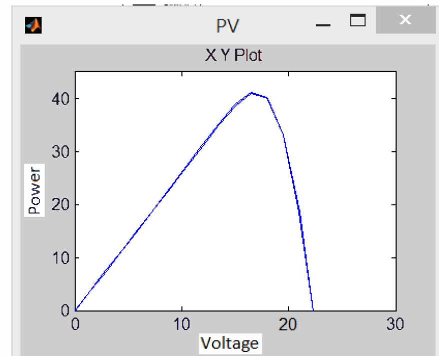

Fig. 3: PV Plot for the PV Module

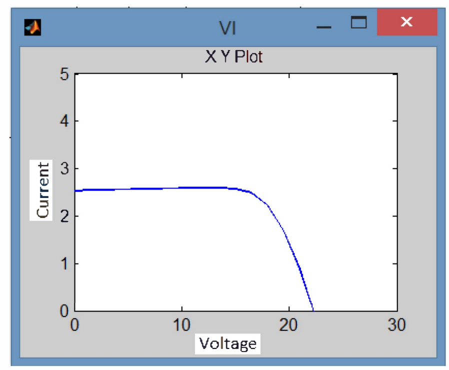

Fig. 4: VI Plot for the PV Module

IV. PERTURB AND OBSERVE ALGORITHM

The process of changing the Photovoltaic Array terminal voltage externally to extract maximum power for different loads is known as Maximum Power Point Tracking (MPPT). There are various techniques used for tracking maximum power point. Some of the most popular ones are: fractional open circuit voltage; fractional short circuit current; perturb and observe; incremental conductance method; etc. In this paper Perturb and Observe technique for MPPT will be discussed. In this technique of maximum power point tracking; the operational voltage or current of the solar photovoltaic module is perturbed. By observing the power which is calculated by multiplying the voltage and current; the direction in which further changes in the voltage or current has to be made is decided. The direction of changing the voltage or current is kept same if the calculated power increases with perturbation until the power begins to fall. From the figure 5 shown below it can be seen that when operating on the left side of the maximum power point; on increasing the voltage the power increases while when operating on the right side it decreases the power. Similarly; when operating on the left side of maximum power point on decreasing the voltage the power decreases while when operating on the right side it increases the power. Hence; the successive perturbation is kept in the same direction if an increase in the power is there in order to reach the maximum power point but if there is a decrease in the power; the next perturbation should be reversed.

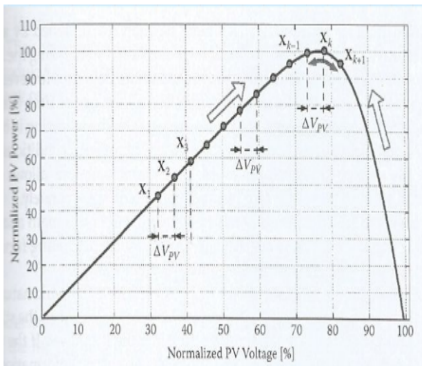

Fig. 5: Perturb and Observe Algorithm [16]

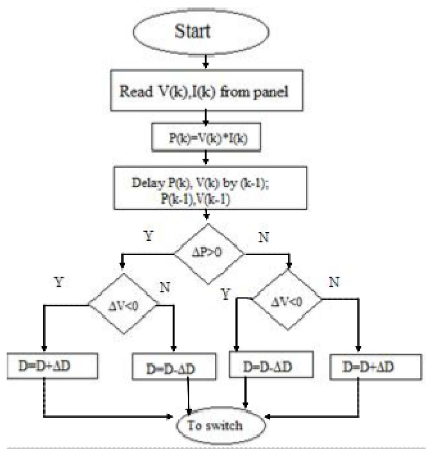

Fig. 6: P&O Algorithm Flowchart

The figure 6 above shows the flowchart for the Perturb and Observe algorithm. The inputs to the algorithm are voltage and current of the solar photovoltaic module. As seen from the flowchart the instantaneous voltage; V(k) and current; I(k); are measured by the algorithm and the instantaneous power; P(k); is calculated by multiplying them. The calculated power is then compared with the last calculated power; P(k-1). The system is constantly perturbed by the algorithm if the variation in operational point is positive; or else the direction of perturbation is swapped. It can be seen from the flowchart that if both the change in power and change in voltage is positive or negative then the duty cycle is reduced by a factor of ΔD in order to produce the successive cycle of perturbation and to force the operational point to move towards the maximum power point. Similarly; if the change in the voltage is positive and the change in power is negative or vice-versa then the duty cycle is increased by a factor of ΔD for the next cycle of perturbation. The advantages of the perturb and observe algorithm are simple structure; easy implementation and less required parameters.

The figure 7 below shows the simulation diagram for the Perturb and Observe algorithm in Matlab/ Simulink. It can be seen that the model requires two inputs that are voltage and current of the solar photovoltaic module and the output is duty cycle which is given to the gate of the converter. The factor ΔD by which the duty cycle is increased or decreased as required is taken as 0.001.

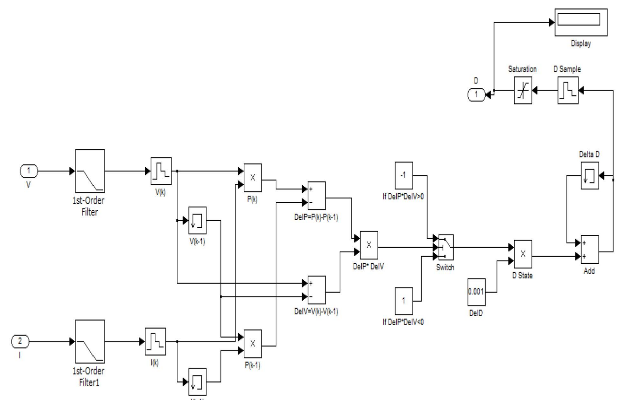

Fig. 7: Simulation of P&O Algorithm

V. DC-DC Converters

The power electronics circuits which are used to transform a DC voltage into different levels of DC voltage are known as DC-DC converters. This can be done using different types of methods of conversion such as electronic; linear; switched mode. The circuits expressed in this paper are classified as switched mode DC-DC converters. There are a variety of DC-DC converters. In this paper two converters are used namely Buck converter and Boost converter.

A. Buck DC-DC Converter

A Buck DC-DC converter chops or attenuates the input voltage and a lower amplitude voltage is obtained at the output.

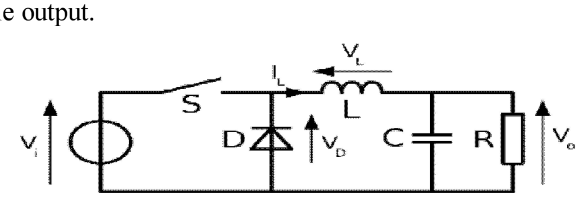

Fig. 8: Buck Converter [16]

The figure 8 above shows the circuit of a Buck Converter which includes a switch; diode; inductor; capacitor and load. On tuning ON the switch; the voltage at the input is applied to the load. During the ON period the diode becomes reverse biased and therefore it is off. The energy gets stored in the inductor during ON period. On turning OFF the switch; the output voltage becomes zero. The diode is forward biased i.e. it conducts in OFF period and hence the energy which was stored in the inductor during ON period discharges across it. The output voltage across the load is obtained by the following equation:

$$Vo = \alpha Vin \qquad (3)$$

Where:

Vo-Output Voltage in Volt

Vin-Input Voltage in Volt

α–Duty cycle = ton/T

In the simulation diagram of the Buck Converter used in this paper the value of inductor L is 0.459mH and capacitor C is 0.0844mF for a duty cycle of 0.466.

B. Boost DC-DC Converter

A Boost DC-DC Converter boosts or increases the input voltage to a higher value of voltage at the output.

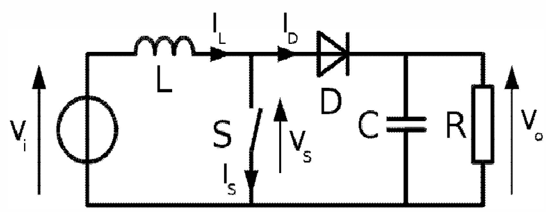

Fig. 9: Boost Converter [16]

The figure 9 above shows the circuit of a Boost converter which includes an inductor; switch; diode; capacitor and load. In this converter on turning ON the switch the inductor starts storing energy. As no current flows through the load; the output voltage is zero. On turning OFF the switch the voltage at the input gets applied to the load. In the OFF period the energy stored in inductor during the ON period also discharges through the load. Hence the output voltage becomes more than the input voltage. The output voltage across the load is obtained by the following equation:

$$Vo = {}^{Vin}\!/_{(1-\alpha)} \qquad (4)$$

In the simulation diagram of the Boost converter used in this paper; the value of inductor L is 0.961mH and capacitor C is 0.19mF for a duty cycle of 0.488.

VI. SYSTEM SIMULATION

A. Photovoltaic System with P&O Algorithm and Buck Converter

The figure 10 below shows the simulation of MPPT of solar photovoltaic system with Buck DC-DC Converter using Perturb and Observe Algorithm for a resistive load. The Buck Converter reduces the input voltage to a lower value of output voltage according to the duty cycle applied to its gate input. It can be seen that the output of the Perturb and Observe algorithm is given to the gate of the Mosfet in the Buck converter so that whenever there is a change in the irradiance or temperature; the duty cycle of the converter can be adjusted in order to get maximum power at the load side. The simulation has been performed for a progressive change of solar irradiance from 1000 to 500W/m^2 for different values of temperature.

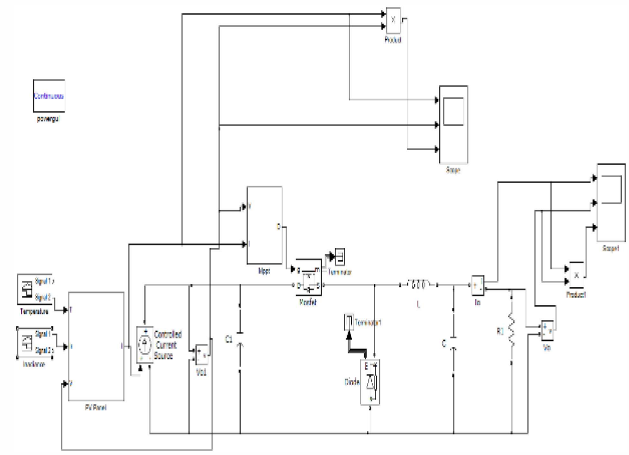

Fig. 10: Simulation Diagram of Photovoltaic System with P&O Algorithm and Buck Converter

B. Photovoltaic System with P&O Algorithm and Boost Converter

The figure 11 below shows the simulation of MPPT of solar photovoltaic system with Boost DC-DC Converter using Perturb and Observe Algorithm for a resistive load. The Boost Converter increases the input voltage to a greater value of output voltage according to the duty cycle applied to its gate input It can be seen that the output of the Perturb and Observe algorithm is given to the gate of the Mosfet in the Boost converter so that whenever there is a change in the irradiance or temperature; the duty cycle of the converter can be adjusted in order to get maximum power at the load side. The simulation has been performed for a progressive change of solar irradiance from 1000 to 500W/m^2 for different values of temperature.

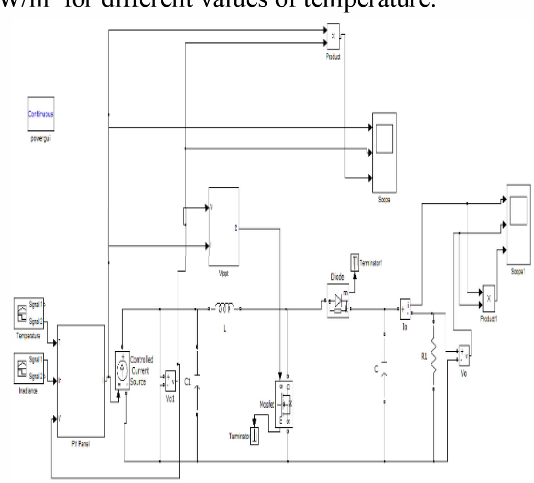

Fig. 11: Simulation Diagram of Photovoltaic System with P&O Algorithm and Boost Converter

VII. Results And Discussion

A. Photovoltaic System with P&O Algorithm and Buck Converter

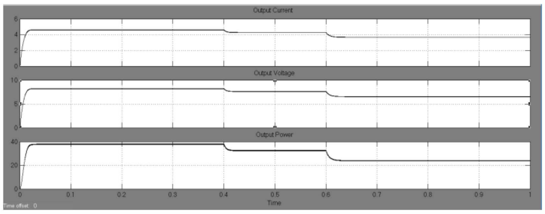

Fig. 12: Output Current; Voltage and Power at 25°C Temperature and Varying Irradiance

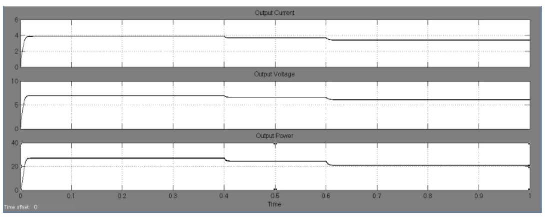

Fig. 13: Output Current; Voltage and Power at 50°C Temperature and Varying Irradiance

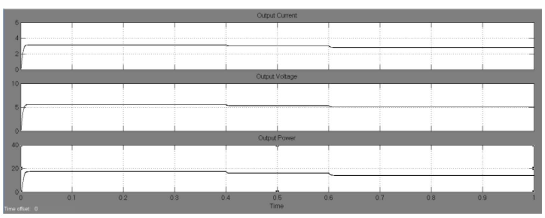

Fig. 14: Output Current; Voltage and Power at 75°C Temperature and Varying Irradiance

The figures 12; 13 and 14 above show the output current; voltage and power for irradiance varying from 1000W/m^2 to 500W/m^2 and temperature varying from 25°C to 75°C for a PV System working with a Buck Converter using Perturb and Observe Algorithm. The system has been designed for a duty cycle of 0.466. Hence; the input voltage of 17.4V has been reduced to 8.2V under standard conditions i.e. 1000w/m^2 irradiance and 25°C temperature. It can be noticed that the current; voltage and power are at their maximum at 1000W/m^2 and 25°C. They decrease as the value of irradiance decreases from 1000W/m^2 to 500W/m^2 and temperature increases from 25°C to 75°C.

B. Photovoltaic System with P&O Algorithm and Boost Converter

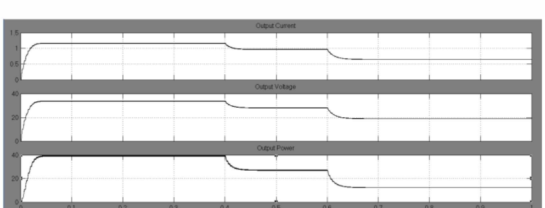

Fig. 15: Output Current; Voltage and Power at 25°C Temperature and Varying Irradiance

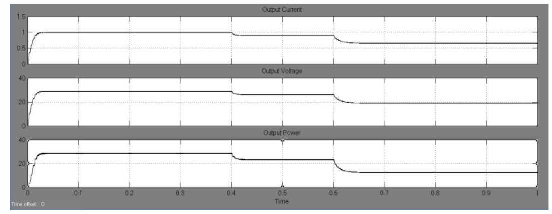

Fig. 16: Output Current; Voltage and Power at 50°C Temperature and Varying Irradiance

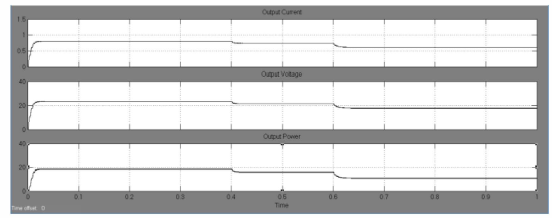

Fig. 17: Output Current; Voltage and Power at 75°C Temperature and Varying Irradiance

The figures 15; 16 and 17 above show the output current; voltage and power for irradiance varying from 1000W/m^2 to 500W/m^2 and temperature varying from 25°C to 75°C for a PV System working with a Boost Converter using Perturb and Observe Algorithm. The system has been designed for a duty cycle of 0.488. Hence; the input voltage of 17.4V has been boosted to 34V under standard conditions i.e. 1000w/m^2 irradiance and 25°C temperature. It can be noticed that the current; voltage and power are at their maximum at 1000W/m^2 and 25°C. They decrease as the irradiance decreases from 1000W/m^2 to 500W/m^2 and temperature increases from 25°C to 75°C.

VIII. Conclusion

The main target of this paper was to simulate Perturb and Observe algorithm for solar photovoltaic module with different converters. From the obtained results it can be noticed that the photovoltaic module output voltage can be enhanced (using Boost converter) or curbed (using Buck converter) to any value of voltage by modifying the duty ratio of the converters as required. Thereby; allowing the photovoltaic system to be used as source for any value of load voltage. Moreover from the results obtained by varying irradiance and temperature it can be concluded that as the irradiance decreases less amount of solar energy is received by the photovoltaic system and hence the output current; voltage and power reduces.

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