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Design and Development of Perturb & Observe MPPT Technique for Solar PV based Energy Conversion System

Ahteshamul Haque[1]

Assistant Professor, Dept. of Electrical Engineering, Jamia Millia Islamia (A Central University), New Delhi, India[1]

Abstract: The use of solar PV based energy conversion system is becoming very common. This energy conversion system still faces the challenge of low efficiency. It becomes essential to extract maximum power from solar PV (Photovoltaic) under all ambient conditions. Perturb & Observe (P&O) is one of the Maximum Power Point Tracking (MPPT) technique is used to achieve this task. The main objective of this work is to design and develop P&O mppt for solar PV system and check its performance under change load condition. The simulation work is done using PSIM simulation software. A prototype hardware is made in the lab. A buck DC – DC converter is used to implement P&O MPPT technique. The convergence time and tracking factor is evaluated and compared with simulation result.

Keywords: Solar PV, MPPT, Power Electronics, DC-DC Converter.

I. INTRODUCTION

Energy has become the basic need of human being. The demand of Electrical energy is increasing exponentially [1]. This increase in demand leads to concerns of global energy crisis as the reservoirs of fossils fuels are limited. The other concern is of environmental threats due the emission of greenhouse gases from fossil fuels i.e. from thermal power plants etc. Among other available sources of energy like nuclear possess serious safety concerns for the human being.

This concern leads the researchers to look for alternate sources of electrical energy. Renewable energy sources (RES) has got tremendous attention as an alternate source of electrical energy. RES consist of Solar, Wind, and Tidal etc. Among all renewable energy sources solar energy is considered as the most acceptable source of energy as it is available in abundant, available free of cost and have very less safety concerns [2].

Solar Photovoltaic (PV) is used to convert the solar energy into electrical energy. Solar PV has a nonlinear characteristic as its output varies with solar irradiation and with ambient temperature [3]. Also the other constraint is the efficiency of solar PV is very low. It is essential to extract maximum power from solar PV under normal and varying solar irradiation and ambient temperature condition. To achieve this task an algorithm known as Maximum Power Point tracking (MPPT) is developed [4]. Various types of MPPT algorithms are proposed mainly are fixed duty cycle, constant voltage, short circuit current, Perturb & Observe (P&O), Incremental Conductance (IC) methods etc. Many researchers have designed and evaluated these various types of MPPT techniques [5-9]. The modified power electronics converters are also proposed to improve the performance [10]. Even the MPPT control is modified to adaptive nature for better performance [12]. Among all these evaluations the main focus is on the variation of solar irradiation and of ambient temperature.

This paper is an attempt to give a complete design of MPPT considering the various factors like ambient conditions, load etc. The design is done with simulation experimental setup. The PSIM software is used for simulation work. P&O/Hill Climbing MPPT algorithm is used to for the presented work. 40W Solar PV and Buck DC-DC converter is chosen for this design work. The approximate cost is also evaluated. This work may be useful for the design of Solar PV system for Industry and academic application.

II. MODELLING & CHARACTERISTICS OF SOLAR PV

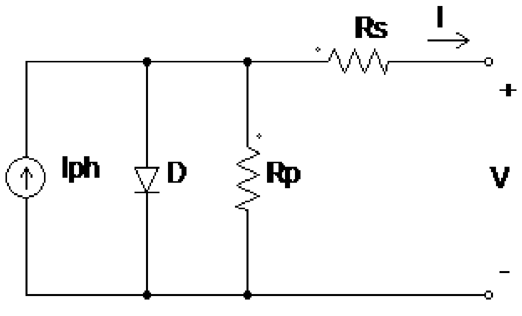

Fig. 1: Equivalent model of PV Cell

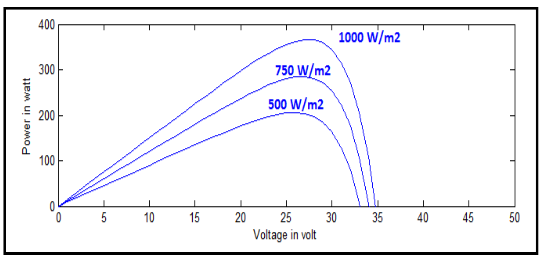

Fig.2: Solar PV Power Characteristics with different Solar Irradiation level.

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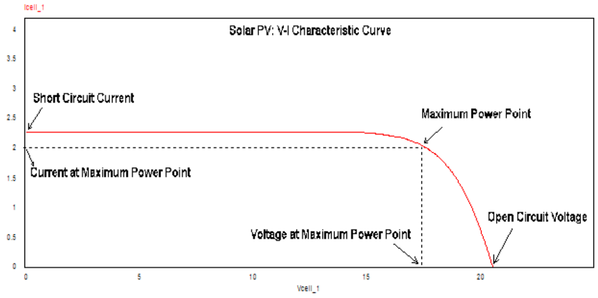

Fig. 3: Solar PV: V – I Characteristics

The basic element of solar PV system is PV cells. These cells are connected to form modules. It is further expanded in the form of arrays as per the power requirements. These PV cells exhibit nonlinear charateristics. The output of the PV cell varies with solar irradiation and with ambient temperature. The equivalent circuit model of PV cell given in Fig (1). The characteristic equation of PV cell based on this model is given by equation 1, 2 and 3 [3].

$$I = I_{ph} - I_{os} \{\exp [(q/AKT)(V + I R_s)] - 1\} - (V + I^*R_s)/R_p \quad (1)$$

$$I_{os} = I_{or} \exp [q E_{GO}/ Bk ((1/T_r) - (1/T))][T/T_r]^3 \quad (2)$$

$$I_{ph} = S[I_{sc} + K_I (T - 25)]/100 \quad (3)$$

Where I is the PV module output current, V is the PV cell output voltage, R_p is the parallel resistor, R_s is the series resistor. I_{os} is the PV module reversal saturation current, A, B are ideality factors, T is temperature (^oC), k is boltzmann's constant, I_{ph} is the light-generated current, q is electronic charge, K_I is short-circuit current temperature coefficient at I_{SC}. S is solar irradiation (W/m^2), I_{SC} is short-circuit current at 25^oC and 1000 W/m^2, E_{GO} is bandgap energy for silicon, T_r is reference temperature and I_{or} is saturation current at temperature T_r. The plot of solar PV output power and current versus voltage is shown in Fig (2) and Fig (3) respectively. It can be seen that the power and current varies non-linearly with the variation in solar irradiation and with ambient temperature. At the same plot in Fig (2) and Fig (3), the maximum power point (MPP) is marked. This MPP point varies with ambient conditions. It is a task of the researchers to make this moving point as the fix operating point to extract the maximum power.

III. PERTURB & OBSERVE MPPT TECHNIQUE

The flow chart of the P&O/ Hill Climbing method is shown in Fig (4). The main aim is to reach to the MPP. To achieve it the system operating point is changed by applying a small perturbation in the duty cycle. After each perturbation the power output is measured. If the value of power measured is more than the previous value then the perturbation is continued in the same direction. At any point if the new value of solar PV power is measured less than the previous one then perturbation is to apply in the opposite direction. This process is continued till MPP is reached. The issue with this method is it becomes oscillatory around MPP. These oscillations can be minimized by reducing the step size of perturbation. But care should be taken that a smaller step may slow down the MPPT. [5-8]

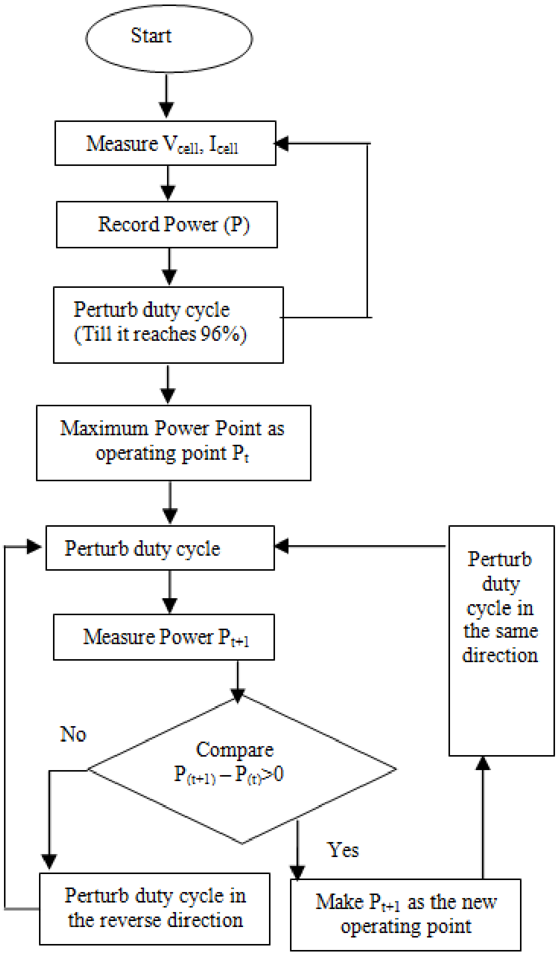

Fig. 4: Flowchart of Perturb & Observe/Hill Climbing MPPT method.

IV. BUCK DC – DC CONVERTER

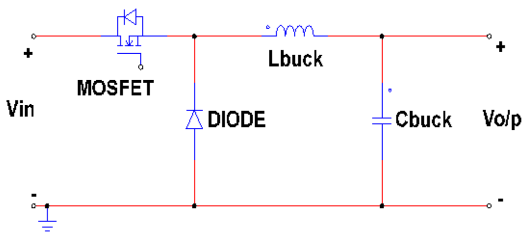

Fig. 5: Schematic: DC-DC Buck Converter

TABLE I: PARAMETERS OF DC-DC BUCK CONVERTER

S.No.	Name of the Parameter	Values
1	Vin	V_{MPP} : when MPP is working $V_{MPP} < Vin \leq Voc$: In NO MPP Zone
2	MOSFET	20A, 600V
3	DIODE	12A, 1000V
4	L_{buck}	1mH, 15A Saturation
5	C_{buck}	1000 uF
6	Vo	$d * V_{MPP}$: when MPP is working $V_{MPP} < d * Vin \leq Voc$: In NO MPP Zone
7	R_{LOAD}	Variable
8	Frequency	20 kHz
9	Power Output	40W

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P&O MPPT scheme is used to control the duty cycle of MOSFET switch of buck converter (Fig. 5) to regulate the power point at maximum value [13]. The parameters of buck DC-DC converter is listed in Table I.

V. EXPERIMENTAL SETUP

The block diagram of experimental setup is consist of Solar PV is connected with DC-DC buck converter whose output is connected with a load (resistive for this work). The PV terminal voltage and current is sensed using sensors and given as an input to the MPPT controller. The MPPT controller is implemented using microcontroller PIC-16F887. Using this microcontroller PWM signal is generated based on MPPT algorithm and is given to the mosfet of buck converter using and opto-coupler driver IC. The microcontroller is also connected with a data logger to record the parameters. The value of R_{LOAD} is also recorded by measuring the voltage and current at the load end.

VI. SIMULATION AND EXPERIMENTAL RESULTS

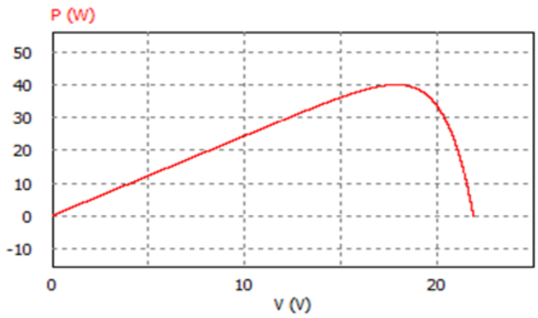

Fig. 5: Simulation Result: Power (P)-Voltage (V) curve

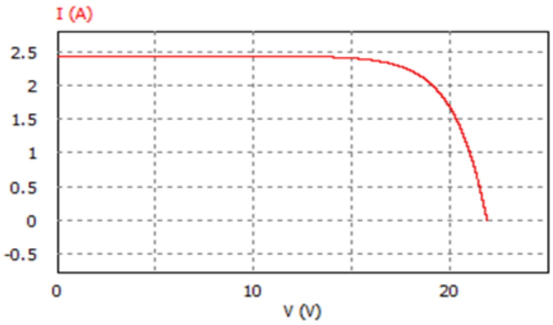

Fig. 6: Simulation Result: Current (I)-Voltage (V) curve

The Modelling of solar PV parameter using the data given by vendor ELDORA is done in PSIM. The P-V and I-V characteristic curve is plotted in Fig 5 and Fig 6 respectively. These results are at standard test conditions i.e. at solar irradiation of 1000 W/m^2 and at ambient temperature of 25 degree celcius. The 40W solar PV is tested in actual sun light and its PV curve is plotted using data logger by varying the load. The measured value of ambient condition at the time of testing is solar irradiation: 700 W/m^2 and ambient temperature: 35 degree celcius. The maximum power achieved under this ambient condition is 23.0 Watt. The simulation and experimental results i.e. P-V curve of 40 W solar PV is shown in Fig. 7 and Fig. 8 respectively. I – V curve of solar PV is measured and simulation and experimental results are shown in Fig. 9 and Fig. 10 respectively.

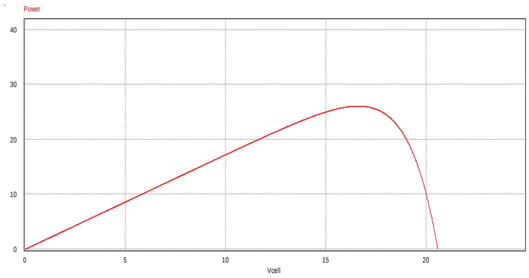

Fig. 7: Simulation Result: Solar PV: P-V Curve (Solar irradiation: 700 W/m^2, Ambient Temp: 35 deg cel)

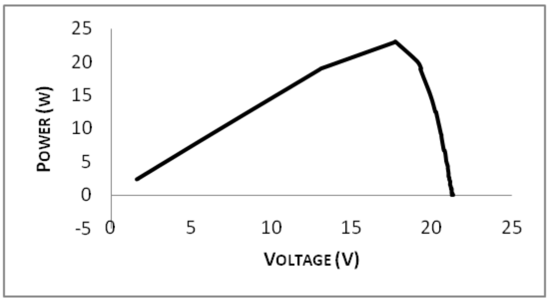

Fig. 8: Experimental Result: Solar PV: P-V Curve (Solar irradiation: 700 W/m^2, Ambient Temp: 35 deg cel)

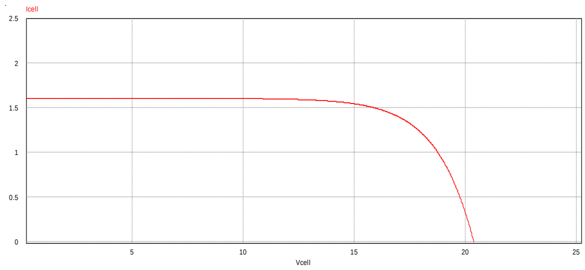

Fig. 9: Simulation Result: Solar PV: I-V Curve (Solar irradiation: 700 W/m^2, Ambient Temp: 35 deg cel)

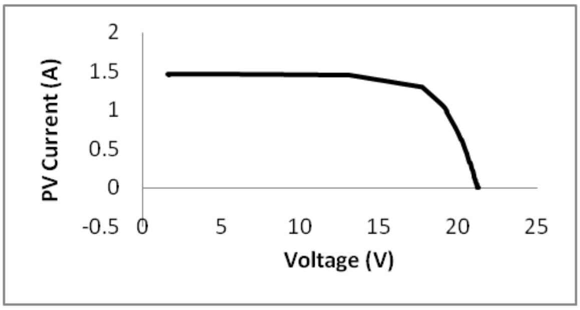

Fig. 10: Experimental Result: Solar PV: I-V Curve (Solar irradiation: 700 W/m^2, Ambient Temp: 35 deg cel)

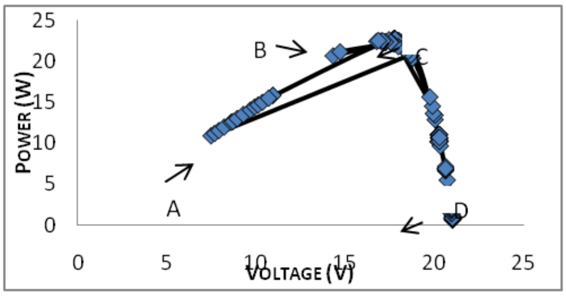

Fig. 11: Experimental Result: Solar PV: P-V Curve with MPPT
(Solar irradiation: 700 W/m^2, Ambient Temp: 35 deg cel)

The numerical values are summarized in Table II.

TABLE II: MEASURED VALUES OF SOLAR PV CHARACTERISTICS

S.No.	Name of the Parameter	Test Condition	Simulation Result	Experimental Result	% error
1	Open Circuit Voltage: V_{OC} (Volt)	- Solar Irradiation: 700 W/m^2	20.59	21.3379	3.5
2	Short Circuit Current: I_{SC} (Amp)		1.6309	1.46289	11.48
3	MPP Voltage: V_{MPP} (Volt)	-Ambient Temp: 35 deg cel	17.96	17.7246	1.32
4	MPP Current: I_{MPP} (Amp)		1.3725	1.3007	5.5
5	Maximum Power P_{MPP} (Watt)		24.02	23.0558	4.18

The P&O MPPT scheme is implemented in the experimental set up of Fig. 9. The P-V and I-V curve of solar PV is plotted shown in Fig. 16 & Fig. 17 respectively. As described in previous section that duty cycle is perturbed in a step of 4% starting from 8% to 92%. At point D of Fig. 11 the perturbation is started. It keeps perturbing and the operating point is in NO MPP Zone as long as $R_{Load} > R_{MPP}$. It can be understood that if the load power is less than the MPP power then MPP scheme will not work. Operating zone shown between Point C and D is no MPP operating zone in Fig. 9. The operating zone left of Point C is the MPP operating zone. The MPP point lies in the vicinity of Point C towards left. The small points in the vicinity of point C are due to the perturbation in the duty cycle and corresponding shift in the operating point. In case I: The load is increased and the operating point is shifted from point C to point A and at this point the MPP algorithm works to adjust the duty cycle and bring the operating point back at MPP point i.e. from A to C. in case II: A small load change gives the same results between point C and point B. The effectiveness of MPPT is checked by changing the load and plotting the curve from the experimental data stored using data logger.

VII. CONCLUSION

The objective of the work presented in this paper is to design and develop P&O MPPT for solar PV energy conversion system and evaluate its performance under load varying condition. It is evident from the result that the proposed P&O MPPT is capable of restoring MPP (Maximum power point) with the change in load.

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BIOGRAPHY

Dr. Ahteshamul Haque is working as Asisstant Professor in the Department of Electrical Engineering, Jamia Millia Islamia (A Central University) New Delhi. His area of research is Power Electronics and its application in Renewable Energy, drives, electric control system for artificial lighting, Power quality improvements, smart grids, wireless power transfer, hybrid vehicles, electric traction, smart cities etc. He did B.Tech in Electrical Engineering from AMU and M.Tech from IIT-Delhi. He completed his PhD from Jamia Millia Islamia in the area of power electronics and renewable energy. Prior to Jamia Millia Islamia, he was working in the Power Electronics R&D units of world reputed Multi-National Companies. His inventions are patented and awarded in USA and Europe. He has published and presented his research papers in many International conferences and peer reviewed Journals.