Load Variation effect on Maximum Power Point Tracker (MPPT) for Solar Photovoltaic (PV) Energy Conversion System

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Abstract—Solar energy has got tremendous attention from the researchers among all renewable energy sources in the last few decades. It is available in abundant and free of cost. Solar Photovoltaic (PV) is used to convert the solar energy into unregulated electrical energy. Maximum power point tracker (MPPT) is an algorithm used to extract maximum power from solar PV. Power Electronics converters are used to regulate the power generated from Solar PV. The behaviour of these converters along with MPPT needs to be analysed with load variations. The objective of this paper to design MPPT considering the load factor. A modified P&O MPPT technique is used for this study. The simulation study is done using PSIM simulation software and a prototype is made to validate the results.

Keywords—Solar Energy, MPPT, Buck converter, Perturb and observe, Hill Climbing, PSIM

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 non-linear 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 [12-13]. 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.

The paper is organised as following: Section 2 give the details of modified MPPT technique. In Section 3 load analysis with MPPT technique and buck converter is discussed. The experimental and simulation results are discussed in Section 4.
II. MODIFIED PERTURB & OBSERVE MPPT TECHNIQUE

There is a minor difference between P&O and Hill climbing method. In P&O the perturbation is given either in the PV voltage or in the PV current (either of which is taken as a reference signal), but in hill climbing the perturbation is given in the duty cycle which indirectly perturbs the reference signal [5-6]. The flow chart of the P&O/Hill Climbing method is shown in Fig (1). 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.

III. LOAD ANALYSIS OF MPPT WITH BUCK DC-DC CONVERTER

MPPT algorithm is implemented to harvest the maximum power from sun through solar PV under an ambient condition. It is essential for researcher and design engineer to evaluate MPPT with load variations also. In the previous section it is elaborated that by varying the duty cycle of dc – dc converter (Buck converter used in this paper) the impedance is matched to transfer the maximum power from solar PV to load.

For dc – dc buck converter the maximum value of duty cycle is 1 and if \( R_{Load} \) increases beyond a certain value then MPP will not work. This certain value of \( R_{Load} \) is \( R_{MPP} (V_{MPP}/I_{MPP}) \).

If the \( R_{Load} \gg R_{MPP} \) the duty cycle variation will fail to match it will \( R_{in} \). This may lead to the failure of MPP. It can be understood in other terms i.e. of the load power is less than the MPP power then MPP fails, meaning which solar PV is derated. Table I gives the summary of MPP limitation. Fig. 2 shows the two zones i.e. MPP ZONE and NO MPP ZONE on the V – I Characteristic of solar PV.

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Fig. 1: Flowchart of Modified Perturb & Observe Hill Climbing MPPT method.

Fig. 2 shows the two zones i.e. MPP ZONE and NO MPP ZONE on the V – I Characteristic of solar PV.
The Buck converter works in the following two modes:

A. When MPPT is working

During this mode of operation the input voltage is $V_{MPP}$ and the output voltage varies depending on duty cycle. As described earlier the range of duty cycle is from 4% to 92%. i.e. the output voltage varies between $0.4V_{MPP}$ to $0.92V_{MPP}$.

B. In No MPPT Zone

During this mode of operation the input voltage is either greater than $V_{MPP}$ or less than or equal to open circuit voltage $Voc$. So the output voltage in this mode varies with duty cycle times the input voltage. These two operating conditions are summarized in Table II.

While designing the buck dc-dc converter the important factor is to calculate the value of inductor keeping the frequency of operation and duty cycle range in mind. The other aim is to calculate the maximum inductor current to decide the saturation limits and also the allowable ripples in the output voltage [10]. The parameters of buck dc-dc converter are given in Table II.

| S.No. | $R_{load}$ | MPP Scheme | $P_{load}$ |
|-------|------------|-------------|------------|
| 1     | < $R_{MPP}$ | Working     | $P_{MPP}$  |
| 2     | = $R_{MPP}$ | Working     | $P_{MPP}$  |
| 3     | > $R_{MPP}$ | Fail        | < $P_{MPP}$|

**TABLE I: PARAMETERS OF DC-DC BUCK CONVERTER**

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

**TABLE II: PARAMETERS OF DC-DC BUCK CONVERTER**

P&O/Hill climbing MPPT scheme is used to control the duty cycle of MOSFET switch (Fig. 2) to regulate the power point at maximum value.
The role of duty cycle to control the power is analysed below:

The maximum power can be transferred with source to load when impedance at source side matches with load impedance. The resistance of solar PV is the input resistance \( R_{in} \) for DC-DC converter. Since the MPPT is implemented and the operating point is MPP so the corresponding resistance at input is \( R_{MPP} \). The resistance connected at the output of DC – DC converter is \( R_{LOAD} \).

\[
R_{in} = \frac{R_{Load}}{d^2}
\]  
(1)

The relationship between the input resistance, output resistance and duty cycle is shown by equation (1). Its variation is plotted in Fig (3).

At the maximum power point (MPP) on the PV curve of solar PV the input resistance (i.e. the resistance of solar PV) is matched with \( R_{Load} \) by adjusting the duty cycle with the above empirical relation. Once the \( R_{Load} \) is changed the duty cycle is adjusted to make MPP as operating point. The detailed results are given in later section.

III. EXPERIMENTAL SETUP

The block diagram of experimental setup is shown in Fig. 4. 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.

Fig. 3: Input Resistance versus duty cycle

Fig. 4: Block diagram of Experimental setup.
IV. SIMULATION & EXPERIMENTAL RESULTS

The P&O/ Hill Climbing MPPT scheme is implemented in the experimental setup of Fig. 4. The P-V and I-V curve of solar PV is plotted shown in Fig. 5 & Fig. 6 respectively. Fig 7 & 8 are simulation and experimental result of PV characteristics.

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

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

Fig. 7: Simulation Result: Solar PV: P-V Curve (Solar irradiation: 700 W/m², Ambient Temp: 35 deg cel)

Fig. 8: Experimental Result: Solar PV: P-V Curve (Solar irradiation: 700 W/m², Ambient Temp: 35 deg cel)
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. 09, 10 the perturbation is started. It keeps perturbing and the operating point is in NO MPP Zone as long as \( R_{\text{Load}} > R_{\text{MPP}} \). 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. 09 and 10. 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.

![POWER vs VOLTAGE CURVE WITH MPPT](image1)

**Fig. 09:** Experimental Result: Solar PV: P-V Curve with MPPT (Solar irradiation: 700 W/m\(^2\), Ambient Temp: 35 deg cel)

![I vs V CURVE WITH MPPT](image2)

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

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.

The other check of MPP algorithm is under change atmospheric conditions. The experimental result of P-V curve is plotted in Fig. 11. The results are stored under ambient condition of solar...
irradiation of 200 W/m² and ambient temperature of 22 degree celcius. The result shows that designed MPPT is working effectively.

![POWER vs VOLTAGE WITH MPPT AT LOW IRRADIATION](image)

**Fig. 11:** Experimental Result: Solar PV: P-V Curve with MPPT (Solar irradiation: 200 W/m², Ambient Temp: 22 deg cel)

**C. Analysis of results:**

As discussed in previous sections MPPT is designed to adjust the duty cycle for fixing the operating point at MPP when \( R_{Load} \) is less than \( R_{MPP} \). Table III gives the experimental results for \( R_{Load} \), \( R_{MPP} \) and duty cycle. The variation in duty cycle waveform is captured with change load and is given in Fig. 12, and Fig. 13 respectively.

![Duty Cycle](image)

**Fig. 12:** Experimental Result: Duty Cycle

![Duty cycle when load is increased](image)

**Fig. 13:** Experimental Result: Duty cycle when load is increased
The result shown in Table III explains the status of MPP. MPP is working as long as $R_{LOAD}/D^2$ is equal to $R_{MPP}$. The point after which $R_{LOAD}$ is greater than $R_{MPP}$ maximum power point racking scheme fails. Fig. 12 is the waveform of the duty cycle. Fig. 13 is the waveform of duty cycle when load is increased. Fig. 14 is the photograph of experimental setup done for this design.

**TABLE III: MEASURED VALUES OF $R_{LOAD}$, $R_{MPP}$ AND DUTY CYCLE**

| S.NO. | $V_{MPP}$ (V) | $I_{MPP}$ (A) | $R_{MPP}$ (Ohm) | $R_{LOAD}$ (Ohm) | Duty Cycle (%) | $R_{LOAD}/D^2$ | MPP Status   |
|-------|---------------|---------------|-----------------|------------------|----------------|----------------|-------------|
| 1     | 17.72         | 1.3           | 13.63           | 1.984            | 38             | 13.73         | WORKING     |
| 2     | 17.72         | 1.3           | 13.63           | 0.55             | 20             | 13.75         | WORKING     |
| 3     | 19.2          | 0.7           | 13.63           | 15               | 60             | 27.77         | FAILED      |

![Fig. 14: Experimental Setup](image-url)

D. **Cost:**
The major cost of this system is of Solar PV i.e. around $150 for 40W panel. The cost of other components used i.e. in DC-DC buck converter, sensors, microcontroller etc is around $25. The BOM (bill of material) cost is around $175. This cost is a rough BOM cost which does not include the cost of casing, manufacturing etc.

E. **Safety:**
In this design the system is operating even at short circuit current because the power is low. In actual practise a safety zone should be defined (may be 10% from Isc) in which the circuit should be disabled to avoid catastrophic failures.

**V. CONCLUSIONS**

In this paper a detail design procedure of solar PV energy conversion system is described. As a sample 40W solar PV is chosen for this work. The experimental data is compared with simulation results and analysed with concepts of MPPT scheme. An approximate cost of the whole design is also discussed. This method may be very useful for industry and researchers to develop and improve the design of solar PV energy conversion system. The same procedure is valid if either the wattage of the system is increased or the power electronics converter is changed.

**REFERENCES**

1. AEO (2013) Annual Energy Report. Department of Energy, USA. [http://www.eia.gov](http://www.eia.gov).
2. Solanki S. Chetan. (2012): ‘Solar Photovoltaics: Fundamentals, Technologies and Applications’, New Delhi: PHI.
3. M. G. Villalva, J. R. Gazoli, E.R. Filho. (2009). Comprehensive approach to modelling and simulation of photovoltaic arrays. IEEE Transaction on Power Electronics 5: 1198-08.
4. Esram Trishan, Chapman L. Patrick (2007) Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques. IEEE Transaction on Energy Conversion, Vol. 22, No.2.
5. De Brito M A Gomes, Galotto Luigi, Poltronieri Leonardo, E Melo Guilherme de Azevedo e Melo, Canesin carlos Alberto (2013) Evaluation of the Main MPPT Techniques for Photovoltaic Applications. IEEE Transaction on Industrial Electronics, Vol. 60, No. 3.
6. A. Haque, “Maximum power point tracking (MPPT) scheme for solar photovoltaic system,” Taylor & Francis Group, LLC, *Energy Technology & Policy* (2014) 1, pp. 115–122.

7. Zaheeruddin, SK Mishra, Ahteshamul Haque, “Performance evaluation of modified perturb & observe maximum power point tracker for Solar PV system”, *Springer Internat. Journal, System assurance engg. & manag.*, pp. 1-10, Jun. 2015.

8. Safari Azadeh, Mekhilef Saad (2011) Simulation and Hardware Implementation of Incremental Conductance MPPT with direct control method using Cuk Converter. IEEE Transaction on Industrial Electronics, Vol. 58, No.4.

9. Salas V., Olias E., Lazaro A., Barrado A.(2005) New Algorithm using only one variable measurement applied to a maximum power point tracker. Elsevier Journal on Solar Energy materials and Solar cells, Vol. 87, pp. 675-684.

10. Sayed Khairy, Abdel-Salam Mazen, Ahmed Adel, Ahmed Mahmoud (2012) New high Voltage Gain Dual-boost DC-DC Converter for Photovoltaic Power Systems. Taylor & Francis International Journal of Electric Power Components and Systems, Vol. 40:7, pp. 711-728.

11. Deasi P Hardik, Maheshwari Ranjan, Sharma N. Shambhu, Shah Varsha (2012) Maximum Power Extraction from Photo-Voltaic Power Generator with Adaptive MPP Tracker. Springer Journal of Applied Solar Energy, Vol. 46, No. 4, pp. 251-257.

12. A.Haque, “Maximum Power Point Tracking (MPPT) Scheme for Solar Photovoltaic System,” *Energy Technol. Policy*, vol. 1, no. 1, pp. 115–122, 2014

13. Zaheerudin, Sukumar and M. Ahteshamul, “Performance evaluation of modified perturb & observe maximum power point tracker for solar PV system,” *Int. J. Syst. Assur. Eng. Manag.*, vol. 7, no. 1, pp. 229–238, 2015.