Design and Implementation of Improved Fractional Open Circuit Voltage Based Maximum Power Point Tracking Algorithm for Photovoltaic Applications

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Abstract- To tap maximum available power from a non-linear energy source such as solar panel, maximum power point tracking (MPPT) algorithms are used. This paper presents an improvised version of fractional open circuit voltage based MPPT algorithm. Maximum power point of non-linear input source varies with various parameters. In the case of a solar panel, maximum power point fluctuates based on the variations in the temperature and light intensity. Hence the conventional fractional open circuit voltage based MPPT algorithm fails to extract maximum available power from the system. Based on the new algorithm presented in this paper, maximum power point tracking is possible even during the variation of temperature and irradiance received in the solar panel. Algorithm is implemented using a 250W solar panel and results are discussed in the later section of the paper.

Keywords MPPT; Power converter; microcontroller; solar panel.

1. Introduction

Excessive dependence on non-conventional energy system increases pollution level in the planet, as well as the sustainability of the system is also at stake. Energy demand is also rising in an exponential way. All these factors necessitate the use clean and green energy technology for meeting the energy demand of the present generation. Solar panel based energy source, is one of the main contributors to such green energy resources [1]. But the problem with such a source is that this energy availability is highly fluctuating, which varies with insolation and temperature. Adding to it is the non-linear characteristics of the photovoltaic system. [2] The photovoltaic effect is the basic principal process by which a PV cell converts sunlight into electricity. When light shines on a PV cell, it may be reflected, absorbed, or pass right through. The absorbed light generates electricity. Each type of PV module has its own specific characteristics corresponding to the surrounding condition such as irradiation, and temperature and this makes the tracking of maximum power point (MPP) a complicated problem. To overcome this problem, many maximum power point tracking (MPPT) control algorithms are developed [3]. A detailed overview of conventional methods used for maximum power point tracking of any given solar panel is also discussed in [3]. This paper modifies fractional open circuit based maximum power point tracking given in [3] to form a new MPPT algorithm. [4] gives detailed functioning of perturb and observe MPPT algorithm implemented for running solar pumps. [5] discusses an improved version of perturb and observe MPPT technique that can overcome partial shading condition. [6] proposes a new fuzzy-based MPPT system using SEPIC power converter. It focuses on analysis and response of convergent distribution of membership function over symmetrically distributed membership function. [7] proposes a basic fractional open circuit based MPPT mechanism for PV application. But problems arising during tracking under variable insolation condition or during temperature variation of solar panels is not discussed. The advantage of using fractional open circuit voltage (FOCV) based MPPT is that the controller requires only a single sensor. Computational intensity of this proposed algorithm is also much lesser as compared to other conventional algorithms mentioned in [3].

This paper is organized into six sections. Section II analyses solar panel and its characteristics during temperature variations and during insolation fluctuations. Solar panel characteristics is also analyzed under partial shaded conditions. Section III describes basic fractional open circuit voltage (FOCV) based MPPT algorithm and then about improved FOCV MPPT algorithm. Section IV provides details regarding selection of power converter for the aforesaid application with the selected solar panel. Section V gives results of the conventional FOCV mechanism and reformed FOCV MPPT technique and discusses the improvements in the proposed technique. The conclusion is provided in Section VI.

2. Effect of Temperature Variation And Insolation Change In Solar Panel

A comprehensive analysis of solar panel and its modelling provided in [8]. Fig. 1 shows one diode model of a solar cell. Iph or photon current is the factor which varies with input insolation. Forward biased voltage of the diode is assumed as the open circuit voltage, Voc of the solar panel. Series and shunt resistances changes its values based on the temperature, which in turn affects open circuit voltage of the panel.

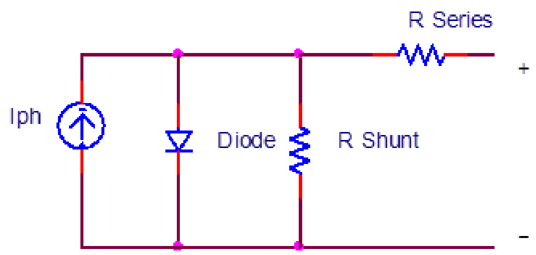

Fig. 1. One diode model of solar cell

Iph or photon current is the factor which varies with input insolation. Forward biased voltage of the diode is assumed as the open circuit voltage of the solar panel. Series and shunt resistances changes its values based on the temperature, which in turn affects open circuit voltage of the panel. Based on details provided in [8] insolation in the solar panel determines photon current and open circuit voltage in the panel is determined by temperature.

Fig. 2 shows power – voltage characteristics of a 250W solar panel under three different solar irradiance conditions. Solar panel used for testing has a power rating of 250W, open circuit voltage of 44V, maximum power voltage of 36V, short circuit current of 8.2A and maximum power current of 7A at a rated irradiance level of 1000W/m^2 and temperature of 25^{o}C.

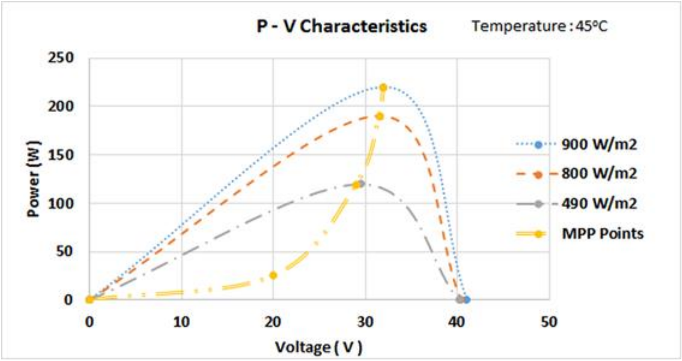

Fig. 2. P-V Characteristics of solar panel, under different insolation

Characteristics of solar panel is experimentally observed and analyzed under various insolation conditions and also under various temperature levels. It is observed from the characteristics that, with variation of irradiance seen by the solar panel, maximum power output of the panel is getting affected. But open circuit voltage of the solar panel is almost constant irrespective of the change in intensity of sunlight. By extrapolating the maximum power points under each irradiance condition, Fig. 2 also depicts variation of maximum power points under aforementioned irradiance levels.

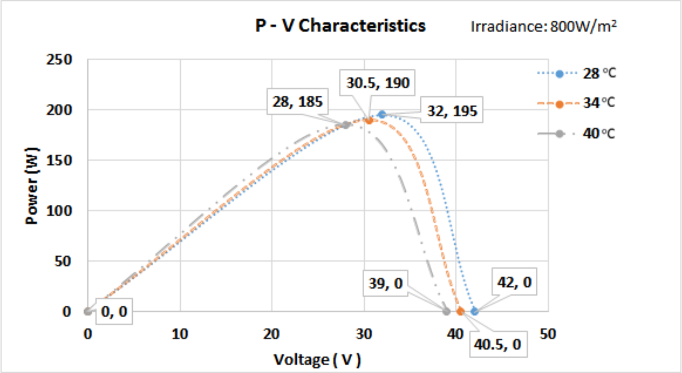

Fig. 3. P-V Characteristics of solar panel, under different temperatures

Fig. 3 gives a view on variation of characteristics of the selected solar panel in accordance with variation of temperature. Intensity of the solar ambience is at 800 W/m2. Fig. 3 gives a clear view of the variation of open circuit voltage and maximum power point when there is a change in temperature. It can be seen that both maximum power point and open circuit voltage of the panel is affected in a way that maximum power point voltage always lies between 0.7 and 0.79 times the open circuit voltage of the panel. From Fig. 2, it is also observed that maximum power point voltage always lies in between 0.7 to 0.78 times the open circuit voltage of the solar panel.

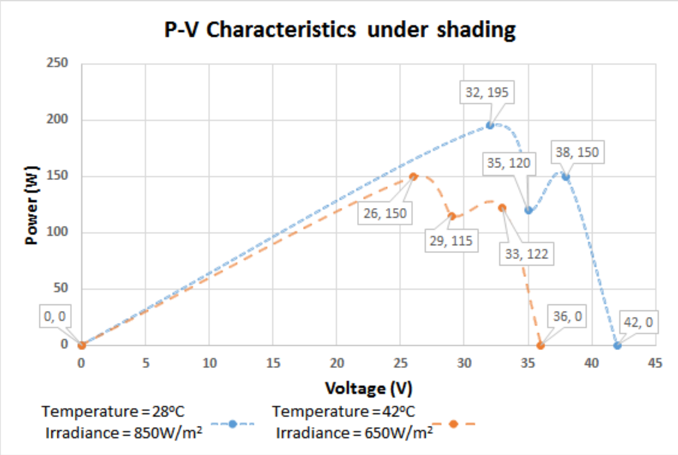

Fig. 4. P-V Characteristics of solar panel, under shaded condition

Fig. 4 depicts the characteristics of solar panel when there is shading appeared across the panel cells. There are two P-V characteristics shown in Fig. 4 under two different insolations and temperatures. It can be seen that there are multiple maxima and minima present in the system when there is partial shading. If conventional perturb and observe algorithm is used, it can result in maximum power point lock in local minima. [4] has performed a detailed analysis and study conventional perturb and observe algorithm for maximum power point applications. An advanced version of the same is proposed and implemented in [5, 14, 16, 21] that takes care of local maxima and makes the system work in global maximum power point. It is clear from the Fig. 4 that, even under partial shaded conditions, maximum power point voltage of the panel is still between 0.7 to 0.78 times the open circuit voltage of the solar panel.

3. Improved Fractional Open Circuit Voltage Algorithm

Analysis of solar panel characteristics during insolation variations, temperature change and under partial shaded conditions shows that maximum power point voltage of the solar panel lies broadly between 0.6 to 0.8 times the open circuit voltage of the solar panel. Fractional open circuit voltage based tracking algorithm uses this technique [11,20] to perform maximum power point tracking. With the help of power converter modules, input voltage of the converter, which is same as the solar panel terminal voltage is maintained at 0.7 times its open circuit voltage. In real time, changes in temperature, intensity of sunlight, presence of shades can vary the open circuit voltage. Hence the conventional FOCV based maximum power point tracking algorithm becomes less efficient as the environmental factors affect the characteristics of solar panel drastically. Under constant temperature, constant insolation states and in a condition where there is no shades, conventional FOCV works without any flaws.

To overcome this issue, a time based open circuit voltage check is performed, where temporarily, energy drawn from solar panel is temporarily halted by providing necessary switching sequence to the power converter. When the panel becomes open circuit, voltage across the panel is monitored and stored. Then conventional FOCV based algorithm is applied with the newly obtained panel open circuit voltage. This technique overcomes the effect of reduction in MPPT efficiency in conventional FOCV mechanism due to the variation of open circuit voltage of the panel due to temperature variations. Other conventional MPPT algorithms and improved versions of these conventional algorithms [5,15,17,18,19] need at least two sensing units, one for measuring current and other for measuring voltage. For example, if perturb and observe MPPT algorithm [4] is considered, power is measured by processing voltage and current signals captured with the help of sensors. The same condition is true in the case of its advanced or modified types also [5,6,7,19]. The advantage of this technique is that it requires only a single sensor to monitor voltage, and computational load in performing tracking is much lesser compared to other conventional and improvised algorithms.

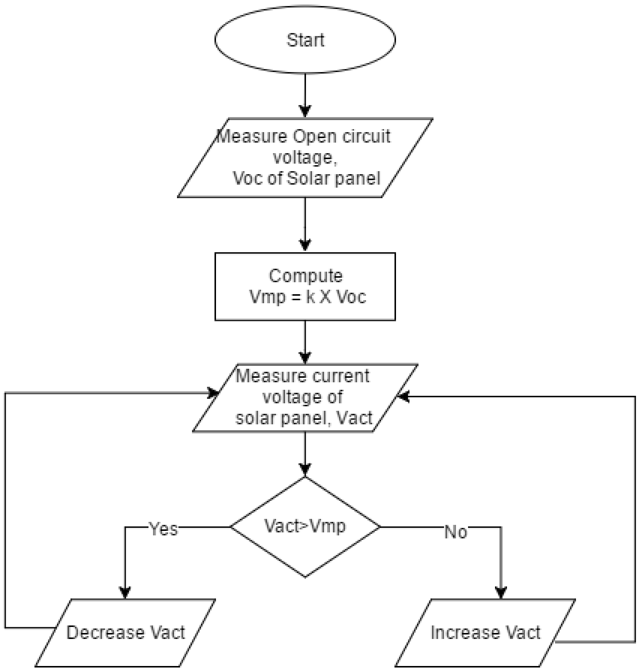

Fig. 5. Flow chart of conventional Fractional open circuit voltage based MPPT algorithm

Fig. 5 shows algorithm used for performing maximum power point tracking using conventional fractional open circuit voltage based MPPT algorithm. In this algorithm, an experimentally computed factor, k is used for finding maximum power point voltage of the solar panel or solar panel array. By performing experiments, it was observed that maximum power voltage of the solar panel lies between 0.7 to 0.78 times the open circuit voltage of the solar panel. Hence, k value is kept as 0.75. Algorithm also asks controller to either increase or decrease open circuit voltage, which achieved by proper switching of interfacing power converter. Here in the conventional algorithm, maximum power voltage Vmp, is computed based on the instant at which Voc is measured.

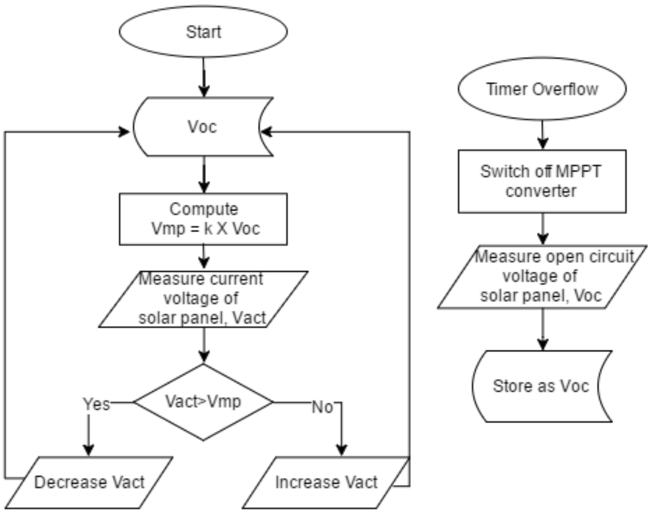

Fig. 6. Flow chart of Improved Fractional open circuit voltage based MPPT algorithm

As the time passes, there can be variations in temperature, and intensity of sunlight. Hence maximum power voltage, Vmp is not a fixed value, rather it is a function of Voc, temperature and intensity of the sunlight falling on the solar panel.

Algorithm used in improved fractional open circuit voltage based MPPT algorithm is depicted in Fig. 6. Here, with the help of timer overflow concept in microcontroller, on the event of a timer overflow interrupt, Voc of the solar panel is computed and the value is stored as Voc. This information is retrieved in the infinite loop, where Vmp is calculated based on this newly obtained Voc. Terminal voltage of the solar panel, is hence maintained to Vmp based on the dynamically computed value of Voc. This compensates the variation Voc due to changes in atmospheric conditions and other factors.

4. Power Converter Selection For MPPT

An interface is required between the fluctuating energy source and load inorder to maintain a steady voltage level, or to extract maximum available power from the system. This necessitates power converter for MPPT application. The fluctuating energy source in this case is a 250W solar panel and load selected for the utilizing the energy extracted from the solar panel is 24V, 7.2 AH lead acid battery. MPPT converter charges the lead acid battery by performing MPPT. When MPPT converter works in its full capacity, 250W is extracted from the solar panel. Ideally, it will inject 10.4A at 24V to the battery system. This amount of current is much more than a 7.2AH lead acid battery can handle. Hence a 7A resistive load is connected to the battery unit so as to reduce the current injected to the battery at the time of maximum power point tracking. [9,10] gives a detailed overview on various DC to DC converters used in industries.

Here, the input voltage ranges from 29V to 40V depending on insolation, temperature and amount of load in the solar panel. Output voltage varies between 21V to 27V, based on the state of charge and strength of the battery system. To suit such a input to output voltage level, buck converter is selected as interface converter for the system. Since voltage levels are less than 50V, need of isolation between input and output is also not necessary. Hence buck regulator is selected for the aforesaid application.

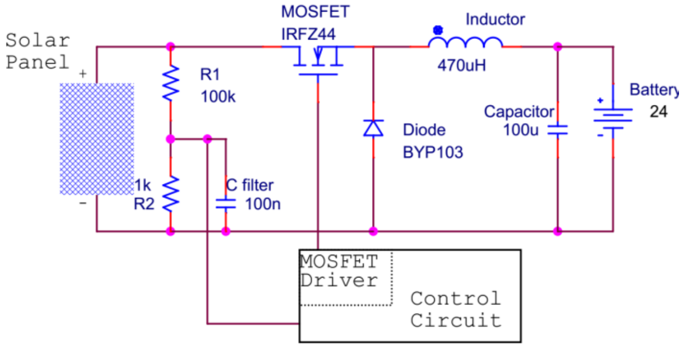

Fig. 7. Circuit used for MPP tacking

Detailed analysis on power stage calculation of buck regulator is given in [12]. Based on the design, an inductance of 470μH and a capacitance of 100μF is obtained for the selected power converter. In Fig. 7, resistor divider network, with capacitor C filter connected across the resistor R2 is the signal conditioning circuit used for measuring solar panel voltage. Control circuit involves AVR based ATMega16[13] microcontroller for running the IFOCV algorithm in real time. MOSFET driver circuit is a bootstrap based circuit that triggers the MOSFET in the buck regulator based on algorithm running in the control circuit. In Fig. 7 signal from the signal conditioning circuit is fed to ADC unit of ATMega16 microcontroller. Timer0 is used for generating periodic timer interrupts for calculating open circuit voltage of the solar panel in regular intervals.

5. Experimental Results

To analyze and understand the performance of the proposed algorithm, experiments are conducted two solar panels of same rating, with two MPPT circuits, one running the conventional algorithm and other running the proposed algorithm. Experiment is run for a duration of 40 Minutes, so as to include variation in the solar panel characteristics due to insolation change and temperature variation.

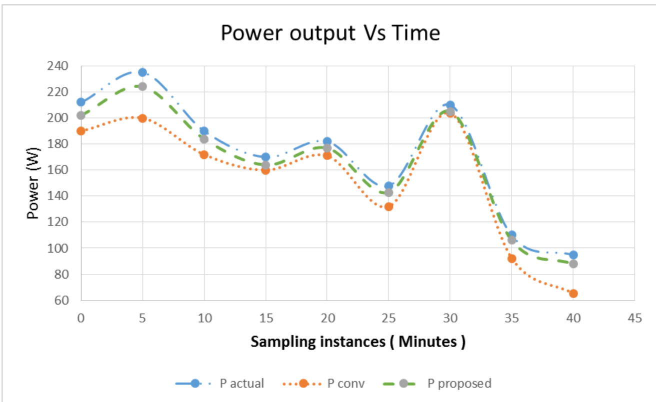

Fig. 9. Power tracking curve of conventional and proposed algorithm under different instances of time

In every 5 minutes, parameters in both the systems are analyzed. Along with that using IV analyzer, characteristics of the solar panel is also measured so as know the actual maximum power that can be tapped from the solar panels. In the Fig. 9, Pactual indicates the global maximum power point, Pconv indicates the power obtained from the solar panel using conventional FOCV MPPT algorithm Pproposed indicates the power tapped from the solar panel using the proposed IFOCV MPPT algorithm. It is evident from the graph that proposed algorithm has higher tracking efficiency than the conventional MPPT algorithm. But the Pproposed is not matching with Pactual. This is because of the losses incurring in the interfacing power converter. In a practical scenario, multiplier value with Voc also may not be that accurate, which also adds to a slight reduction in tracking efficiency. It is also inferred from the experimental analysis that tracking efficiency of the proposed algorithm lies broadly between 94% to 98%. Whereas tracking efficiency of the conventional algorithm lies between 70% to 92%.

6. Conclusion

A detailed experimental analysis of an improved version of fractional open circuit voltage based MPPT algorithm is presented in this paper. Effects maximum power point tracking due to variation in atmospheric conditions and shading of solar panel is analyzed based on conventional and proposed algorithms. Experimental results proved that proposed IFOCV algorithm has a higher tracking efficiency compared with conventional algorithms. The experimental results are also validated by comparing MPPT output obtained using conventional FOCV algorithm and proposed IFOCV algorithm. The new algorithm is also much simpler, efficient and computationally less intensive as compared to other MPPT algorithms.

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