Proceedings of the International Conference on Mechanical Engineering and Renewable Energy 2015(ICMERE2015) 26 – 29 November, 2015, Chittagong, Bangladesh

ICMERE2015-PI-060

MEASURING EFFICIENCY OF BUCK-BOOST CONVERTER USING WITH AND WITHOUT MODIFIED PERTURB AND OBSERVE (P&O) MPPT ALGORITHM OF PHOTO-VOLTAIC (PV) ARRAYS

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Abstract- *Solar photovoltaic (PV) arrays are a great source of generation of renewable energy. Green energy generations namely from PV cells have become great importance result in lower maintenance cost and environmental friendly. Nevertheless, there are few drawbacks of using PV systems which are low energy conversion efficiency and high investment of installing PV systems. Many researches are done to mitigate those problems, P&O algorithm is one of them. In this work, a modified P&O algorithm is implemented through the Buck-Boost converter. This algorithm allows the PV systems to work at its maximum power point. The modified P&O algorithm will draw the power directly from PV cells controlled by microcontroller. Experimental results reveal that the efficiency of Buck-Boost converter is much higher than the efficiency of that converter without implementing MPPT algorithm. Entire range of the duty cycle needs to be used for using this modified algorithm. Without adding much additional cost a desired efficiency is obtained. A microcontroller based PV system is used in this work.*

Key words: Renewable Energy, Photovoltaic (PV) Array, P&O Algorithm, Buck-Boost Converter, MPPT, Duty Cycle, Green Energy, Microcontroller.

1. INTRODUCTION

Solar photovoltaic array (PV) is becoming an increasing attractive way to generate power around the world in the last few years. The fact is that solar energy can be directly converted into electrical energy without any intermediate conversion process. Since the present world faces both energy crisis and global warming. Photovoltaic energy can mitigate these global problems. It does not emit CO_2 emission resulting in environmentally friendly and pollution free. However, extracting energy from photovoltaic arrays is still expensive and inefficient in terms of technological view point compared to other sources of energy so it is important to optimize the efficiency of PV panels. Ameliorating the efficiency of panel can be a challenging task because weather conditions change the PV voltage and current un-predicatively. A lot of research has been conducted to address this matter [1, 2].

Energy induced by photovoltaic arrays is a clean, neat, hassle –free and abundant source of nature, so it is considered as a green source of energy. An extensive research has been conducted to improve the conversion efficiency of PV cells [3]. A typical solar panel characteristic basically depends on the weather conditions changing (Temperature, illumination). A typical solar panel has its own optimal operation point called maximum power points (MPP) which is greatly very as good as cell temperature and sunlight. These climate dependencies make it difficult to keep it maximum power point, when a typical power curve is varied.

Various methods and techniques have been implemented to overcome this problem for optimum efficiency [10]. The technology which is widely used is a device that continually finds the maximum power point of a solar array termed as maximum power point tracker (MPPT) [4]. Many sophisticated algorithms have come up with control this device. Some of them are P&O (Perturb and Observe) method, the incremental conductance (IC) method, the ripple based method and the constant voltage method [3, 6]. These methods are still in the active research with a view to growing demand of solar energy. P&O algorithm is widely used due to its simplicity and easy implementation.

S. Kolsi et al. [7] showed the output sensing method implementing P&O just slightly modified it using MATLAB simulator and measured converter efficiency. A. Bouallegue et al. [8] applied the P&O algorithm through Boost converter using MATLAB and ISIS software use PIC 16F877 microcontroller. N. Kahoul et el. [11] proposed an adaptive P&O MPPT for a photovoltaic module connected to the Buck-Boost converters using MATLAB for current, voltage and output power for different solar irradiation. H. N. Zainudin et al. [12] proposed the comparison between two algorithms P&O and incremental conductance method through Buck, Boost and Cuk converter using MATLAB. A. M. Atallah et al. [13] presented in details implementation of P&O MPPT using Buck and Buck-Boost converter through MATLAB. This paper investigated the system can track the maximum power point quickly when the external environment changes suddenly.

In this paper, a modified P&O algorithm is implemented through Buck-Boost converter controlled by duty cycle using automatic controlled with the help of microcontroller. Generally, a DC-DC converter acts as an interface between the solar panel and load operated by duty ratio. Numerous scientific papers published on this topic simply use computer simulation rather than implementing real hardware. This research article implemented the algorithm in hardware.

The most popular of MPPT technique (Perturb and Observe (P&O) method, Buck-Boost DC-DC converters will involve in Implementation phase is as shown in Fig. 1[9].

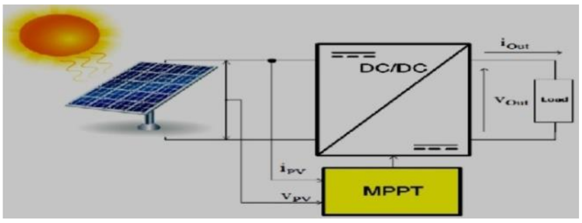

Fig.1: PV Module and DC/DC Converter with MPPT

The remaining paper is organized as follows. In Section II, Theoretical background is described. In Section III, System design and description is given. In Section IV, Modified MPPT algorithm is explained. System performance and analysis are given in Section V. The paper is concluded in Section VI.

2. THEORETICAL BACKGROUND

2.1 PV Module Modeling

A solar PV array is considered as a P-N junction semiconductor. When light is incident on a semiconductor material a DC current is generated. The produced current is linearly dependant with solar irradiance. This semiconductor P-N Junction acts as a current source. A one single diode equivalent circuit of a solar cell is considered as one of the most popular mathematical model for solar arrays, almost all practical solar cells work under this mathematical principle [14].

The current through the diode is measured by Eq. (1).

$$I_d = I_o[e^{\frac{(V+IR_S)}{AV_t}} - 1] \quad (1)$$

While, the solar cell output current is measured by Eq. (2) and (3).

$$I = I_{ph} - I_d - I_{sh} \quad (2)$$

$$I = I_{ph} - I_0\left(e^{\frac{(V+IRs)}{AV_t}} - 1\right) - \frac{V + IRs}{R_{sh}} \quad (3)$$

Where, I is the cell current (A), I_L is the light generated current (A), I_0 the diode saturation current , A is diode quality factor, V_t is thermal voltage, Rs and R_{sh} are cell series and shunt resistance (ohms) and V is the cell output voltage (V).

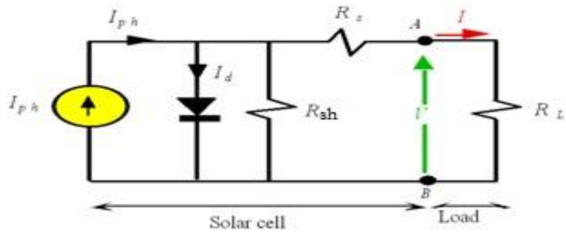

Fig.2: Equivalent Circuit of PV Solar Cell

Making a better mathematical model, the calculation of I_{ph}, I_d, and R_s parameter including temperature effects should be taken into account. The R_{sh} and 'A' parameters are considered constant. Attaining the best match with the typical I-V curves on the data sheet of the given PV panel, the value of R_{sh} and 'A' should be estimated.

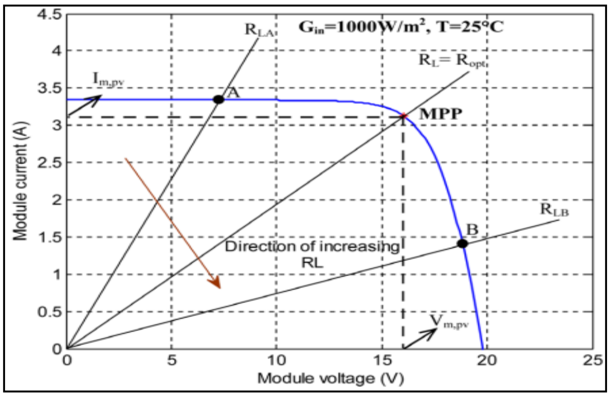

Fig.3: Solar Panel IV Curve with MPPT

2.2 MPPT in PV Solar System

MPPT [4] is for Maximum Power Point Tracking for the case of solar cell to draw maximum power possible from them, for the specified environmental and structural condition. MPPT is automatic electronic control to adjust the electrical load. These are the algorithms developed and applied in designing and driving the on grid /off grid specialized converters / inverters, which are to use in between solar cell and load center. Main causes to search for MPP are ambient temperature and irradiance related is as shown in Fig. 3.

The amount of solar irradiation is dependent upon geographical position, rain condition over years and other issues. But, still a MPPT can be useful to increase the power drawn during these conditions, to 5% more if effectively employed [4]. Now every PV panel has its own I-V pattern because of manufacturing tolerance, shading difference, dust deposited angular displacement in mounted position.

For a specific panel with a fixed environmental condition, the maximum power can be corresponds to the knee point in I-V curve is as shown in Fig. 4.

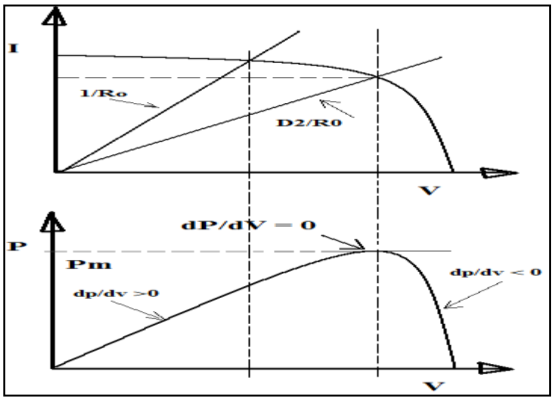

Fig.4: Working principal of any MPPT algorithm

So, for the definite pattern, an algorithm will search for that V_m, to vary a converter / inverters, duty / input resistance to get that V_m at the output. The resultant P_m is drawn to the load.

Let the controller is taking P and V as in samples.

Then, difference is measured by it as:

$dp= \{p(k+1) – p(k)\}$

$dv= \{v(k+1) – v(k)\}$

so, dp/dv is compared to be > or = or < zero.

Satisfying, dp/dv =0, the MPPT controller will drive an output to vary the input resistance to the PV panel shown in Fig. 4, for maximum power to draw.

Now this controller can be a DC-DC converter of either Buck or Boost, situated in between the PV panel and load for what, duty can be varied as to get to the MPP. Considering, a Buck converter,

$V_{out} = D \times V_{in}$

For impedance transferring, it becomes:

$R_{out} = D^2 \times R_{in}$

So, $R_{in} = R_{out} / D^2$

Here, output resistance is fixed and duty of the converter is accordingly varied to reach the R_i which corresponds to the maximum power point for that PV panel. In this way, a MPPT works. Now, to do it in automatic mode, several techniques are employed. Like as:

1. Perturb & observe (P&O)
2. Incremental conductance (IC)
3. Parasitic capacitance (PC)
4. Voltage based peak point tracking (VPPT)
5. Current based peak point tracking (IPPT)

Based on the facts that, for unidirectional error, no 1 is suitable to reach nearer the peak point quickly and for a quickly varying peak point, incremental conductance is suitable to avoid fluctuation and stay at the peak point. So we are going to propose the modified MPPT algorithm.

3. SYSTEM DESIGN AND DESCRIPTION

The objective of the paper is to present a cost effective and efficient microcontroller based MPPT system for solar photovoltaic system to ensure the maximum power point operation at all changing environmental condition. The modified MPPT algorithm is used to control the maximum transfer power from a PV panel. This algorithm is executed by a PIC16F73 microcontroller using the PV voltage and current data to compute the maximum power. This computed maximum power is compared with instantaneous actual power from PV panel. The difference between the maximum power (reference power) and actual power drives the converter which is controlled by Pulse Weight Modulation (PWM) from the microcontroller. The system block diagram is as shown in Fig. 5.

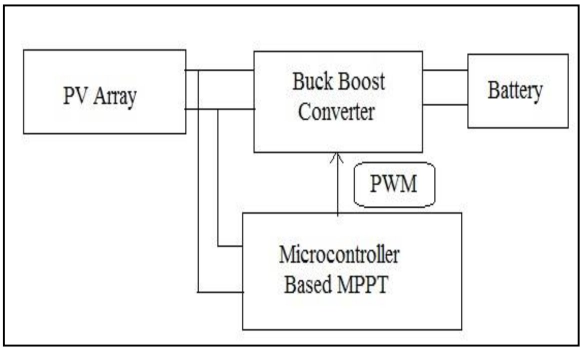

Fig.5: System Block diagram

3.1 Microcontroller

The MPPT control circuit is implemented in a microcontroller PIC16F73 that has 8-bits analog-to-digital (A/D) converters and two PWM mode signals. The buck boost converter is controlled by the microcontroller. It read the voltage and current of the solar panels through the A/D port of controller and calculates the output power. The PIC16F73 is a perfect combination of performance, features, and low power consumption for this application. The control circuit compares the PV output power before and after a change in the duty ratio of the DC to DC converter control signal. It is expected that the MPP presents a very little oscillation inherent to the algorithm.

3.2 Buck Boost Converters

A non-inverting Buck-Boost converter is essentially a cascaded combination of a Buck converter followed by a Boost converter, where a single inductor-capacitor is used for both. As the name implies, this converter does not invert the polarities of the output voltage in relation to the polarities of the input. This converter requires the use of two active switches and is designed by combining a Buck converter and Boost converter design in the same topology. Due to this design this converter can work as Buck-only, Boost-only or Buck-Boost converter. It provides an output voltage that may be less than or greater than the input voltage –hence the name "Buck-Boost".

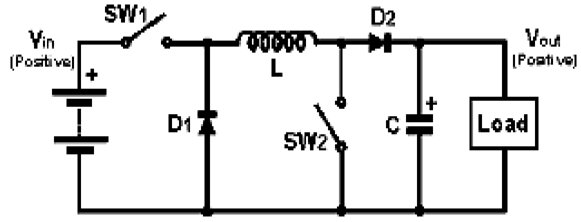

Fig. 6: Basic Buck-Boost converter

4. MODIFIED MPPT ALGORITHM

A generic I-V characteristic of PV module shows the maxim power point (MPP) is as shown in Eq. (4).

$$P_{max} = \frac{V_{max}}{I_{max}} \quad (4)$$

Where, V_{max} and I_{max} is the PV max voltage and current respectively. Since these quantities vary in accordance with climate changes particularly temperature and irradiance of sunlight. It is always critical to set a maximum power point. To get a maximum power point, a technique is required which can locate the exact position of MPP called MPPT algorithm.

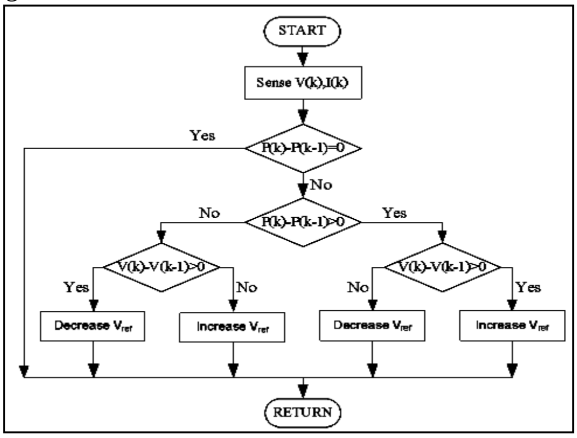

Fig.7: The flowchart of the P&O MPPT method

There are several algorithms but P&O algorithm is one of them, which is as shown in Fig. 7. The idea behind the traditional P&O algorithm is that it changes the PV-voltage or current until reaching the optimum point termed as MPP. The modified algorithm works as same as traditional one except some modification is introduced. The flow chart of this modified algorithm is presented in Fig. 8. This algorithm starts with setting the PWM duty cycle value at half of duty cycle or any other values.

The flow chart of the modified method containing the additional block set of the duty cycle at its initial value. Reading the voltage and current from PV panel, this algorithm calculated the present power. Comparing the difference of present power and past power which is put into algorithm as zero initially and then algorithm decide the next step.

When the power difference is greater than zero, it increment the duty cycle until the position of correct MPP and vice versa. At this point, the present power is equal to past power; here the duty cycle value is incremented or decremented with a fixed step size.

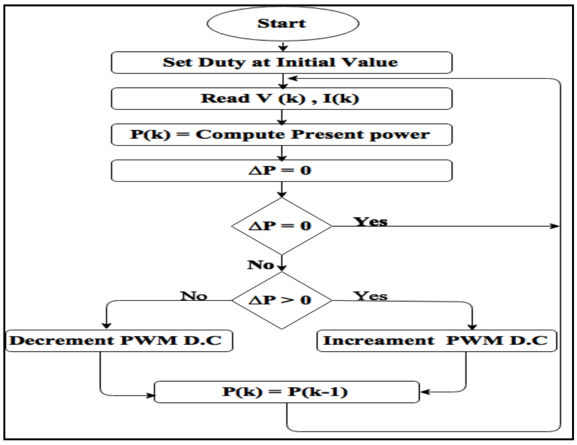

Fig.8: Flowchart of the Modified MPPT algorithm

The algorithm implemented in this work is called power reading algorithm since it works sensing the power of PV array.

Fig.9: Measuring data with solar panel

5. SYSTEM PERFORMANCE AND ANALYSIS

A prototype MPPT system has been developed for Buck-Boost converter using the above described methods and tested experimentally. The PV array, which is to be used with this system giving a 50 W maximum power and an 21.6 V open –circuit voltage at an irradiation of 1 kW/m^2 and temperature of 25^{0}C.

Table 1: Specification of the PV Module

Maximum power	**50 W**
Open circuit voltage	**21.60 V**
Short circuit current	**3.23 A**
Voltage at max power	**17.20 V**
Current at max power	**2.91 A**
Cell Temperature	**25°C**
AM	**1.5**
Irradiation	**1000 W/m^2**
Weight	**5 Kg**

In this section we presents in details implementation of modified P&O MPPT technique using Buck-Boost converter. Some results such as current, voltage and output power for solar irradiation levels have been measured applying real time hardware for both MPPT and Non-MPPT.

The Table 2 data was measured at 1st July, 2015, Chittagong in Bangladesh for Non-MPPT through Buck-Boost converter which was showing circuit response.

Table 2: Measured value from circuit response

Time	Input Voltage	Input Current	Output Voltage	Output Current	Output Power
11:20	17.8	0.41	12.9	0.27	3.48
11:25	17.2	0.56	12.9	0.50	6.45
11:30	17.1	0.56	12.9	0.49	6.32
11:35	17.08	0.54	12.9	0.49	6.32
11:40	17.05	0.53	12.9	0.46	5.93

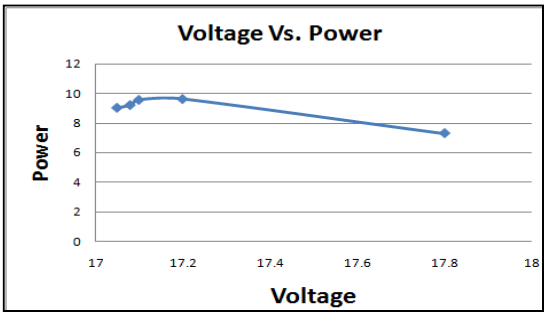

Fig.10: Voltage Vs. Power characteristics for Non-MPPT

The Table 3 data was measured at 1st July, 2015, Chittagong in Bangladesh using modified MPPT algorithm through Buck-Boost converter.

Table 3: Measured value by MPPT algorithm

Time	Input Voltage	Input Current	Duty Cycle	Output Voltage	Output Current
12:40	18.5	3.62	97	12.9	3.7
12:45	19.1	3.59	100	12.9	3.7
12:50	19.6	3.58	42	12.9	3.68
12:55	19.4	3.65	50	12.9	3.64
1:00	19.6	3.71	96	12.9	3.58

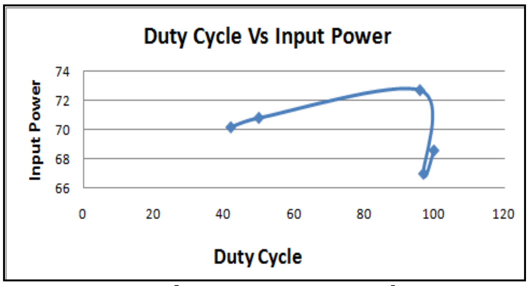

Fig.11: Duty cycle Vs. Input power characteristics

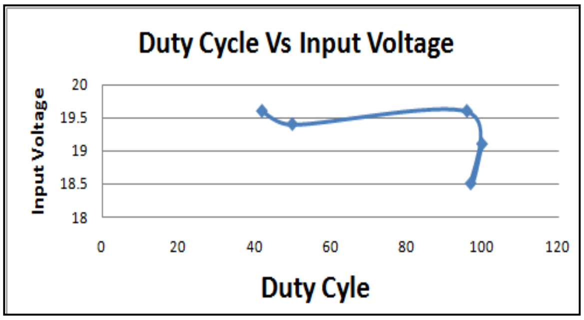

Fig.12: Duty cycle Vs. Input voltage characteristics

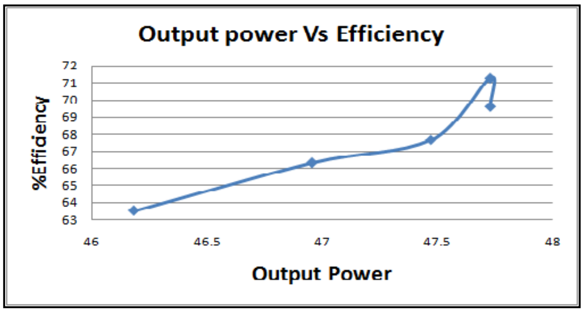

Fig.13: Output power Vs. Efficiency characteristics

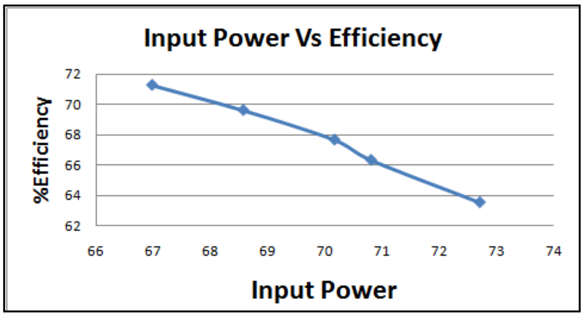

Fig.14: Input power Vs. Efficiency characteristics

Table 4: Average Input and output power

Input Power		Output Power	
MPPT	**Non-MPPT**	**MPPT**	**Non-MPPT**
66.97	9.22	47.73	3.48
68.57	9.63	47.73	6.45
70.17	9.57	47.47	6.32
70.81	9.22	46.96	6.32
72.72	9.03	46.18	5.93
Average			
69.85	**9.33**	**47.21**	**5.7**

The equation to calculate the efficiency of MPPT than Non-MPPT is as shown in Eq. (5).

$$\%\text{Efficiency} = \frac{\text{Total power (with MPPT)} - \text{Total power (Non-MPPT)}}{\text{Total power (with MPPT)}} * 100 \quad (5)$$

Comparative efficiency results of MPPT than Non-MPPT system are discussed in Table 5 using the Eq. (5).

Table 5: Comparative result of MPPT and Non-MPPT

MPPT Efficiency than Non-MPPT	
According to Average Input Power	**According to Average Output Power**
86.64%	**87.93%**

From Table 2 we see that the input voltage and current is greater than output voltage and current showing the characteristic of Buck-Boost converter. From Table 3 we see that the output powers are fluctuate very little.

In our solar panel the indicated power is 50W. We extracted average output power from solar panel for MPPT and Non-MPPT is 47.21W and 5.7W respectively which are around 94.4% for MPPT and 11.4% for Non-MPPT.

From above analysis we observed that applied modified algorithm works efficiently regardless of weather conditions.

6. CONCLUSION

There are obvious advantages of employing MPPT with solar panel installation. The initial cost is low compared with Non-MPPT. Our results show that very little power is wasted compare to Non-MPPT, resulting in making efficient and cost effective. This paper investigated these issues. We see that the average output power extracted from PV panel is about 94.4% when connected to MPPT controller whereas the output power drawn from the PV panel is 11.4% when connected to Non-MPPT controller. In addition to this, the result reveals that MPPT is more efficient than Non-MPPT which is about 87.93% according to average output power.

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