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Comparative Experimental Analysis with and without Proposed Algorithm for MPPT using a DC-DC Converter for PV Array

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ABSTRACT--- ***Solar Photovoltaic (PV) array is an enormous source of green energy generation. Low efficiency and high cost is the great challenge of the solar systems. Various power electronic converter and algorithms are design to mitigate this challenge, Perturb and Observe (P&O) algorithm is one of them. In this paper a proposed algorithm is implemented through DC-DC converter. This proposed algorithm allows the PV array to work at its highest efficiency. Results from experiments show that the proposed MPPT algorithm improves overall system efficiency which is 89.37% higher compared to non MPPT system. To maximize the efficiency of the PV panel from zero to the maximum output, the entire range of the duty cycle needs to be used for the implementation of the proposed MPPT algorithm. In addition to this, a microcontroller based control system has been used in this work.***

Keywords --- Photovoltaic (PV) Array, P&O algorithm, DC-DC converter, MPPT, Duty cycle, Green energy.

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1. INTRODUCTION

Renewable sources of energy acquire growing importance due to massive consumption and exhaustion of fossil fuel. Among several renewable energy sources, photovoltaic arrays are used in many applications such as Water Pumping, battery charging, hybrid vehicles and grid connected PV systems.

The usage of modern efficient photovoltaic solar cells (PVSCs) has featured as a masterminding alternative of energy conservation, renewable power and demand-side management. Due to their initial high expensive, PVSCs have not yet been an exactly a tempting alternative for electrical usage who are able to purchase less expensive electrical energy from the utility grid. However, they have been used widely for air conditioning in remote , water pumping and isolated or remote areas where utility power is not available or is high costly to transport. Although PVSC prices have decreased considerably during the last years due to new developments in the film technology and manufacturing process [1][3]. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. Those changes in insulation conditions strongly influence the efficiency and output power of the PV modules. A great deal of research has been accomplished to improve the efficiency of the photovoltaic system. Several methods to track the maximum power point of a PV module have been suggested to solve the problem of efficiency and products using these methods have been made and now commercially available for consumers [4][9]. As the market is now flooded with species of these MPPT that are intentional to improve the efficiency of PV modules under different isolation conditions. A maximum power point tracker is used for obtaining the maximum power from the solar PV module and conversion to the load. A non isolated DC-DC converter (step up/ step down) offers the purpose of conversion maximum power to the load. A DC-DC converter acts as an interface between the load and the module. By varying the ratio of duty cycle the impedance of load as it appears by the source is varied and matched at the peak power point with the source so as to conversion the maximum power [5][17].

Therefore maximum power point tracker methods are required to maintain the PV array's working at its MPP. Many MPPT methods have been suggested in the literature example are the Perturb and Observe (P&O) methods, Incremental

Conductance (IC) methods and constant voltage methods. etc. [10][14]. In this paper the most popular of MPPT technique (Perturb and Observe (P&O) method, Buck DC-DC converters will involve in Implementation phase shows in Fig. 1 [13].

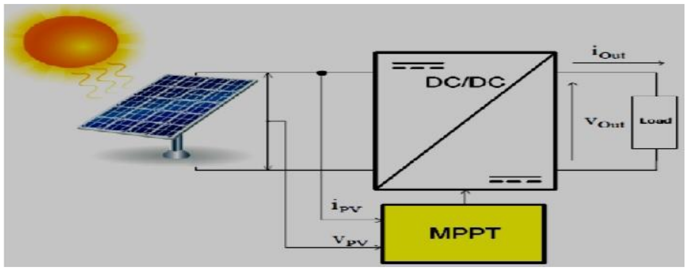

Figure 1: PV Module and DC/DC Converter with MPPT

The remaining paper is organized as follows. In section II, PV System Characteristics is described. In section III, System Description is given. In section IV Proposed MPPT Method is explained and Performance and Analysis are given in section V. The paper is concluded in section VI.

2. PV SYSTEM CHARACTERISTICS

A solar cell basically a p-n semiconductor junction. When exposed to light, a dc current is generated. The generated current varies linearly with the solar irradiance. The standard equivalent circuit of the PV cell is shown in Fig. 2.

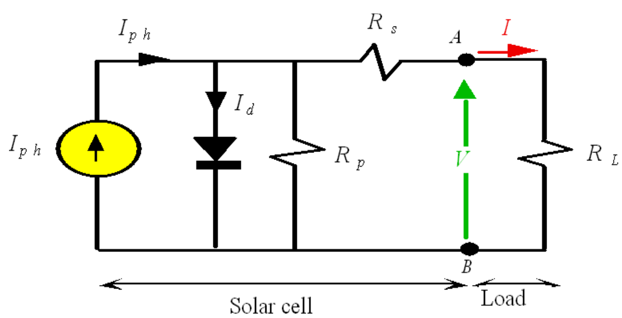

Figure 2: Equivalent Circuit of PV Solar Cell

The basic equation that describes the (I-V) characteristics of the PV model is given by the following equation:

$$I = I_L - I_0\left(e^{\frac{q(V+IRs)}{kT}} - 1\right) - \frac{V + IRs}{IRp} \tag{1}$$

Where,

I is the cell current (A)

I_L is the light generated current (A)

I_0 the diode saturation current

q is the free charge of electron $=1.6x10^{-19}$ (coul)

K is the Boltzmann constant(J/K)

T is the cell temperature (K)

Rs and Rp are cell series and shunt resistance (ohms)

V is the cell output voltage (V).

Solar panels convert photons from the sun striking their surfaces into electricity of a characteristic voltage and current. The solar panel's electrical output can be plotted on a graph of voltage vs. current: an I-V curve. We represent the current in amps and V represents the voltage in volts. The resulting line on the graph shows the current output of the panel for each voltage at a specific light level and temperature shows in Fig. 3. The current is constant unit reaching the higher voltages, when it falls off rapidly. This I-V curve is applicable to the electrical output of all solar panels.

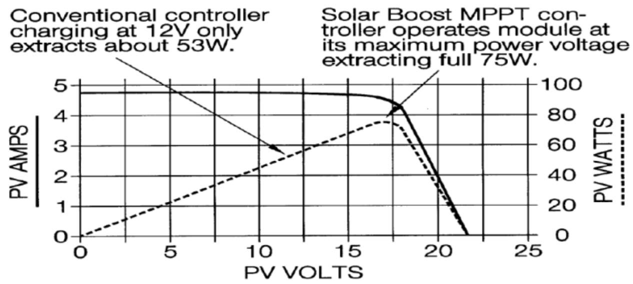

Figure 3: Solar Panel IV Curve with MPPT

2.1 MPPT in PV Solar System

MPPT [6] is for Max 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. This 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. As temperature rises, the output power decreases up to 22% for 50 degree which is seen in fig 3.

The causes behind this temperature effect are:

i. Increased temperature makes the outer band electrons to gain more energy. So that, the effective band gap becomes smaller then.

ii. Most of the parameters are affected by lower band gap energy to produce less output voltage and power. Mostly, the open circuit voltage.

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 condition, to 5% more if effectively employed [6][18].

Now every PV panel has its own I-V pattern because of:

1. Manufacturing tolerance

2. Shading difference

3. Dust deposited

4. Angular displacement in mounted position.

5. Miscellaneous

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

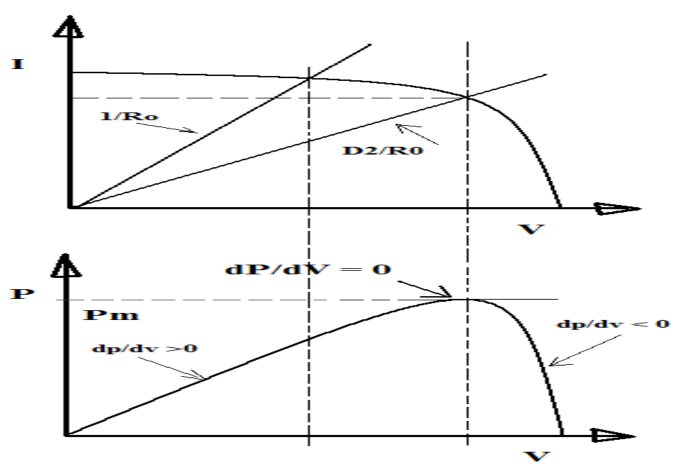

Figure 4: Working Principal of any MPPT Algorithm

So, for the definite pattern, an algorithm will search for that Vm, to vary a converter / inverters, duty / input resistance to get that Vm at the output. The resultant Pm 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, 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 Ri 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 following MPPT algorithm.

However, the P&O method can fail under rapidly changing atmospheric conditions. Several research activities have been carried out to improve the traditional Hill-climbing and P&O methods. Reference [7] proposes a three-piont weight comparison P&O method that compares the actual power point to the two preceding points before a decision is made about the perturbation sign. Reference [11] proposed a two stage algorithm that offers faster tracking in the first stage and finer tracking in the second stage. TO prevent divergence from MPP, modified adaptive algorithm is proposed in [12].

3. SYSTEM DESCRIPTION

The objective of the paper is to present a novel 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 proposed 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 control the duty cycle of a pulse width modulation signal applied to a DC-DC converter [2]. The system block diagram shows in Fig. 5.

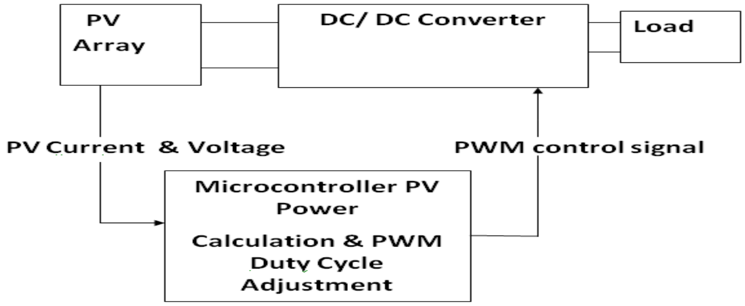

Figure 5: System Block Diagram

The PV array is interfaced with load using a DC-DC converter to deliver stable power output. PV array output voltage and current is unstable and frequently changing with atmosphere. The DC-DC converter maintains output voltage at a stable level. The voltage and current input to DC-DC converter is measured by different sensor and applied to microcontroller. Microcontroller acts as a switching control unit of this system. It calculates the power input to converter and make necessary adjustment of the PWM duty cycle. The PWM control signal is then applied to DC-DC converter to change the switching frequency and deliver maximum available power to load.

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 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 constant oscillation inherent to the algorithm.

3.2 DC-DC Converter Analysis

3.2.1 Buck Converter

There are several topologies available for DC-DC converter. Among them buck converter is in an increasingly popular topology, particularly in battery powered applications, as level of the output voltage can be changed with respect to input voltage. The commonly used a converter in PV systems is a DC-DC power converter. It ensures, through a control action, the transfer of the maximum of electrical power to the load. The structure of the converter is determined according to the load to be supplied. In this article we focus on the step-down DC-DC converter (Buck converter). MPPT uses the same converter for a different purpose, such as regulating the input voltage at the Maximum power point and providing load matching for the maximum power transfer.

3.3 Pulse Width Modulation (PWM)

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. What's more, many microcontrollers include on-chip PWM controllers, making implementation easy.

PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the duty cycle of a square wave is modulated to encode a specific analog signal level. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the periods during which that supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM.

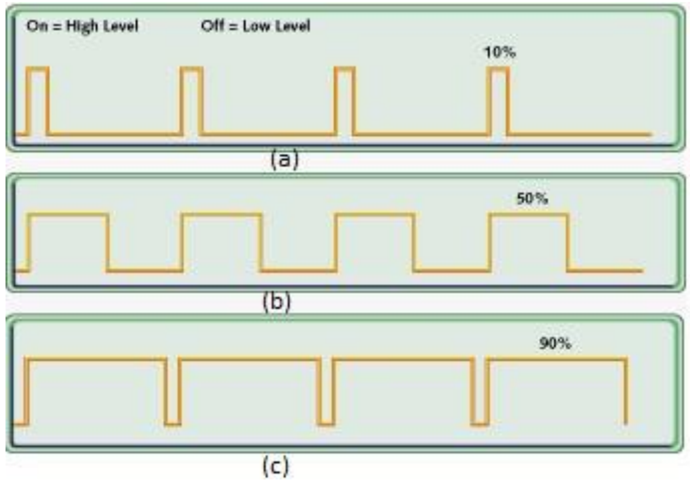

Figure 6 (a), (b), (c): PWM Signals of Varying Duty Cycles

Fig. 6 shows three different PWM signals. Figure 6a shows (a) PWM output at a 10% duty cycle. That is, the signal is on for 10% of the period and off the other 90%. Fig. 6(b) and 6(c) show PWM outputs at 50% and 90% duty cycles, respectively. These three PWM outputs encode three different analog signal values, at 10%, 50%, and 90% of the full strength. If, for example, the supply is 9V and the duty cycle is 10%, a 0.9V analog signal results [15].

The charging of the battery at Maximum Power Point (MPP) is achieved by carrying out the process of Pulse Width Modulation (PWM) at the switch mode of the DC-DC converter. The pulse width modulation uses time proportioning. This divides the signals into high and low states. The proportion of time spent in the high state is known as the duty cycle. Our algorithm uses different duty cycles to match the impedances of the PV array and the battery to reach the MPP. The duty cycle like the ADC, must be quantized into digital outputs. The duty cycle of the PWM pin (CCP1/ pin 12) is set with a quantized value which is 0 for minimum (0%) duty cycle and 255 for maximum (100%) duty cycle. If the battery is in need of charging, it only charged if the panel voltage is greater than 15V and less than or equal to 20V. The panel voltage and current flows to Buck converter which is activated by a Mosfet connected to the PWM port CCP1 (pin 12).

PORTB and PORTC are declared as outputs and the PWM port is initialized with input.

In this paper, when compute the maximum power from solar panel by using Microcontroller. Every moment the power can vary. When power increases that time pulse wide modulation also increases, and when power decreases PWM are also decreases.

3.4 Problem Overview

The MPPT method consider is to automatically find the current I_{MPP} or voltage V_{MPP} at which a PV array should work to extract the maximum output power P_{MPP} under a given temperature and irradiance. Most of MPPT methods respond to variations in both irradiance and temperature, but some are precisely more useful if temperature is approximately constant. Most MPPT methods would automatically respond to various in the array due to aging, though some are open-loop and would require periodic fine tuning [8]. In our context, module will typically be connected to a DC-DC converter that can vary the current coming from the PV array to the load.

4. PROPOSED MPPT METHOD

Most MPPT techniques attempt to find (search) the PV voltage that results in the maximum power point V_{MPP} , or to find the PV current I_{MPP} corresponding to the maximum power point. Perturb & Observe (P&O) Algorithm is the heart of the MPPT. In this system, the tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. So, the duty cycle of the dc chopper is changed and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. So, to solve this problem the proposed algorithm tracks neither the V_{MPP} nor the I_{MPP}. The algorithm detects the maximum power point of the PV. The computed maximum power is used as a reference value (set point) of the control system. . ON/OFF power controller with PWM switching control the operation of a Buck chopper such that the PV module always operates at its maximum power computed from the MPPT algorithm. Actually our proposed MPPT, We can modify from the Hill climbing and Perturb & Observe method. The major difference between the proposed algorithm and other techniques is that the proposed algorithm is used to control directly the power drawn from the PV.

The proposed MPPT has several advantages: simplicity, high convergence speed, and independent on PV array characteristics.

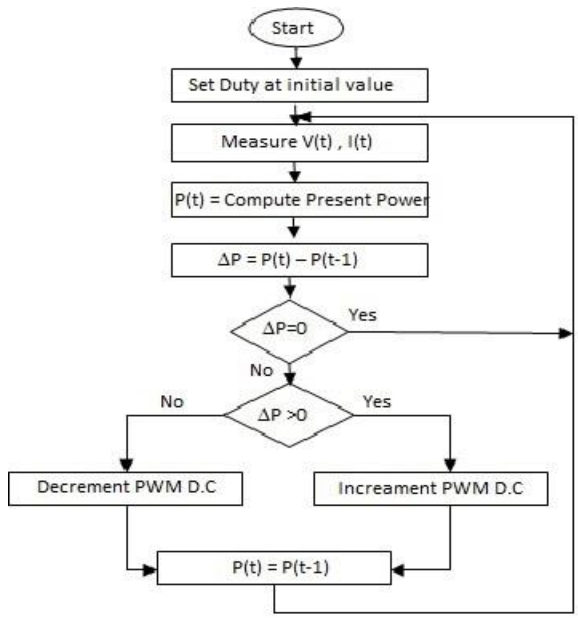

Figure 7: Flowchart of the Proposed MPPT Algorithm

It tracks directly the maximum possible power P_{MAX} that can be extracted from the PV. The flowchart of the proposed MPPT method is shown in Fig. 7.

Actually, the algorithm shown in Figure 7 starts by setting PWM to an initial value (half or any other Duty value). Actual PV voltage and current are measured. Then, the instantaneous value of PV power $P_{Present}$ is computed. The error between $P_{Present}$ and P_{past} is input to main MPPT algorithm. The output of the controller is used to drive the power mosfet of the Buck Chopper such that the $P_{Present}$ tracks P_{MAX}. Till now, the real maximum power is not tracked. To track the maximum power, the error between $P_{Present}$ and P_{past} is checked. If the error is lower than a certain upper limit (0.4 Watt), this means that the power drawn from the PV is within allowable value, so we can increment PWM by a certain step size. This new value of $P_{Present}$ is stored and used to control the actual power of the PV to track this new value. Then the algorithm is repeated again. When the error between $P_{Present}$ and P_{past} exceed the upper limit it means that the PV is no longer able to deliver this value of P_{MAX}. Therefore, we have to decrement of PWM by a certain step size.

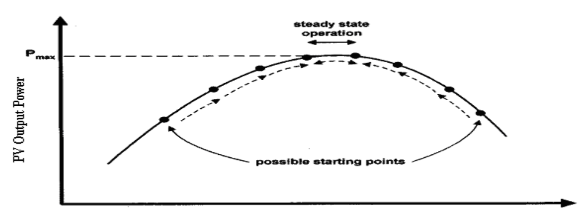

Figure 8: Ideal MPPT Tracking Process

The MPPT tracking process shown in Fig. 8 the starting point vary, depending on the atmospheric condition while the duty cycle of system is changed continuously. The tracking process is smoother and slope of the curve is same in either direction from the maximum power point. This curve is obtained under standard testing condition at irradiation level1kw/m2 and at 25^0 c [16].

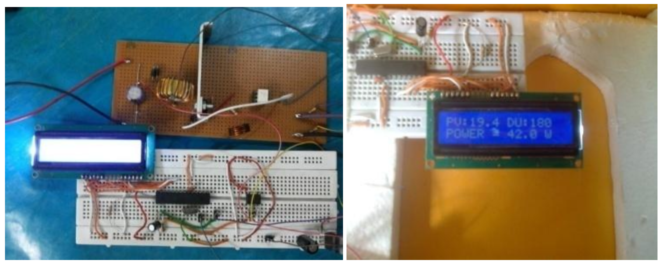

Figure 9: Data Measurement with Solar Panel

5. SYSTEM PERFORMANCE AND ANALYSIS

A prototype MPPT system has been developed using the above described methods and tested in the laboratory. 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^{o}C**
AM	**1.5**
Irradiation	**1000 W/m^2**
Weight	**5 Kg**

The maximum duty cycle ratio is considered at 90% and the minimum is set at 10% and therefore contributes to efficient power transfer to the converter. In our context, the duty cycle is put 250.

The following data was measured at 10th December, Chittagong at Bangladesh.

Table 2: Measured value from circuit response

10th December, Chittagong in Bangladesh								
Time at 10.00 am			**Time at 12.30 pm**			**Time at 2.00 pm**		
PV Volt	**Duty Cycle**	**Power (watt)**	**PV Volt**	**Duty Cycle**	**Power (watt)**	**PV Volt**	**Duty Cycle**	**Power (watt)**
17.3	149	40.4	19.4	174	42	16.4	98	35.3
18.0	155	43.1	17.8	156	41.2	17.0	120	38
17.0	140	39	18.0	162	46	16.5	110	36
16.3	138	37	20.1	180	46.8	19.4	170	42.3
18.4	165	46	20.0	180	43.6	18.0	160	44.1
17.2	98	38.7	17.1	150	40.2	17.5	145	40
16.8	104	38	19.5	178	43	18.7	165	40.6
19.4	170	42	16.3	135	37	19.4	174	42

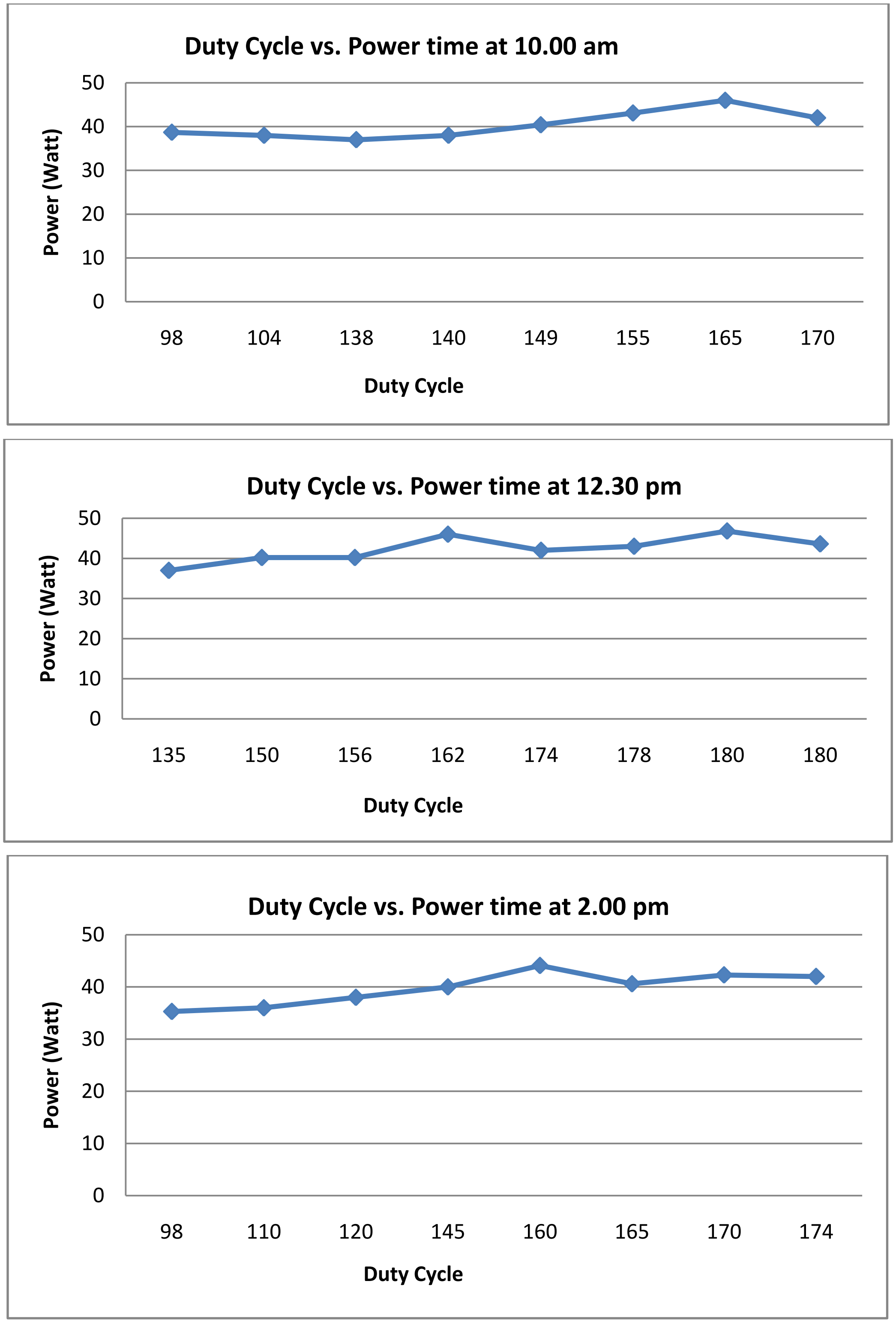

Figure 10: Duty Cycle vs. Power Characteristics

In Fig. 9, we can see that, Power delivered to output at different instant of tracking process also changes between different periods of day time. Initially, the output power varies significantly with duty cycle indicates by the slope of the curve in figures. When voltage increases that time power also increases. And when voltage increases that time duty cycle also increases. This figure sees that at the time of 10.00 am, when duty cycle is at 165 that time output power is maximum at 46W. And duty cycle is at 138 that time output power is minimum at 37W. For time at 12.30 pm and 2.00 pm, when duty cycle is at 180 and 160 that time output powers are 46.8 W and 44.1 W, the duty cycle is 135 and 98 that time output powers are 37W and 35.3W respectively.

These experimental values revel that the output powers are changed with environmental condition. This is because of PV nature of solar panel which depends on temperature and irradiance labels.

Comparative results of non MPPT and MPPT Systems were discussed by Table 3.

Table 3: Comparative result of Non MPPT and MPPT

Solar	Voltage at load	Current at load	Power at load	MPPT Efficiency than Non MPPT
Normal	13.8 V	1.5 A	20.7 W	89.37 %
With MPPT	14.0 V	2.8 A	39.2 W	

6. CONCLUSION

In this paper proposed MPPT algorithm with buck converter and PWM controlled by microcontroller was employed and compared with non MPPT technique. The proposed method is deemed as a modified P&O MPPT algorithm where cost effective hardware and software is recommended. Nevertheless, the basic difference between proposed algorithm and the remaining algorithm is that, the proposed method calculates the maximum power and governs directly the extracted power from the photovoltaic to that calculated value where as the remaining algorithms try to reach the maximum point by the knowledge of the voltage or current corresponding to that maximum point. The implementation of the proposed method is simple and can be easily instructed to reach and acceptable efficiency of the PV. The results also indicate that the proposed method tracking the PV array at maximum power in comparison with non MPPT method.

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