

# Comparison of Maximum power point Technique for solar Photovoltaic array

P.Parthasaradhi<sup>1</sup>, S.R.REDDY<sup>2</sup>, V.C.Shekar<sup>3</sup>

<sup>1</sup>GNITC, EEE Department, Professor, Ibrahimpatnam Hyderabad, India.

<sup>2</sup> GNITC, EEE Department, Asst Professor, Ibrahimpatnam Hyderabad, India.

<sup>3</sup> GNITC, EEE Department Professor, Hyderabad, India.

\*\*\*

**Abstract** - In this paper the control mechanism of Maximum power point tracking using DC-DC converters is presented. First the photovoltaic module is analyzed using SIMULINK software. The main aim of this paper is to track the maximum available power from the solar PV module in accordance with irradiation conditions using different MPPT algorithms to utilize the efficiency of the solar panel. The DC-DC converter is used along with a Maximum Power Point Tracking control mechanism. The MPPT is responsible for extracting the maximum possible power from the photovoltaic and feed it to the load via the DC-DC converter which steps up/down the voltage to the required magnitude. The algorithms utilized for MPPT are generalized algorithms and are easy to model or use as a code. The algorithms are written in m files of MATLAB and utilized in simulation. This project presents in detail the comparative study between two most popular algorithm techniques which is incremental conductance algorithm and perturb and observe algorithm. The DC-DC converter circuit is driven by the PWM pulses obtain by comparison of triangular wave and Duty cycle obtained from the MPPT embedded function block. The output of the DC-DC converter circuit matches the impedance of the panel and the converter circuit in order to transfer the maximum power.

**Key Words:** Solar PV module, DC-DC converter, MPPT control, incremental conductance algorithm, Perturb and observe Controller algorithm

## 1. INTRODUCTION

This As people are much concerned with the fossil fuel exhaustion and the environmental problems caused by the conventional power generation, renewable energy sources and among them photovoltaic panels and wind-generators are now widely used. So Solar Energy is a good choice for electric power generation. The solar energy is directly converted into electrical energy by solar photovoltaic module. Photovoltaic sources are used today in many applications such as battery charging, water pumping, home power supply, swimming-pool heating systems, satellite power systems etc [1]. They have the advantage of being maintenance and pollution-free but their installation cost is high and in most applications; they require a power conditioner (DC/DC or DC/AC converter) for load interface. Since PV modules still have relatively low conversion efficiency, the overall system cost can be reduced using high

efficiency power conditioners which, in addition, are designed to extract the maximum possible power from the PV module. We know that the efficiency of the solar PV module is low about 13%. To increase the efficiency of the PV module it is desirable to operate the module at the maximum power point condition. So that the maximum power can be delivered to the load under varying temperature and isolation conditions. Hence it improves the utilization of the solar PV module. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the load. The maximum power is achieved with the help of a dc/dc converter by adjusting its duty cycle [2]. The duty cycle was achieved by the following methods. 1. Perturb and observe. 2. Incremental Conductance 3. Parasitic Capacitance 4. Voltage Based Maximum Power Tracking 5. Current Based Maximum power Tracking. In which two most popular algorithm techniques which is incremental conductance algorithm and perturb and observe algorithm are compared. The comparison of two algorithms is observed using hard ware and software (MATLAB) Simulations. This paper is organized as follows: Section 2. Presents Solar Cell Modeling, Section 3. Maximum power point Tracking, Section 4. DC-DC Converter, Section 5. Presents Results and Discussion, finally Section 6. Presents Conclusion.

## 2. SOLAR CELL MODELING

Practical behavior of solar cell is deviated from ideal due to the optical and electrical losses. Hence to model the practical solar cell appropriate components should be added with the ideal current source [3]. Fig-1. Shows the mathematical model of a solar cell. Fig-2. Shows the Simulink model of a solar cell

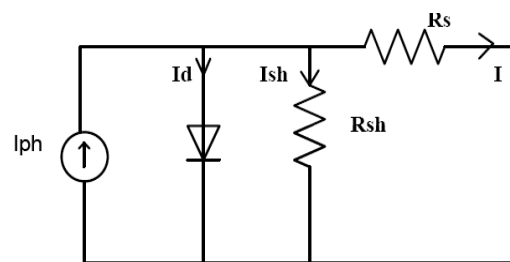


Fig-1. Shows the mathematical model of a solar cell.

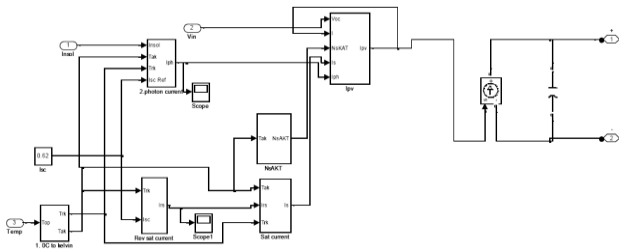


Fig-2. Simulink model of a solar cell.

The mathematical model design of a solar cell is given by using the equations (1) – (4).

The output current of PV module is

$$I = N_p \times I_{ph} - N_p \times I_s \left[ e^{\frac{q(V+I \cdot R_s)}{N_s K A T_{AK}}} - 1 \right] - \frac{\left( N_p \times \frac{V}{N_s} + I \cdot R_s \right)}{R_{sh}} \quad (1)$$

Where  $I_{ph}$  is Module photo current

$$I_{ph} = \left[ (T_{AK} - T_{rK}) \cdot K_i + I_{scr} \right] \times \frac{S}{1000} \quad (2)$$

Modules reverse saturation current ( $I_{rs}$ )

$$I_{rs} = \frac{I_{scr}}{e^{\left[ \frac{q \cdot V_{OC}}{N_s K A T_{AK}} - 1 \right]}} \quad (3)$$

Module saturation current  $I_s$  varies with the cell temperature, which is given by

$$I_s = I_{rs} \left[ \frac{T_{AK}}{T_{rK}} \right]^3 e^{\frac{q E_g}{K A} \left[ \frac{1}{T_{rK}} - \frac{1}{T_{AK}} \right]} \quad (4)$$

abbreviations in the title or heads unless they are unavoidable.

### 3. MAXIMUM POWER POINT TRACKING

Solar panel converts 30-40% of energy incident on it to electrical energy. A Maximum Power Point Tracking algorithm is necessary to increase the efficiency of the solar panel. Maximum Power Point Tracking is done to extract the maximum power from solar cell or module by operating it at maximum power point of its I-V characteristics. MPPT mechanism makes use of an algorithm. Many techniques have been developed for the maximum power point techniques. These techniques use the principle of impedance matching between load and PV-module [4]. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/step down) serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load & module.

#### 3.1 Methods of Maximum Power Point Tracking

Sample The maximum power is reached with the help of a dc/dc converter by adjusting its duty cycle. The duty cycle was achieved by the following methods.

1. Perturb and observe
2. Incremental Conductance
3. Parasitic Capacitance
4. Voltage Based Maximum Power Tracking
5. Current Based Maximum power Tracking

The algorithms are implemented in a microcontroller to implement the maximum power point tracking. The algorithm changes the duty cycle of the DC/DC converter to maximize the power output of the module and make it operate at the maximum power point of the module. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPP and several other economic reasons [5].

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

#### 3.1.1 Perturb and observe (P&O) method

Sample Hill climbing method is one form of the P&O method. However, the hill climbing method uses the condition to judge. It is applied by perturbing the duty cycle D at regular intervals and by recording the resulting array current and voltage values, thereby obtaining power. Once power is known, a check for the slope of the P-V curve or the operating region (current source or voltage source region) is carried out and then the change in D is effected in a direction so that the operating point approaches MPP on the power-voltage characteristics. Referring Fig-3.the algorithm can be explained as follows.The algorithm for this scheme is described below along with mathematical expressions [6].

In the current source region,

$$\frac{\partial p}{\partial v} > 0 \rightarrow D = D - \Delta D (i.e \text{ increment in } D) \quad (5)$$

In the voltage source region,

$$\frac{\partial p}{\partial v} < 0 \rightarrow D = D + \Delta D (i.e \text{ increment in } D) \quad (6)$$

At MPPT,

$$\frac{\partial p}{\partial v} = 0 \rightarrow D = D \text{ or } \Delta D = 0 (i.e \text{ retain } D) \quad (7)$$

As per the equations above, if is greater than zero the duty cycle is to decreased. This means the slope is positive and the module is operating in current source region. In case the slope is negative, the duty ration is increased, as module is operating in voltage source region, in this case.

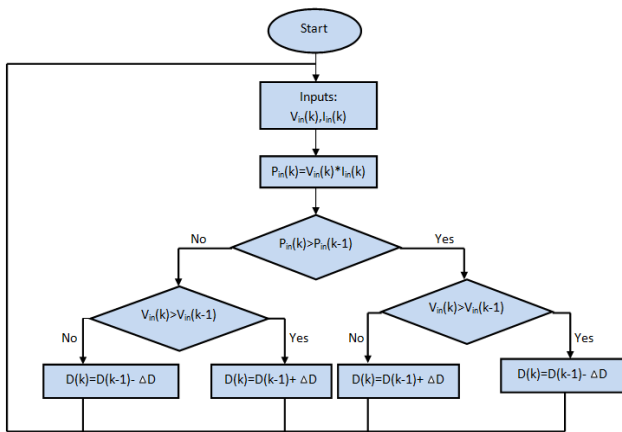


Fig-3. Flow chart for Hill climbing method

### 3.1.2 Incremental Conductance Method

In the incremental conductance method, the MPP is tracked by matching the PV array impedance with the effective impedance of the converter reflected across the array terminals. The latter is tuned by suitably increasing or decreasing the value of the duty cycle. Referring to Fig-4. The algorithm can be explained as follows [7].

In the voltage source region,

$$\frac{\partial I_{pv}}{\partial V_{pv}} = -\frac{I_{pv}}{V_{pv}} \rightarrow D = D - \Delta D \text{ (i. e Decrement in D)} \quad (8)$$

(Rate of change of current with respect to voltage is high)

In the current source region,

$$\frac{\partial I_{pv}}{\partial V_{pv}} = -\frac{I_{pv}}{V_{pv}} \rightarrow D = D + \Delta D \text{ (i. e increment in D)} \quad (9)$$

(Rate of change of current with respect to voltage is low)

$$\frac{\partial I_{pv}}{\partial V_{pv}} = -\frac{I_{pv}}{V_{pv}} \rightarrow D = D \text{ or } \Delta D = 0 \text{ (i. e retain D)} \quad (10)$$

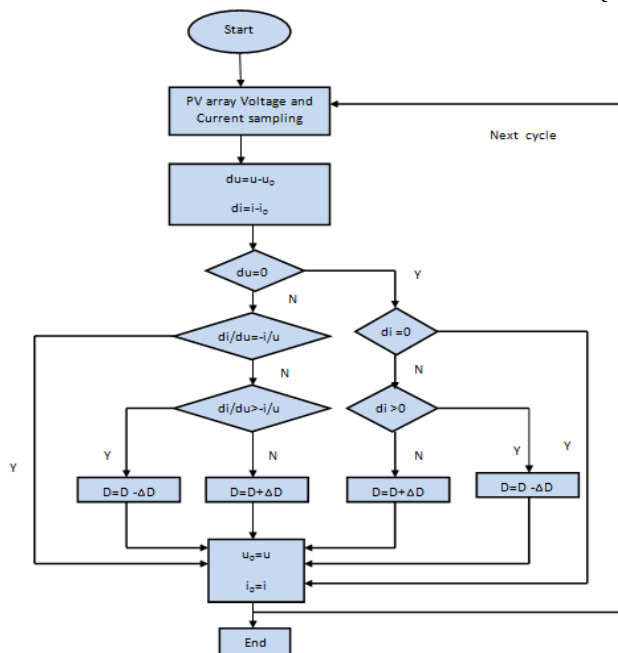


Fig-4. Flow chart for incremental conductance method

### 3. MAXIMUM DC-DC CONVERTERS

Solar panel A DC-DC converter one it control the output voltage level, either to a higher or a lower value. This is done by controlling a switch that will feed a load with a voltage in pulses with different width this control method is known as pulse width modulation (PWM). PWM control is the most comely used control method for all applications and also in this paper same control method has been used. Generally three DC-DC converter configurations as Used

- Buck Converter (Step Down)
- Boost Converter (Step Up)
- Buck Boost Converter (Step Down / Step Up)

In this paper buck converter is used for MPPT Tracking method.

### 4.1 Methods Buck Converter

The step-down dc-dc converter, commonly known as a buck converter, is shown in Fig-5. It consists of dc input voltage source VS, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R. Typical waveforms in the converter are shown in Fig-6. Under the assumption that the inductor current is always positive [8].

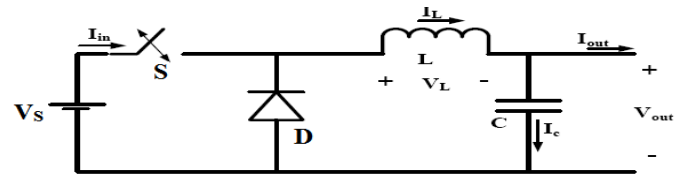


Fig-5. Buck converter

The state of the converter in which the inductor current is never zero for any period of time is called the continuous conduction mode. It can be seen from the circuit that when the switch S is commanded to the on state, the diode D is reverse-biased. When the switch S is off, the diode conducts to support an uninterrupted current in the inductor. The relationship among the input voltage, output voltage, and the switch duty ratio D can be derived, for instance, from the inductor voltage VL waveform (see Fig-6). According to Faraday's law, the inductor volt-second product over a period of steady-state operation is zero. For the buck converter [9].

$$V_{out} = DV_{in} \quad (11)$$

### 4.2 Modes of Operation

The DC-DC converters can operate in two distinct mode switch respect to the inductor current iL. Fig-6. Depicts the CCM in which the inductor current is always greater than zero. When the average value of the output current is low (high R) and/or the switching frequency f is low, the converter may enter the discontinuous conduction mode (DCM).

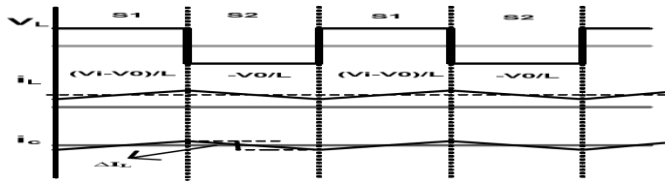


Fig-6. Waveforms of various signal of a Buck converter

In the DCM, the inductor current is zero during a portion of the switching period. The CCM is preferred for high efficiency and good utilization of semiconductor switches and passive components [10]. The DCM may be used in applications with special control requirements because the dynamic order of the converter is reduced (the energy stored in the inductor is zero at the beginning and at the end of each switching period). It is uncommon to mix these two operating modes because of different control algorithms.

### 4.3 Buck Converter Design

For the buck converter, the value of the filter inductance that determines the boundary between CCM and DCM is given by

$$\frac{\Delta i_L}{I} = \frac{V_{dc}}{L} (1 - D) DT \tag{12}$$

$$L = \frac{V_o(1 - D)}{\Delta i_L * f_s} \tag{13}$$

To regulate  $V_o$  with variations in  $V_i$ , the value of  $D$  should be changed. Thus if  $V_{imax}$  is the maximum input voltage swing, then  $D_{min}$  will be the corresponding minimum duty cycle to obtain a specified  $V_o$ . If  $V_{imin}$  is the minimum input voltage swing, then  $D_{max}$  will be the corresponding maximum duty cycle to obtain the specified  $V_o$ . Thus, for a regulated  $V_o$ ,

$$V_o = V_{imax} * D_{min} = V_{imin} * D_{max} \tag{14}$$

The values  $V_o$ ,  $V_{imax}$ ,  $V_{imin}$  are known from specifications of the converter.  $D_{max}$  is a design choice that is dependent on the specific application [11]. Then

$$D_{min} = \frac{V_o}{V_{imax}} = \frac{V_{imin} * D_{max}}{V_{imax}} \tag{15}$$

The inductor current should have a current ripple that is less than or equal to the specified  $\Delta i_L$ . Therefore the inductor should be at the duty ratio corresponding to  $D_{min}$ . Thus,

$$L = \frac{V_o(1 - D_{min})}{\Delta i_L * f_s} \tag{16}$$

Where  $\frac{\Delta i_L}{I}$  is ripple current generally 1 to 10%.  $V_{dc}$  is the input DC voltage,  $D$  is duty ratio, where  $f_s$  is switching frequency

The Value of the capacitor is calculated by applying the amp-second rule. Referring to the capacitor current waveform

given in Fig-6. If there is to be no charge build up or charge reduction in the capacitor, then the area under the capacitor current curve in one period should be zero. The area under the positive portion of the current curve implies charging of the capacitor and that under the negative portion implies discharging of the capacitor. For charge balance both these areas should be equal. The change in the capacitor charge  $\Delta Q$  is given by the area under either positive or the negative portion of the capacitor current curve [12]. Thus,

$$\nabla Q = C \Delta V = \frac{1}{2} \text{Base} * \text{Height} = \frac{1}{2} \frac{T_s}{2} \frac{\Delta I_L}{2} = \frac{\Delta I_L}{8 f_s} \tag{17}$$

Where  $\Delta V_0$  is voltage ripple generally 1 to 10%. The value of  $C$  should be greater than the value calculated by Eq-16.

## 5. RESULTS AND DISCUSSION

The modelling of PV module connected with Buck converter with MPPT simulation along with the discussion of the results. When the PV model is connected without MPPT there is loss of output power. For increasing the out power of PV model, the PV Model is connected to MPPT through the buck converter. The Hardware & Software result with Buck converter is observed.

### 5.1 Software Simulations

Fig-7. Shows the simulink model of the PV module connected to the load through MPPT. Where 10W panel is taken as the reference module for simulation.

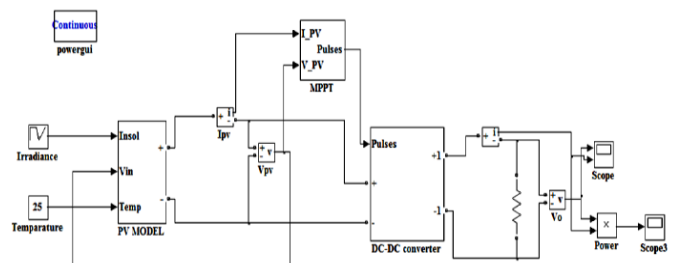


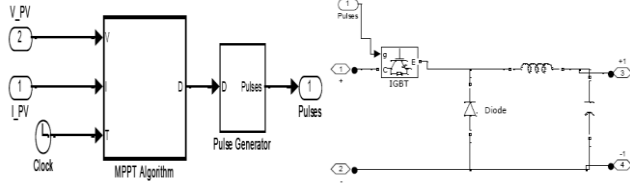
Fig-7. Simulink model of PV module with MPPT.

Where a 10W panel is taken as the reference module for simulation and name-plate details are mentioned in Table-1. The electrical specifications are under test conditions of irradiance of 1000W/m<sup>2</sup>, spectrum of 1.5 air mass and cell temperature of 25°C.

Table-1. Electrical Characteristics data of Waaree 10W panel

Rated power	10W
Voltage at maximum power ( $V_{mp}$ )	17V
Current at maximum power ( $I_{mp}$ )	0.59A
Open circuit voltage ( $V_{oc}$ )	21V
Short circuit current ( $I_{sc}$ )	0.61A
Current temp. coefficient	4.4mA/°C
Voltage temp. coefficient	-0.123V/°C
Number of cells in series $N_s$	36

Fig-8(a).Shows the subsystem for the MPPT block connected to the Load for operates the PV Model in maximum power point tracking mode. Fig-8(b).Shows subsystem system simulink model for Buck converter.



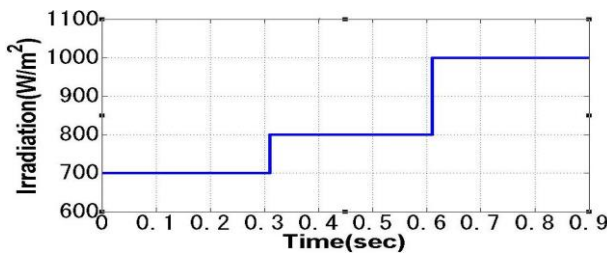
**Fig-8(a).** Subsystem of the MPPT Block

**Fig- 8(b).** Subsystem for Buck converter

a. Output Results of MPPT with the Buck converter Here simulated the Buck converter with the PV model shown in Fig-7.

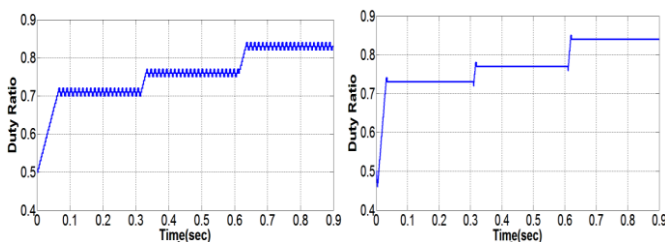
$V_{oc}=21$ ,  $V_{mp}=17$ ,  $I_{sc}=0.62$ ,  $I_{mp}=0.59$ ,  $P_{in}=10W$   
 $R_L = 10$  ;  $L= 2mH$ ;  $C= 10\mu F$   
 Switching Frequency= 20 kHz

Fig-9.shows the increasing irradiation level at every 0.3 sec.



**Fig-9.** Irradiation Level of Buck Converter

Fig-10.shows variation of the duty ratio to reach MPP at respective irradiation levels applied by using P&O (Perturb and Observe) method and Inc(Incremental Conductance) method.

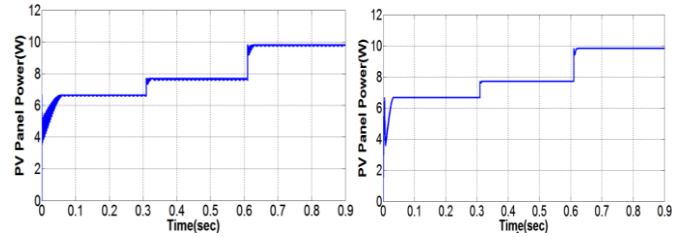


**Fig- 10(a)**

**Fig- 10(b)**

**Fig-10(a).** Duty Ratio of Buck Converter P&O method. **Fig-10(b).** Duty Ratio of Buck Converter Inc method.

Fig 11(a) and (b) shows the variation of PV Panel power for P&O method and Inc method respectively for respective irradiations levels shown in Fig -9. From the Fig-11. It is observed P&O method oscillates at MPP and Inc method reaches MPP efficiently

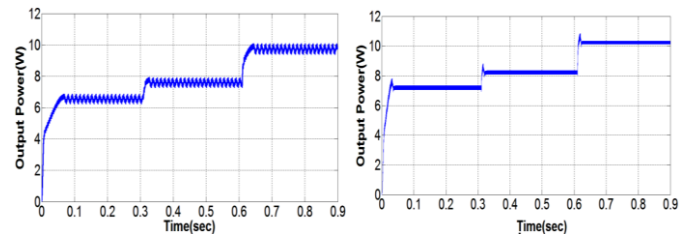


**Fig- 11(a)**

**Fig-11(b)**

**Fig-11(a).** Panel Power P&O method. **Fig-11(b).** Panel Power (b) Inc method

Fig-12. (a) And (b) shows the variation of load (output) power for P&O method and Inc method respectively for respective irradiations levels shown in fig-9. From Fig-11.and Fig-12. it is observed the maximum power tracked by the P&O and Inc method was transferred from source to load by using buck converter



**Fig- 12(a)**

**Fig-12(b)**

**Fig-12(a).** Boost Converter Output Power P&O method. **Fig-12(b).** Boost Converter Output Power Inc method.

Buck converter transfers the maximum power with 98% efficiency which can be observed from the Table 1 and 2.

Table -2. Efficiency of Buck Converter (P&O method)

Irradiation (w/m <sup>2</sup> )	Panel power (w)	Panel voltage (v)	Panel current (a)	Load (ω)	Duty ratio	Output power (w)	Efficiency (%)
1000	9.81	17	0.58	20	0.83	9.55	97.4
800	7.7	16.5	0.47	20	0.76	7.5	97.4
700	6.66	16.5	0.4	20	0.71	6.55	98.3

Table -3. Efficiency of Buck Converter (Inc method).

Irradiation (w/m <sup>2</sup> )	Panel power (w)	Panel voltage (v)	Panel current (a)	Load (ω)	Duty ratio	Output power (w)	Efficiency (%)
1000	9.81	17	0.58	20	0.84	9.65	98.2
800	7.7	16.5	0.47	20	0.77	7.6	98.7
700	6.66	16.5	0.4	20	0.73	6.55	98

At 1000 W/m<sup>2</sup> actual PV panel power mentioned by the manufacturer shown in the Table -1. Are 10 W. Form the Table-2 and 3. It is observed both P&O and Inc method tracks the maximum power with the efficiency of 98%. But only the difference is oscillation at the MPP was reduced in Inc method when compared to the P&O method.

By observing the Table 4. Buck converter is more efficient. Incremental conductance methods track the maximum power very efficiently but perturb and observe method oscillates at the maximum power.

Table-4. Comparison of MPPT algorithms

MPPT method	Buck converter
P&O	97%
INC	98%

Under the assumption that the inductor current is always positive [8].

### 5.2 Hardware Implementation

The development of prototype model in the laboratory, the necessary interface circuits and software control algorithm. A 10W solar panel with DC-DC converter was built with necessary control carried out through STM32F4 microcontroller Kit. The simulated system was downscaled due to limitations of available devices in laboratory. The experimental setup and the block diagram of the implemented hardware are shown in Figure 13.

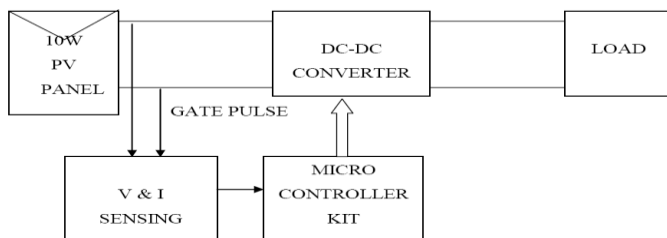


Fig- 13. Block diagram of complete hardware setup

The complete image setup of the MPPT system as shown in Fig-14.



Fig- 14. Image of complete hardware set up

Hardware circuit was built and tested in the laboratory the results obtained by implementing the MPPT methods through embedded C code written in STM32F4 microcontroller kit. Measurements were carried out using display given in STM32F4 controller and Tektronix TDS 2014C digital storage oscilloscope.

The duty ratio of the Buck converter was adjusted automatically by using P&O method. The following data was taken on 25-6-2014 from 11am to 4pm with an interval of one hour. Load is kept at 10Ω.

Table -5. P&O data with buck converter

Time	Voc	Isc	Vmp	Imp	Pm	D
11AM	19.36	0.46	14	0.43	6.02	0.54
12PM	19.25	0.56	13.6	0.50	6.93	0.58
1PM	19.35	0.55	14.03	0.49	6.88	0.57
2PM	19.25	0.50	13.9	0.43	5.97	0.54
3PM	19.30	0.37	14.3	0.34	4.86	0.47
4PM	19.18	0.28	14.9	0.24	3.57	0.39

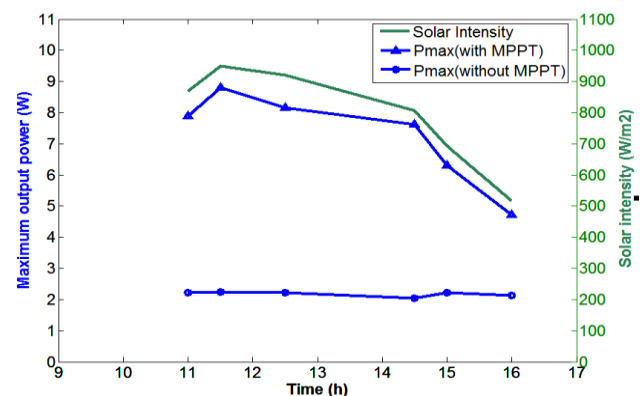


Fig-15. Buck converter with P&O method

Fig-15. Shows the variation of maximum power with respective irradiation level when panel is connected to load with buck converter P&O method MPPT system.

The duty ratio of the Buck converter was adjusted automatically by using Inc method. The following data was taken on 27-4-2015 from 11am to 4pm with an interval of one hour. Load is kept at 10Ω.

Table-6. Inc method data with buck converter

Time	Voc	Isc	Vmp	Imp	Pm	D
11AM	19.40	0.49	17.3	0.38	6.64	0.49
12.30	19.25	0.53	16.2	0.42	6.804	0.55
1PM	19.35	0.43	16.3	0.32	5.216	0.47
2PM	19.1	0.54	16.2	0.40	6.48	0.57
2.30PM	18.92	0.46	16.1	0.33	5.313	0.49
3PM	18.98	0.44	15.9	0.31	5.11	0.44
3.30PM	18.91	0.36	17.4	0.24	4.176	0.36

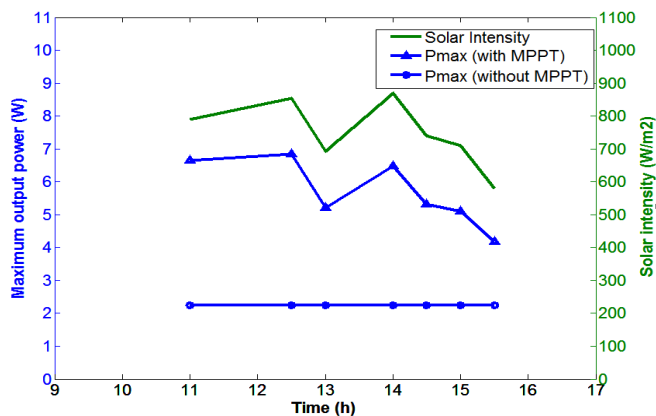


Fig-16. Buck converter with Inc method

Fig-16. Shows the variation of maximum power with respective irradiation level when panel is connected to load with buck converter Inc method MPPT system.

### 3. CONCLUSIONS

In this work was to study the most conventional MPPT's for Photovoltaic and to implement the same in MATLAB/SIMULINK as well as to make a hardware prototype using STM32F4 micro controller. To achieve this Goal initially the PV array model was prepared in MATLAB/SIMULINK. Results of the simulated PV array model showed satisfactory performance. Then the design of the boost and buck converter was presented. It showed satisfactory results when simulated with MPPT control of PV array. The two most usual (perturb & observe and incremental conductance) methods used for MPPT. It is interesting to point out that the differences in performances among the analyzed MPPTs are very slight, and these algorithms must be evaluated according to each situation. Overall, the outcome of the P&O algorithm tests were quite good. It responded faster and performed better than the Inc algorithm. Boost converter transfer the input power to the load better than buck converter because in buck converter switch is connected in series with the switch.

### REFERENCES

- [1] Chetan Singh Solanki, "Solar Photovoltaic's Fundamentals, technologies and Applications", Second edition, published by Asoke K. Ghosh, 2011, PHI Learning Private Limited, New Delhi.
- [2] Trishan Eswam, Patrick L. Chapman "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Transaction on Energy Conservation, VOL. 22, NO. 2, June 2007.
- [3] Power Electronics, Converters, Applications and Design, Book by Mohan, Undeland, Robbins.
- [4] Power Electronics Essentials & Applications, L UMANAND.

- [5] Soren Bakhojkar, "Evaluation of the "Hill Climbing" and the "Incremental Conductance" Maximum Power Point Trackers for Photovoltaic Power Systems" , IEEE Transaction on Energy Conservation, VOL. 27, NO. 4, DECEMBER 2012
- [6] Kinal Kachhiya, Makarand Lokhande, Mukesh Patel "MATLAB/Simulink Model of Solar PV Module and MPPT Algorithm" National Conference on Recent Trends in Engineering & Technology in 13-14 May 2011.
- [7] Eftichios Koutroulis, Kostas Kalaitzakis, "Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System" IEEE Transactions On Power Electronics, Vol. 16, No. 1, January 2001.
- [8] Kun Ding, Xin Gao Bian, Hai Hao Liu, and Tao Peng "A MATLAB-Simulink-Based PV Module Model and Its Application Under Conditions of Non uniform Irradiance" , IEEE Transaction on Energy Conservation, vol. 27, no. 4, December 2012
- [9] M.Lokanadham, K.Vijaya Bhaskar "Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System" International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue 2, Mar-Apr 2012.
- [10] Swati Singh, Lini Mathew, Shimi S.L., "Design and Simulation of Intelligent Control MPPT Technique for PV Module Using MATLAB/ SIMSCAPE" International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 9, September 2013
- [11] Hairul Nissah Zainudin, Saad Mekhilef, "Comparison Study of Maximum Power Point Tracker Techniques for PV Systems", Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 278.

Moacyr Aureliano Gomes de Brito, Luigi Galotto, Jr., Leonardo Poltronieri Sampaio, Guilherme de Azevedo e Melo, and Carlos Alberto Canesin, "Evaluation of the Main MPPT Techniques for Photovoltaic Applications", IEEE Transactions On Industrial Electronics, Vol. 60, No. 3, March 2013.