MPPT Based Solar Battery Charger Using Buck-Boost Converter by Incremental Conductance Technique

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ABSTRACT

The basic need of present century is energy, more specifically renewable energy sources. The transformation from conventional energy source to renewable energy source has increased the dependency on these resources. This renewable energy can be generated from numerous devices, but Solar PV Array plays a major role in it. This energy can be stored in the battery for later use. The major drawback with Solar PV Array is their efficiency and reliability. The parameter that influences the efficiency and reliability are Temperature and Solar Irradiation. The optimal solution to improve the efficiency and reliability is implementing MPPT (Maximum Power Point Tracing) to the Solar PV Array system. There are numerous techniques available to implement MPPT; here we implemented Incremental Conductance technique due to its simplicity and effectiveness.The Incremental Conductance algorithm is fed to the controller, so as to control the duty cycle of the buck-boost converter to operate at maximum power point. Thus this power can be stored to battery. The result obtained by this technique is more optimum and have comparably lesser oscillation than Perturbation and Observation (P&O) Technique.

KEYWORDS: Solar PV Array, MPPT, Incremental Conductance technique, Buck-Boost Converter.

1. INTRODUCTION

One of important renewable energy source which has the greater potential to offer a replacement to fossil energy is solar energy. India lies on equator therefore can get the benefit of availability of solar energy all days in year. In India there are about 300 clear and sunny days in a year, the calculated solar energy incidence on India's land area is about 5000 trillion kilowatt-hours(KWh) per year. The daily average solar power plant generation capacity in India is 0.30 KWh per meter square. Most of India's land receives 4-7 KWh per m a day. A Photovoltaic system is needed to harvest the solar energy, and it has some advantages such as environment friendly and low maintenance cost. The main disadvantages of PV are high installation cost for manufacturing and setup and it has a low efficiency (less than 20%). The power output of a Solar PV module changes with change in direction of sun, changes in solar insolation level and with varying temperature. To improve its efficiency, a PV must work at maximum power point which is a changing one. The change depends on sun irradiation and temperature. A change of temperature and irradiation increase or decrease the maximum power point and reduce the PVs efficiency. The maximum power point tracking (MPPT) usually is implemented by a power electronic circuit which provides an interface between PV and load. Some researches were conducted to optimize solar panel's efficiency byusing some of MPPT methods, for example: Constant voltage control, Perturb & Observe, Incremental Conductance,
Fuzzy Logic and Neural Network. Constant voltage control is a facile method and it has been implemented for traffic light application. Perturb & Observe methods or also well known as Perturbation Methods is widely used because of its simple implementation procedure. One drawback of this method is its ripple increases along with the power curve.

After the power of PV reaches the peak, the power will decrease and the disturbance becomes larger and larger. Another main drawback of this method is it introduces an oscillation on maximum power point region and this makes it a unviable solution at an environment which suffer from frequent change in temperature and irradiance. Other alternativesof Perturb and observe method are Fuzzy Control and Neural Network. Fuzzy control has been used to improve the MPPT and used to control the boost converter used in electric car which is powered by solar energy. Fuzzy control and Neural Network also have some of disadvantages like complexity of fuzzy rules design process and on learning process. Out of all these methods, Incremental Conductance (IC) offers faster tracking time,a better performance and has fewer oscillation. A DC to DC converter is needed for implementing MPPT. The DC-DC converter delivers the maximum power from PV module to load by adjusting the duty cycle and able to distribute a maximum power when load characteristics changes. Some common DC-DC converter configuration for implementing MPPT are Buck converter, Boost converter, CUK converter, Full bridge converter and Buck Boost converter. The performance of IC method beats the performance of Perturb and observe method when it implemented at Buck converter or Boost converter. Another research had shown incremental conductance method using CUK converter can able to find the maximum power point and had an efficient performance on some different weather condition. This research was dealing with implementation of IC on Buck Boost converter by adjusting its PWM duty cycle. Buck Boost converter generates bigger or lower voltage output depends on the duty cycle. The system was simulated on Simulink by injecting some irradiant and temperature changes during simulation periods. The IC was observed and its capability to retain the system to works at the maximum power point is studied and the performance was compared to PO method.

In this paper, incremental conductance algorithm is proposed for optimizing the MPPT. The paper is organized as follows. Section I discusses the conversion of Solar Power and Section II explains about maximum power point tracking algorithm. The incremental Conductance Technique is discussed in Section III. Buck Boost converter is discussed in Section IV. Simulation Circuits and Results are discussed in Section V and VI. Conclusion is discussed in Section VII.

I. SOLAR POWER

The PV cell is a P-N semiconductor junction diode that converts solar energy in to electrical energy which can be done by following two ways

1) By using photovoltaic (PV)

2) By using concentrated solar power i.e. focusing at intensity of sun thereby using lenses, mirrors and tracking systems.

3) Solar Heating and Cooling.

PV cells (semiconductors) which emits electrons on absorption of heat and converts solar energy to electrical energy, batteries which store solar power systems mainly consist of solar panel made up of the power generated. The movement of electron produces the electric current. A number of PV panels connected in series and/or in parallel giving a DC output out of the incident irradiance. Orientation and tilt of these panels are important design parameters, as well as shading from surrounding obstruction.

The change in irradiation and temperature shows different characteristics. The figure. 1 shown below shows the characteristics difference due to change in the parameters.

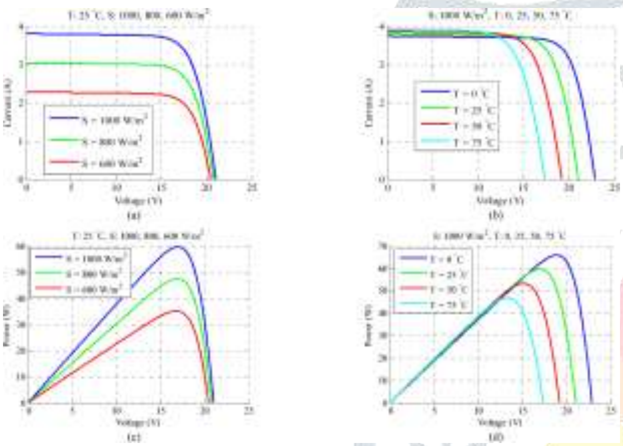


Figure 1 PV and IV characteristics for different parameters

II. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is an electronic system which operates PV to gain a maximum power. MPPT is not a mechanical tracking however a MPPT can be used simultaneously with a mechanical tracking system. Maximal Power Point (MPP) does not lie at a particular point but it moves around P-V curve depends on light intensity and temperature. The widely known MPPT algorithm is P&O and the flowchart of this algorithm can be seen on Figure. 2.

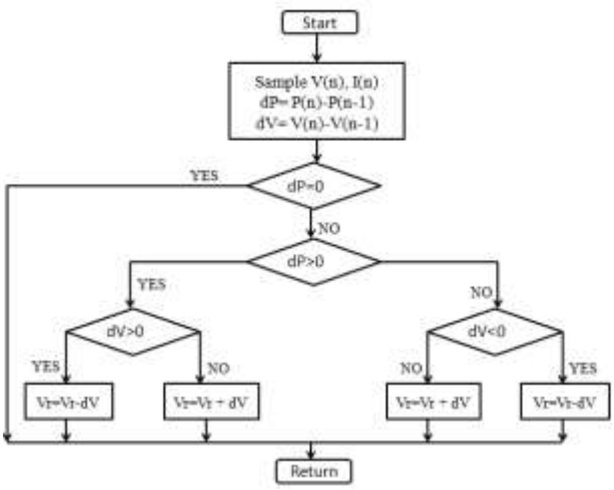


Figure 2 flow chart for Perturb and observe method

The key point of P&O methods is by comparing recent PV power P(n) with the previous photovoltaic power P(n-1). Photovoltaic power is determined by measuring current (I) and voltage (V). When the different between previous power and recent power is not 0, this algorithm will try to find the optimal point in the left or right side of recent position. The maximum power is obtained when ΔP is equal to 0. P&O method is implemented on buck-boost by adjusting the PWM's duty cycle. If the recent power is bigger than the previous, the duty cycle will be increased until the MPP is found. The drawback of this method is it introduces an oscillation on the steady state and the voltage variation is large. This method also needs a long tracking time and it has a slow response to the irradiant and temperature changes.

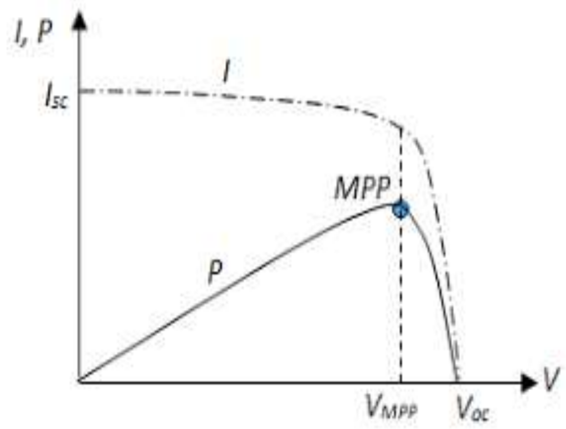


Figure 2 condition for MPPT

III. INCREMENTAL CONDUCTANCE TECHNIQUE

A typical solar panel converts about 30-40 % of the incident solar insolation in to electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to maximum power transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence the problem of tracking the maximum power point reduces to an impedance matching problem. There are several techniques to track the MPPT but this paper deal with Incremental conductance.

Incremental Conductance method uses the information of source voltage and current to find the desired operating point. From the P-V curve of a PV module shown in Fig. 1 it is clear that slope is zero at maximum point, so the formulas are as follows,

$$(dP/dV)_{mpp} = d(VI)/dV \quad (1)$$

$$0 = I + V\,(dI/dV)_{mpp} \quad (2)$$

$$(dI/dV)_{mpp} = -I/V \quad (3)$$

Equation (3) is the condition to achieve the maximum power point, when the variance of the output conductance is equal to the negative of the output conductance, the module will work at the maximum power point. The flow chart of the incremental conductance is shown in Figure. 4

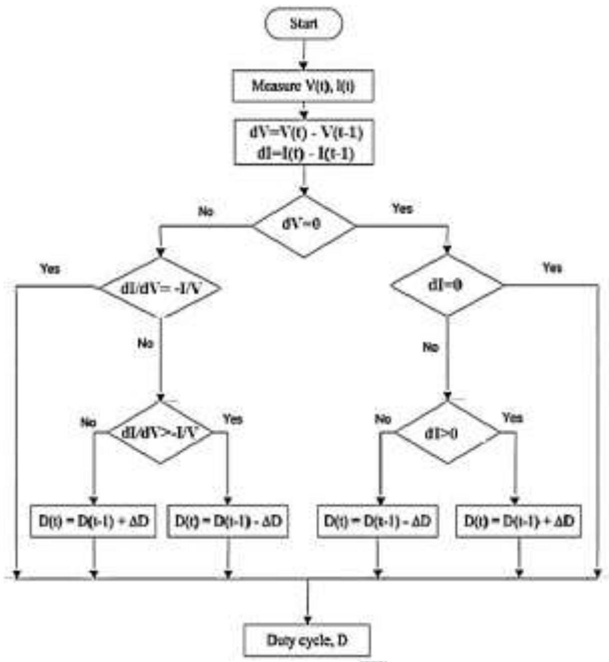


Figure 4 Incremental conductance curve

In this flow chart, V(t) is the new detection voltage and I(t) is the new detection current, V(t-1) and I(t-1) is previous detection values. When the new value is read in to the program, it calculates the previous value compare with the new one, and then determine the voltage differentials is zero or not, according the voltage differentials is zero, the current difference can be determined zero or not. If both of them are zero, it shows that they have the same value of impedance and the value of duty ratio will remain the same as before. If the voltage differential is zero, but the current differential is not zero, it shows that the insolation has changed. When the difference of the current values is greater than zero, duty ratio will increase, when the difference of the current value is less than zero the duty ratio will decrease. If the voltage differential is not zero determine it whether satisfy the eq. 3 or not, when eq. 3 is satisfied the slope of the power curve will be zero that means the system is operating at MPP, if the variance of conductance is greater than the negative conductance values, it means the slope of the power curve is positive and the duty ratio is to be increased, otherwise it should be decreased. The intersection of current-voltage (I-V) curve and the load line gives the operating point of directly coupled PV module to the load which is shown in the figure.5

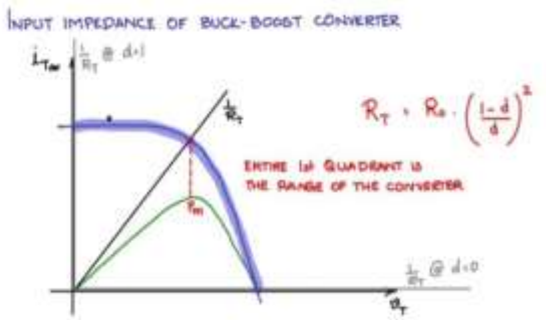


Figure 5 Input impedance of buck boost converter

This point should be at the MPP of the PV module to extract the maximum power. The performance of DC-DC converter depends on the input impedance and the connected load RL. For the boost converter the selected load resistance R_T should be greater than the R_{MP}i.e. (R_T>R_{MP}). And the tracking region for boost converter lies below the load line. For the buck converter the selected load resistance R_T should be less than the (R_{MP}) (R_T<R_{MP}) and the tracking region for buck converter operation should be above the load line.

For Boost converter voltage gain and load matching resistance expression are given in eq.

$$V_0/V_{in} = 1/(1-D)$$

$$R_T = R_0\ (1-D)^2$$

For Buck converter voltage gain and load matching resistance expression are given in eq.

$$V_0/V_{in} = D$$

$$R_T = R_0/D^2$$

Where Vg,V0 are the input and output voltages, R_{in} is the input resistance seen by the PV panel at the source side of the converter, R_0 is the resistance which is connected at the load side of the converter and D is the duty ratio.

IV. BUCK-BOOST CONVERTER

DC-DC converters are also known as Choppers. The **Buck Boost converter** which can operate as a DC-DC Step-Down converter or a DC-DC Step-Up converter depending upon the duty cycle, D.

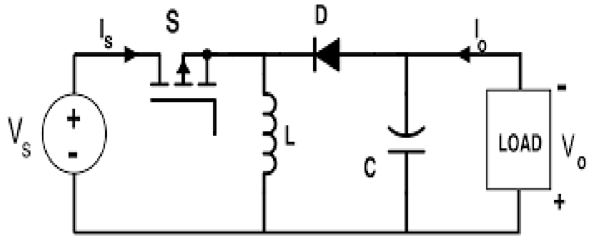


Figure 6 buck boost converter circuit

The input voltage source is connected to a solid state device. The second switch used is a diode. The diode is connected, in reverse to the direction of power flow from source, to a capacitor and the load and the two are connected in parallel as shown in the figure above.
The controlled switch is turned on and off by using Pulse Width Modulation(PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

The **Buck Boost converter** has two modes of operation.
1) Mode 1 (Switch is ON)
2) Mode 2 (Switch is OFF)

A. MODE 1

In this mode the Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and the inductor and back to the DC input source.

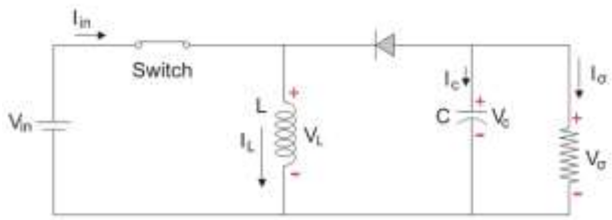


Figure 7 switch is ON

The inductor stores charge during the time the switch is ON and when the solid state switch is OFF the polarity of the Inductor reverses so that current flows through the load and through the diode and back to the inductor. So the direction of current through the inductor remains the same.

Let us say the switch is on for a time T_{ON} and is off for a time T_{OFF}. We define the time period, T, as

$$T = T_{ON} + T_{OFF}$$

and the switching frequency,

$$f_{switching} = 1/T$$

Duty Cycle, $D = T_{ON} / T$

$V_{in} = V_L$

$V_L = L di_L/dt = V_{in}$

$di_L/dt = \Delta i_L/\Delta t = \Delta i_L/(d)t = V_{in}/L$

When switch is closed at $T_{ON} = (D)T$

$(\Delta i_L)_{closed} = (V_{in}/L)(D)T$

B. MODE 2

In this mode the polarity of the inductor is reversed and the energy stored in the inductor is released and is ultimately dissipated in the load resistance and this helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in conjunction with the input source.

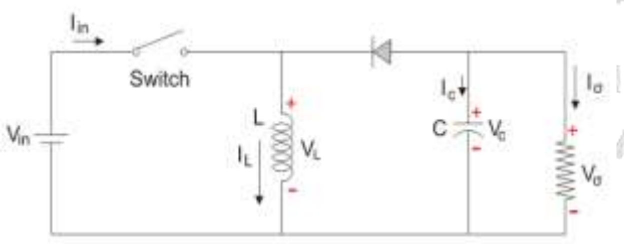


Figure 8 switch is OFF

But for analysis, we kept the original conventions to analyse the circuit using KVL.

$V_L = V_0$

$V_L = L di_L/dt = V_0$

$di_L/dt = \Delta i_L/\Delta T = \Delta i_L/(1-d)T = V_0/L$

$T_{OFF} = T - T_{ON} = T - (d)T = (1-d)T$

We can say that,

$\Delta t = (1-D)T$

$(\Delta i_L)_{closed} + (i_L)_{open} = 0$

$(V_0/L)(1-d)T + (V_{in}/L)(d)T = 0$

$V_0/V_{in} = - d/(1-d)$

We know that d varies between 0 and 1. If d> 0.5, the output voltage is larger than the input; and if d< 0.5, the output is smaller than the input. But if d = 0.5 the output voltage is equal to the input voltage.

V. SIMULATION CIRCUIT OF MPPT BASED SOLAR CHARGER

Circuit diagram of Incremental Conductance Technique is shown below.

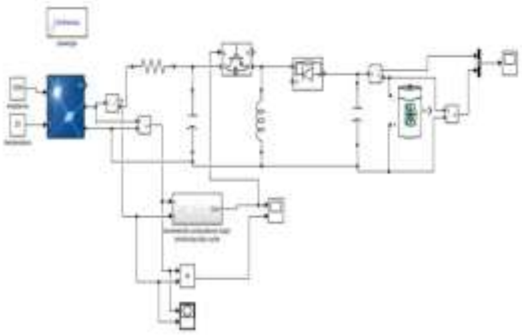


Figure 9 simulation circuit of MPPT based solar charger

The solar PV Array harvests the power and it is stored in the battery. The incremental conductance algorithm is fed in the controller, the condition such that the slope at the maximum power "zero" must met to maintain the maximum efficient operation. The parameters such as irradiation and temperature is varied so as to check the maximum power point tracking, the changes in the slope is eliminated by using the derived formula and then the resulting pulse is used to generate PWM pulses. These pulses were used to control the duty cycle of the switch used in Buck-Boost converter. The Buck-Boost converter can vary the duty cycle throughout the entire region on both sides of the load line. Thus the battery connected to the array is charged more efficient and reliably.

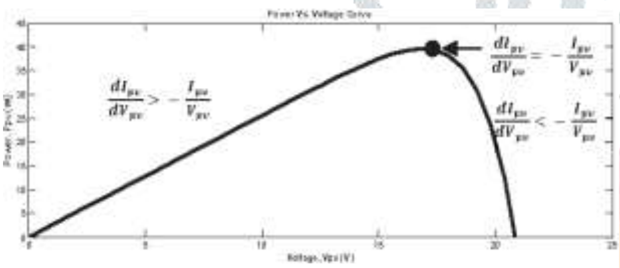


Figure 10 Incremental conductance curve

This algorithm uses the instantaneous conductance dI/dV for MPPT. Depending on the relationship between the two values, as expressed in (1) and (3), the location of the operating point of the PV module in the PV module in PV curve can be determined, i.e. (1) indicates the PV module operates at the MPP, whereas (2) and (3) indicate the PV module operates at the left and right side of the MPP in the PV curve respectively.

dI/dV = -I/V………(1)

dI /dV > -I/V……...(2)

dI/dV< -I/V………(3)

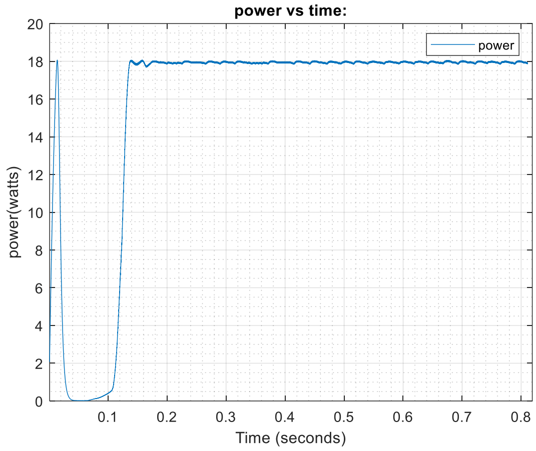
The above equations are obtained from the concept where the slope of the PV curve at MPP is equal to zero, i.e.:

dP/dV = 0 ………… (4)

By rewriting the equation (4) the following equation is obtained:

I + (V*dI/dV) == 0……(5)

In the incremental conductance algorithm, (5) is used to detect the MPP, and the voltage and current of the PV module are measured by the MPPT controller. If (2) is satisfied, the duty cycle of the converter needs to be decreased, and vice versa if (3) is satisfied, whereas no change on the duty cycle if (5) is satisfied.



A. PARAMETERS OF THE SIMULATION MODEL:

The parameters of PV panel:-

Open circuit voltage (V):23.1V
Short circuit current (I):1.44A
Current at MPP (I):1.03A
Voltage at MPP (V):17.5V

The parameters of buck boost converter:-

Value of inductance: 50mH
Value of input capacitance: 1mF
Value of output capacitance: 0.67mF
Value of PWM frequency: 5000 HZ

VI. RESULTAND ANALYSIS

Theresult of Incremental conductance method is obtained and power curve is obtained for different irradiance and temperature values

The IV characteristic curve of the solar panel with open circuit voltage of 23.1V and short circuit current of 1.44A is shown in XY plot in figure 11

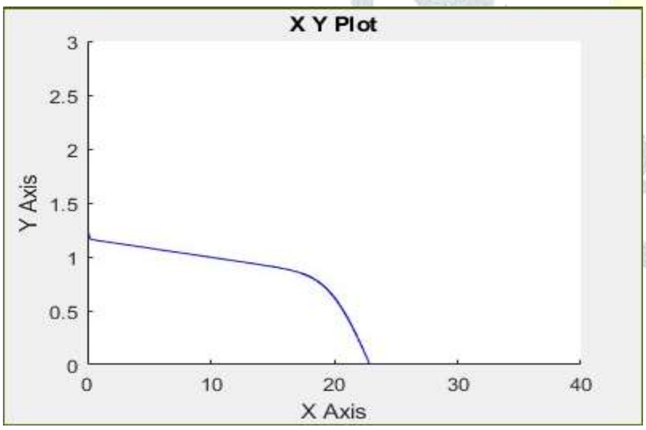


Figure 11 IV characteristic curve with x axis indicates voltage and Y axis indicates current .

For 1000 irradiance and 25 degree Celsius:(MPP is at 18.02w)

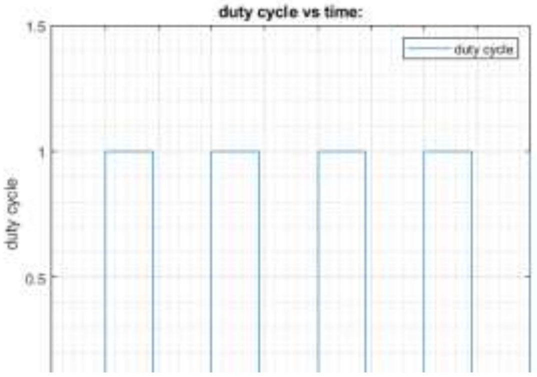


Figure 13 power vs time curve for 1000 W/m^2 and25 degree Celsius IC method.

For the 1000 irradiance and 25 degree Celsius condition the PO method shows oscillations:

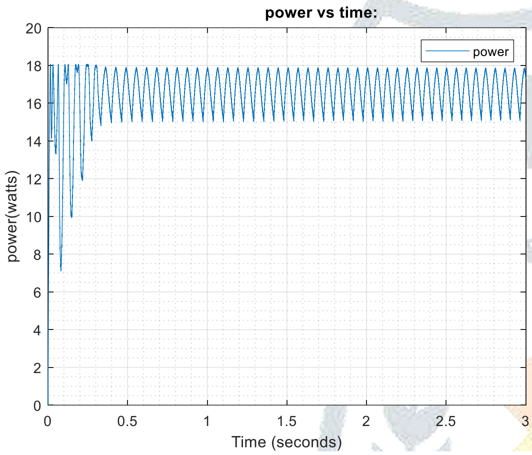


Figure 14 power vs time curve PO method

(PO method produces more oscillation compared to IC method)
The power vs time curve for the various temperature and irradiance conditions are shown below:

For 900 irradiance and 25 degree Celsius:
(The maximum power point is changed to 16.3W)

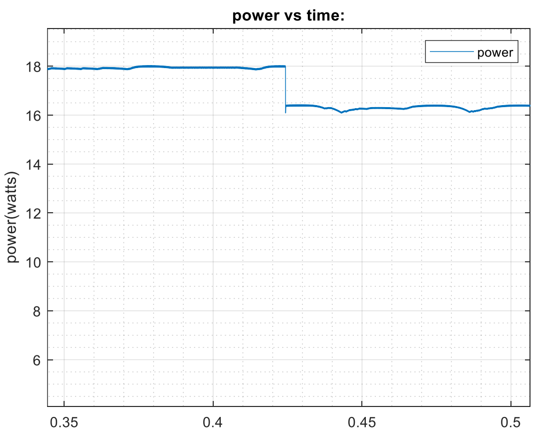


Figure 15 power vs time graph when irradiance changes to 900 W/m^2.

3. For 1000 irradiance and when temperature is changed from 25 to 30 degree Celsius (MPP is drops to 17.7W)

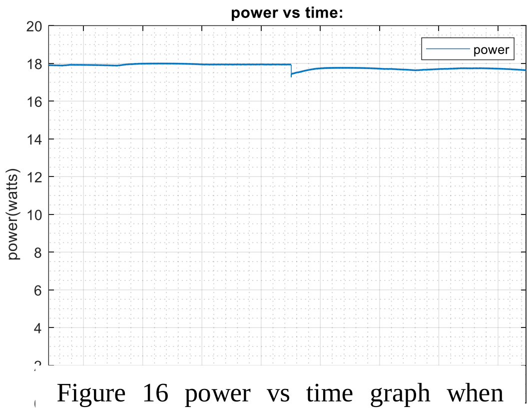


Figure 16 power vs time graph when temperature changes to 30 degree Celsius

For 1000 irradiance and 25 degree Celsius temperature
the battery charging voltage and charging current is shown in figure 17 and 18 respectively.

Output voltage is 13.09 Volt and Output current is 2.15A

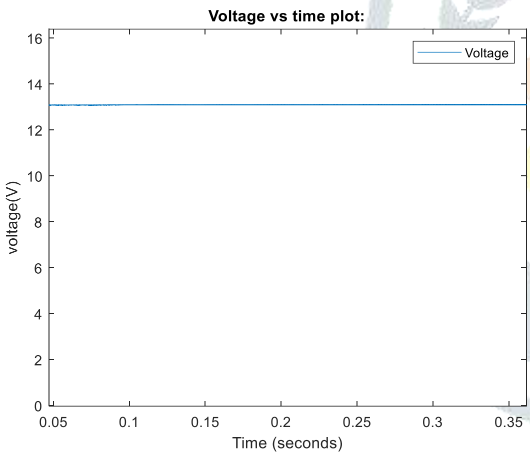


Figure 17 output voltage vs time graph.

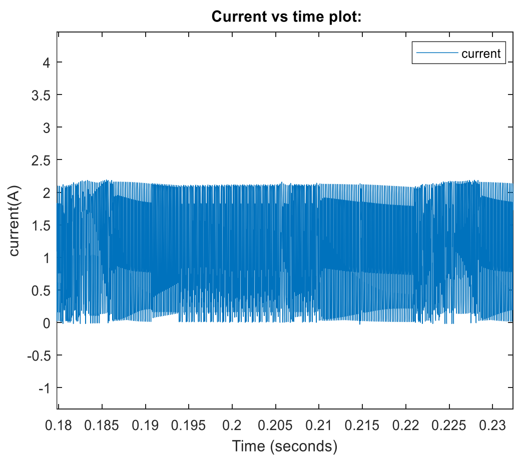


Figure18 output current vs time graph.

VII. CONCLUSION

This research was targeted to analyze MPPT implementation on buck-boost converter by using Incremental Conductance method. The performance was compared to P&O algorithm.PV system, MPPT and Buck-Boost converter were simulated on Matlab Simulink. The simulation result shown that IC method had a better performance than P&O method. The IC method also successfully suppressed the oscillation around MPP point but the drawback is it had a slower tracking time. The tracking time can be improved by adjusting the increment/decrement step of duty cycle. The increment/decrement step also could be adaptively changed to achieve a better time response.

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