

# **SIMULATION AND ANALYSIS OF PHOTOVOLTAIC SYSTEM USING VIRTUAL INSTRUMENTATION**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Electrical Engineering

By

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National Institute of Technology, Rourkela  
Rourkela-769008, Odisha, India.**

**May 2015**

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**May 2015**



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**CERTIFICATE**

This is to certify that the Thesis Report entitled **SIMULATION AND ANALYSIS OF PHOTOVOLTAIC SYSTEM USING VIRTUAL INSTRUMENTATION** submitted by K.K.Tejaswini (213EE5355) of **Electrical Engineering** during May 2015 at National Institute of Technology Rourkela is an authentic work by her under my supervision and guidance.

Place: Rourkela

Date: 25/05/2015

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**K.K.Tejaswini**

**Roll No: 213EE5355**

**Rourkela, May, 2015**

## **ABSTRACT**

Renewable energy sources demand has been increasing rapidly due to their abundance in nature, environment friendly and also serves as decentralized power sources in rural areas. Solar energy is one such renewable energy source which produces electricity by means of photovoltaic effect. The disadvantage of solar energy is its output power depends on factors like temperature, intensity of sun light, sun angle of incidence. To extract maximum power from the solar array it has to be operated at maximum power point (MPP).

Virtual Instrumentation (VI) is widely used in testing, measurement and control application as it is easy to understand and implement. In this thesis, maximum power point tracking (MPPT) of solar array is demonstrated using a virtual instrument (VI) created in LabVIEW. Voltage and current signals sensed from photo voltaic (PV) array are fed as input to the VI and control signal is obtained as output. The duty cycle of a buck converter which is placed between solar array and the load is controlled using the control signal. Incremental conductance (INC) algorithm is used for creating a LabVIEW VI that tracks maximum power. Faster tracking of power in the range of millisecond is observed.

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# Chapter 1

## 1. INTRODUCTION

### 1.1 Introduction

Due to the depletion of non-renewable sources of energy and increase in demand for electricity man has to search for alternative sources like renewable energy sources. Solar energy is one such renewable sources of energy which works on the principle of photovoltaic effect. Solar cell is the main element which converts solar energy into electrical energy. Solar cells are connected in series or parallel depending on requirement to form solar module. Solar modules are again connected in series or parallel depending on the current and voltage requirement to form solar array. Solar cell provides clean and pollution free energy unlike traditional source of energy like coal, diesel, natural gas, nuclear energy. It is has certain disadvantage of low efficiency compared to other renewable sources of energy. This problem is overcome by using maximum power point tracking (MPPT) technique as discussed in this work.

### 1.2. Motivation

The efficiency of solar array is very less under normal operating conditions and also further decreases with varying load, environmental conditions. To increase the efficiency of solar array different control algorithms called Maximum Power Point Tracking (MPPT) are being used now a days. The objective of all these algorithms is to match the source impedance with that of load impedance such that maximum power is delivered from the array [3]. This impedance matching is achieved by using pulse width modulation of dc to dc converters which are used between solar array and load. One of the widely used methods for this purpose is Incremental conductance (INC) method. This MPPT method is being

implemented in analog and digital domain. Although analog method works faster, digital method is easy to implement and modify.

Digital method is being widely implemented by using different types of controllers like DSP processor, Microprocessor, Microcontrollers etc., where the MPPT algorithm is written as a coded program. However, graphical programming is simpler to understand, implement and modify. Matlab/Simulink and LabVIEW are software that are used to acquire data from real world, process the data and generate output that is either displayed or send to output port as control signal. In this paper, a simulation study is carried out implementing INC method in MATLAB Simulink. Having obtained simulation results on MPPT in Simulink, the same is implemented in hardware using LabVIEW software.

## **1.2 Literature survey**

Many literatures are available on the topic of modeling and MPPT of solar array. M. G. Villalva *et.al.* [1] Proposed method to model the solar cell and the main objective is to find the parameters of solar cell I-V equation. In this paper the effect of temperature and irradiation on the parameters of solar cell is also discussed. Chiang *et.al.* [2] introduced domestic photovoltaic energy storage system, in which the output PV power is controlled by a DC-DC converter with MPPT controller and transferred to a small battery.

T. Esham *et.al.* [2] explained and compared different MPPT techniques available in literature. The author has given summary of these MPPT techniques and their implementation methods which helped in choosing the appropriate MPPT method for given PV systems. A. Safari *et.al.*[11] discussed incremental conductance (INC) method and practical implementation of this method. R. Gules *et.al.* [10] analysed, designed and implemented a parallel connected MPPT system for a stand -alone photovoltaic power generation.

### 1.3 Objective and Scope

The overall objectives and scope of the work can be summarized as follows

- Studying the I-V (Current-Voltage) and P-V (Power-Voltage) characteristics of solar array under different temperature and irradiation.
- Simulating the maximum power point tracking (MPPT) using incremental conductance method (INC) in MATLAB Simulink.
- Determining maximum power point of solar array in LabVIEW.
- Hardware implementation of maximum power point using incremental conductance method in LabVIEW.

In **chapter 2**, we described various types of solar photovoltaic systems and also seen difference between grid connected PV system and hybrid PV system.

In **chapter 3**, modeling of solar cell and the dependency of solar cell characteristics on irradiation and temperature is seen.

In **chapter 4**, the modes of operation of buck converter used for MPPT technique has been discussed.

In **chapter 5**, various MPPT techniques are described with their advantages and disadvantages.

In **chapter 6**, mathematical description of MPPT is given and INC MPPT technique has been chosen for tracking MPP and variation of MPP with change in temperature and irradiation is observed.

In **chapter 7**, MPPT is implemented using hardware components and LabVIEW software by INC algorithm

## **Chapter 2**

### **2. CLASSIFICATION OF PHOTOVOLTAIC SYSTEM**

#### **2.1 Solar photovoltaic system**

Photovoltaic system is meant to generate electricity from the solar cells and supply to the ac or dc load. The photovoltaic system can supply energy only during day time, if we want electricity during night time battery storage system must be used.

#### **2.2 Types of photovoltaic systems**

##### **2.2.1 Stand-alone PV system**

The Stand-Alone PV System consists of battery storage system to provide power to the load when there is no sunlight. The array of solar panels must be large enough to provide power to all loads at the site and recharge the batteries [10].

##### a) Unregulated standalone system with DC load

In this type the solar panel is directly connected to the DC load and the solar panel is not operated always at its maximum power since there is no controller. This is usually used for low power applications. This type of system can only provide energy during day time but not night time since there is any energy storage system available. Figure 2.1 shows the diagram of unregulated standalone system with DC load.

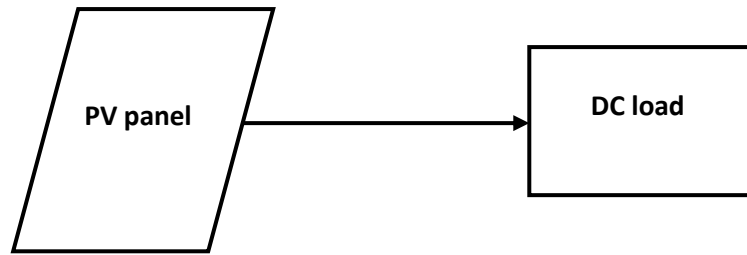


Figure 2.1: Unregulated standalone system with DC load

b) Regulated standalone system with DC load

In this type of system a DC-DC converter is installed between PV panel and DC load as shown in figure 2.2. The duty cycle of the switch used in DC-DC converter is controlled by MPPT controller so that the solar panel always gives out maximum power.

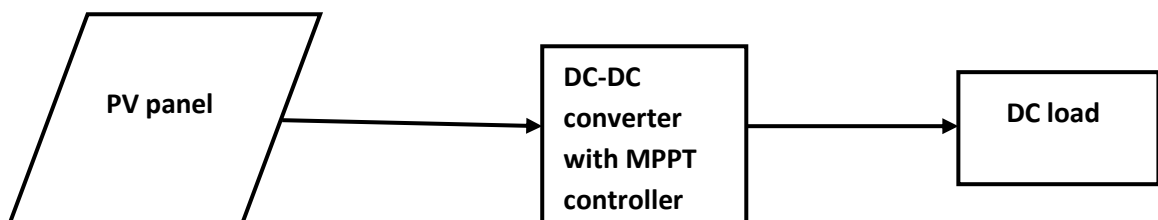


Figure 2.2: Regulated standalone system with DC load

c) Regulated standalone system with battery and DC load

The difference between this and previous system is that the extra power delivered by the solar panel is stored in the battery storage system as shown in figure 2.3. When the solar panel is unable to supply power to load then battery supplies the required power. A charge controller is must for this type of system because battery life is less compare to PV module and also the cost of the system increases.

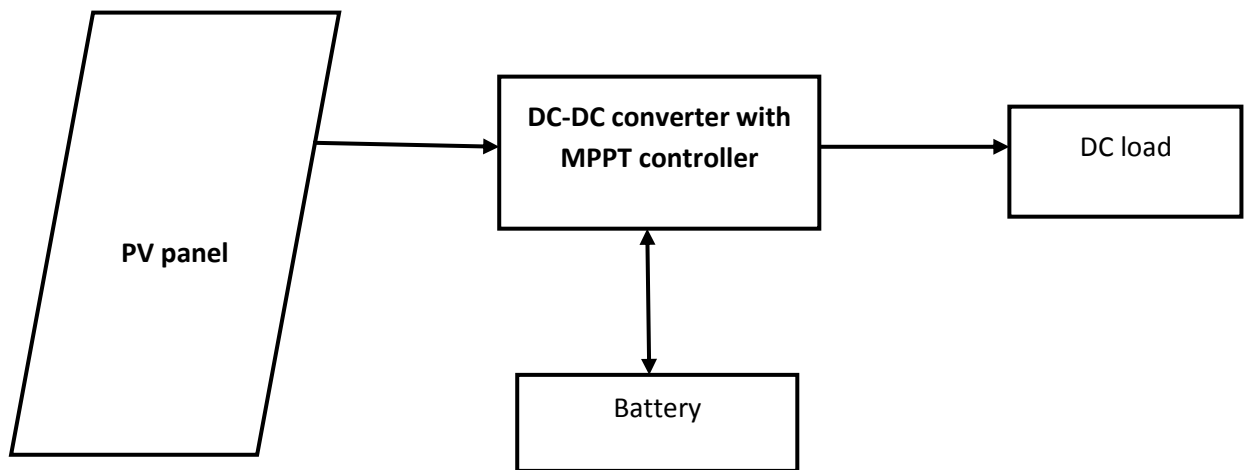


Figure 2.3: Regulated standalone system with battery and DC load

d) Regulated standalone system with battery, AC and DC loads

This system is similar to the previous one but the ac load also draws power from the system as shown in figure 2.4 so an inverter is essential so the cost and complexity increases.



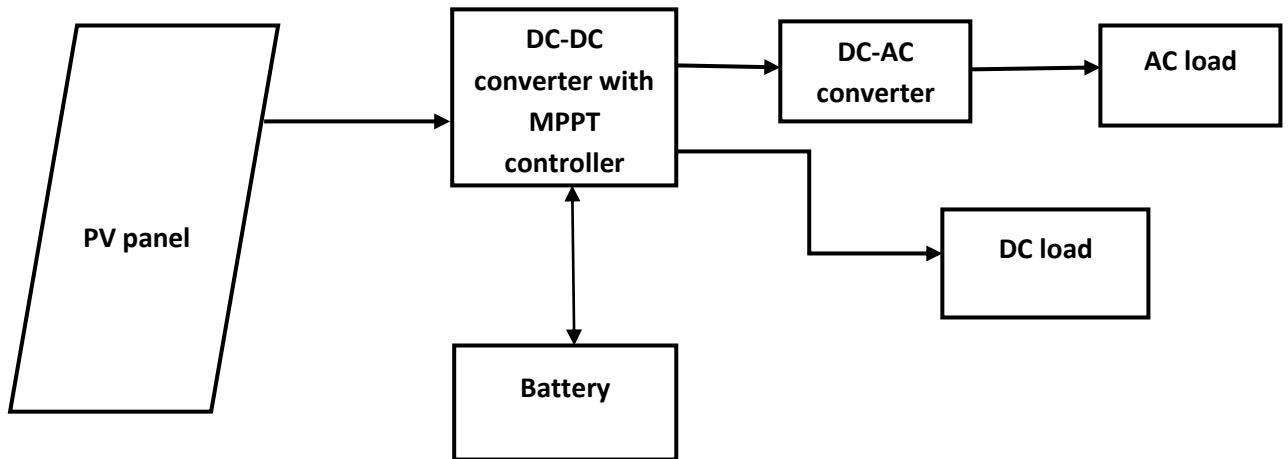


Figure 2.4: Regulated standalone system with battery, AC and DC loads

### 2.2.2 Grid interactive PV system

This type of system consists of PV panel interacted with grid through inverter. The excess power left after the load utilization is fed to the grid as shown in figure 2.5.

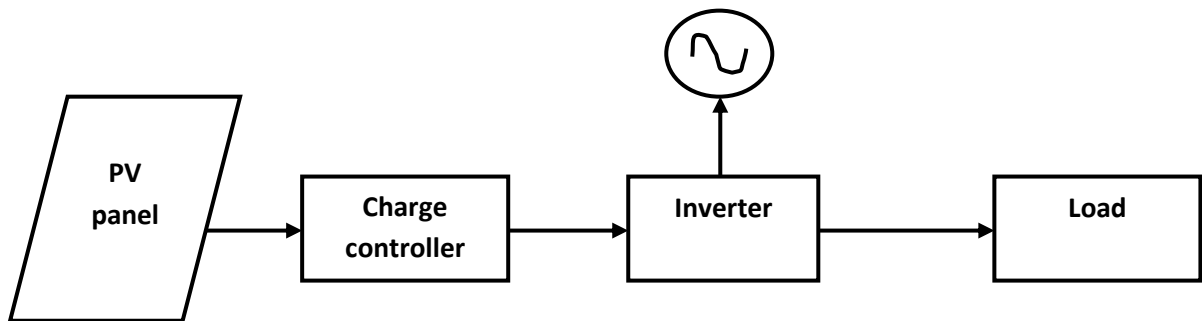


Figure 2.5: Grid interactive PV system

### 2.2.3 Hybrid system

In this the PV system is used in interaction with wind generator, diesel generators, micro turbines etc., as shown in figure 2.6.

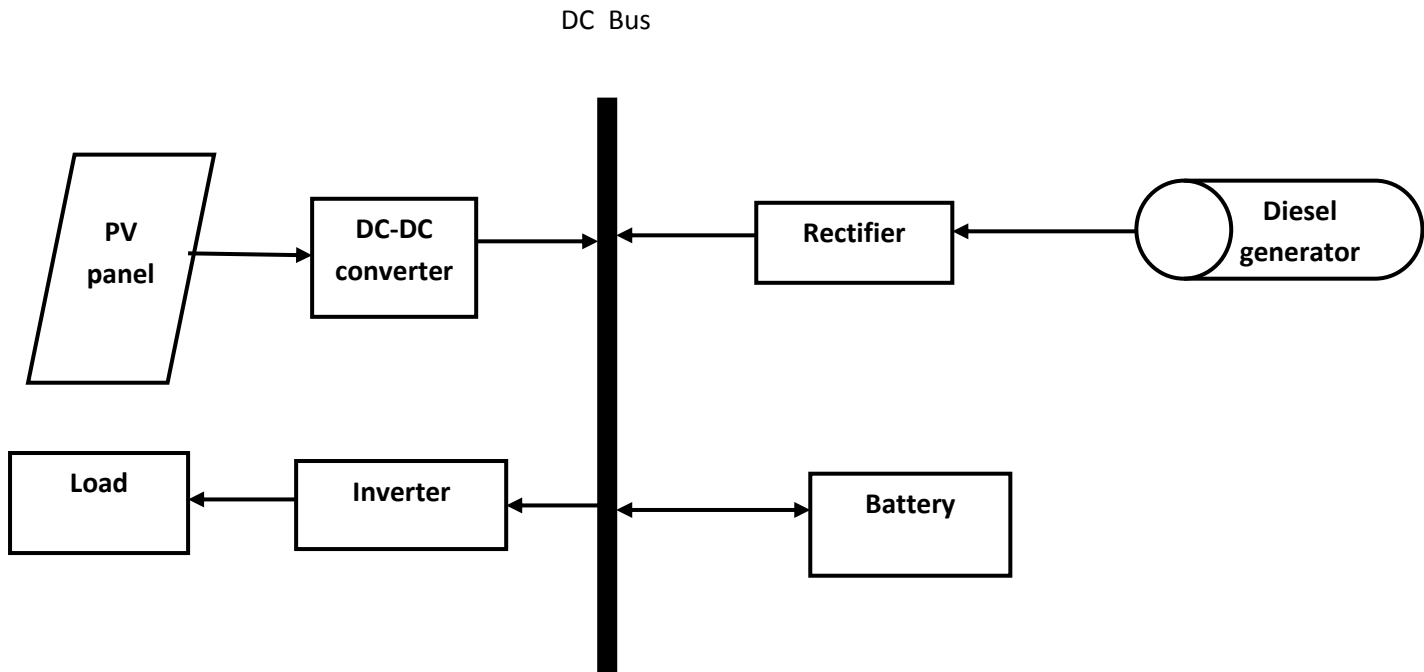


Figure 2.6: Hybrid system

## Chapter 3

### 3. MODELLING AND SIMULATION OF SOLAR CELL

#### 3.1 Modeling of Solar cell

Solar cell works on the principle of photo-voltaic effect by which light energy is converted to electrical energy. There is single diode model, two diode model and three diode model to represent the equivalent circuit of solar cell [4]. Single diode model is simple and accurate so for power electronics practitioners it helps for easy analysis. The well-known single diode model of solar cell is shown in figure 3.1. The photo current  $I_{ph}$  generated depends upon irradiation and temperature. The basic equation describing I-V characteristics of solar cell is given by [6]:

$$I = I_{ph} - I_0 \left\{ e^{\frac{q(V + R_s I)}{AKT}} - 1 \right\} - \frac{V + R_s I}{R_{sh}} \quad \dots\dots\dots (3.1)$$

- I      Load current (A)
- $I_{ph}$       Generated current from PV cell (A)
- $I_0$       Reverse saturation current of diode (A)
- V      Load voltage (V)
- $R_{sh}$       Shunt resistance ( $\Omega$ )
- $R_s$       Series resistance ( $\Omega$ )
- K      Boltzmann constant ( $1.38 \times 10^{-23}$  J/K)
- q      Charge of electron ( $1.6 \times 10^{-19}$  C)
- A      Curve fitting factor

In equation (3.1) usually  $R_{sh}$  will be very high so the term containing it will be neglected. From this we can see that current from solar cell depends upon temperature.  $I_{ph}$  is light generated current which accounts for the electron-hole pairs formed and this depends on the irradiance. The standard test conditions (STC) for solar cell is irradiation of  $1000 \text{ W/m}^2$ , temperature of  $25^\circ\text{C}$ , Air Mass of 1.5

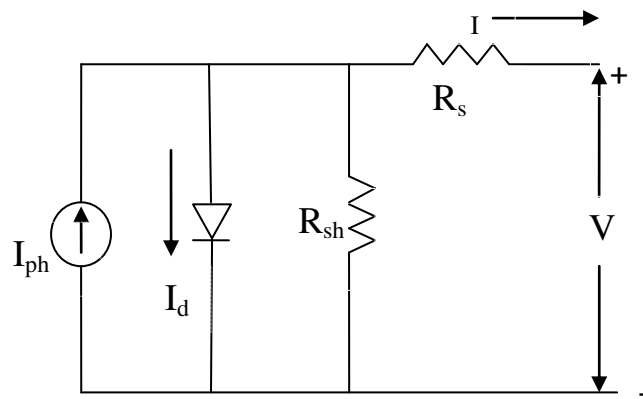


Figure 3.1: Equivalent single diode model of solar cell

Solar MSX-60 has been used for the simulation whose parameters are given below:

Table 3.1 Module ratings

Typical maximum power ( $P_p$ )	60 W
Open circuit voltage ( $V_{oc}$ )	21.1 V
Short circuit current ( $I_{sc}$ )	3.8 A
Voltage at peak power ( $V_{pp}$ )	17.1 V
Current at peak power ( $I_{pp}$ )	3.5 A
Temperature coefficient of $V_{oc}$	- 0.00379 / $^\circ\text{C}$
Temperature coefficient of $I_{sc}$	0.00065 / $^\circ\text{C}$

## 3.2 Characteristics of solar array

### 3.2.1 I-V curve of PV array

I-V curve of the solar array shown in figure 3.2 is plotted by varying the load resistance under STC in MATLAB simulink. When  $I_{PV}=0$  then we will get the open circuit voltage ( $V_{oc}$ ) of solar panel and when  $V_{PV}=0$  then we get the short circuit current ( $I_{sc}$ ). In the figure 3.2 the star point indicates the maximum power point of the solar panel under STC with corresponding voltage  $V_{pp}$  and current  $I_{pp}$ .

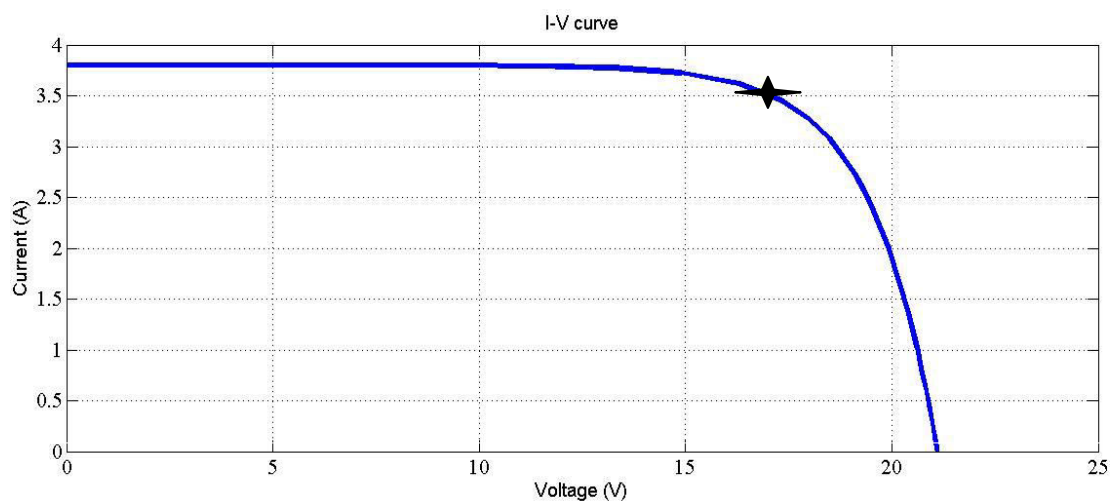


Figure 3.2: I-V curve of solar module under STC

### 3.2.2 P-V curve of solar array

The output power of solar module is obtained by multiplying output voltage and output current and at some point the maximum power is obtained. Figure 3.3 shows the P-V curve of solar module operated under STC and star mark shows the maximum power.

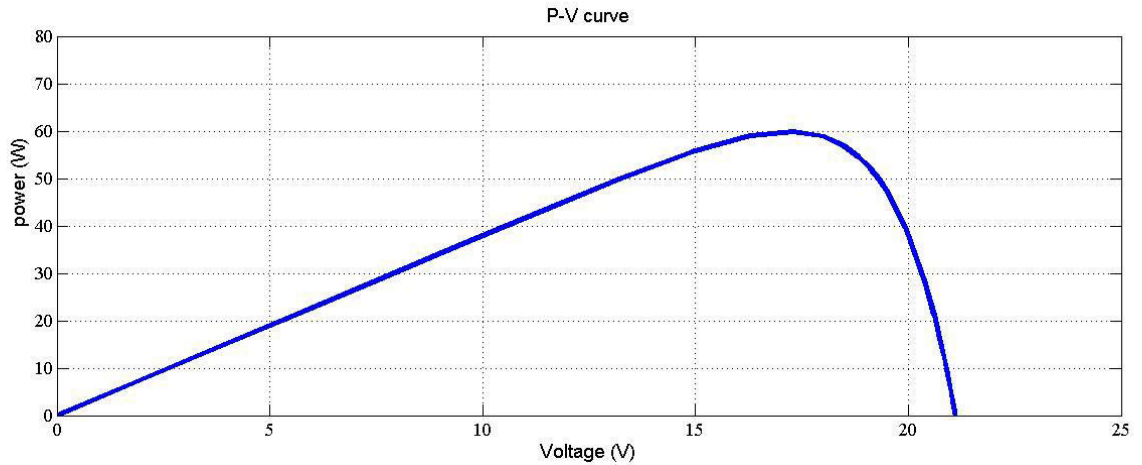


Figure3.3: P-V curve of solar module under STC

### 3.3 Dependency on temperature and irradiation

The voltage and current of a PV module change with irradiance and temperature. Hence, the effect temperature and irradiation must be taken into consideration in the PV module model. The mathematical expressions for short circuit current and open circuit voltage of solar array at any temperature and irradiation are given below:

$$I_{SC} = I_{SC,ref} \left[ 1 + \alpha (T - T_{ref}) \right] \frac{S}{S_{ref}} \quad \dots\dots\dots (3.2)$$

$$V_{OC} = V_{OC,ref} \left[ 1 + a \ln \frac{S}{S_{ref}} + \beta (T - T_{ref}) \right] \quad \dots\dots\dots (3.3)$$

$V_{oc,ref}$             Open circuit voltage under STC (V)

$I_{sc,ref}$             Short circuit current under STC (A)

$I_{sc}$	Short circuit current (A)
$V_{oc}$	Open circuit voltage (V)
T	PV module temperature ( $^{\circ}C$ )
$T_{ref}$	PV array temperature under STC ( $^{\circ}C$ )
S	Solar irradiance ( $W/m^2$ )
$S_{ref}$	Irradiance under STC ( $W/m^2$ )
$\alpha$	Temperature coefficient of $I_{sc}$ ( $/^{\circ}C$ )
$\beta$	Temperature coefficient of $V_{oc}$ ( $/^{\circ}C$ )
$a$	Irradiance correction factor of $V_{oc}$ .

So from equation (3.2), equation (3.3) as temperature increases open-circuit voltage decreases and it has negligible effect on short circuit current. As irradiation increases the short circuit current increases and it has negligible effect on open-circuit voltage. Figure 3.4; figure 3.5 are simulated under different irradiation and different temperature respectively

### Simulation study:

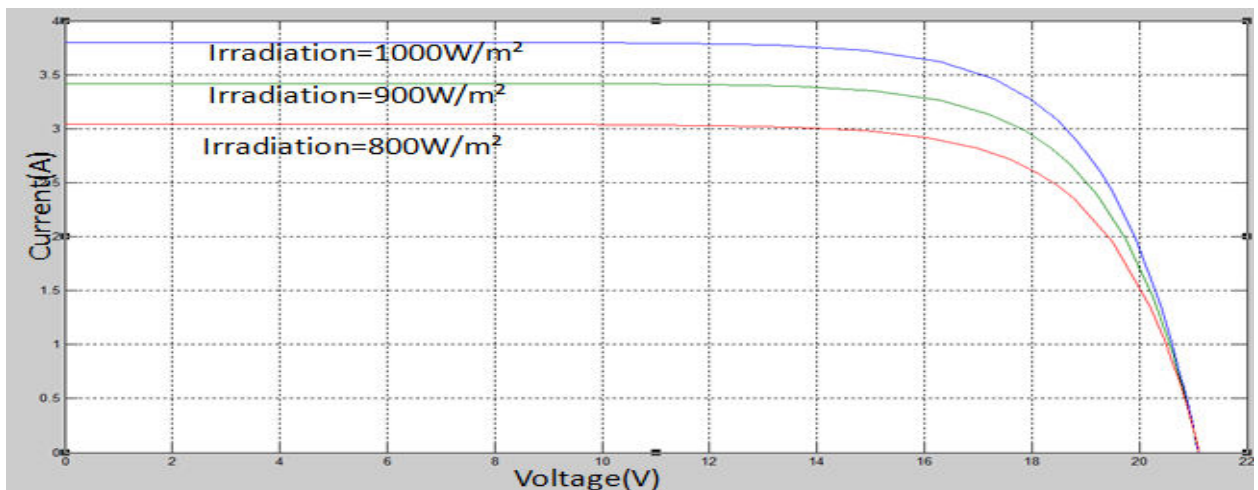


Figure 3.4: I-V curve with different irradiances and at temperature of 25°C

In figure 3.4 I-V curves are drawn at irradiances of 1000 W/m<sup>2</sup>, 900 W/m<sup>2</sup>, 800 W/m<sup>2</sup> at a temperature of 25°C. As the irradiation increases short circuit current increases but has negligible effect on open-circuit voltage.

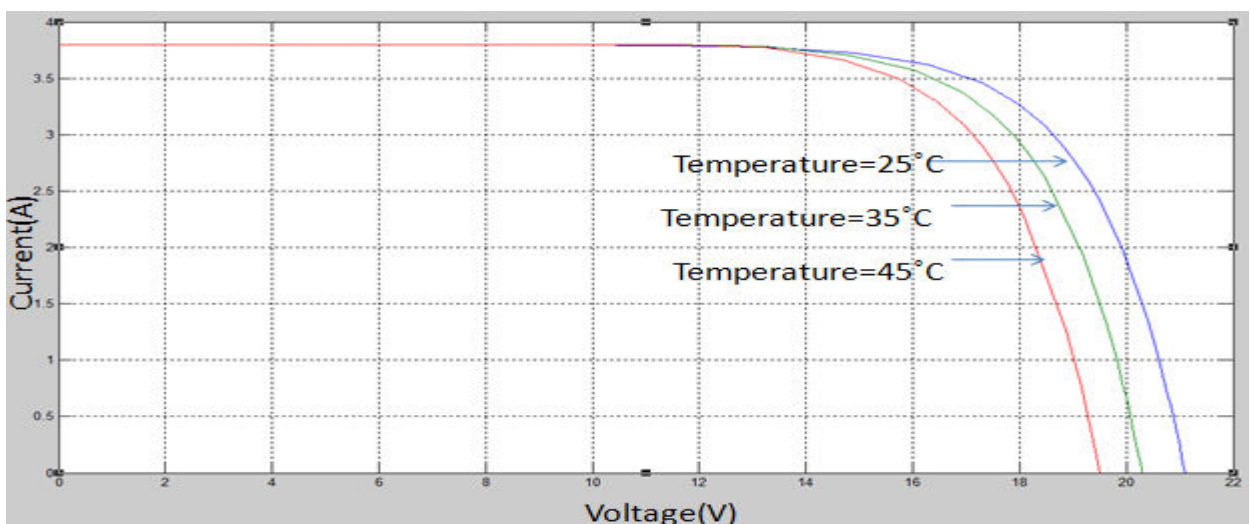


Figure 3.5: I-V curve under different temperatures at irradiation of 1000W/m<sup>2</sup>

In the figure 3.5 I-V curves is drawn at temperatures of 25°C, 35°C, 45°C and at constant irradiation of 1000 W/m<sup>2</sup>.as temperature increases the open circuit voltage decreases and there is a negligible increase in short circuit current.



## Chapter 4

### 4. BUCK CONVERTER

#### 4.1 Introduction to buck converter

Buck converter steps down the input source voltage to the required value of output voltage. The essential components of buck converter are inductor, diode, high frequency switch and capacitor as shown in figure 4.1. These are connected in such a manner to supply voltage at a lower level compared to the input voltage. The control strategy is change of the duty cycle of the switch which causes the voltage change [13].

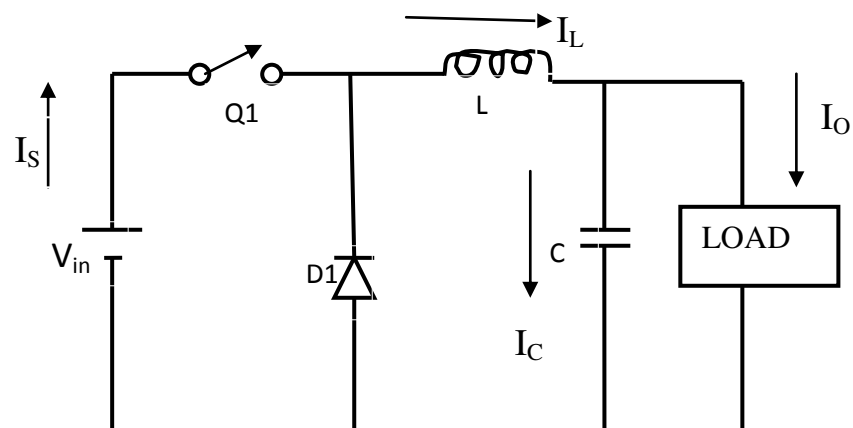


Figure 4.1: Circuit diagram of buck converter

Where  $I_s$  source current (A)

$I_C$  current through capacitor C (A)

$I_L$  current through inductor L (A)

$I_O$  load current (A)

## 4.2 Modes of operation

There are two modes of operation of buck converter. The charging mode in which the switch Q1 is closed and the inductor L stores energy. The discharging mode in which the switch is open and the inductor L supplies energy to the load though the source is disconnected from load.

### 4.2.1 Charging mode

In charging mode of operation the switch Q1 is closed and the inductor L gets charged from source  $V_{in}$ . The current in the inductor L raises exponentially but for simplicity it has been taken as linear [13]. The capacitor acts as a filter to make the output current almost constant.

### 4.2.2 Discharging mode

In discharging mode of operation the switch Q1 is opened and the load gets disconnected from the source. The diode gets forward biased and the energy required by the load is supplied by the inductor L. The current in the inductor L discharges exponentially and assumed to be linear for simplicity.

### 4.3 Waveforms

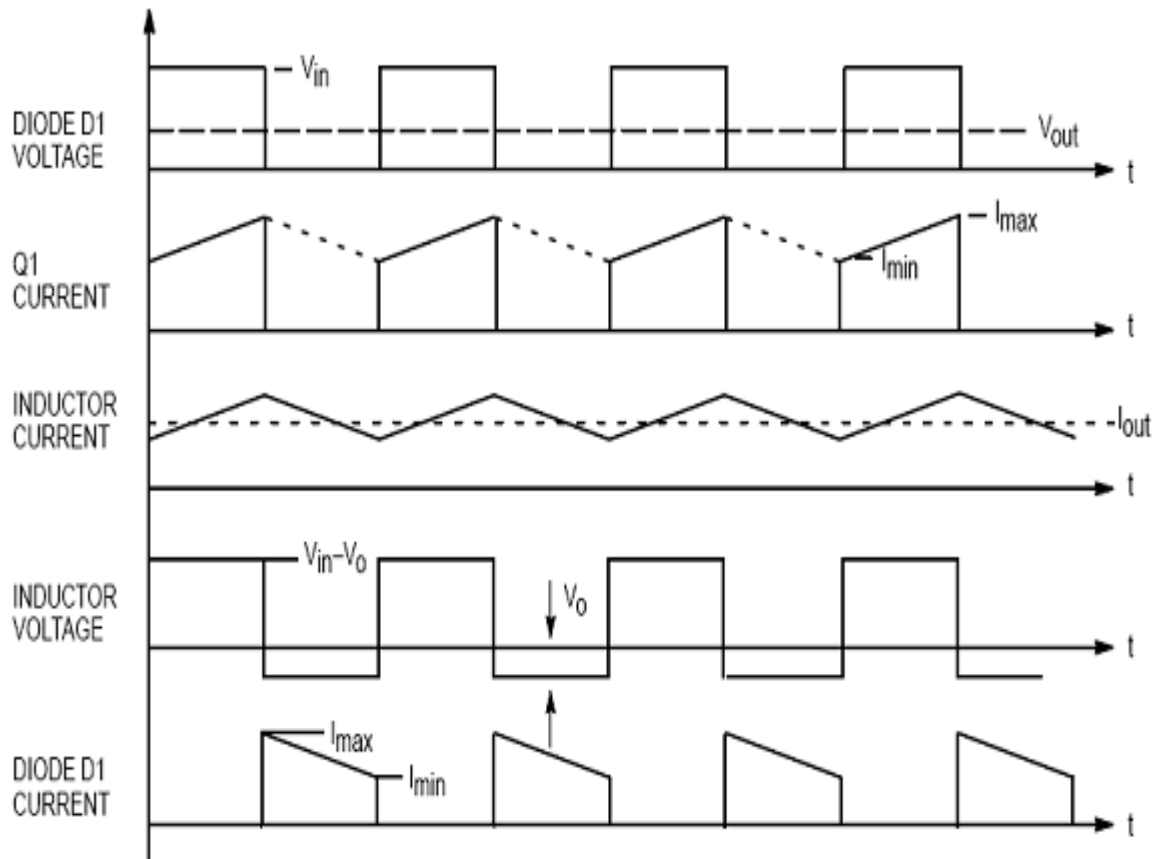


Figure 4.2: Buck converter waveforms [13]

## Chapter 5

# 5. MAXIMUM POWER POINT TRACKING TECHNIQUE (MPPT)

### 5.1 Maximum power point tracking

From figure 5.1 solar arrays has non-linear current-voltage and power-voltage characteristics that varies with irradiation and temperature. In order to track the maximum power point of the solar array the MPPT technique plays a prominent role in the PV systems. The job of a MPPT technique in a photovoltaic (PV) system is to continuously tune the system so that solar array operates always at maximum power point irrespective of weather or load conditions [12].

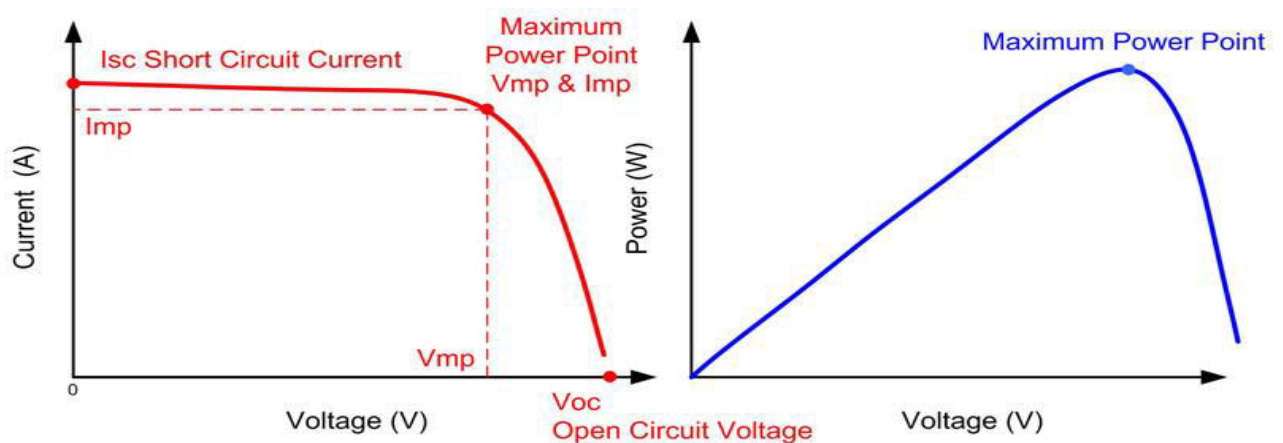


Figure 5.1: I-V and P-V curves of solar cell indicating the maximum power point [3]

#### Basic principle:

According to maximum power transfer theorem, the power delivered to the load is maximum when the impedance of source matches the impedance of load. Thus, the impedance seen from the converter side matches the internal impedance of the solar array.

## 5.2 MPPT methods

There are various methods to track the maximum power point; some of them are given below [11]:

### 1. Perturb and observe method

Perturb and observe method deals with the change of voltage to track the maximum power and it is simple and cheap. The disadvantage is that it cannot track the maximum power efficiently under varying weather conditions.

### 2. Incremental conductance method (INC)

INC method is based on the I-V curve of the solar module. Incremental conductance method deals with the change in the duty cycle of the converter used between the solar panel and load to track the maximum power point. This method requires both current and voltage sensor so it is costly and complex. INC method can track the MPP efficiently under varying weather conditions.

### 3. Fractional open circuit voltage method

The open circuit voltage of solar module is directly proportional to the voltage at maximum power

$$V_{OC} = K_1 V_{PP} \quad \dots \dots \dots (5.1)$$

$K_1 \cong 71\%$  to  $78\%$ . In this method the converter switch needs to be opened frequently which results in power loss. This method is less efficient and cannot be used for partial shading purpose.

#### 4. Fractional short circuit current method

Short circuit current of solar module is directly proportional to the current at maximum power

$$I_{SC} = K_2 I_{PP} \dots \dots \dots (5.2)$$

$K_2 \cong 78\%$  to  $92\%$  .in this method to measure the  $I_{SC}$  one extra switch is needed and it is not an accurate method to track MPP.

## Chapter 6

### 6. SIMULATION OF MPPT

#### 6.1 Mathematical description of INC method

Incremental conductance technique has been used to track the maximum power point in which the incremental value of conductance is equal to the instantaneous value of conductance at maximum power point. This is based on the I-V curve of the solar cell.

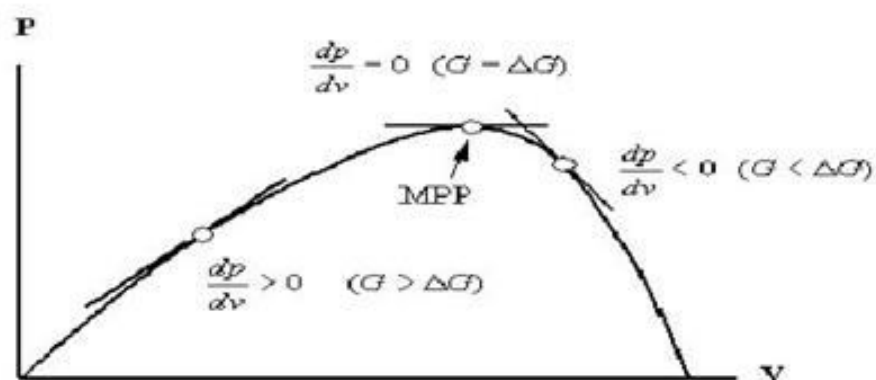


Figure 6.1: P-V curve explaining the incremental conductance method

From figure 6.1 Where  $G = -I/V$ ,  $\Delta G = dI/dV$

$dI/dV = -I/V$  at MPPT

$dI/dV < -I/V$  to the right side of MPPT

$dI/dV > -I/V$  to the left side of MPPT

In INC method the instantaneous voltage and current from solar array is sensed and if the value of instantaneous conductance of solar array equal to incremental value of conductance solar array then the operating point is at MPP, if the value of instantaneous conductance of solar array is greater than incremental conductance of solar array then the

operating point is to the right of MPP, if value of instantaneous conductance of solar array is less than incremental conductance of solar array then the operating point is to the left of MPP [11] . In this way maximum power point is tracked by changing the duty cycle of MOSFET of buck converter in turn changing the voltage and current of solar array. The block diagram of the MPPT method is shown in figure 6.2.

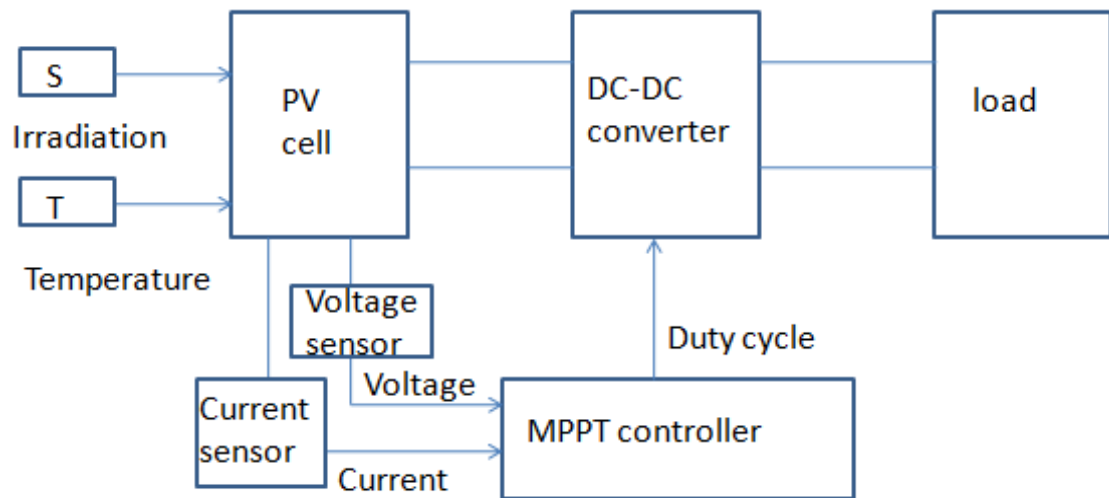


Figure 6.2: Block diagram of PV cell with MPPT controller



Flow chart in figure 6.3 explains the process for achieving the MPP using INC method

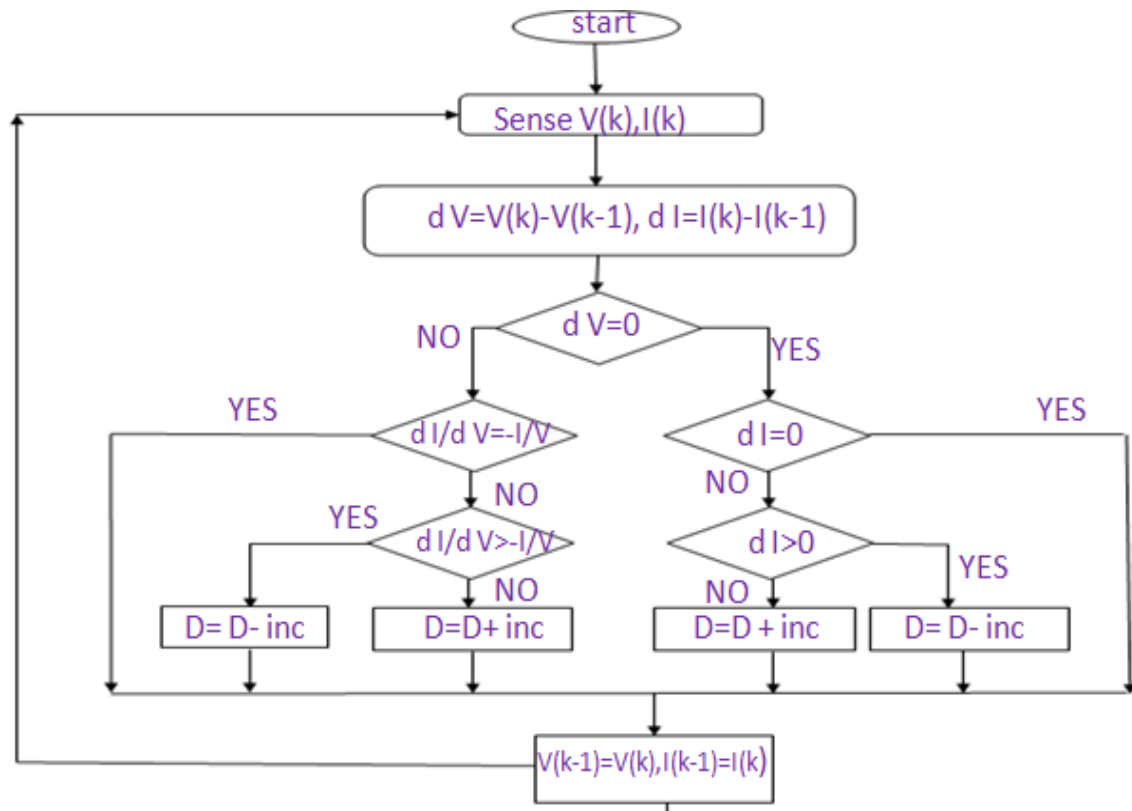


Figure 6.3: Flow chart of incremental conductance method.

## 6.2 Simulation of MPPT using INC method

Buck converter has been used and the maximum power point has been tracked according to the flow chart shown in figure 6.2. Using MATLAB Simulink and the parameters of solar module used for simulation is given in Table.3.1. Output voltage, output power, output current curve is plotted and these are constant with some ripple in output. Figure 6.4 shows out-put power of solar module, figure 6.5 shows output voltage of solar module, figure 6.6 shows output current of solar module.

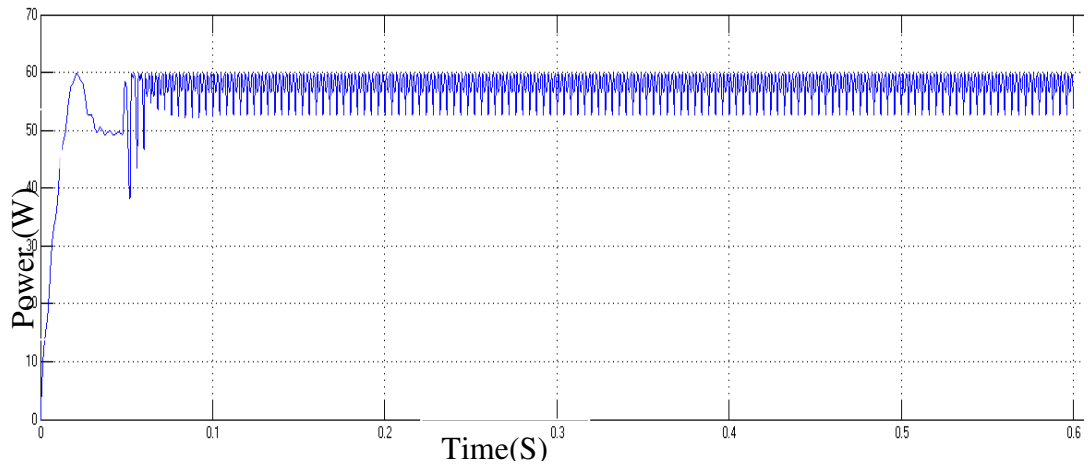


Figure 6.4: MPPT using INC method under STC

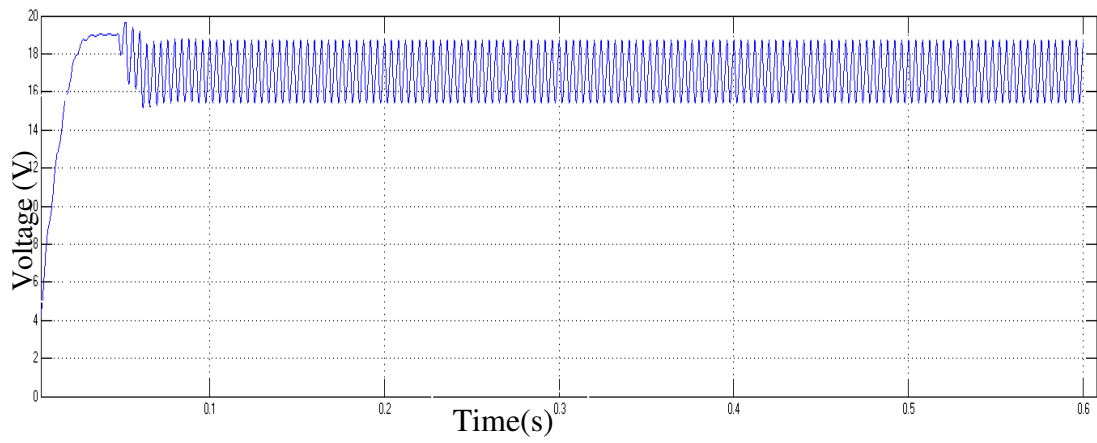


Figure 6.5: Output voltage of solar module during MPPT using INC method under STC

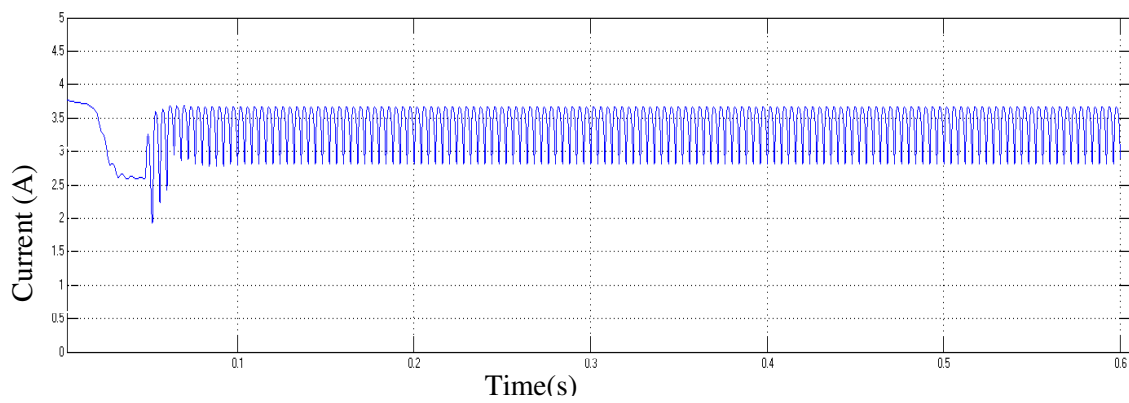


Figure 6.6: Output current of solar module during MPPT using INC method under STC

### 6.3 Simulation of INC MPPT method under varying irradiation

Figure 6.7 shows output power of solar module as the irradiation increases power increases and INC method is properly tracking the MPP with change in irradiation.

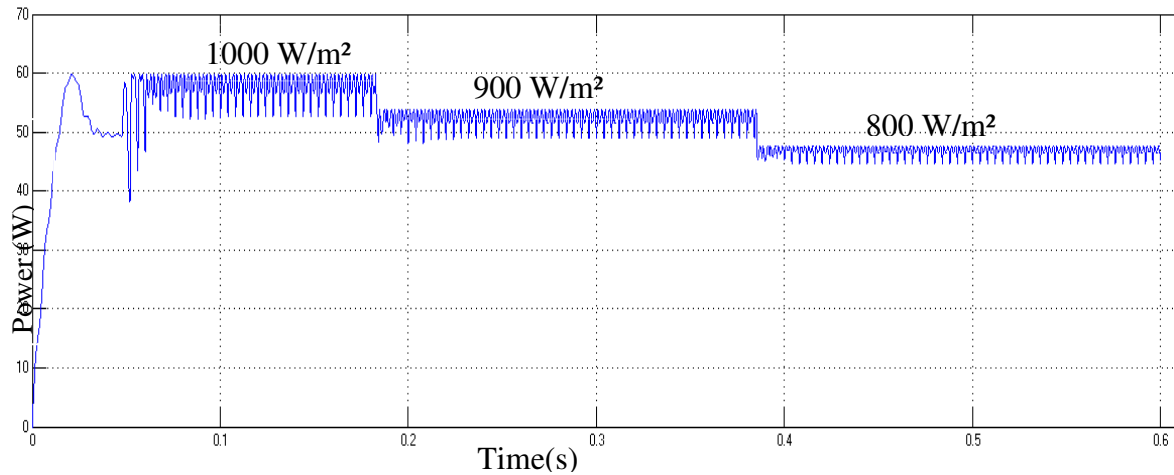


Figure 6.7: MPPT under varying irradiation and constant temperature of 25°C using INC method

### 6.4 Simulation of INC MPPT method under varying temperature

Figure 6.8 shows output power of solar module as the temperature increases power decreases and INC method is properly tracking the MPP with change in temperature.

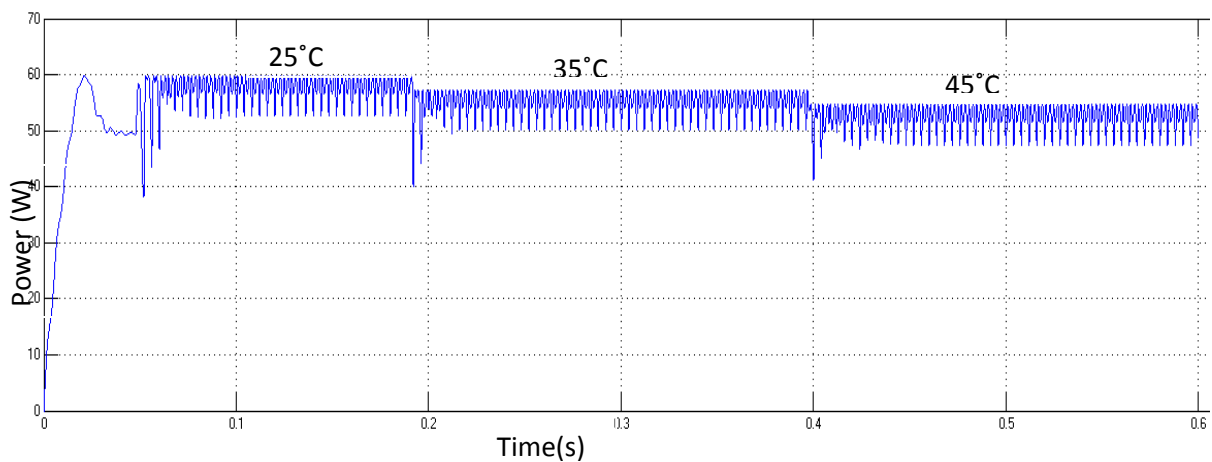


Figure 6.8: MPPT under varying temperature and constant irradiation of 1000 W/m² using INC method

## Chapter 7

### 7. HARDWARE IMPLEMENTATION OF INC MPPT METHOD

#### 7.1 Hardware system description

MPPT is practically demonstrated by using an illuminated solar panel with ratings given in the table 7.1

Table 7.1 Solar array specifications used for hardware implementation

PV module type	1220
Typical peak power	20 W
Open circuit voltage	21.90 V
Short circuit current	1.25 A
Current at peak power	1.16 A
Voltage at peak power	17.25 V
Power tolerance	$\pm 5\%$
Electrical parameters tolerance	$\pm 10\%$

The panel is illuminated by two incandescent bulbs of 100 W rating each from a single phase ac supply of 230 V. A fixed resistor of 150  $\Omega$  is used as a load. A non-isolated buck converter [9] is used for impedance matching. Solar panel is connected at the input terminals of the buck converter and load resistor at the output as shown in block diagram figure 7.1. The buck converter consists of a MOSFET IRFZ44N that is connected at the low voltage side. The source is connected to ground and hence the triggering pulse magnitude is low.

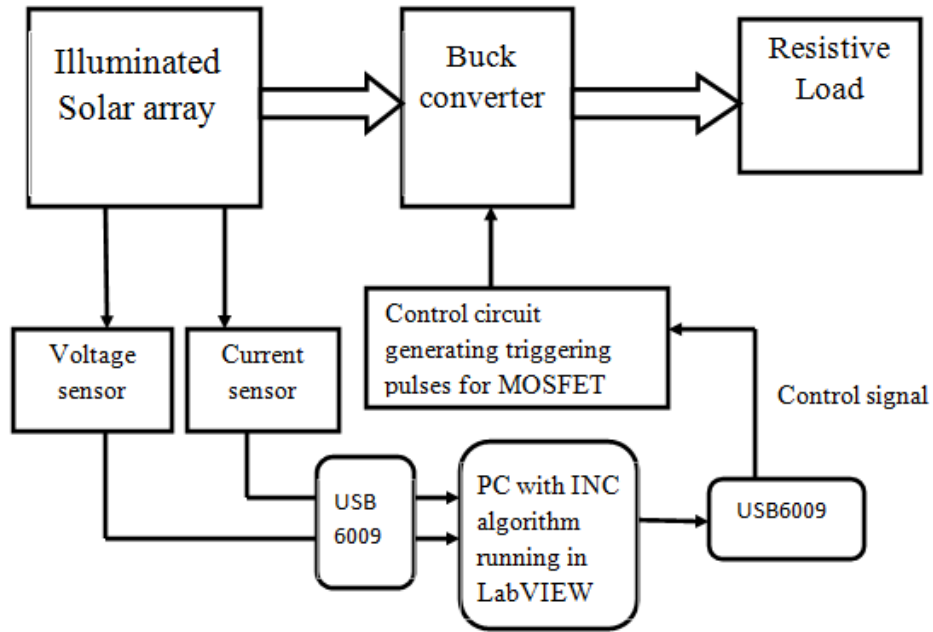


Figure 7.1: Block diagram of MPPT using LabVIEW

For generation of PWM signal for MOSFET a saw-tooth signal and a control signal are necessary. SG3524 generates saw-tooth signal of different frequencies depending upon the values of resistor ( $R_T$ ) and capacitor ( $C_T$ ) connected at pin numbers 6 and 7 respectively [8]. The frequency ( $f$ ) of saw-tooth signal generated by SG3524 is given by equation (7.1).

$$f \approx \frac{1.30}{R_T C_T} \quad \dots \dots \dots (7.1)$$

The permissible value of  $R_T$  ranges from 1.8 K $\Omega$  to 100 K $\Omega$  and permissible value of  $C_T$  ranges from 0.001  $\mu$ F to 0.1  $\mu$ F. So the frequency of saw-tooth signal ranges from 130 Hz to 722 KHz. The value of frequency chosen for this work is approximately 50 KHz that is adjusted by using variable resistance pot as shown in figure 7.2. The saw-tooth signal has maximum value of 3.68 V and minimum voltage of 0.72 V.

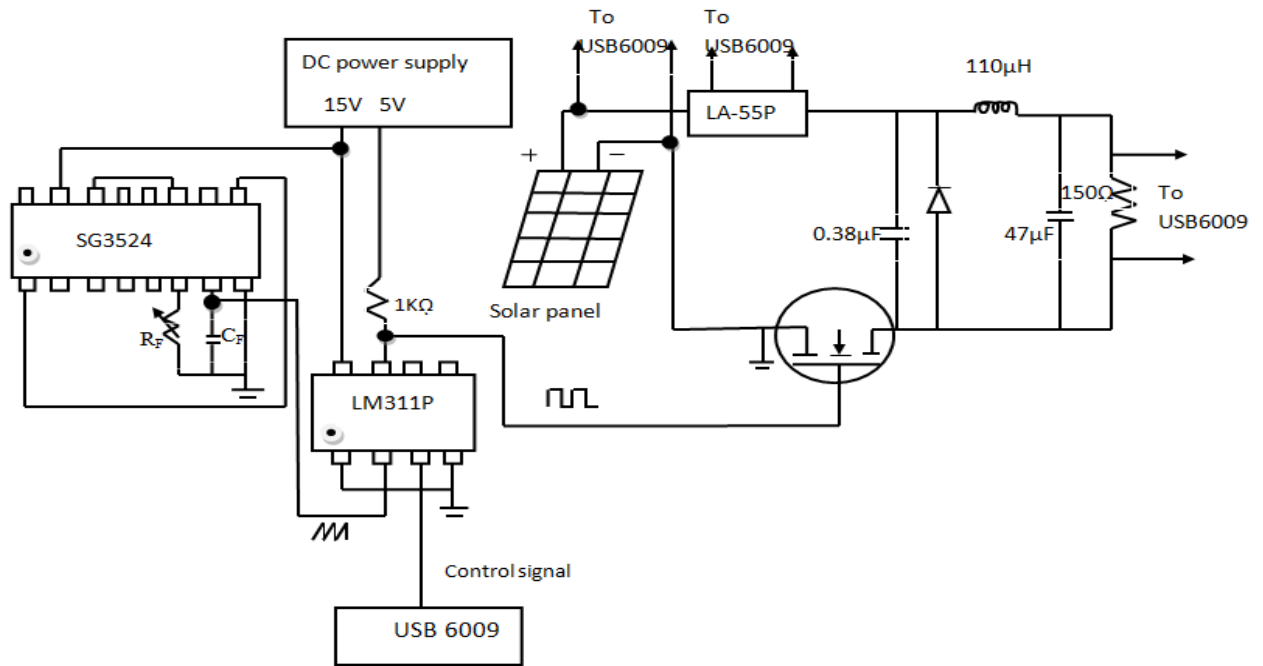


Figure 7.2.: Circuit diagram of hardware implementation of MPPT

Array voltage and current are given as inputs to a data acquisition device (NI USB6009). The data acquisition device is connected to a PC with LabVIEW software as shown in figure 7.3. Solar array voltage is sensed using potentiometer that reduces the voltage to a level that is within the input voltage rating of USB6009. Solar array current is sensed using current transducer LA-55P whose output voltage is proportional to the array current. These voltages (one proportional to array voltage and other to array current) are processed using INC algorithm implemented in LabVIEW and a control signal is generated.

This control signal is given as voltage output using USB6009 at a rate of 150 samples per second. This control signal is restricted between the same limits as that of saw-tooth signal magnitude (3.68 V-0.72 V). This ensures the duty cycle of triggering pulse between 0 and 1. LM311P compares the control signal, saw-tooth signal and gives triggering pulses of same frequency as saw-tooth signal for MOSFET of buck converter.

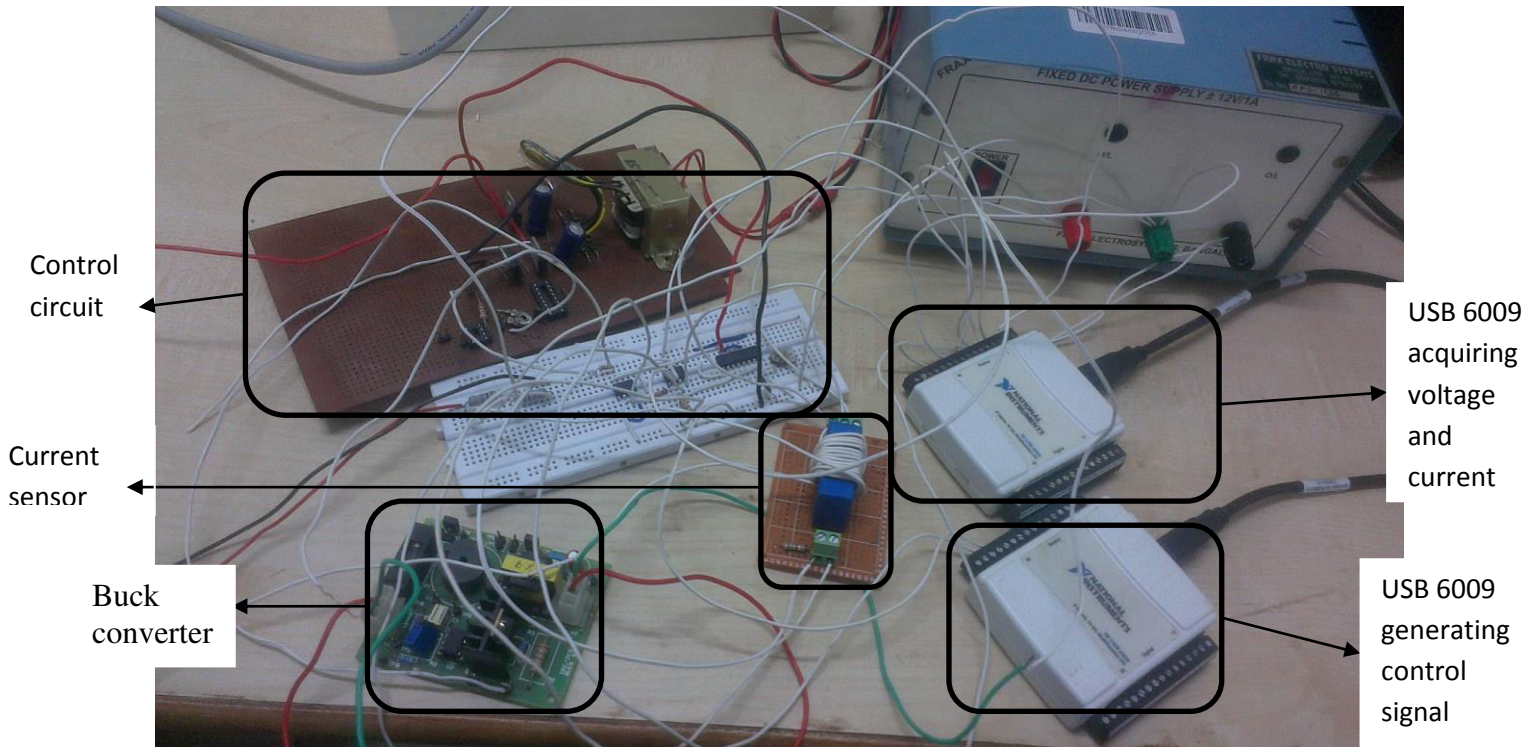


Figure 7.3: Picture showing hardware components for MPPT implementation

## 7.2 Determining maximum power of solar array in LabVIEW

Since the solar panel is not illuminated from sunlight directly so the power output from solar panel will be less than normal peak power so we have to find the maximum power before proceeding to the MPPT. This can be done using LABVIEW in which the load is changed by means of changing duty cycle by 0.01 and determining the MPP.

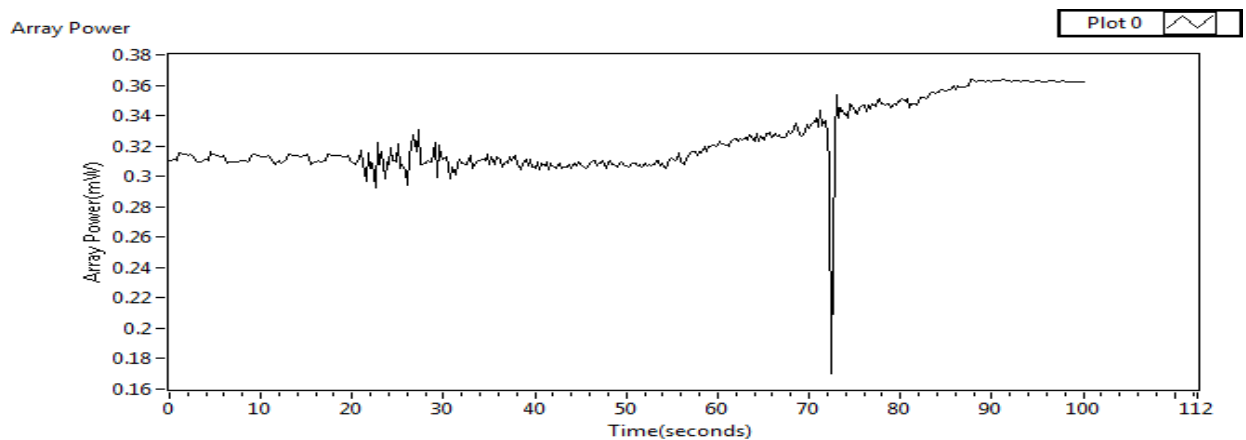


Figure 7.4: Array power waveform of solar panel with varying duty cycle

From the figure 7.4 maximum array power obtained is about 0.365 mW. Now when this is operated using INC method output power tracked must be 0.365 mW.



### 7.3 MPPT using INC method

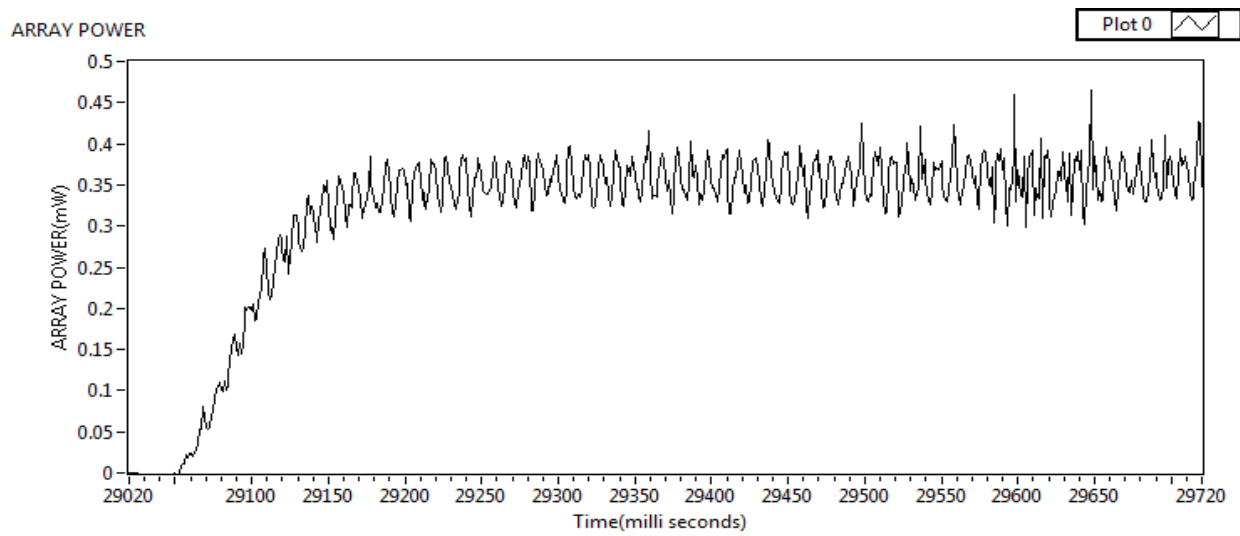


Figure 7.5: Array power waveform of MPPT using INC method

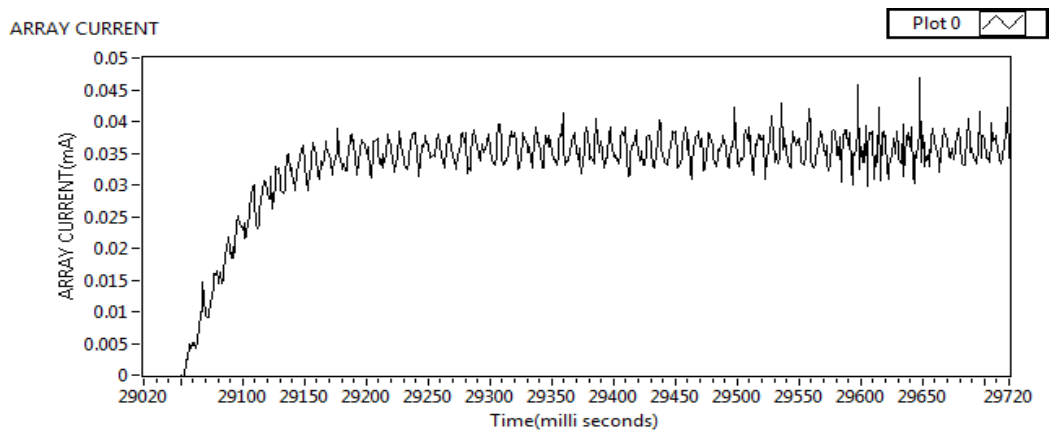


Figure 7.6: Array output current during MPPT

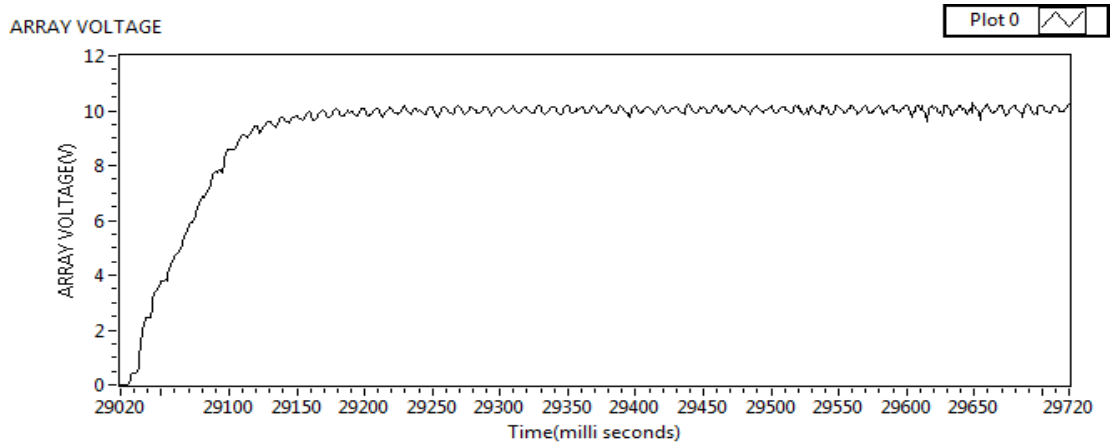


Figure 7.7: Array output voltage during MPPT

Thus the maximum power has been tracked using INC method in LABVIEW. From figure 7.4, figure 7.5; figure 7.5 the maximum power is tracked within 100 ms and the maximum power is 0.365 mW at a current of 0.0365 mA and voltage of 10 V.

## Chapter 8

### 8. CONCLUSION

#### 8.1 Summary

The maximum power point of solar array can be rapidly tracked by using incremental conductance method under normal and also varying weather conditions. In the hardware implementation of MPPT the pulses given to MOSFET are not exactly square wave at lower value of duty cycles so the power is not becoming zero at lower duty cycles. In order to avoid that voltage driver circuit has to be used. In this work MPPT is implemented by considering the maximum power derived from figure 7.4.

#### 8.2 Future scope

The work done in this project can be implemented to track the maximum power point of solar array under varying weather conditions using LabVIEW. MPPT of solar array cannot be implemented under partial shaded conditions using INC method. Module integrated converters has to be used to track MPPT under partially shaded conditions.

#### 8.3 References

1. M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays," *IEEE Trans. on power Electron.* vol. 24, no. 5, May 2009.
2. S. J. Chiang, K. T. Chang, and C. Y. Yen, "Residential photovoltaic energy storage system," *IEEE Trans. on Ind. Electron.*, vol. 45, no. 3, pp. 385-394, June 1998.
3. M. chen and G. A. Rincon-mora, "Accurate electrical battery model capable of predicting runtime and I-V performance," *IEEE Trans. on Energy convers.*, vol. 21, no. 2, June 2006.

4. Paul A. Lynn, "Electricity from sunlight" third edition, *Pearson publications*, 2009.
5. M. Berrera, A. Dolara, "Experimental test of seven widely-adopted MPPT algorithms", *IEEE Bucharest Power Tech Conference*, 2009.
6. A. K. Mukerjee and N. Thakur, Photovoltaic systems analysis and design, *PHI Learning private limited*, 2011.
7. R. J. Wai, Wen-Hung and C. Y. Lin, "High performance stand-alone photovoltaic generation System," *IEEE Trans. on Ind. Electron.*, vol. 55, no. 1, Jan. 2008.
8. Data sheet of regulated pulse width modulators SG3524 by national instruments.
9. Raju.N, Mariappan.V, Jeyaprakash.K, Sathya.A, "Teaching Aids in SMPC Construction Project in the Curriculum of Switched Mode Power Conversion", IISC, Bangalore.
10. R. Gules, J.D.P. Pacheco, H.L. Hey and J. Imhoff, "A maximum power point tracking system with parallel connection for PV stand –alone applications," *IEEE Trans. on Ind. Electron.*, vol. 55, no. 7, July 2008.
11. A Safari and S. Mekhilef, "Simulation and hardware implementation of Incremental conductance MPPT with direct Control Method using Cuk converter," *IEEE Trans. on Ind. Electron.*, vol. 58, no. 4, April 2011.
12. T. Eswam and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Trans. on Energy Conversion*, vol. 22, no. 2, June 2007.
13. Muhammed H. Rashid, "Power Electronics: Circuits, Devices, and Applications", second edition, *Pearson publications*, ISBN- 10: 013678996X, 1993.