

Modeling and Implementation of a Stand-alone PV System using Boost Converter

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Modeling and Implementation of a Stand-alone PV System using Boost Converter

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CERTIFICATE

This is to certify that the project entitled “**Modeling and Implementation of a Stand-alone PV System using Boost Converter**” submitted by **Mr. Arun Kumar Singh (213EE5351)** in partial fulfillment of the requirements for the award of Master of Technology degree in Industrial Electronics, Department of Electrical Engineering at National Institute of Technology, Rourkela is a genuine work carried out by him under my supervision and guidance. The matter illustrated in this thesis has not been submitted to any other Institute for the award of any Degree to the best of my knowledge.

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ABSTRACT

Now a days renewable energy sources have become a popular alternative electrical energy source, even governments are also making plans towards increasing the amount of power generation from renewable energy sources because viability and crisis of conventional energy sources will increase. In addition to this government liberalization and technical developments encourage the use of renewable energy sources. This thesis deals with a PV energy system which is an alternative for conventional source of electrical energy like other renewable energy sources viz. thermal and hydro power generation. Here power extracts from the incoming sun light radiation calling solar energy. It deals with the design and hardware implementation of a simple and efficient solar photovoltaic power generation system. The photovoltaic generator exhibits nonlinear V-I characteristics and its maximum-power point varies with solar isolation. So a simple control technique is adopted here, which is cost effective has been proposed to track the operating point at which maximum power can be coerced from the PV system under continuously changing environmental conditions. Solar Photovoltaic (PV) power generation system is comprising several elements like solar cells, DC/DC converter, Maximum power point tracking circuit, battery charge controller and the load; these subsystems are designed in PROTEUS software. A software simulation model is developed in Matlab/Simulink.

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CHAPTER 1

INTRODUCTION

- 1.1 Introduction
- 1.2 Literature Survey
- 1.3 Motivation
- 1.4 The System under Consideration
- 1.5 Objective
- 1.6 Thesis Organization

1.1 Introduction

This chapter gives a synopsis on Photovoltaic cell. It gives a basic idea on the parameters used in the project. It mainly deals with literature survey. It gives a synopsis on literature survey, main objective, system under consideration.

1.2 Literature Survey

India has become the top country in the world to make a law of minister called Minister of New and Renewable energy for non-conventional energy resources. Being the tropical country India has high solar isolation so the best renewable green energy source is solar energy. Our country is the 5th largest producer. From research it is noted that, by March 2017, the demand of electricity will be increased from 900 billion kilowatt-hours to 1400 billion kilowatt-hours. Consequently it is in verge of energy lack with a huge gap of demand and supply. To fulfill the required demand, solar energy is needed. It is the only entirely available renewable alternative energy source with the fundamental capability to satisfy the energy needs of our country. Based on PV installed capacity, India has become fourth After Japan, Germany and U.S. A major drive has also been initiated by the Government to trade Indian PV products, systems, technologies and services. From [1], it is clear that, the performance of the photovoltaic panel is affected by the environmental condition like Temperature & Solar Irradiation. In addition to these factors it also shows how the shadow affects it. Under shaded condition, PV characteristics get more complicated and difficult to analyze. Hence to make it easily understandable, different methods are adopted so far by the researchers. By those techniques I-V & P-V curves are recovered from partial shading condition. In [2], importance of solar energy, PV module and its uses in different field are illustrated. Its working procedures, equivalent model with all sets of equations are also discussed. Different factors affecting the characteristics of PV module are manifested. In [5] & [3], PV module simulated considering the variation in Temperature and Solar irradiation. Behavior of the characteristics is all together listed. In [4], need of MPPT controller circuit is discussed. Basically MPPT controller circuit helps in tracking the maximum possible output power, so that further operation can be easily carried out without any interruption, as initially the curve of PV module is nonlinear. Different methods of MPPT also described in this paper. In [6], approach for battery charge controller for stand-alone PV system is manifested. Various charge algorithms are discussed along with their terminology. Brief introduction on battery charge performance characteristics are all considered. The studies in [3] and [8]

show that when the PV array is under partially shaded conditions, the array characteristics become more complex with multiple MPPs. Partial shaded condition is defined as the circumstance where one or more of the PV modules in the array received less amount of solar irradiance. In [9], [11], [14], it has been clear that the battery provides the dc link constant voltage to the load and also it prevents high voltage stress problem. From PV panel current and voltage are extracted through current and voltage sensor respectively and given to battery for maintaining constant dc link voltage.

1.3 Motivation

The key motivation is fascinating the scientists more to research in this field of power generation. A key point for encouraging to the use of solar power generation system is, many governments giving centre of attention to their investments in renewable and clean energy sources, because every country has limited sources of conventional energy. Even in India, govt. also aims to achieve generating capability of 20 GW from solar energy by year 2020. and the most bulk part i.e. 40% of it will generate by PV power generation system according to JNNSM (Jawaharlal Nehru National Solar Mission) India. In this method solar panel directly convert the sunlight irradiation into electricity by the photovoltaic effect. It has many advantages like clean and no pollution due to solar power generation as it won't release any greenhouse gases. The reason behind using the specified model is to minimize the reverse effect of temperature and irradiation changes in the PV array. The challenge of the project and the new area of study were the motivations behind the project.

1.4 The System under Consideration

PV system under constant temperature and irradiation

As shown in Fig. 1.1 system consist of a PV module, DC-DC boost converter, MPPT with constant resistive load. Boost converter consist of two switches S1 and S2, an inductor L, two capacitors C1 and C2 and load resistance R. Switches are operate by control logic, develop by MPPT. MATLAB coding is use to make MPPT, its purpose is to track maximum power so that PV module utilizes maximum.

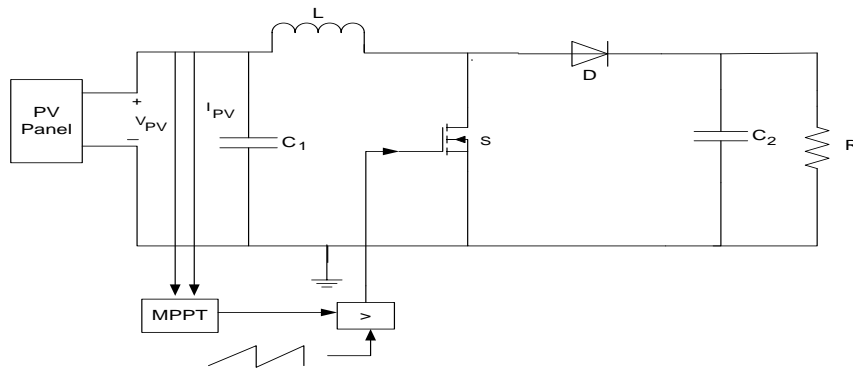


Fig. 1.1 PV modules with boost converter

PV system under constant temperature and varying irradiation

Dynamic atmospheric condition affects the output of PV panel, so output of boost converter also, our purpose is to track maximum power deliver by the module in any atmospheric conditions. Our MPPT should be robust enough to track MPP. System discussed in previous section is for 4 constant atmospheric conditions, same system consider again but for different irradiancies and constant temperature.

PV system under varying temperature and constant irradiation

Temperature is inversely proportional to the voltage, so as the temperature increases voltage decreases, it affects the output power.

PV system under partial shading condition

Fig. 1.2 shows two modules in a array, one module is shaded, because of shaded module P-V and I-V curve changes; we will have one local maxima and other global maxima. How this partial shading condition is affecting the P-V and I-V curves we will discuss in this section.

Fig. 1.3 shows the circuit diagram of partial shaded module.

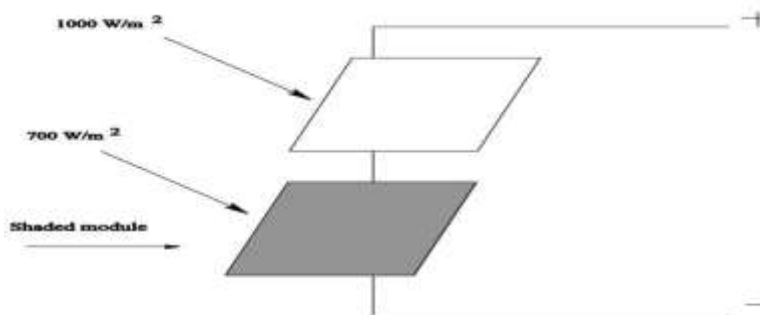


Fig. 1.2 Block diagram of partial shaded module

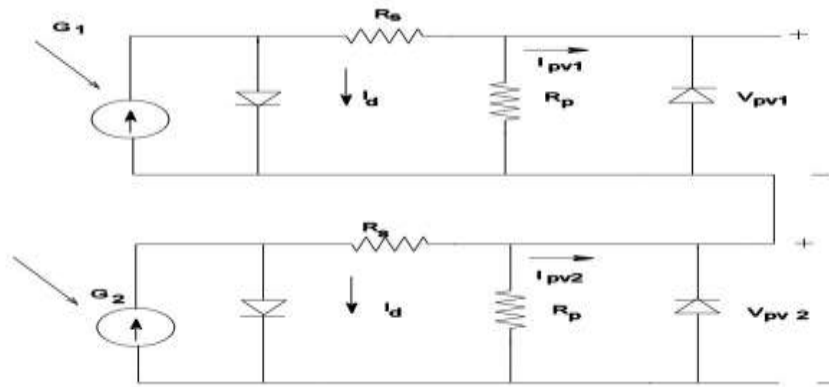


Fig. 1.3 Circuit diagram of partially shaded module connected in series

1.5 Objective

The mainline objective of this project work is to – “Modeling and hardware implementation of a stand-alone Solar PV power generation system for small load rating Up to 5 KW”. And this objective is further divided into following parts for simplicity of implementation.

- To study and model PV cell, PV array and PV panels.
- To study the characteristic curves and effect of variation of environmental conditions like temperature and irradiation on them.
- To study the PV module’s behavior under partial shading condition.
- To trace the maximum power point of operation the PV panel irrespective of the changes in the environmental conditions.
- To design and implementation of a DC-DC (Boost) converter and simulating it in PROTEUS software.
- To design of a battery charging & discharging in MATLAB and its implementation.
- To design and hardware implementation of a single phase solar inverter.

1.6 Thesis Organization

This thesis is organized in 6 chapters as listed below:

Chapter 1 describes an overview on why we have to increase power generation from renewable energy sources. A kin look on advantages of solar PV power generation system. Motivation for this project with mainline objective is divided into subparts.

Chapter 2 illustrates modeling of PV cell with relevant equation. Its dependency on solar

irradiance & temp along with partial shading condition is presented.

Chapter 3 gives basic idea on MPPT and its importance in solar PV power generation. What are the MPPT's requirements are described. Hardware implementation also presented here. It also adds about DC/DC converter especially Boost converter and its need in solar power generation system. A design of Boost converter in Proteus software is shown. Also hardware implementation of boost converter is presented.

Chapter 4 About Battery charging & discharging, its reason for need and its functions are described. A proposed battery charging & discharging is modelled in MATLAB.

Chapter 5 A proposed single phase non sinusoidal inverter for isolated system is designed on Proteus and its hardware is implemented.

Chapter 6 presents conclusion with all the scope for future.

CHAPTER 2

SOLAR PHOTOVOLTAIC ENERGY SYSTEM

2.1 Introduction

2.2 Modeling of Solar PV Array

2.3 Modeling of partial shading phenomena in PV system

2.4 Impact of Solar Irradiation on I-V Characteristic of a Solar Panel

2.5 Impact of Temperature on I-V Characteristic of a Solar Panel

2.6 Simulation Results

2.7 Summary

2.1 Introduction

This chapter deals with the modeling of PV cell. It gives a basic idea on PV cell, module, and array. It explains the theory of PV cell along with the modeling equation. It also considers the effect of partially shading condition, and effect of varying solar irradiation & temperature.

2.2 Modeling of Solar PV array

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device [4]. The Fig. 2.1 manifests the equivalent circuit of PV cell. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as,

$$I = I_{PV} - I_O \left[\exp\left(\frac{V + IR_S}{aV_T}\right) - 1 \right] - \left(\frac{V + IR_S}{R_p}\right) \dots\dots\dots (2.1)$$

Where

I_{PV} —Photocurrent,

I_O —diode's Reverse saturation current,

V —Voltage across the diode,

a — Ideality factor

V_T —Thermal voltage

R_s — Series resistance

R_p —Shunt resistance

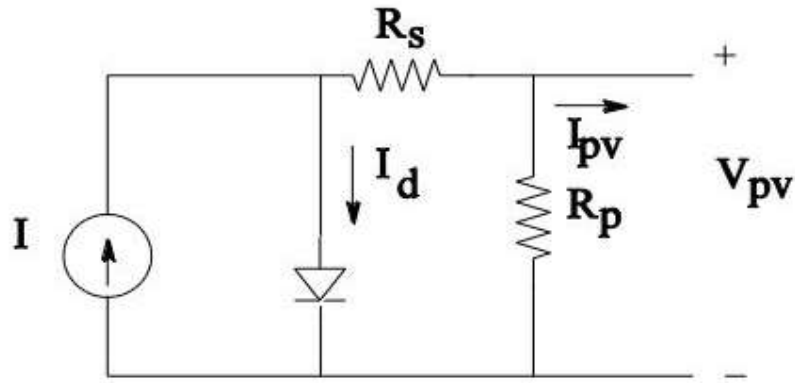


Fig. 2.1 Equivalent circuit of Single diode model of a solar cell

PV cell photocurrent, which depends on the radiation and temperature, can be given as,

$$I_{PV} = (I_{PV_STC} + K_I \Delta T) \frac{G}{G_{STC}} \dots\dots\dots (2.2)$$

Where

K_I – cell’s short circuit current temperature coefficient

G –solar irradiation in W/m^2

G_{STC} –nominal solar irradiation in W/m^2

I_{PV_STC} – Light generated current under STC.

The reverse saturation current varies as a cubic function of temperature, which is expressed as,

$$I_o = I_{o_STC} \left(\frac{T_{STC}}{T} \right)^3 \exp \left[\frac{qE_g}{aK} \left(\frac{1}{T_{STC}} - \frac{1}{T} \right) \right] \dots\dots\dots (2.3)$$

Where

I_{o_STC} – Nominal saturation current

E_g – Energy band gap of semiconductor

T_{STC} –temperature at standard test condition

q – Charge of electrons

The reverse saturation current can be further improved as a function of temperature as follows,

$$I_o = \frac{(I_{SC_STC} + K_I \Delta T)}{\exp\left[\frac{(V_{OC_STC} + K_V \Delta T)}{aV_T}\right] - 1} \dots\dots\dots(2.4)$$

I_{SC_STC} – short circuit current at standard test condition

V_{OC_STC} – short circuit voltage at standard test condition

K_V – temperature coefficient of open circuit voltage,

Many authors proposed more developed models for better accuracy and for different purposes. In some of the models, the effect of the recombination of carriers is represented by an extra diode [2]. Some authors also used three diode models which included influences of some other effects that are not considered in previous models. But due to simplicity we use single diode model for our work.

Efficiency of a PV cell does not depend on the variation in the shunt resistance R_p of the cell but efficiency of a PV cell depends on the variation in series resistance R_s . As R_p of the cell is inversely proportional to the shunt leakage current to ground so it can be assumed to be very large value for a very small leakage current to ground.

As the total power generated by a single PV cell is very low, we used a combination of PV cells to fulfil the desired requirement [5]. This grid of PV cells is known as PV array. The equations of the PV array can be represented as,

$$I = I_{PV} N_p - I_o N_p \left[\exp\left(\frac{V + IR_s \left(\frac{N_s}{N_p}\right)}{aV_T N_s}\right) - 1 \right] - \left(\frac{V + IR_s \left(\frac{N_s}{N_p}\right)}{R_p \left(\frac{N_s}{N_p}\right)} \right) \dots\dots\dots(2.5)$$

N_s – Number of series cells

N_p – Number of parallel cells

A small change in series resistance can affect more on the efficiency of a PV cells but variation in shunt resistance does not affect the parameter. For very small leakage current to

ground, shunt resistance assumed to be infinity and can be treated as open. After considering shunt resistance infinity, the mathematical equation of the model can be expressed as.

$$I = I_{PV}N_P - I_0N_P \left[\exp \left(\frac{V + IR_s \left(\frac{N_s}{N_p} \right)}{aV_T N_s} \right) - 1 \right] \dots\dots\dots (2.6)$$

Module ratings use for simulation

KC200GT SOLAR ARRAY is used here at 25°C , 1000 W/m² for simulation, whose parameter ratings are given below:

Module Ratings

Typical max. power (P_{mp})	200.143 W
Voltage at max. power (V_{mp})	26.3 V
Current at max. power (I_{mp})	7.61 A
Short-circuit Current (I_{sc})	8.21 A
Open-circuit Voltage (V_{oc})	32.9 V
Temp. coefficient of Open-circuit Voltage (K_V)	-0.1230 V/K
Temp. coefficient of short-circuit Current (K_I)	0.0032 A/K
Number of cells in series (N_s)	54

I-V and P-V characteristics of PV module are shown in Fig. 2.2 and 2.3 respectively.

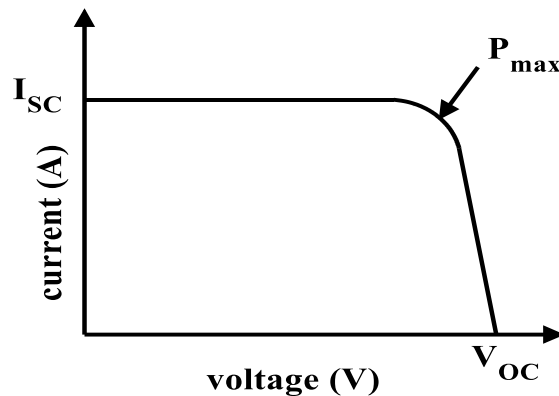


Fig. 2.2 Standard I-V Characteristic of a Solar Panel

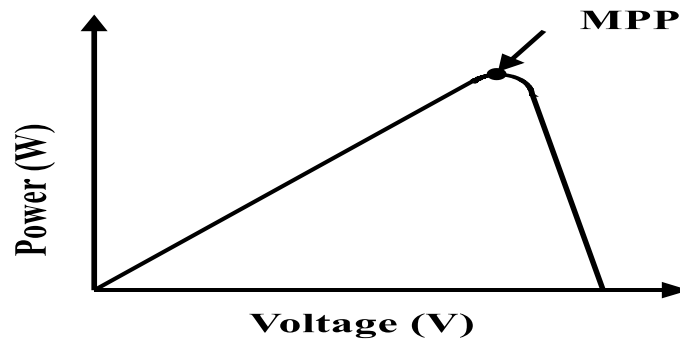


Fig. 2.3 Standard P-V Characteristic of a Solar Panel

The two key parameters which are used to relate the electrical performance are the open-circuit voltage of the cell V_{OC} and short-circuit current of the cell I_{sc} .

The maximum power can be stated as

$$P_{max} = V_{max} I_{max}$$

2.3 Modeling of partial shading phenomena in PV system

When a module or a part of it is shaded it starts generating less voltage or current as compared to un-shaded one. When modules are connected in series manner, same current will flow in entire circuit but shaded portion cannot able to generate same current. But that it has to allow the same current to flow, so shaded portion starts behaving like load and starts consuming power [1]. When shaded portion starts to act as load a problem arise. And that condition is known as hot-spot problem. Without appropriate protection, problem of hot-spot may arise and, in severe cases, the system may get damaged. To reduce the damage in this condition we generally use a bypass diode. Characteristics of PV array in shaded condition are shown in Fig. 2.4.

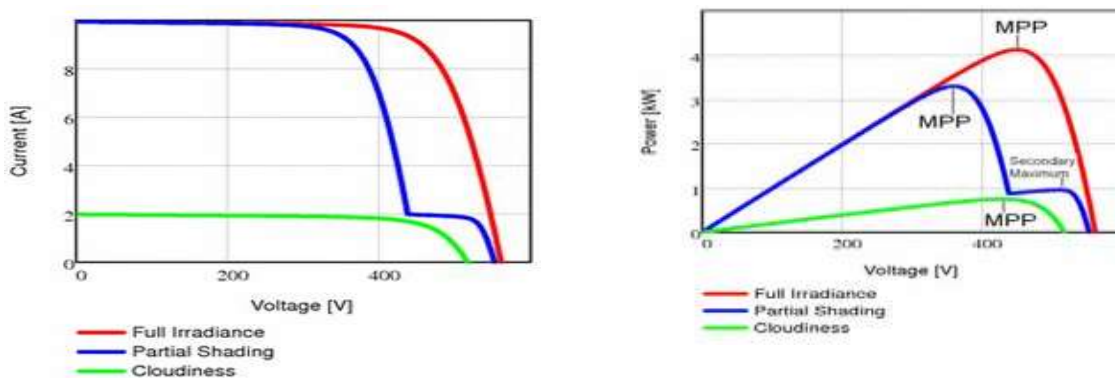


Fig. 2.4 Effect of partial shading on I-V & P-V characteristics

Due to partial shading or total shading PV characteristic become more non-linear, having more than one maximum power point. So for this condition tracking of the maximum power point become very tedious. We can easily see the effect of shading on PV characteristics in the Fig. shown below. There is wastage of power due to the loss contributed by reverse current which results in overheating of shaded cell.

2.4 Impact of Solar Irradiation on I-V Characteristic of a Solar Panel

On this earth ground, highest solar irradiance level is 1000 W/m². This solar irradiance depends on many factors like cloud, earth movement [3]. It decreases due to all these factors. Because of all this factor output current of the solar panel decreases as the output current is directly proportional to the sun irradiance. But variation voltage is much smaller as shown in Fig. 2.5 given below.

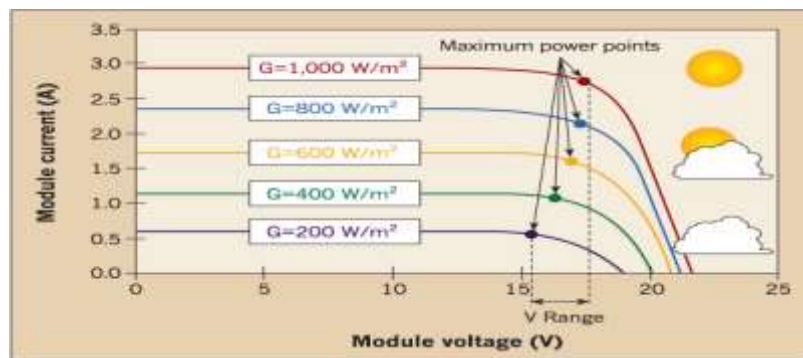


Fig. 2.5 Effect of solar irradiation on I-V curve

2.5 Impact of Temperature on I-V Characteristic of a Solar Panel

Temperature affects the saturation current of solar cell and has small effect on I_{ph} , so V_{oc} has negative (-) temperature coefficient (for silicon -2.3 mV/°C). The Fig. shown below represents the I-V curve for different temperature variation.

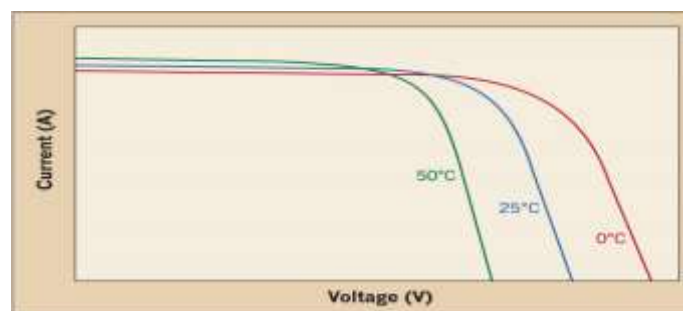


Fig. 2.6 I-V curve for Different Temperatures

2.6 Simulation Results

Fig. 2.7 & 2.8 manifest the I-V & P-V characteristics of a PV module respectively. From Fig. 2.7, it can be observed that short circuit current (I_{sc}) of PV module is around 8.1 A so as that of open circuit voltage (V_{oc}) is 32.9 V. Similarly Fig. 2.8 clearly depicts the maximum power as approximately 200 W & that maximum power occurs at a current of 8.1 A and voltage at 26.3 V.

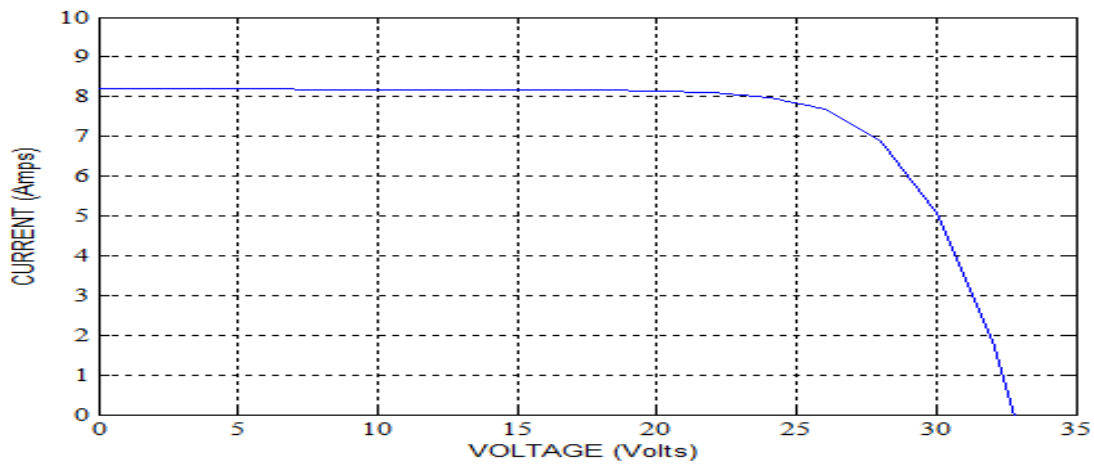


Fig. 2.7 I-V characteristics of PV module

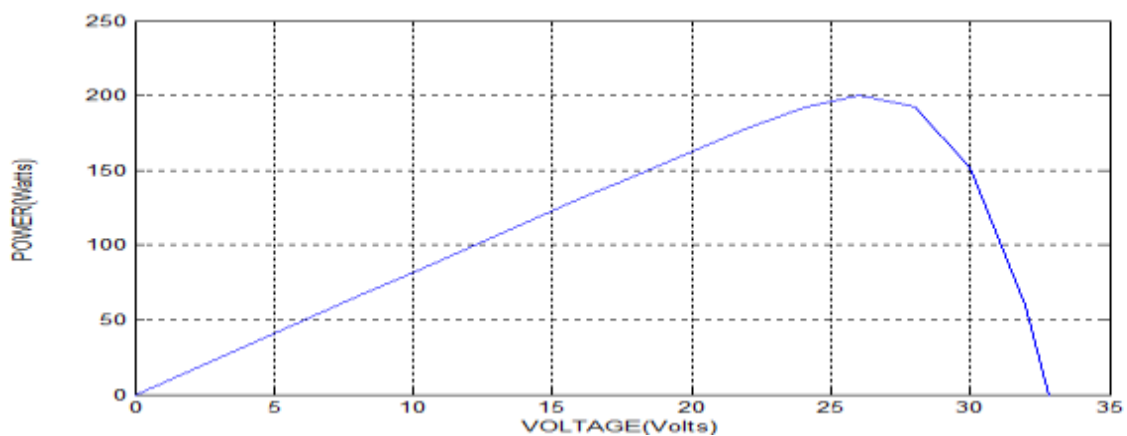


Fig. 2.8 P-V characteristics of PV module

From Fig. 2.9, it can be concluded that as the solar irradiation increased, short circuit current also increased. Variation in solar irradiation commonly affects the current. Hence we can see from the Fig. 2.9, as we increase the value of solar irradiation from 700 W/m^2 to 1000 W/m^2 , accordingly current is increasing from 5.7 A to 8.2 A. But Variation of solar irradiation doesn't affect the voltage. The affect is almost negligible. Fig. 2.10 represents the effect of variation of solar irradiation on P-V characteristics. As with increased solar irradiation, current is increasing, hence it affects power also.

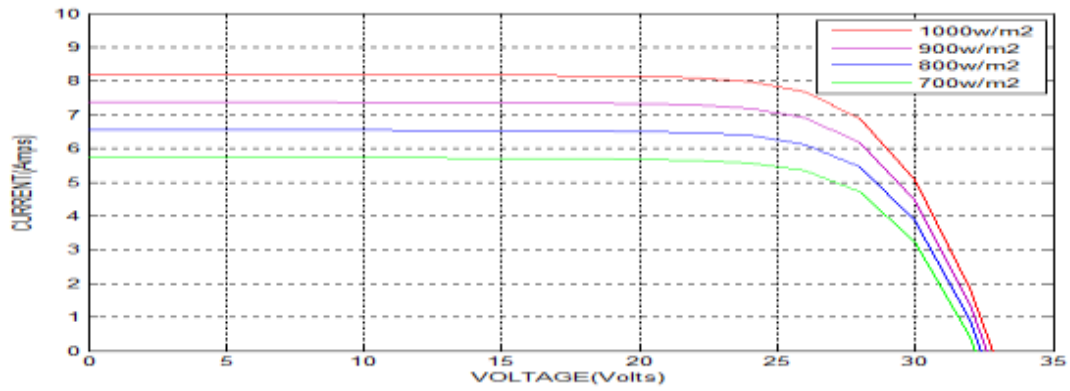


Fig. 2.9 I-V curve at constant temp & varying irradiation

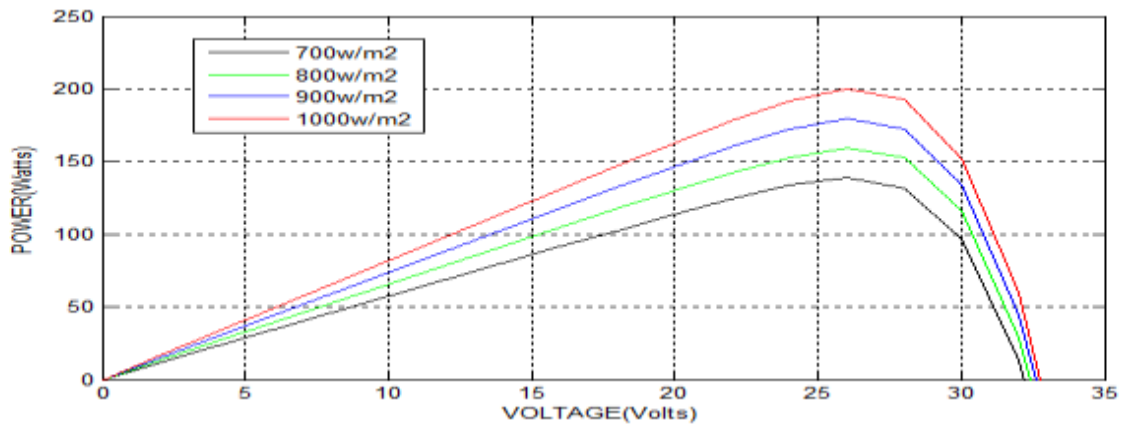


Fig. 2.10 P-V curve at constant temp & varying irradiation

The result of variation of temperature on I-V characteristics is shown in the Fig. 2.11. From the Fig. 2.11, it can be concluded that, the change in temperature alters the voltage but the current remain unaltered. With increase in temp, voltage gradually decreased. Fig. 2.12 depicts the outcome of temperature variation on P-V curve. As temperature increases, power decreases gradually, because increment in temp makes the voltage decrease.

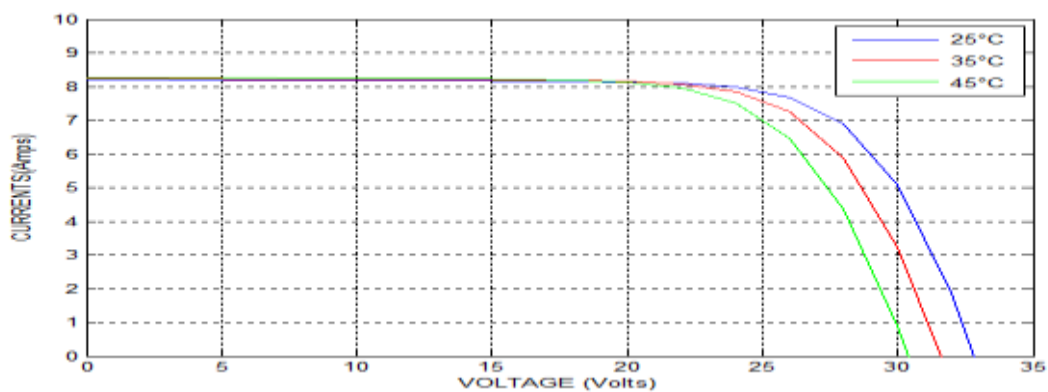


Fig. 2.11 I-V curve at constant irradiation & varying temp

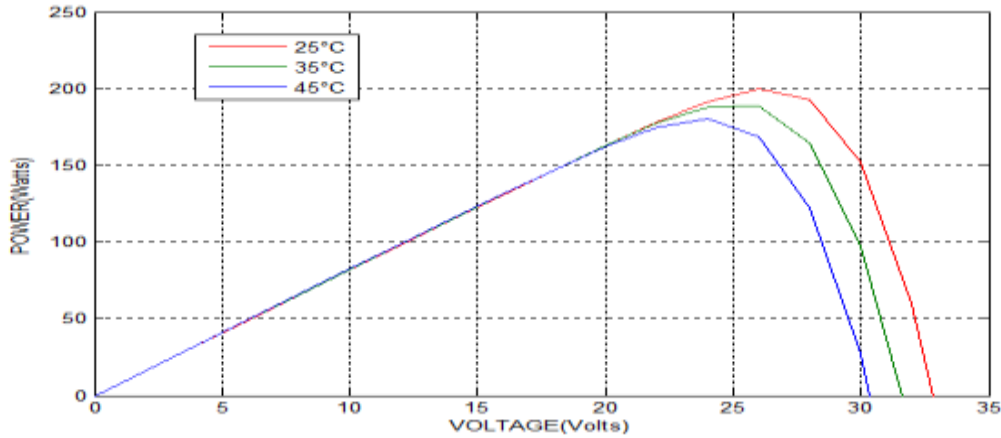


Fig. 2.12 P-V curve at constant irradiation & varying temp

It can be seen the effect of partial shading on I-V, P-V curve of PV module from Fig. 2.13 & 2.14. From the Fig. 2.13, it is clearly seen that the current generated from the shaded portion is less than that of the shaded portion. From Fig. 2.14, it is clearly visible that, partial shading condition yields more than one maximum power peaks.

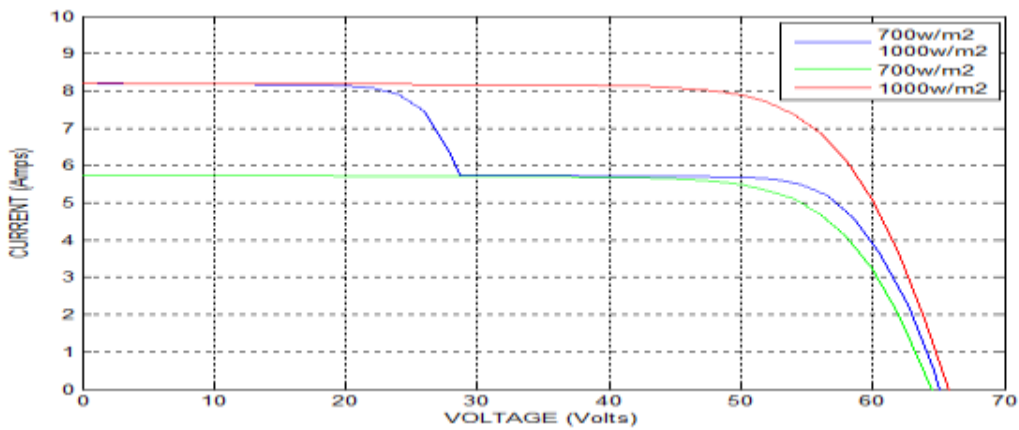


Fig. 2.13 I-V characteristics in partial shading

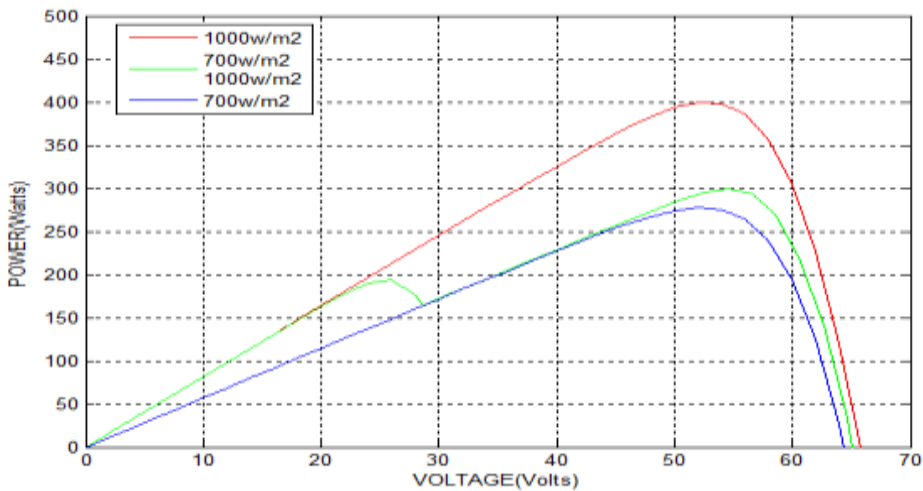


Fig. 2.14 P-V characteristics in partial shading

2.7 Summary

In this chapter a brief introduction on solar PV cell is illustrated. PV cell is successfully modelled along with all the proposed equation. One equivalent single diode PV cell model also considered for good understanding. Many environmental conditions like temperature and irradiation affect the system. So the effect of varying temp on PV module is explained here with P-V and I-V characteristics. Similarly effect of varying solar irradiation on PV module also properly stated. Partially shading effect is also considered here. All the simulated results are stated and verified.

CHAPTER 3

MODELLING OF PV SYSTEM WITH MPPT

- 3.1 Introduction
- 3.2 Overview on Maximum Power Point Tracking
- 3.3 Necessity of Maximum Power Point Tracking
- 3.4 Components required for MPPT
- 3.5 Different Techniques of MPPT
 - 3.5.1 Perturb and observation method
 - 3.5.2 Incremental Conductance method
 - 3.5.3 Parasitic Capacitance method
 - 3.5.4 Constant Voltage method
 - 3.5.5 Constant Current method
- 3.6 Flow Chart of MPPT Algorithm
- 3.7 MPPT Hardware Implementation
- 3.8 Need of DC/DC Converter
- 3.9 Types of DC/DC Converter
- 3.10 Boost Converter Operating Modes
- 3.11 Components Calculations
- 3.12 Hardware Implementation of Boost Converter
- 3.13 Simulation & Hardware Results
- 3.14 Summary

3.1 Introduction

This chapter mainly deals with the MPPT control technique. Need of MPPT for PV system is discussed here. It also gives some introduction on MPPT, its types and process of controlling and tracking the maximum power along with components required for MPPT circuit. It also gives the view on DC–DC converter explaining the types of the converter with circuit diagram along with operational modes of Boost converter [6]. Design of Boost converter on a hardware kit is discussed.

3.2 Overview on Maximum Power Point Tracking

Maximum power point tracking (MPPT) system is an electronic control system that can be able to extract the maximum power from a PV system. It does not involve a single mechanical component that results in the movement of the modules changing their direction and make them face straight towards the sun [8]. MPPT control system is a completely electronic system which can deliver maximum power by varying the operating point (V, I) of the modules electrically.

3.3 Necessity of Maximum Power Point Tracking

In the Power Vs Voltage characteristic of a PV module shown in Fig. it can be observed that there exist single maxima i.e. a maximum power point associated with a specific voltage and current. The overall efficiency of a module is very low. It's around 12%. So it is necessary to operate it at the maximum power point so that the maximum power can be provided to the load irrespective of continuously changing weather conditions. This increased power and makes it better for the use of the solar PV module [9]. A DC/DC converter which is placed next to the PV module gets maximum power by matching the impedance of the circuit to the impedance of the PV module and delivers it to the load. Impedance matching can be done by varying the duty cycle of the switching elements.

3.4 Components required for MPPT:

For implementation of MPPT the following things are required,

- Voltage sensor
- Current sensor
- ARDUINO Kit
- Converter

Voltage sensor

For designing P&O MPPT algorithm as hardware circuit, PV panel voltage is required. So for measuring PV voltage sensor required which can sense the voltage and give back to MPPT. For this purpose Hall Effect bases sensor can be used. However it's not cost effective so to keep cost affectivity in mind, simple voltage sensor can be used instead. Simple voltage division theorem is used here.

So to use this simple voltage sensor two resistances (R_1 & R_2) are connected in series across PV panel and a wire come out from the middle of the two resistors and given back to ADC.

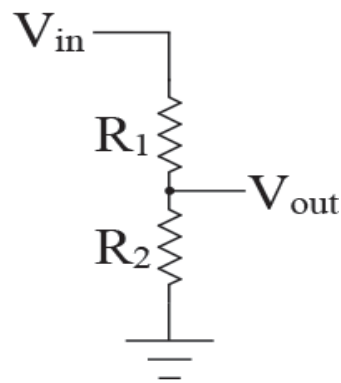


Fig. 3.1 Two resistor connection

One important thing must be kept in mind before doing the connection, R_1 should be greater than R_2 . That must be proportionally reduced with PV voltage and can be read by microcontroller.

Current sensor

Another input is required for MPPT controller circuit. That is PV current. Hence one sensor must be needed for measuring PV current. For this purpose a hall effect based current sensor is used here device named as ACS712.



Fig. 3.2 current sensor

ACS712 current sensor has following listed features,

- Fully integrated linear sensor
- Can sense both AC & DC
- Cheap and compact in size
- Supply voltage is 5V
- Bandwidth is approximately 50 kHz

ARDUINO Kit

For best use ARDUINO complete development board kit has been utilized here. It has on chip ADC and PWM generator.



Fig. 3.3 ARDUINO Kit

3.5 Different Techniques of MPPT

There are many algorithms which help in tracking the maximum power point of the PV module [9]. However widely used methods are as follows:

- a. P&O algorithm.
- b. I&C algorithm.
- c. Parasitic Capacitance method.
- d. Constant Voltage.
- e. Constant Current.

3.5.1 Perturb and observation method

Each and every MPPT algorithm has its own advantages and disadvantages. Perturb and observe (P&O) method is widely used due its simple operation. In this algorithm we introduce a perturbation in the operating voltage of the PV panel. Perturbation in voltage can be done by altering the value of duty-cycle of dc-dc converter.

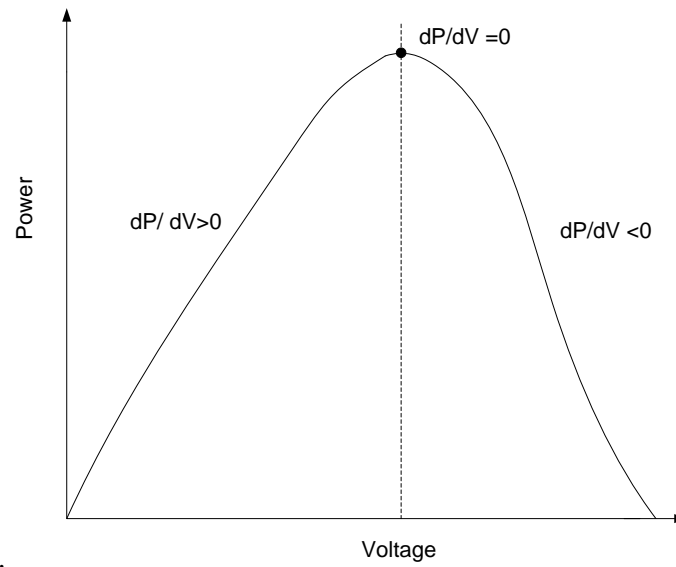


Fig. 3.4 P-V characteristics (basic idea of P&O algorithm)

$$\frac{dP}{dV} > 0 \text{ left side of the curve}$$

$$\frac{dP}{dV} < 0 \text{ right side of the curve}$$

$$\frac{dP}{dV} = 0 \text{ peak of the curve}$$

Fig. 3.4 shows the P-V characteristics of a photovoltaic system, by analysing the P-V characteristics it can be seen that on right side of Maximum Power Point as the voltage decreases the power increases but on left side of Maximum power point increasing voltage will increase power. This is the main idea we have used in the P&O algorithm to track the Maximum power point.

3.5.2 Incremental Conductance method

Basic of INC method comes from P&O algorithm. In P-V curve as shown in Fig. 6.1, slope is positive, negative and zero in left, right and peak point respectively.

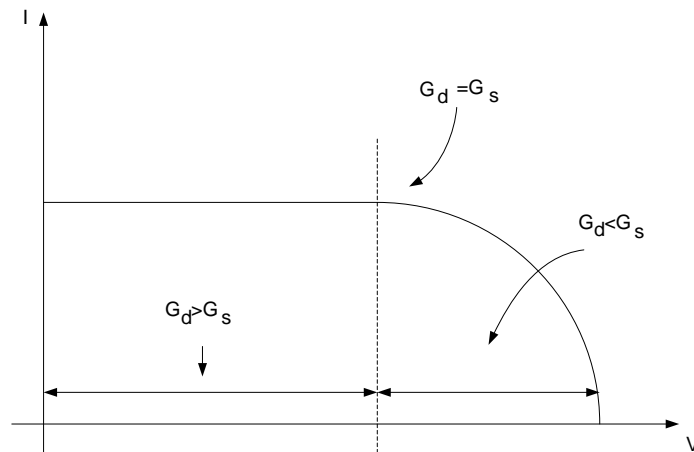


Fig. 3.5 I-V characteristics (basic idea of INC algorithm)

At maximum power point $\frac{dP}{dV} = 0$

Since $P=VI$

$$\text{So } \frac{dI}{dV} = -\frac{I}{V}$$

Here $G_d = \frac{dI}{dV}$ =dynamic (incremental) conductance

$$G_s = -\frac{I}{V} = \text{Static conductance}$$

So

$$\frac{dI}{dV} > -\frac{I}{V} \text{ left side of the curve}$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ right side of the curve}$$

$$\frac{dI}{dV} = -\frac{I}{V} \text{ peak of the curve}$$

According to above expression algorithm is implemented for MPPT, instead of P-V curve, I-V curve is used for Incremental & Conductance method.

3.5.3 Parasitic Capacitance Method

This method is improved version of incremental conductance method. Here one parasitic capacitor is included into the voltage calculation.

3.5.4 Constant Voltage Method

This method is not so much used because, the losses during the operation depends on the relation between the open circuital voltage and the voltage at which maximum power occur. The ratio of these two voltages is mainly constant for a PV cell around 0.76.

3.5.5 Constant Current Method

Like the constant voltage method, this method also depends on the relation between the open circuit current and current at which maximum power occurs. The ratio of these mentioned two currents is basically constant for a PV cell, i.e. approximately 0.95. Thus the short circuit current is obtained experimentally and the operating current is adjusted to 95% of this value.

The Choice is to be made according to the need of algorithm and operating conditions. If the required algorithm is very simple and not much effort is given on the reduction of the voltage ripple, then P&O method is suitable. But if the fluctuation decides the maximum power point is to be reduced than INC method is applicable, but it makes the operation complex and more costly.

Here in my project, P&O method is adopted; hence the flowchart for the above-mentioned method is illustrated below.

3.6 Flow Chart of MPPT Algorithms

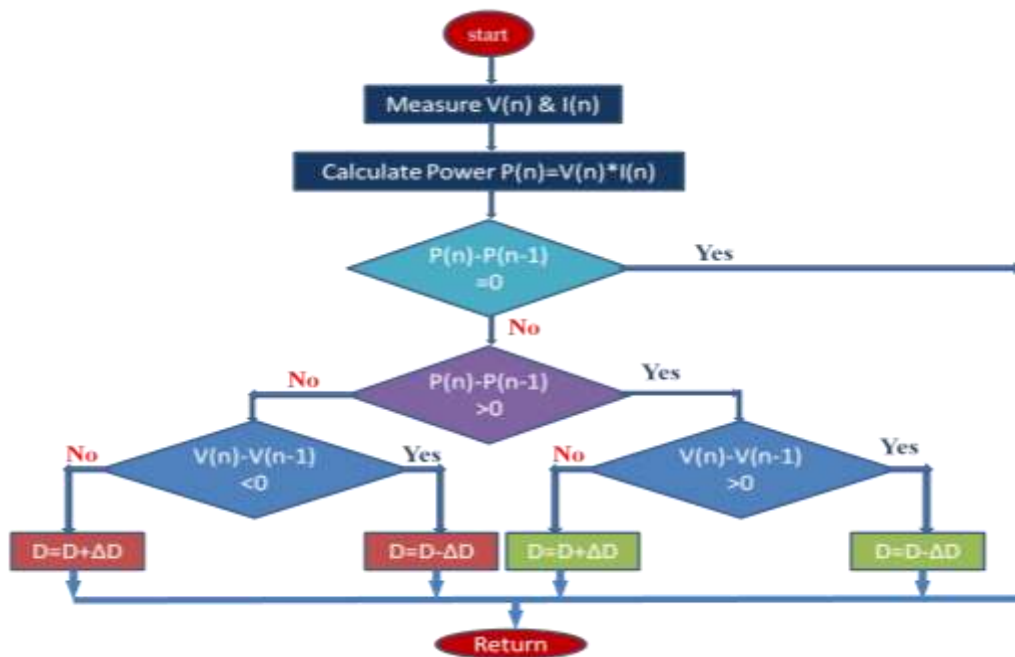


Fig. 3.6 Flow chart for P&O method

3.7 MPPT Hardware Implementation

Fig. 3.7 shows the hardware circuit representation of PV system with MPPT controller circuit. Mainly MPPT circuit trace the maximum operating point where maximum power comes accordingly converter output varies. Here PV panel connected through current sensor to ARDUINO kit [14].

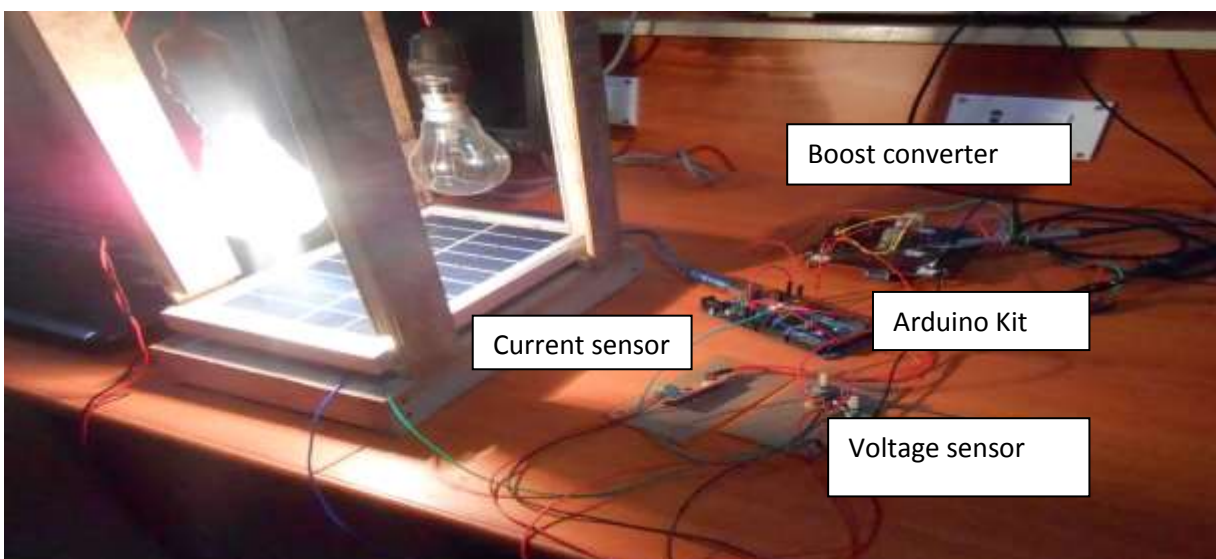


Fig. 3.7 Hardware Circuit arrangement for MPPT

3.8 Need of DC/DC converter

A DC/DC converter is an integral part of any MPPT circuit system. No MPPT circuit can be designed without dc/dc converter.

When a direct connection is carried out between the source and the load, the output of the PV module is irregularly shifted away from the maximum power point. It is necessary to overcome this problem, so I have added one adaptation circuit between the source and the load. And a MPPT controller circuit with a DC-DC converter circuit is used as an adaptive circuit.

3.9 Types of DC-DC converter

DC-DC converter is an electrical circuit whose main function is to transform a dc voltage from one level to another level. It is similar to a transformer in AC source, it can able to step the voltage level up or down whenever required. The variable dc voltage level can be regulated by controlling the duty ratio (on-off time of a switch) of the converters.

There are various kinds of dc-dc converters that can be used to transform the level of the voltage as per the supply availability and load requirement. Some of them are discussed below.

1. Buck Converter
2. Boost Converter
3. Buck-Boost Converter

3.9.1 Buck converter

The functionality of a buck converter is to step down the voltage level. The circuit diagram of the buck converter is manifested in Fig. 3.8.

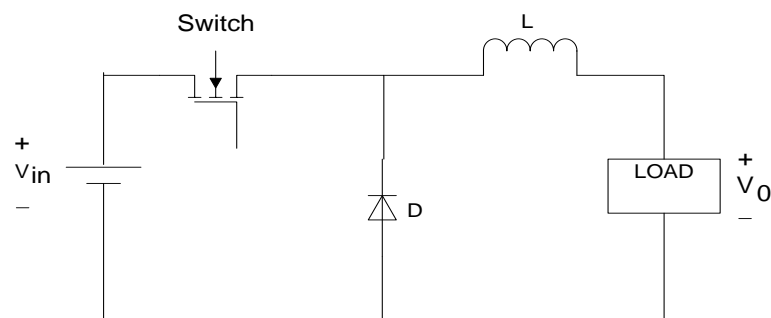


Fig. 3.8 circuit diagram of buck converter

When the switching element is in state of conduction the voltage appearing across the load is V_{in} and the current is supplied from source to the load. When the switch is off, the load voltage becomes zero and the direction of current remains the same. As the power flows from source side to load side, the load side voltage becomes less than the source side voltage. The output voltage is determined as a function of source voltage using the duty ratio of the gate pulse supplied to the switch. It is the product of the duty ratio and the input voltage.

3.9.2 Boost converter

The functionality of boost converter is step up the voltage level. The circuit configuration of the boost converter is manifested in Fig. 3.9.

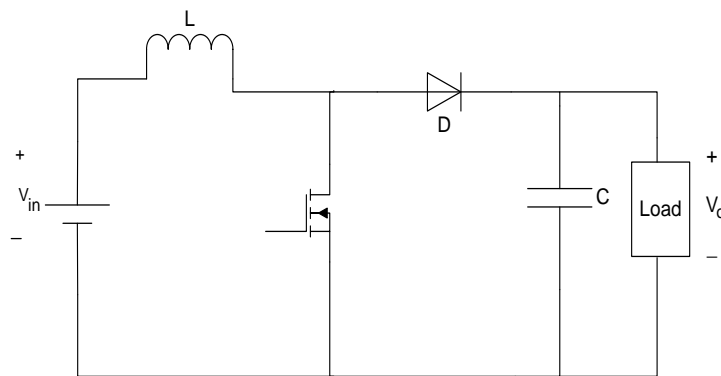


Fig. 3.9 circuit diagram of boost converter

The current carried by the inductor starts rising and it stores energy during ON time of the switching. The circuit is said to be in charging state. During OFF condition, the reserve energy of the inductor starts dissipating to the load along with the supply. The output voltage level exceeds that of the input voltage and is dependent on the time constant. The load side voltage is the ratio of source side voltage and the duty ratio of the switching device.

3.9.3 Buck-Boost converter

The functionality of a buck-boost converter is to set the level of load side voltage to either greater than or less than that of the source side voltage level. The circuit configuration of the buck-boost converter is manifested in Fig. 3.10.

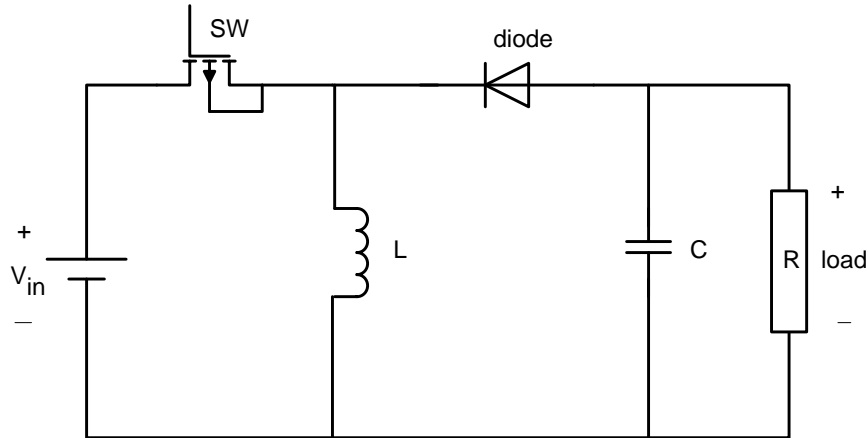


Fig. 3.10 circuit diagram of buck-boost converter

When the switches are in the state of conduction, the current carried by the inductor starts rising and it stores energy in it. The circuit is said to be in charging state. While the switches are in the OFF state, this stored energy of the inductor is dissipated into the load through the diodes. The output voltage can be varied based on the On-time of the switch.

3.10 Boost Converter Operating Modes

Boost converter have two operating modes based on "ON" and "OFF" condition of switching device [24].

Mode1 when MOSFET is "ON".

Mode2 when MOSFET is "OFF".

Mode 1

This mode is also known as charging mode. In this mode when MOSFET is on inductor is energized and start storing the energy from source during on time (t_1) of MOSFET. This time period diode restricts the current flow through it from the source to the load and capacitor is discharging by the load.

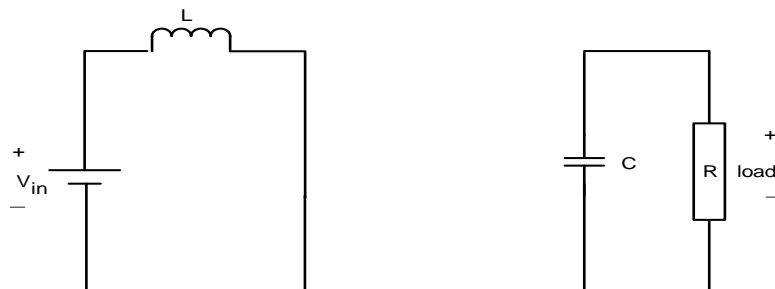


Fig. 3.11 circuit diagram at ON state

Assuming the inductor current is linearly rises between i_1 to i_2 then
 Applying input side KVL,

$$V_{in} - V_L = 0$$

$$V_{Lon} = V_{in} \dots\dots\dots(1)$$

Mode 2

This mode is also known as discharging mode. In this mode when MOSFET is “OFF” and diode is forward bias due to nature of inductor to oppose its cause. In this mode inductor support the source voltage. The circuit becomes,

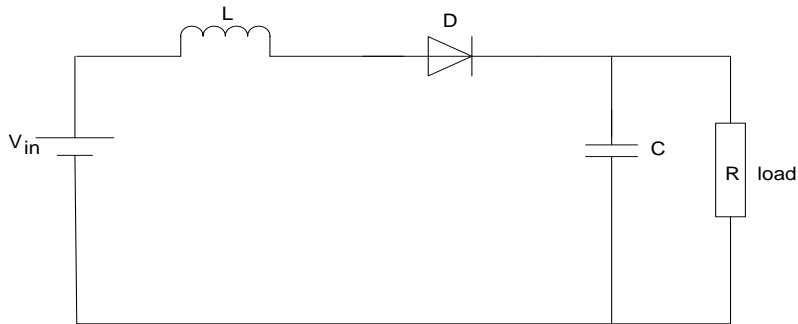


Fig. 3.12 Circuit diagram at OFF state

Applying KVL to the above circuit, the expression will be,

$$V_{in} - V_L - V_0 = 0$$

$$V_{Loff} = V_{in} - V_0 \dots\dots\dots(2)$$

By inductor volt second balance,

$$V_{Lon}DT + V_{Loff}(1 - D)T = 0 \dots\dots\dots(3)$$

Putting eq. (1) and (2), in eq. (3)

$$V_{in}DT + (V_{in} - V_0) (1-D)T = 0$$

By solving the above equation we get,

$$V_0 = \frac{V_{in}}{1 - D}$$

We know, $L \frac{di_L}{dt} = V_{in}$

$$\text{So } \Delta i_L = \frac{V_{in}}{L} DT$$

$$\Delta i_L = \frac{V_0(1-D)}{L}DT$$

When $D=0.5$ we will get maximum ripple value.

$$\text{Hence } L = \frac{V_0(1-D)}{\Delta i_L}DT$$

By using the above formula we can design the L.

We know,

$$\Delta q = I_0DT$$

$$C\Delta V = I_0DT$$

$$\Delta V = \frac{I_0DT}{C}$$

Hence

$$C = \frac{I_0DT}{\Delta V}$$

3.11 Calculations of value of Load Resistance, Inductor, Capacitor & Duty ratio

- **Load Resistance (R_L)**

$$R_L = \frac{V_0}{I_0}$$

Let us assume I_0 to be 0.2A

$$R_L = \frac{24V}{0.2A} = 120\Omega$$

- **Duty Cycle (D)**

$$D = 1 - \frac{V_{in}}{V_0}$$

$$= 0.5$$

- **Capacitor (C)**

$$\Delta V = ESR \left(\frac{I_0}{1-D} + \frac{\Delta I_{Lnew}}{2} \right) = 2.622 \times 10^{-3}V$$

$$C = \frac{I_0 \times D}{f_s \times \Delta V}$$

$$= \frac{0.2 \times 0.5}{50 \times 4.222}$$

$$C = 4.73 \times 10^{-4}F$$

- **Inductor (L)**

$$L = \frac{V_0(1 - D)}{\Delta i_L} DT$$

Ripple current $\Delta i_L = 10\%$ of I_0

$$L = 2.3 \text{ mH}$$

3.12 Design of Boost Converter on Proteus

Proteus design of Boost converter is shown in Fig. 3.13 and also Corresponding component values are shown.

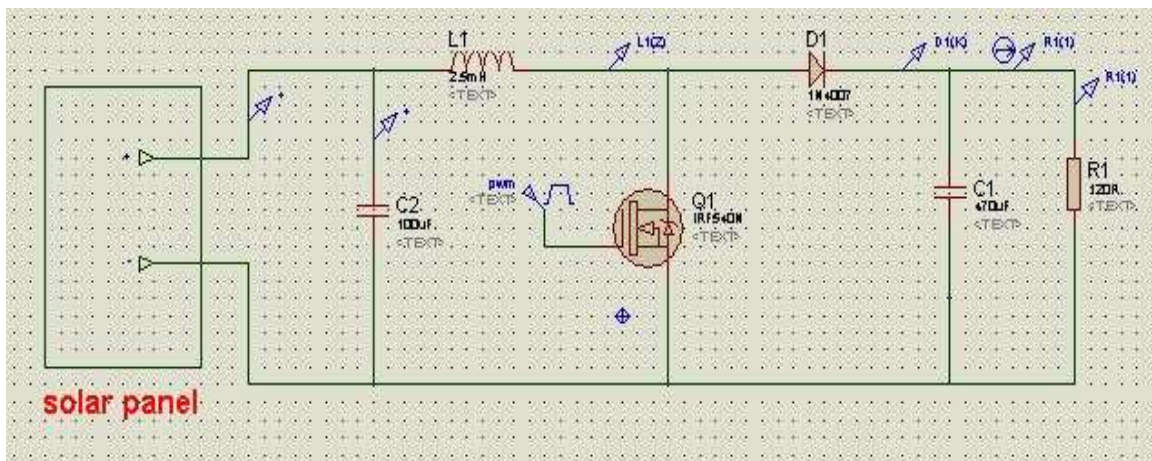


Fig. 3.13 Circuit Design of boost converter on Proteus.

3.13 Hardware Implementation of Boost Converter

According to Proteus design, Boost converter is implemented by taking corresponding values of its elements [13]. Fig. 3.14 shows the photo of hardware of boost converter.

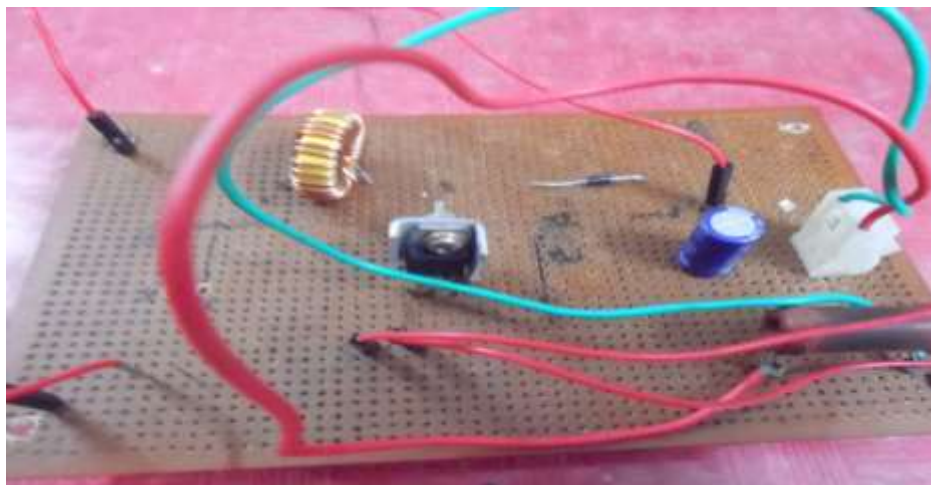


Fig. 3.14 Hardware implementation of Boost circuit

3.14 Simulation and Hardware Results

Fig. 3.15 & 3.16 show the result of PV module after MPPT. From Fig. 3.15, it can be seen that, maximum power achieved at voltage 26.3 V. As it can be observed from Fig. 3.16, maximum power is achieved at voltage 26.3 V; the maximum power is 200.13 W.

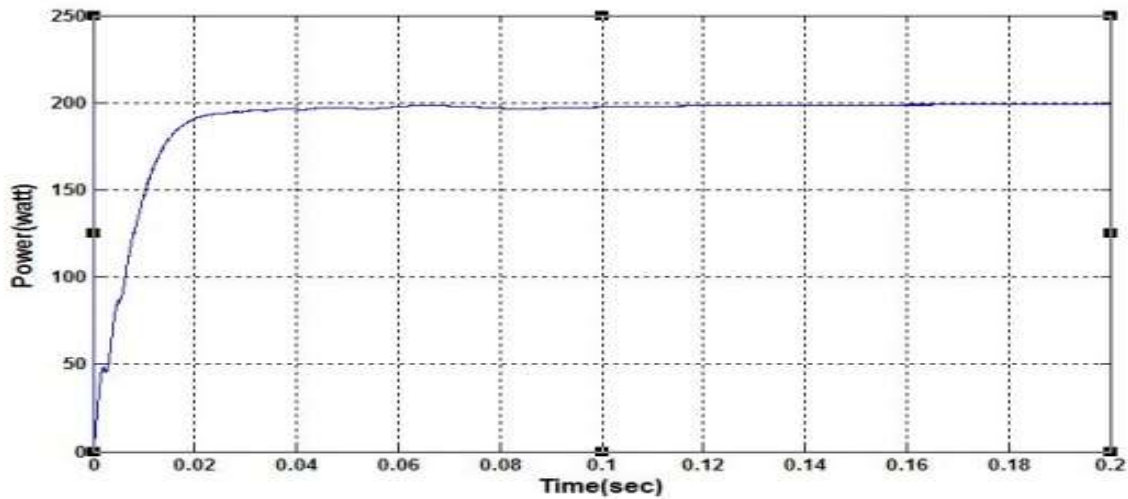


Fig. 3.15 Output Power of PV module

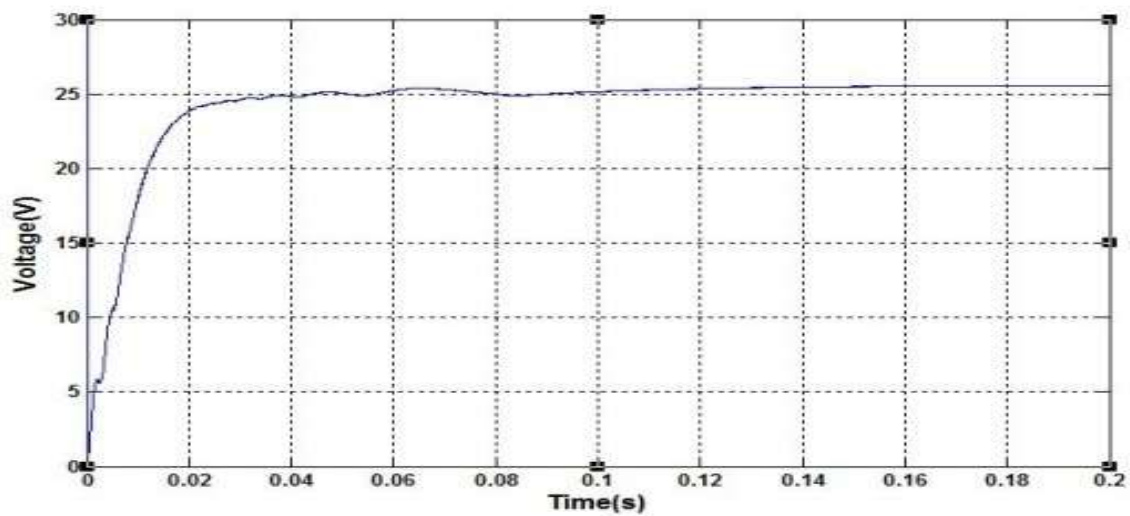


Fig. 3.16 Output Voltage of PV module

In Fig. 3.17 panel (ALEKO 20 watt solar panel) output voltage and current is showing after MPPT circuit is connected to PV panel through a current sensor ACS712, ARDUINO Kit and voltage sensor. After MPPT panel output voltage is fixed to 17.1 V approximately which is V_{mp} of the panel and 1.3 A which is I_{mp} of the panel.

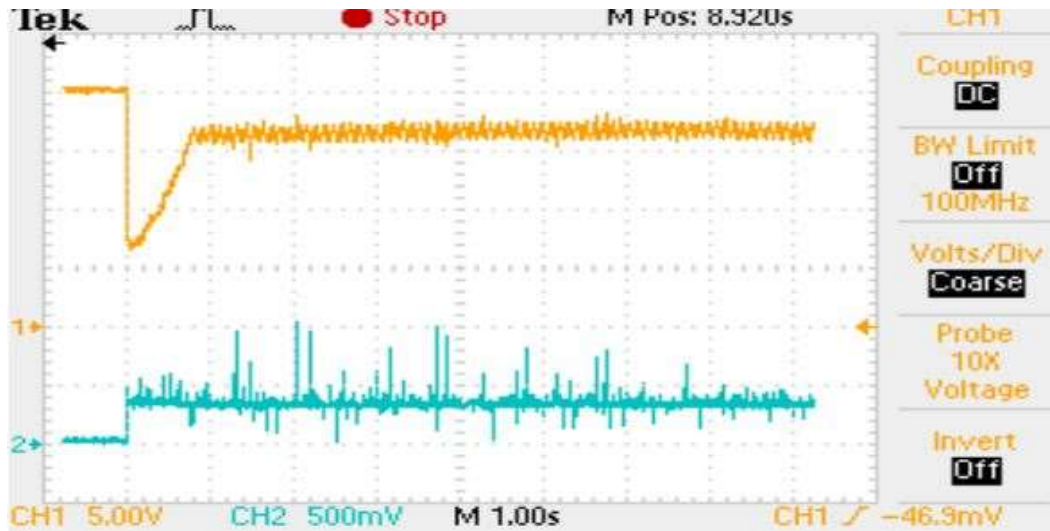


Fig. 3.17 Output Voltage & current of PV module after MPPT

The Fig. 3.18 shows the result of hardware kit of boost converter. The blue colour waveform depicts the output voltage waveform of boost converter and red colour waveform depicts the different duty cycle coming from ARDUINO Kit.

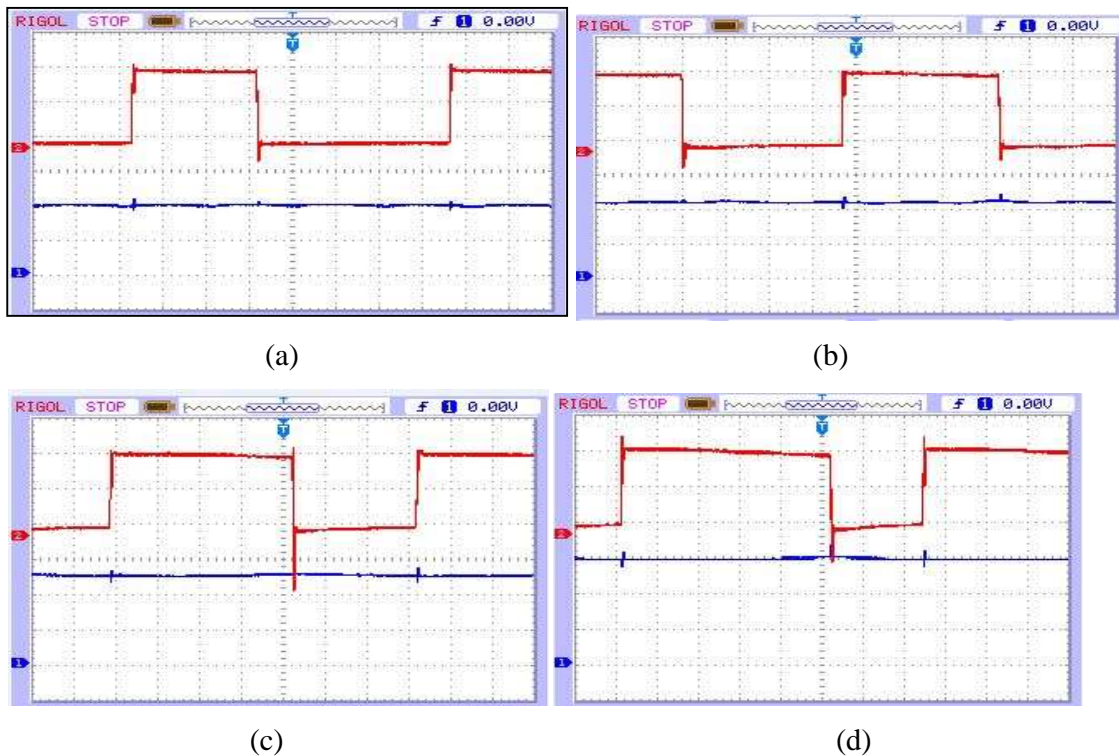


Fig. 3.18 (a), (b), (c), (d) represents Output waveform at 40%, 50%, 55%, 60% Duty Cycle respectively.

3.15 Summary

In this chapter Maximum Power Point Tracking technique is explained. Basically the I-V and P-V characteristics obtained from PV module are nonlinear. Hence we can't do further operation with fluctuating parameter. So as the solution to this problem MPPT controller circuit used here. Types of MPPTs with brief descriptions are illustrated. P & O method is used here for its cost effectiveness. The flow diagram of P & O is manifested showing the working principle. Need of Boost converter for PV module is depicted here. Hardware implementation of MPPT and Boost converter are discussed here. All simulated and hardware results are taken and varied.

CHAPTER 4

BATTERY CHARGING/DISCHARGING

- 4.1 Introduction
- 4.2 Overview on Battery Charging/ Discharging
- 4.3 Bi-Directional DC-DC Converters
- 4.4 Types of Bi-Directional DC-DC Converters
- 4.5 Bi-Directional Converters for Battery Charging
- 4.6 Simulation Results
- 4.7 Summary

4.1 Introduction

This chapter mainly deals with solar battery charge controller. It gives an overview on battery charging technique. It explains the bidirectional dc-dc converter used for battery charging. Hence it presents all the simulated results.

4.2 Overview on Battery Charging

Generally battery is used as storage medium that can store the excess power generated from the system and supply it back when extra power required. PV energy system is connected to the DC supply [16]. However the power flow associated to battery is not unidirectional, hence bidirectional converters required to charge and discharge the battery in case of excess and shortage of power respectively [19].

4.3 Bi-Directional DC-DC Converter

Based on the converter's capability to allow flow of power in both the direction depending up on the need, the name is bidirectional converter. There are many applications of this type of converters like;

- Hybrid Vehicle
- Uninterruptable Power Supply (UPS)
- Storage system powered by fuel cell
- Renewable energy system

4.4 Types of Bi-Directional DC-DC Converter

Based on connection between input and output side, the bidirectional converters are divided into two types. They are,

- Non Isolated type
- Isolated type

4.4.1 Non Isolated type

This type of converter mainly derived from unidirectional converters. However they use bidirectional switches. Buck & Boost Converter do not allow bidirectional power flow as the diode connected in the circuit is a unidirectional device. Hence to avoid this type of problem, MOSFET or IGBT with anti-parallel diode are used. There bidirectional power flow is possible.

The several non-isolated type bidirectional dc-dc converter are listed below.

- Multilevel converter
- Cuk converter
- Sepic converter
- Buck-Boost converter

4.4.2 Isolated type

This type of converter can operate in wide range of power application. The isolation is ensured by using power transformer in the circuit. However transformer works at AC supply only. Because of the AC supply circuit become too complex.

Based on the configuration it can be categorized into two parts. They are,

- A current fed isolated bidirectional DC-DC converter
- A voltage fed isolated bidirectional DC-DC converter

The several isolated types bidirectional converters are listed below.

- Fly-back converter
- Forward fly back converter
- Half bridge converter
- Full bridge converter

4.5 Bi-Directional Converter for Battery Charging

As discussed earlier this type of converters are used for charging and discharging the battery based on surplus and deficit of power respectively [16].

When there is extra power generated from the system, supply becomes greater than the demand. Hence battery is battery allowing the converter to operate in forward direction.

When there is shortage of power, demand becomes greater than the supply. Hence the battery starts discharging supplying the shortage power to the load [17]. This requires the converter to operate in reverse direction.

Charging and discharging of battery is done by the bidirectional converter.

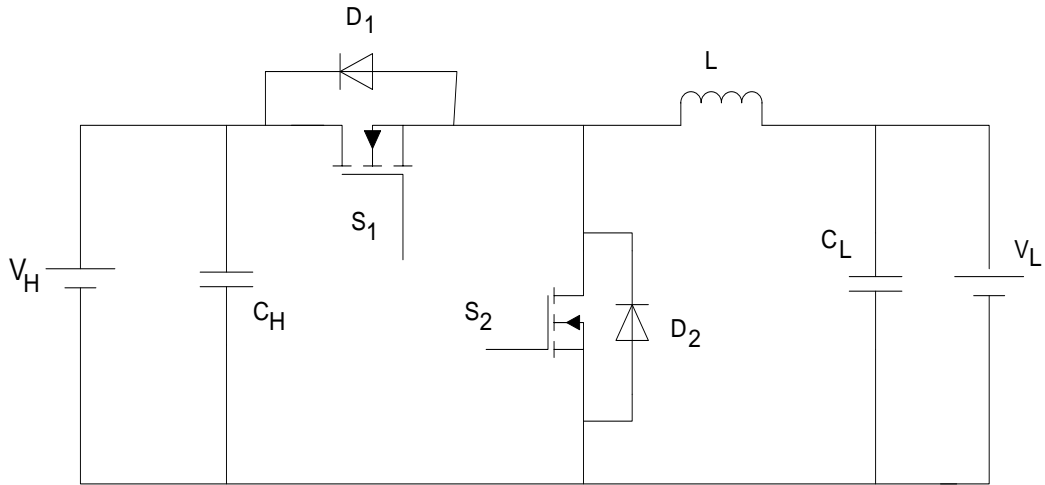
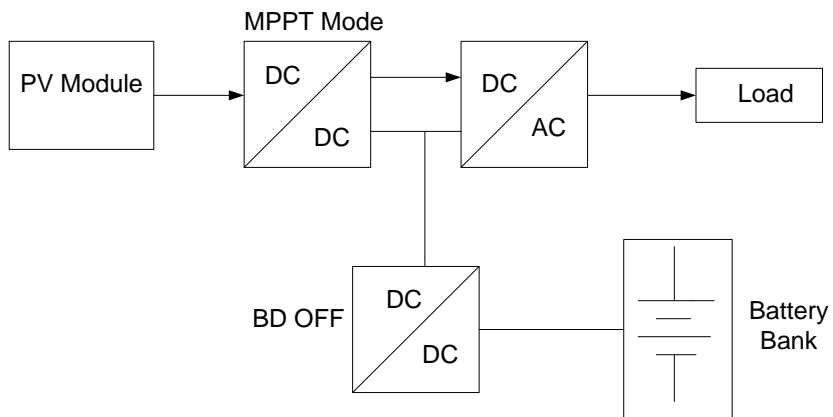


Fig. 4.1 Circuit diagram of the bidirectional converter

Operation Modes

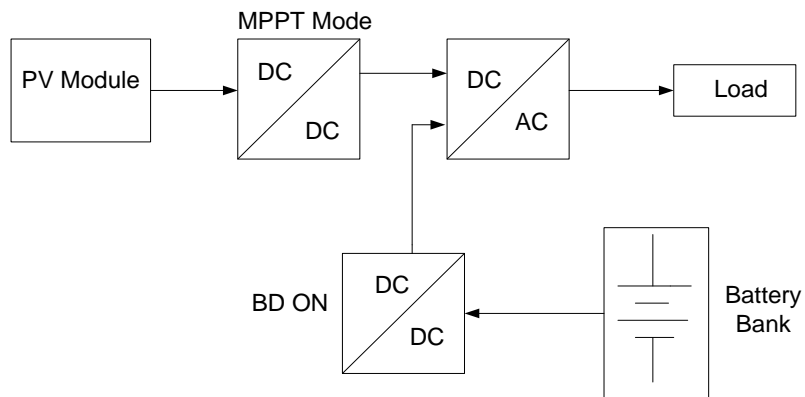
It has four modes of operation based upon the charging and discharging condition of battery.

Mode-1



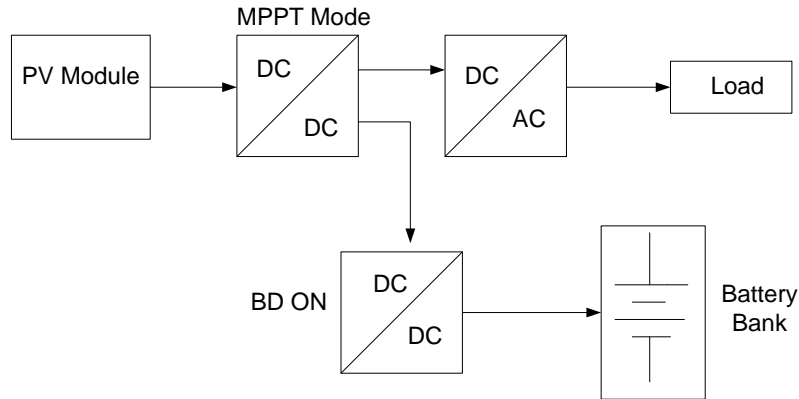
In this mode, power generated by the PV module is equal to the power demand by the load. Hence bi-directional converter doesn't operate.

Mode-2



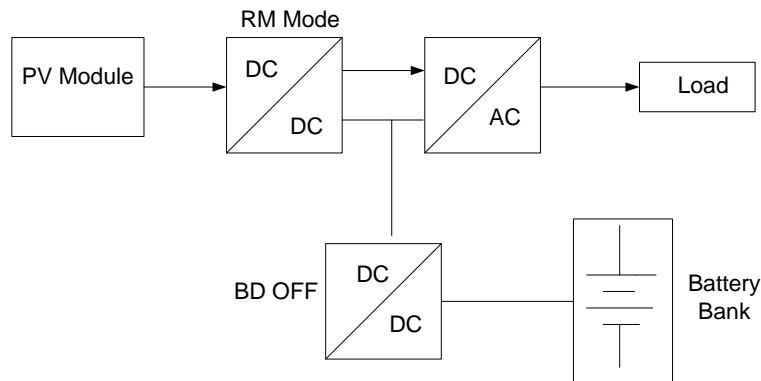
In this mode of operation the power generated from PV Module is lower than the power demand by the load. Hence the bi-directional converter discharges (boost mode), regulating the dc bus at the specified level.

Mode-3



In this mode, the power generated by the PV module is greater than the power demand by the load. Hence bi-directional converter charges the battery bank (buck mode).

Mode-4



In this mode of operation the power generated by the PV module is greater than the power demand by the load. Therefore, the DC-DC input converter turns-off the MPPT mode and sets the regulation mode (RM). Hence the power generated is equal to the power demand by the load.

4.6 Simulation Results

In Fig. 4.2 Voltage & Current vs. time represented. It clearly shows the waveform for charging of battery. From Fig. 4.2 it can be observed that during charging state of charge (SOC) of the battery is gradually increasing and also during charging current is negative. It can be observed that at 40% SOC battery voltage is around 26 V, as state of charge of battery is increased battery voltage exceeded its nominal voltage.

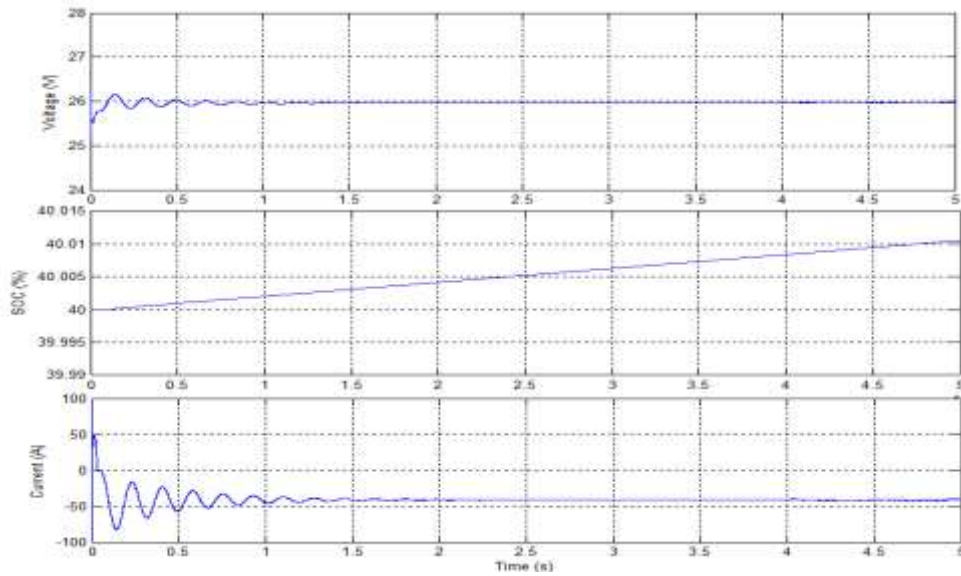


Fig. 4.2 charging characteristics of battery

As it can be seen from Fig. 4.3, during discharging state of charge (SOC) of the battery is gradually decreasing and also during discharging, current become positive which indicate that battery supplying power to the load & voltage remain constant.

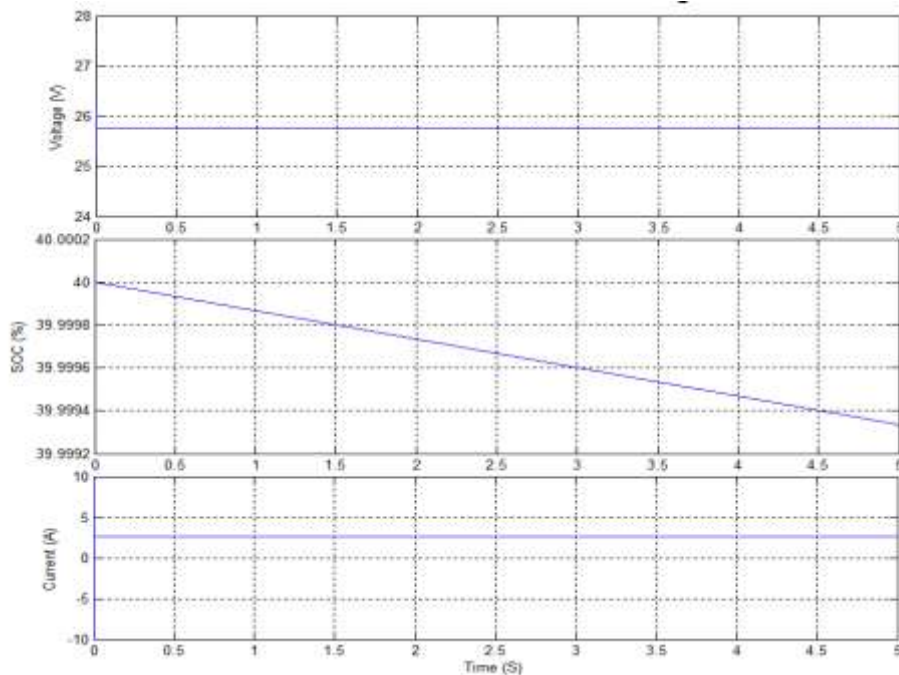


Fig. 4.3 discharging characteristics of battery

4.7 Summary

In this chapter solar battery charging/discharging is described. Techniques of battery charge control also presented with benefits of PWM type. Process is explained using flow chart and hardware design is illustrated. All the simulated results are presented and varied.

CHAPTER 5

1- Φ INVERTER FOR PROPOSED SYSTEM

- 5.1 Introduction
- 5.2 Overview on 1 Φ Inverter
- 5.3 Types of Inverter
- 5.4 Proteus Design of Proposed 1 Φ Inverter
- 5.5 Hardware Implementation of 1 Φ Inverter
- 5.6 Simulation and Hardware Results
- 5.7 Summary

5.1 Introduction

This chapter illustrates the basic idea on single phase inverter. Its need for the PV system is discussed. Types of inverter with proposed circuit diagram and hardware implementation are all described here.

5.2 Overview on 1 Φ Inverter

One of the most important sections in solar power generation system is converting generated DC power to AC power for running or operating or working of the AC loads. A device called Inverter is used here which converts DC power to AC power.

In this earth more than 90% electric equipment are driven by AC, we called it as AC loads. So for using them we must require AC power even for small to very small load, AC power is required either it is grid connected system or isolated system [24]. If we want in isolated system many loads should be DC load for that we have to specially order to the manufacturing company that will increase our expenditure then it is better to purchase AC electric equipment from market that will reduce much more our cost for electric appliances. So when loads are AC then AC power must require and for that we have to convert solar dc power to AC power that's why an inverter is an important part of solar generation system.

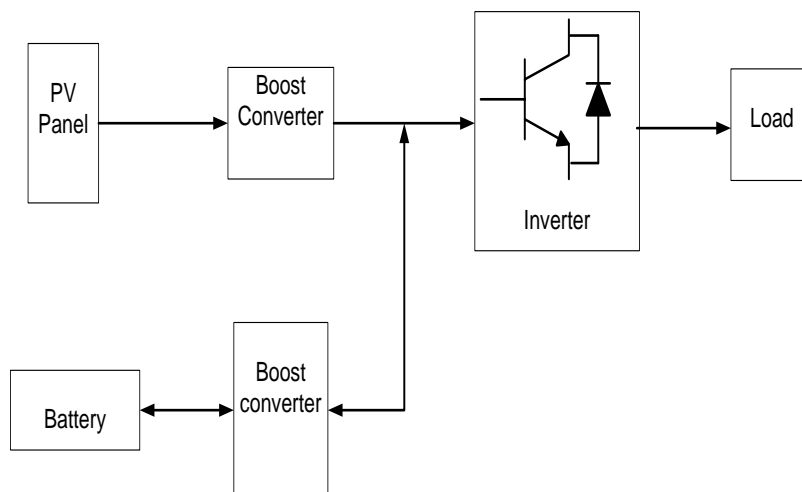


Fig. 5.1 Inverter Position and importance

5.3 Types of Inverter:-

According to the usability the inverter can be divided into two categories-

- **Isolated or stand-alone inverter-** This type of inverter generally takes only DC power from the source like battery or solar panel and converts that power into AC power and give back to the AC load.
- **Grid connected inverter-** This type of inverter sometimes take energy from DC power supply and convert back into AC power and supply to the load. And sometimes it takes energy from grid and charge the battery when DC source is not available.

In this project a very simple compact in size single phase inverter is designed [25]. Because it is cost effective and the system makes it easy in behaviour to use renewable energy sources.

5.4 Proteus Design of Proposed 1 Φ Inverter

Fig. 5.2 showing the Proteus design of simple solar inverter using microcontroller PIC 16F328A for generating square wave with time period of .002 second that is 50Hz in frequency to switching Transistor. In that circuit two NPN Transistor is used for sequentially switching to provide the path for DC current flows through the transformer. Transformer rating is 230/ 2x12 V; the secondary of the transformer is two winding 12 volts each. Transformer is must chose according to load ratings.

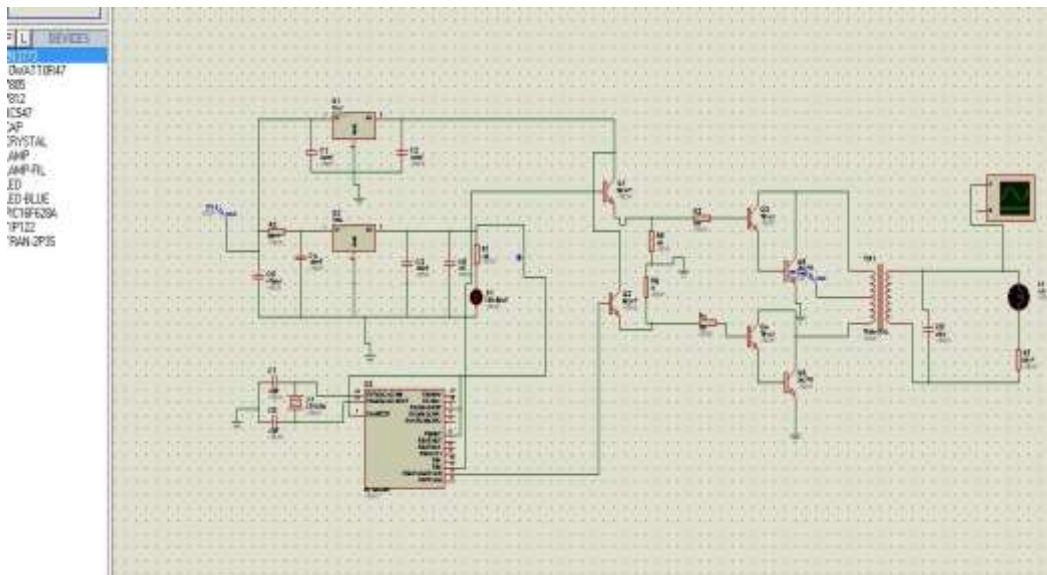


Fig. 5.2 Proteus design of single phase inverter

5.5 Hardware Implementation of 1 Φ Inverter

Single phase inverter is properly designed in bread board. Then it is implemented on PCB by connecting various elements. The hardware implementation diagram is shown in Fig. 5.2. Microcontroller is used here for controlling the pulse to the inverter switches. Transistor is utilized here for amplification purpose.

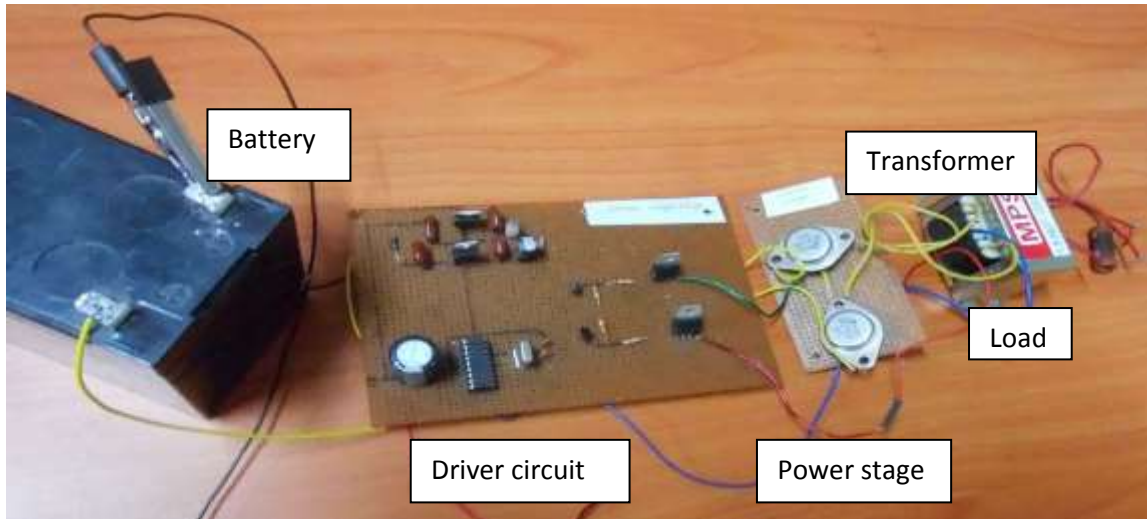


Fig. 5.3 Hardware circuit representation of single phase inverter

5.6 Simulation and Hardware Results

In Fig. 5.4 Input voltage, pulses and output voltages are presented with time in X-axis. The input DC voltage is 5V & the AC output voltage is approximately ± 5 .

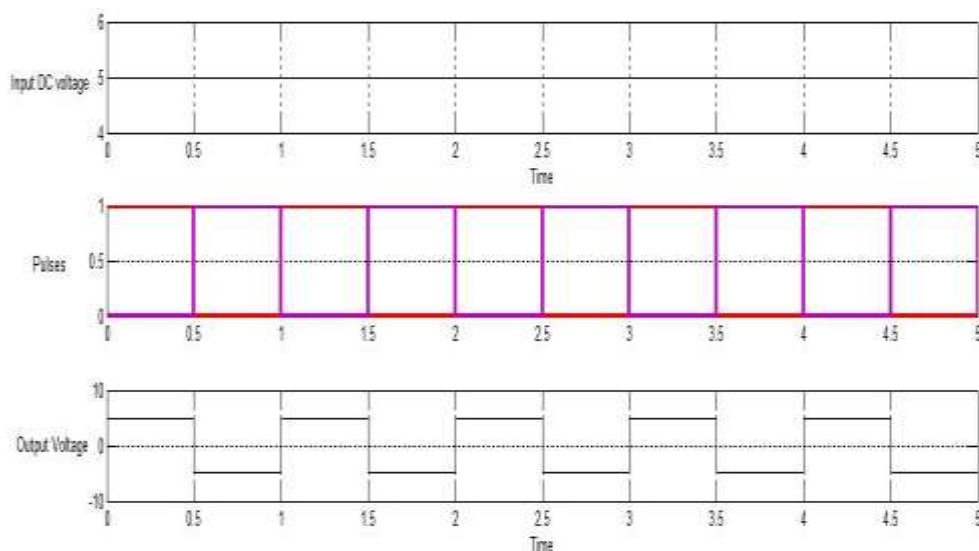


Fig. 5.4 Results for single-phase Inverter

Fig. 5.5 showing the voltage wave form output across 120 ohm load of 5 Watt. This wave form is square due to microcontroller switching continuously both transistors alternatively to

provide the path for grounding for 12 volt DC from transformer terminals. Due to that another side of transformer voltage direction is continuously changing and making square wave as shown in the Fig. 5.5, the transformer should be step up so that voltage will be high at another side.

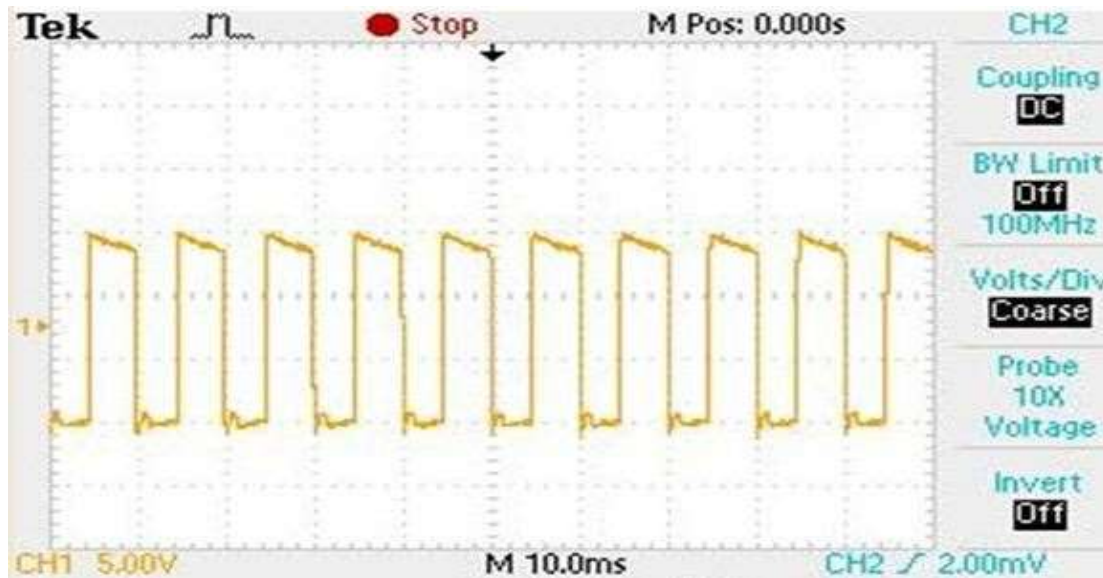


Fig. 5.5 Output Voltage Wave form of 1 ϕ Inverter

5.7 Summary

With the end of this chapter it can be concluded that single phase inverter converts DC to AC. So that the generated power can be supplied to the AC load. Hardware implementation of single phase inverter is successfully illustrated with the circuit diagram drawn in Proteus.

CHAPTER 6

CONCLUSION

- 6.1 Conclusion
- 6.2 Scope for Future Work

6.1 Conclusion

In this project a simple low cost but effective solar PV power generation system for small and not grid connected load is designed in Proteus software and implemented except solar panel that is not implemented only achieved its characteristics.

Many papers written on this project topic are merely using the computer simulations output rather than real hardware outputs. Hall effect based current sensors are very efficient. They are simple in connection and easy in use but little bit expensive.

In the market various type of battery charge controller is available but in this project proposed battery charge controller has a relay that automatically switch the power from battery supply to the other load when the battery is fully charged.

Proteus software is better choice than MATLAB software for electrical circuit connection, because PROTEUS provides the components with their technical names as well as by its technical codes like microcontroller and other integrated chips that are not available in MATLAB library.

6.2 Scope for Future Work

Further work in this area may use different MPPT method and modified algorithms for increased efficiency in fast changing environmental conditions. Try to design such model for solar PV system which should compact size and cheaper and also its operating and maintaining cost should be less. So that people attract to use in behaviour. Inverter can be designed by using SMPS circuits if further implementation will happen from this project.

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