ISSN (Online) : 2455 - 3662
SJIF Impact Factor :5.148

EPRA International Journal of Multidisciplinary Research

Monthly Peer Reviewed & Indexed
International Online Journal

Volume: 5 Issue: 4 April 2019

Published By :EPRA Publishing

Volume: 5 | Issue: 4 | April 2019 || SJIF Impact Factor: 5.148 ISSN (Online): 2455-3662

EPRA International Journal of
Multidisciplinary Research (IJMR) Peer Reviewed Journal

IMPLEMENTATION OF SOLAR PV PANEL WITH BOOST CONVERTER

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ABSTRACT

Compared to the traditional energy resources, photo voltaic (PV) system that uses the solar energy to produce electricity considered as one of renewable energies has a great potential and developing increasingly fast compared to its counterparts of renewable energies. Such system can be either stand-alone or connected to utility grid. While, the disadvantage is that the power generated by PV system depends on weather conditions. The major problem with photovoltaic (PV) systems is the amount of electrical power generated by solar PV modules depends upon a number of atmospheric conditions (i.e. solar irradiance, temperature and angle of incident light etc.). In order to maximize the output of a PV system, continuously tracking the maximum power point (MPP) is necessary. The MPPT is one of the applications of this project. For implementing to extract maximum power and also I-V and P-V characteristics of PV module and under different irradiances are observed. MPPT algorithm plays an important role in increasing the efficiency of PV system. A proposed MPPT algorithm is implemented with boost converter.

1. SOLAR ENERGY

1.1. INTRODUCTION:-

Solar energy is a non-conventional type of energy. Solar energy has been harnessed by humans since ancient times using a variety of technologies. Solar radiation, along with secondary solar-powered resources such as wave and wind power, hydroelectricity and biomass, account for most of the available non-conventional type of energy on earth. Only a small fraction of the available solar energy is used .Solar powered electrical generation relies on photovoltaic system and heat engines.

Solar energy's uses are limited only by human creativity. To harvest the solar energy, the most common way is to use photo voltaic panels which will receive photon energy from sun and convert to electrical energy. Solar technologies are broadly classified as either passive solar or active solar depending on the way they detain, convert and distribute solar energy.

1.2. ENERGY STORAGE METHODS:-

Thermal mass systems can store solar energy in the form of heat at domestically useful temperatures for daily or inter seasonal durations. Thermal storage systems generally use readily available materials with high specific heat capacities such as water, earth and stone. Well-designed systems can lower peak demand, shift time-of-use to off-peak hours and reduce overall heating and cooling requirements.

PHOTOVOLTAICS:-In the last two decades, photovoltaic's (PV), also known as solar PV, has evolved from a pure niche market of small scale applications towards becoming a mainstream electricity source. A solar cell is a device that converts light directly into electricity using the photoelectric effect. The first solar cell was constructed by Charles Fritts in the 1880s. In 1931 a German engineer, Dr Bruno Lange, developed a photo cell using silver selenide in place of copper oxide. Although the prototype selenium cells converted less than 1% of incident light into electricity, both Ernst Werner von Siemens and James Clerk Maxwell recognized the importance of this discovery.

HISTORY:-

The photovoltaic effect was experimentally demonstrated first by French physicist Edmond Becquerel. In 1839, at age 19, he built the world's first photovoltaic cell in his father's laboratory. Willoughby Smith first described the "Effect of Light on Selenium during the passage of an Electric Current" in a 20 February 1873 issue of Nature. In 1883 Charles Fritts built the first solid state photovoltaic cell by coating the semiconductor selenium with a thin layer of gold to form the junctions; the device was only around 1% efficient.

SOLAR CELL:-

A **solar cell**, or **photovoltaic cell** is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.

Solar cells are described as being photovoltaic, irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

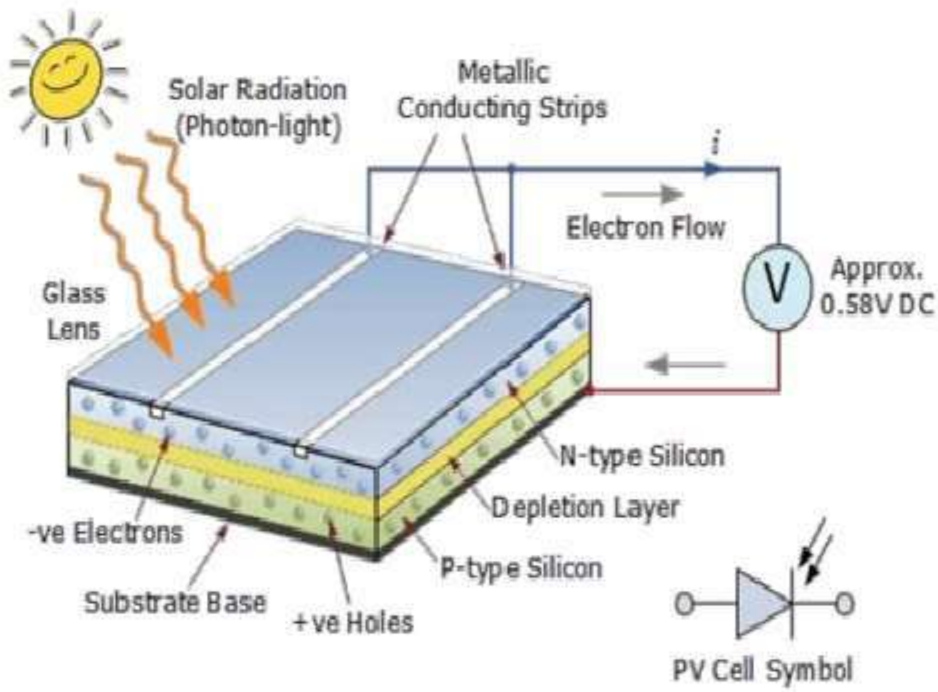


Fig 1.1. Solar cell construction

The operation of a photovoltaic (PV) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs or exactions.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit. The solar cell works in several steps: Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.

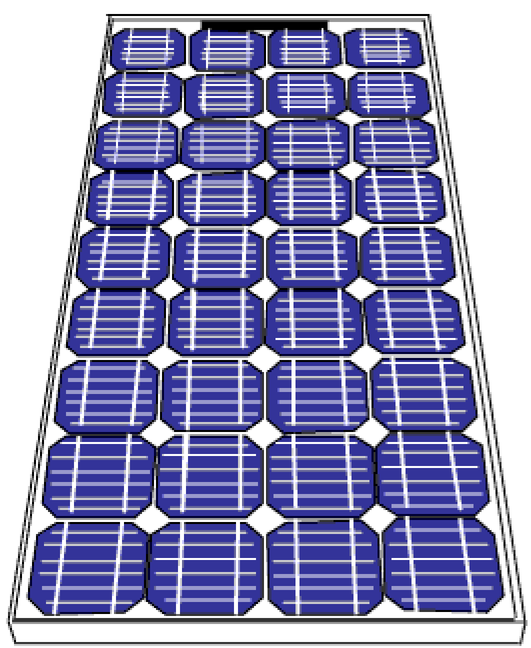


Fig 1.2. Solar module

SOLAR PANEL:-

Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity or heating.

A photovoltaic (PV) module is a packaged; connect assembly of typically 6×10 photovoltaic solar cells. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 365 watts.

The most common application of solar panels is solar water heating systems.

Fig1.3.Solarpanel

SOLAR ARRAY:-

If photovoltaic solar panels are made up of individual photovoltaic cells connected together, then the Solar Photovoltaic Array, also known simply as a Solar Array is a system made up of a group of solar panels connected together. A photovoltaic array is therefore multiple solar panels electrically wired together to form a much larger PV installation (PV system) called an array, and in general the larger the total surface area of the array, the more solar electricity it will produce.

Fig 1.4. Solar array

1.4. EFFICIENCY:-

Solar cell efficiency may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of these individual metrics. A solar cell has a voltage dependent efficiency curve, temperature coefficients, and allowable shadow angles.

In 2014, three companies broke the record of 25.6% for a silicon solar cell. Panasonic's was the most efficient. The company moved the front contacts to the rear of the panel, eliminating shaded areas. In addition they applied thin silicon films to the (high quality silicon) wafer's front and back to eliminate defects at or near the wafer surface. In 2015, a 4-junction GaInP/GaAs//GaInAsP/GaInAs solar cell achieved a new laboratory record efficiency of 46.1 percent (concentration ratio of sunlight = 312) in a French-German collaboration between the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE), CEA-LETI and SOITEC.

A solar cell may operate over a wide range of voltages (V) and currents (I). By increasing the resistive load on an irradiated cell continuously from zero (a *short circuit*) to a very high value (an *open circuit*) one can determine the maximum power point, the point that maximizes V×I; that is, the load for which the cell can deliver maximum electrical power at that level of irradiation. (The output power is zero in both the short circuit and open circuit extremes).

The maximum power point of a photovoltaic varies with incident illumination. For example, accumulatio of dust on photovoltaic panels reduces the maximum power point. For systems large enough to justify the extra expense, a maximum power point tracker tracks the instantaneous power by continually measuring the voltage and current (and hence, power transfer), and uses this information to dynamically adjust the load so the maximum power is always transferred, regardless of the variation in lighting.

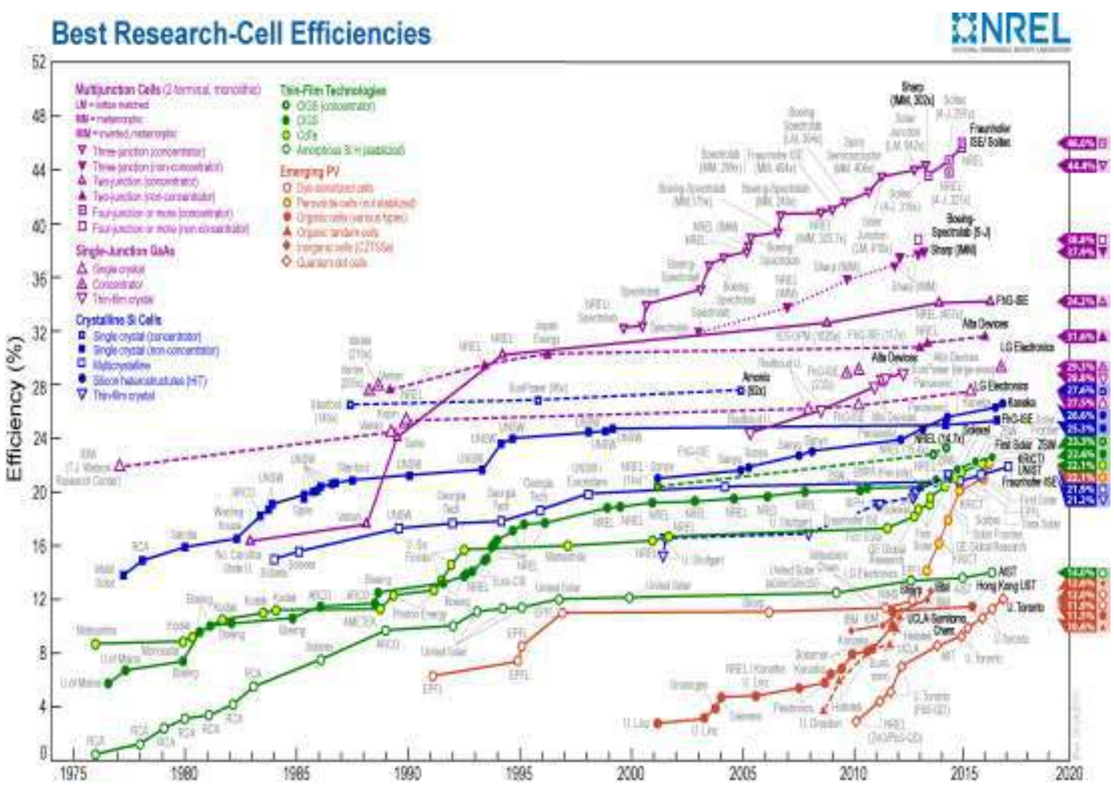


Fig 1.5. Best research cell efficiencies

1.5. MATERIALS:-

Solar cells are typically named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms.

CRYSTALLINE SILICON:-

Crystalline silicon (c-Si) is the crystalline forms of silicon, either multicrystalline silicon (multi-Si) consisting of small crystals, or monocrystalline silicon (mono-Si), a continuous crystal. Crystalline silicon is the dominant semiconducting material used in photovoltaic technology for the production of solar cells. These cells are assembled into solar panels as part of a photovoltaic system to generate solar power from sunlight.

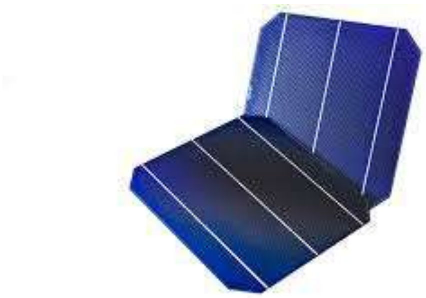


Fig 1.6. Crystalline silicon

POLYCRYSTALLINE SILICON:-

Polycrystalline silicon, also called **polysilicon** or **poly-Si**, is a high purity, polycrystalline form of silicon, used as a raw material by the solar photo voltaic and electronics industry.

Polycrystalline silicon, or multicrystalline silicon (multi-Si) cells are made from cast square ingots—large blocks of molten silicon carefully cooled and solidified. They consist of small crystals giving the material its typical metal flake effect. Polysilicon cells are the most common type used in photovoltaic's and are less expensive, but also less efficient, than those made from monocrystalline silicon.

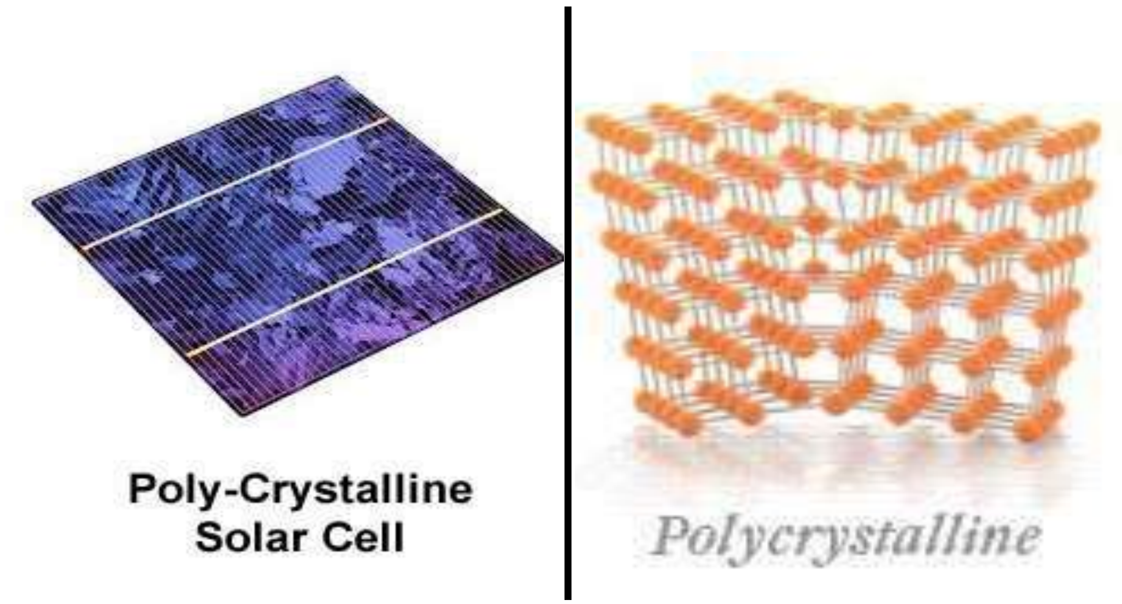


Fig 1.7. Poly-crystalline cell

MONOCRYSTALLINE SILICON:-

Monocrystalline silicon (or "single-crystal silicon", "single-crystal Si", "mono c-Si", or just **mono-Si**) is the base material for silicon chips used in virtually all electronic equipment today. Mono-Si also serves as photovoltaic, light-absorbing material in the manufacture of solar cells.

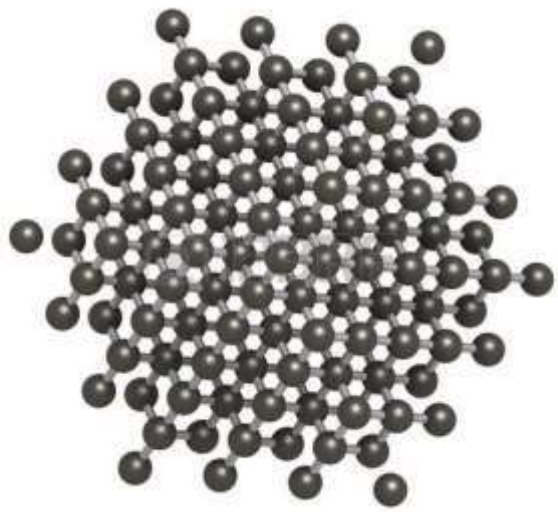


Fig 1.8. Mono-Crystalline solar cell

1.6. MATHEMATICAL MODELLING OF SOLAR CELL:-

Modeling is basic tool of the real system simulation. For modeling, it is necessary to analyze the influence of different factors on the photovoltaic cells and to take in consideration the characteristics given by the producers. The mathematical models for photovoltaic cells are based on the theoretical equations that describe the operation of the photovoltaic cells and can be developed using the equivalent circuit of the photovoltaic cells. The empirical models rely on different values extracted from the I-V characteristic of the photovoltaic cells and they approximate the characteristic equation of the solar panels using an analytical function.

EQUIVALENT CIRCUIT OF TWO DIODE MODEL:-

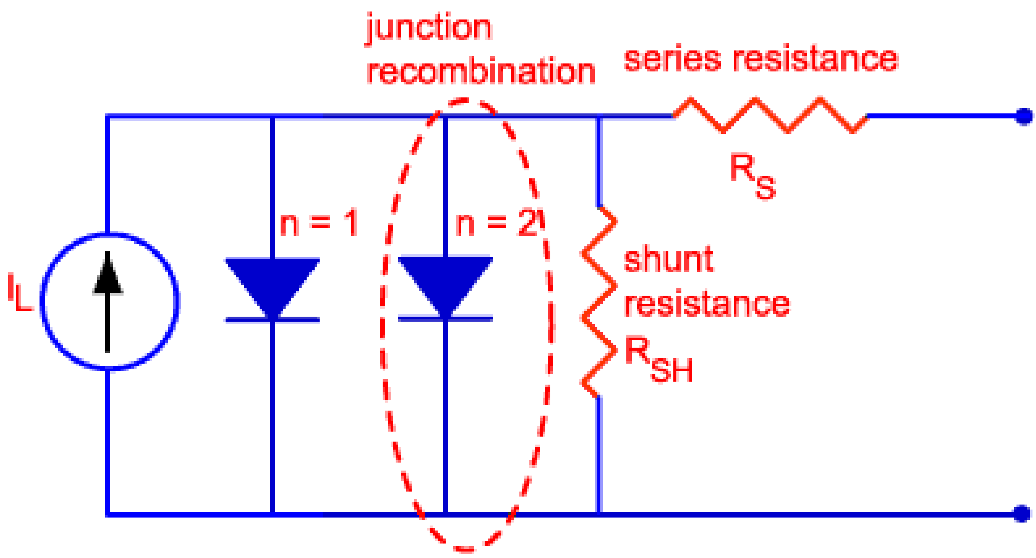


fig 1.9. double diode model of a solar cell

$$J = J_L - J_{01}\left\{exp\left[\frac{q(V+JR_s)}{kT}\right]-1\right\} - J_{02}\left\{exp\left[\frac{q(V+JR_s)}{2kT}\right]-1\right\} - \frac{V+JR_s}{R_{shunt}}$$

$$J = J_{01}\left\{exp\left[\frac{q(V-JR_s)}{kT}\right]-1\right\} + J_{02}\left\{exp\left[\frac{q(V-JR_s)}{2kT}\right]-1\right\} + \frac{V-JR_s}{R_{shunt}}$$

1.7. CHARACTERSTICS OF SOLAR CELL:-

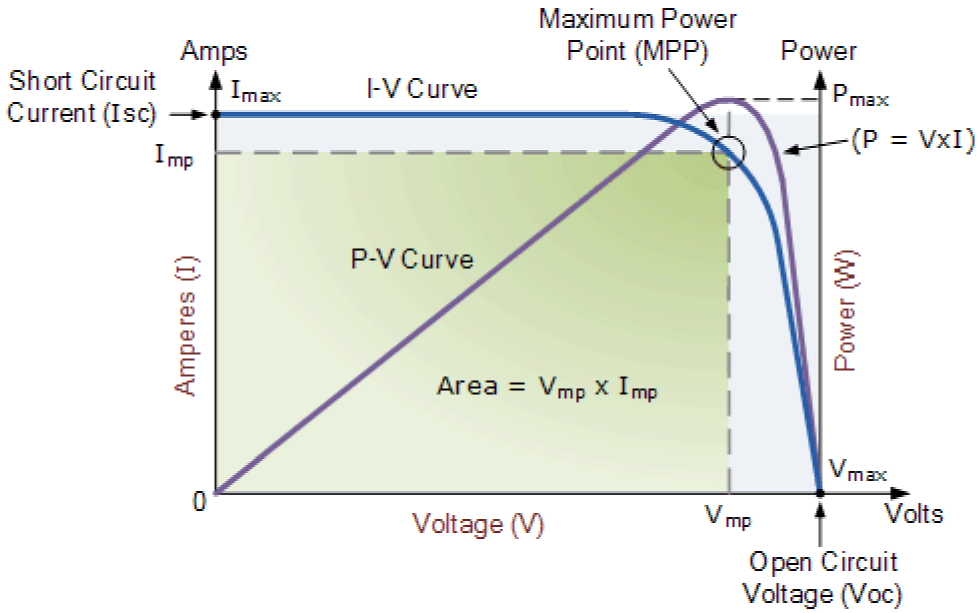


Fig 1.10. Characteristics of solar cell

The above graph shows the current-voltage (I-V), and Power-Voltage (p-v) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a solar cell is the product of current and voltage (I x V). If the With the solar cell open-circuited that is not connected to any load the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells **open circuit voltage**, or Voc. At the other extreme, when the solar cell is

2. BOOST CONVERTER

2.1. INTRODUCTION:-

A **boost converter** (**step-up converter**) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two

multiplication is done, point to point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells **short circuit current**, or Isc.

semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

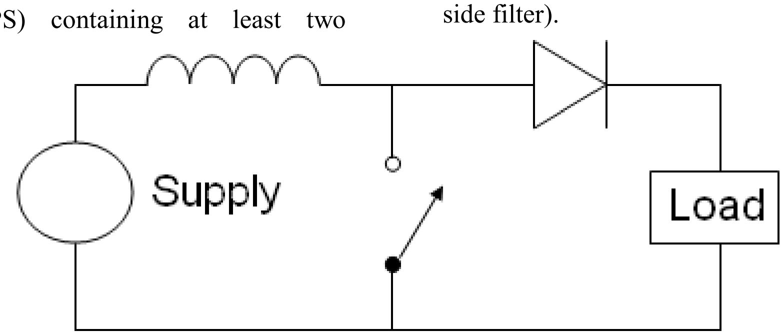


Fig 2.1. Boost converter

2.2. HISTORY:-

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950s represented a major milestone that made SMPSs such as the boost converter possible. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led to the converter's rapid development.

2.3. NECESSITY OF BOOST CONVERTER:-

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereby, the efficiency decreases. The core loss of the inductors limits the high frequency operation. Control voltage Vc is obtained by comparing the output voltage with its desired value. Then the output voltage can be compared with its desired value to obtain the control voltage Vcr. The PWM control signal for the dc converter is generated by comparing Vcr with a saw tooth voltage Vr. There are four topologies for the switching regulators: buck converter, boost converter, buck-boost converter, cứk converter. However my project work deals with the boost converter and further discussions will be concentrated towards this one.

2.4. CIRCUIT ANALYSIS:-

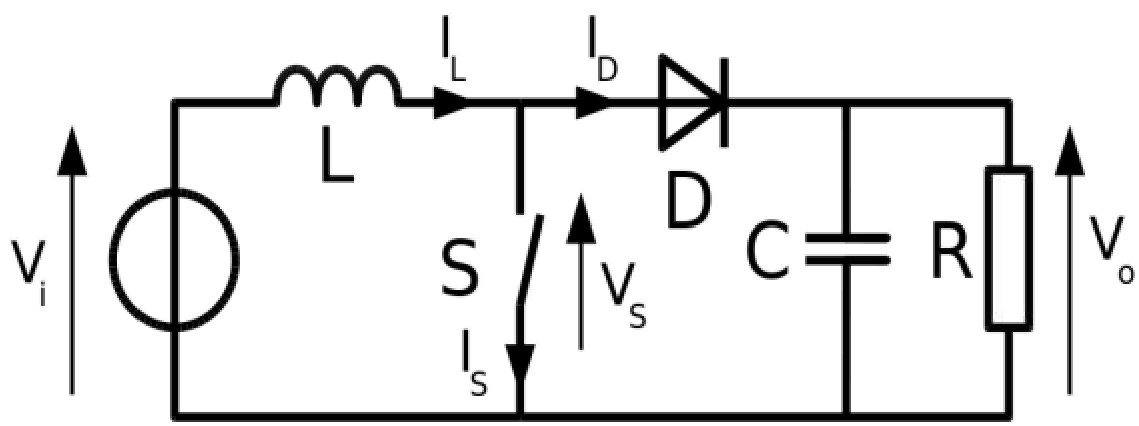


Fig 2.2. Schematic diagram of boost converter

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure.

Case (a):-When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

Case (b):-When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

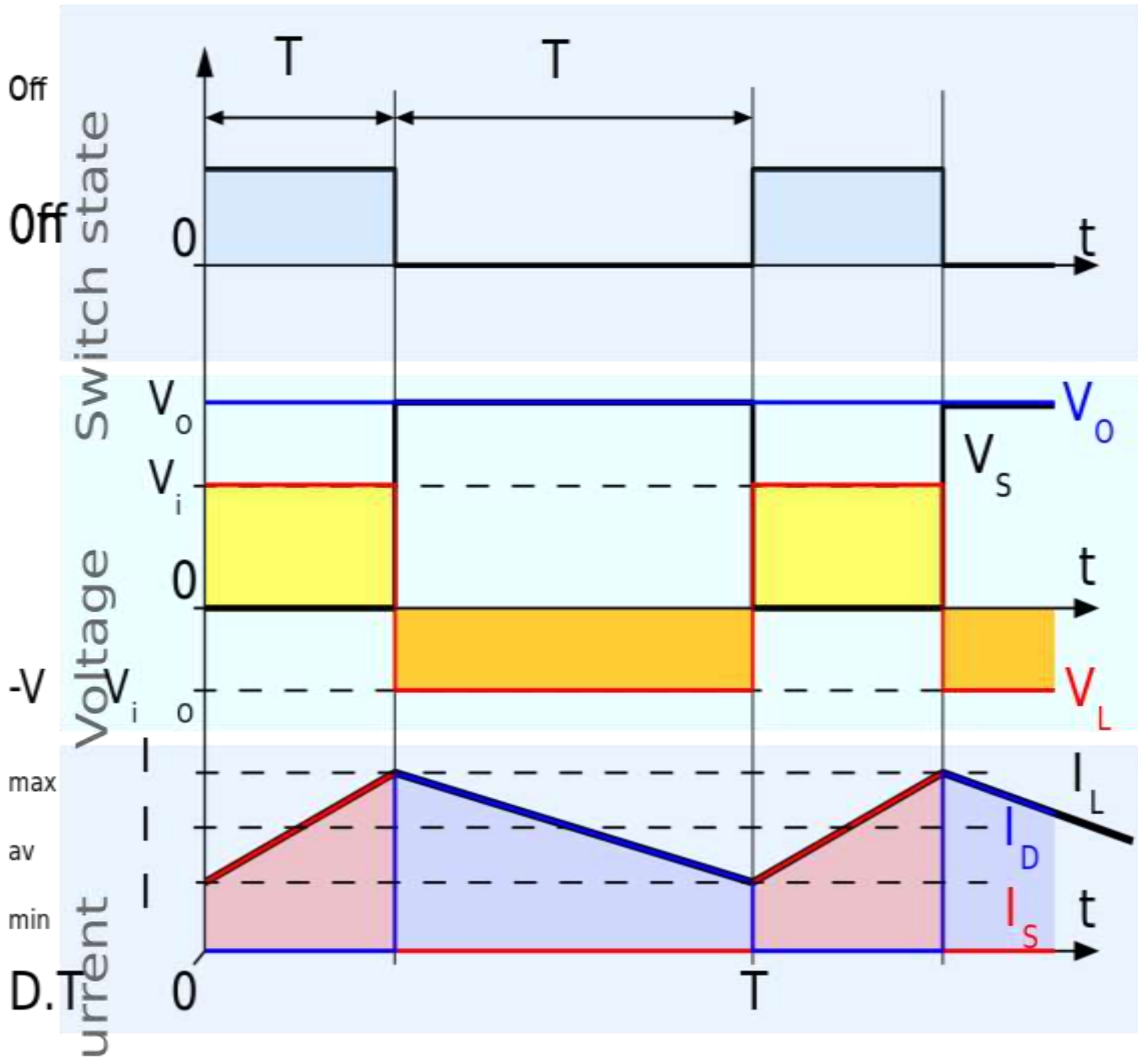


Fig 2.3. Duty cycle and voltage characteristics

CONTINUOUS MODE Operation:-

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L}V_i$$

$$V_i - V_o = L\frac{dI_L}{dt} \quad E = \frac{1}{2}LI_L^2$$

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0$$

$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

$$D = 1 - \frac{V_i}{V_o}$$

DISCONTINUOUS MODE Operation:-

$$I_{L_{Max}} \text{ (at } t = DT) \; I_{L_{Max}} = \frac{V_i DT}{L}$$

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

$$\delta = \frac{V_i D}{V_o - V_i}$$

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$$

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2 L I_o}$$

$$\frac{V_o}{V_i} = \frac{1 + \sqrt{1 + \frac{4D^2}{K}}}{2}$$

where $K = \frac{2L}{RT}$

2.5. DESIGN OF BOOST CONVERTER:-

Taken Reference values:

V = 34.5 Volts

V_{out} = 220 Volts

Frequency = 100KHZ

⇨ Duty cycle can be calculated by using this formula

$D = 1 – (V/V_{out})$

⇨ D = 1 – (34.5/220)

⇨ D = 0.844

⇨ D = 84.4%

We know that the ripple current factor must not exceed 30%

i.e.

ΔI/I = 0.3

Let us assume that, at maximum power point

The output voltage = 220 Volts

Output current = 0.7272 A

Then the resistance R = 220/0.7272

= 303 Ohms

We know that the ripple voltage factor must not exceed 5%

i.e.

ΔV/V = 0.05

From the basics the inductance can be calculated by using

$L = (V_{in}*D) / (F*\Delta I)$

I = 0.7272 A

ΔI = 0.3*0.7272

ΔI = 0.218 A

L = (34.5*0.844) / (100000*0.218)

⇨ L = 1.33 mH

ΔV/V = 0.05

We know that

$\Delta V/V = (D*T_s) / (R_o*C)$

$C = D / (F*R_o*(\Delta V/V))$

C = 0.844 / (100000*302*0.05)

$C = 5.589*10^{-7}$

⇨ C=0.558 μF

The above calculated values are minimum values to work as boost converter

To make our output have low ripples we have to make the inductor and capacitor values to above the rated values

3. SIMULATION

3.1. Electrical Characteristics of BPSX 160 Solar panel:-

- Maximum power (Pmax) 160W
- Voltage at Pmax (Vmp) 34.5V
- Current at Pmax (Imp) 4.35A
- Warranted minimum Pmax 150W
- Short-circuit current (Isc) 4.75A
- Open-circuit voltage (Voc) 43.5V
- Maximum system voltage 600V

3.2. PV MODULE SIMULATION:-

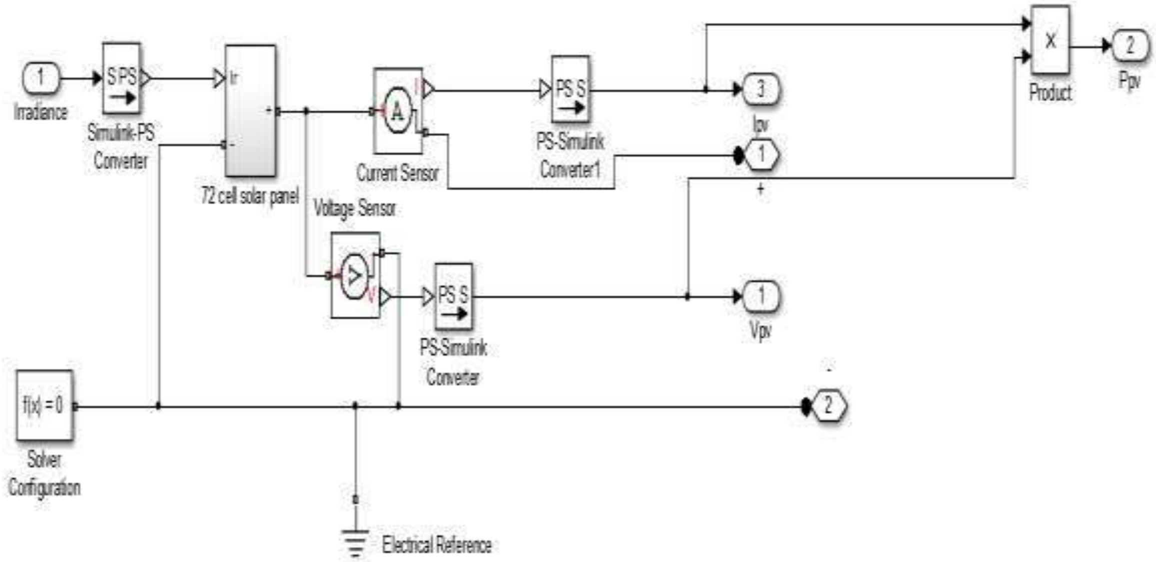


Fig 3.1. PV module simulation

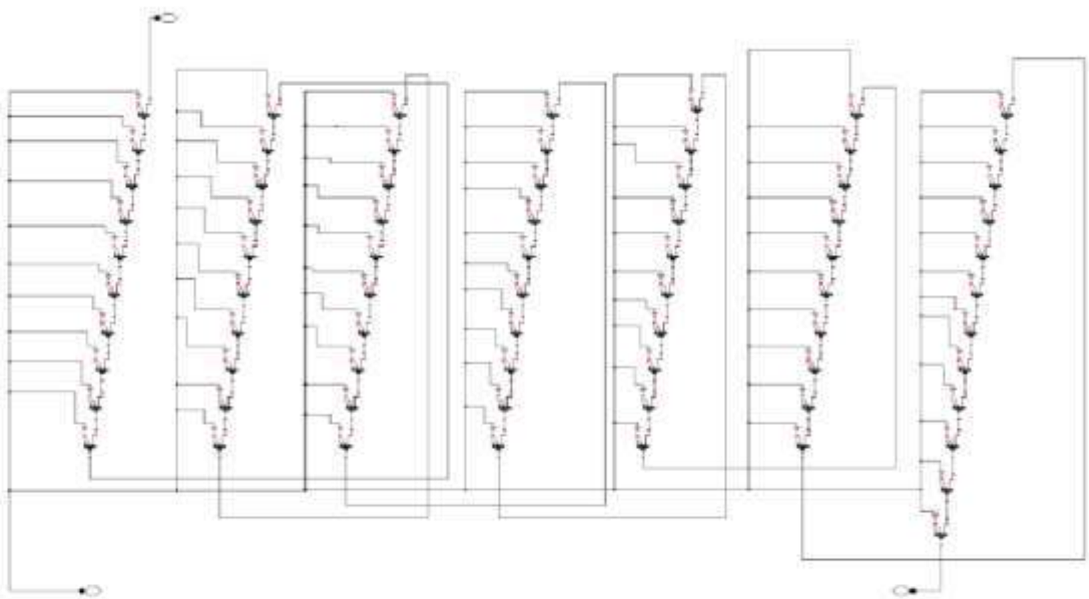


Fig 3.2. 72 solar cells connected in series

3.2. BOOST CONVERTER SIMULINK:-

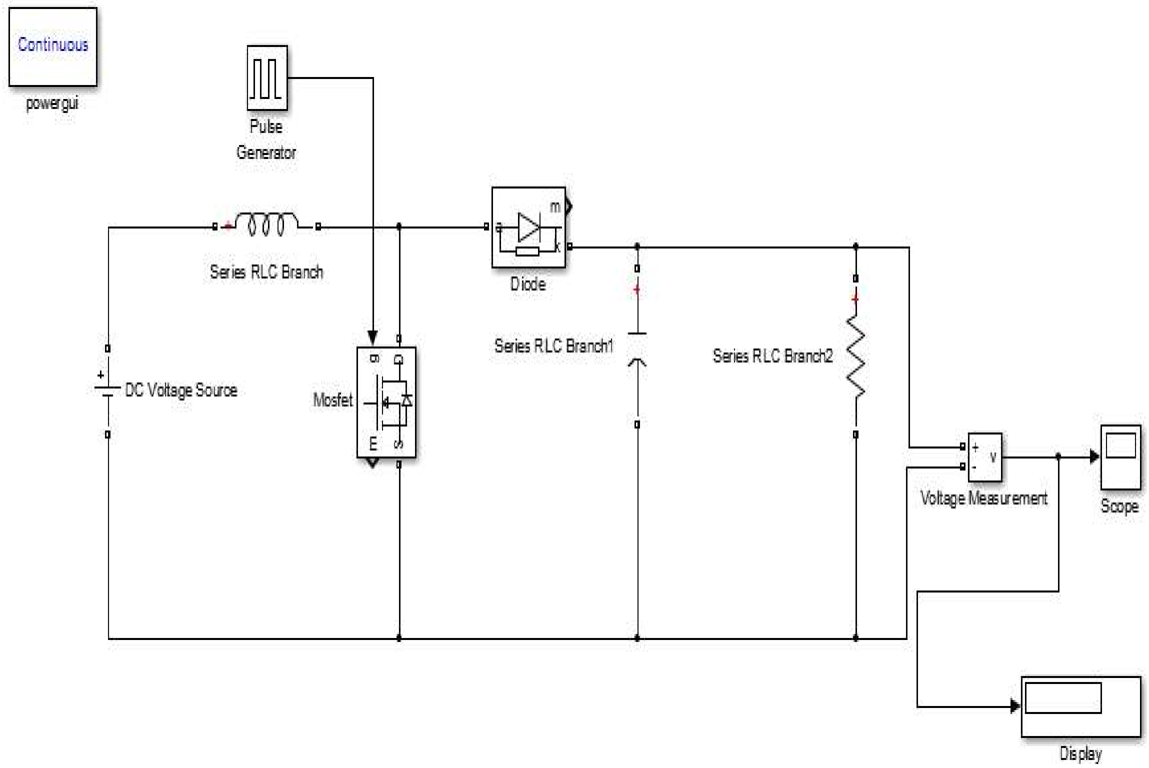
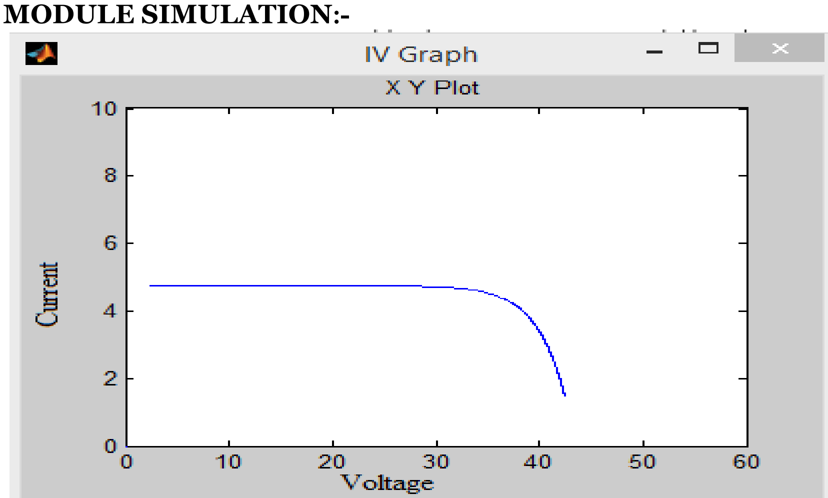
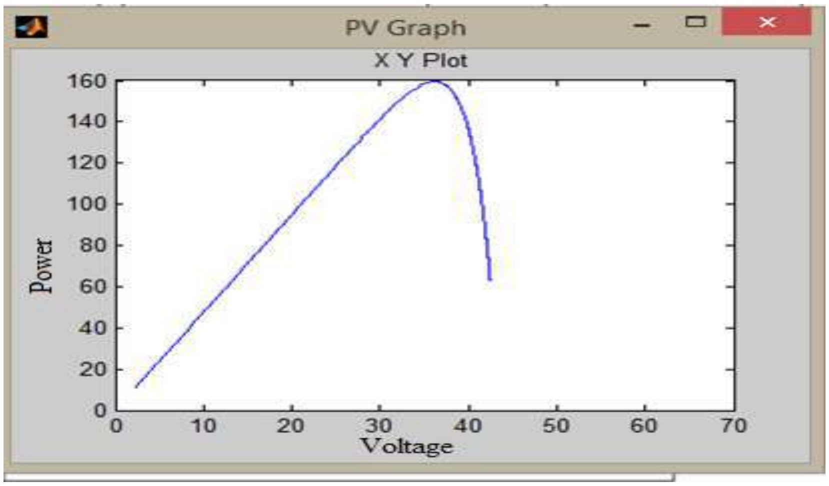


Fig 3.3. Boost converter simulation model

4. SIMULATION RESULTS

4.1. SOLAR PV MODULE SIMULATION:-





4.2.
BOOST CONVERTER SIMULATION OUTPUT:-
OUPUT VOLTAGE:-

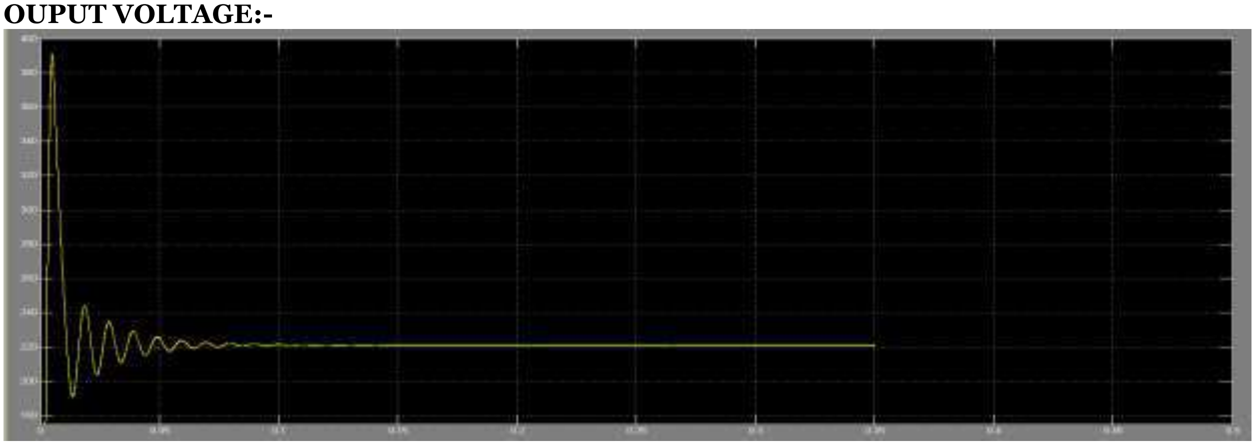


Fig 4.2. Output voltage after simulation

CONCLUSION: - In this paper we developed how the maximum power can be extract from PV module through the designed boost converter. It has been observed the controller track the optimum point where the maximum power can transfer from the source i.e. PV module to the load at maximum power point operating voltage. Thus the solar panel works at maximum power point for any load with any value of irradiance. Through simulation it is observed that the system completes the maximum power point tracking successfully despite of fluctuations. When the external environment changes suddenly the system can track the maximum power point quickly. The boost converter used in this project also successfully stepped up the input voltage.

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