CONTENTS

NOMENCLATURE:

V_{oc}: Open circuit voltage of PV cell

I_{sc}: Short circuit current of PV cell

R_s: Series resistance

R_p: Parallel resistance

I_{ph}: Photo current

I_d: Diode current

V: the voltage imposed on the diode.

I_o: the reverse saturation or leakage current of the diode (A)

V_t: called the thermal voltage because of its exclusive dependence of temperature

T_c: Temperature of the cell

K: Boltzmann constant, 1.381 × 10−23 J/K

q: Charge, 1.602 × 10−19 C

Ns: Number of series cells

A: Ideality of the diode

a: Modified ideality factor

G: Irradiance (w/m2)

D: Diffusion factor

G e: Material band gap energy (eV), (1.12 eV for Si)

M_{sc}: Coefficient temperature of short circuit current (A/K)

R_o: Load resistance of boost converter

L: Value of inductance in mH

C: Value of capacitance in 'uf'

T_s: Total time period

F_s: Switching frequency

D: Duty ratio of boost converter

ABSTRACT

Maximum Power Point Techniques (MPPT) are employed in photovoltaic system to make full utilization of P-V array output power. The output power of PV array is always changing with weather conditions i.e., solar irradiation and atmospheric temperature. PV generates power by converting sunlight into electricity. The electric current generated is proportional to solar radiation. PV cell can generate around 0.5 to 0.8 volts. During cloudy weather due to varying insolation levels the output of array keeps varying. The MPPT is a process which tracks the maximum power from array and by varying the ratio between voltage and current, increase the output power of the system. There are many different MPPT techniques based on different topologies and varying complexity, cost and production efficiency.

In this thesis, a fuzzy logic control (FLC) based MPPT technique is proposed to improve the efficiency of a standalone solar energy system. Using fuzzy controller is an intelligent way of tracking maximum power point (MPP). This thesis presents in details fuzzy logic controller algorithm applied to a DC-DC boost converter device. The boost converter increases the output voltage; it depends on the duty cycle of switching device. The proposed controllers are adjusting the duty cycle of the DC-DC boost converter to track the maximum power of a solar PV array. Finally performance of fuzzy logic controller method has been carried out which has result shown in the effectiveness of fuzzy logic controller to draw more energy, decreases fluctuations and fast response, against change in variable weather conditions. The final result shows that the fuzzy logic controller exhibits a better performance compared to other conventional methods. After all modifications the desired DC voltage is given to the PWM inverter to convert DC to AC power. The final output power will be used for our AC appliances.

LIST OF FIGURES **PG.NO**

CHAPTER 1

1.1 Introduction:

There are two major problems presently that the world is presently facing i.e. energy crisis and climate changes. The increasing energy consumption due to the development of the technology is another major issue in the world both the problems can be overcome at the same time by introducing the renewable energy sources which are clean, economical, and abundant and they do not cause harm to the environment by emitting harmful CO2 gases. Solar energy, wind energy, hydro energy, geothermal energy, tidal energy and biomass are the sources of renewable energy.

Out of all these energies, solar energy is the most reliable source since; sun is an infinite energy reservoir. The solar energy that hits the earth's surface in one hour is equivalent to the energy consumed by all human activities in a year. The sunlight is converted into electricity by using the photovoltaic effect.

This Photovoltaic effect is a phenomenon through which a collection of light-generated carries by the P-N junction causes a movement of electron to the N-type side and holes to the P-type side of junction. This acts as a source of current. Due to the high cost of PV modules, optimal utilization of the available solar energy is imperative. This requires an accurate, reliable and comprehensive simulation is a very important factor that affects the output of the PV cell. Temperature (T), Irradiance (G), have influence on the open circuit voltage (Voc) and short circuit current (I_{sc}) which determine the power generation. The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel (in commercial PV panels it is between 8-15% [3]), the efficiency of the inverter (95-98 %) and the efficiency of the maximum power point tracking (MPPT) algorithm (which is over 98%). Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. Instead, improving the tracking of the maximum power point (MPPT) with new control algorithms is easier, not expensive and can be done even in plants which are already in use by updating their control algorithms, which would lead to an immediate increase in PV power generation and consequently a reduction in its price.

1.2 Objective

The basic objective would be to study MPPT and successfully implement the MPPT algorithms either in code form or using the Simulink models. Modeling the converter and the solar cell in Simulink and interfacing both with the MPPT algorithm to obtain the maximum power point operation would be of prime importance.

1.3 Thesis outline

This thesis has been broadly divided into 8 chapters. The first one being the introduction, chapter 2 is on modeling of a solar energy. Chapter 3 is on PV system. In chapter 4 modeling of PV cell are presented. Chapter 5 consists of MPPT controller and fuzzy logic method. Chapter 6 consists of boost converter and its design and waveforms. Chapter 7 includes simulation circuits and waveforms. Conclusion and future work are listed in chapter

CHAPTER 2

SOLAR ENERERGY

2.1 Solar Energy Introduction:

Solar energy is a non-conventional type of energy. Solar energy is radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic, solar thermal energy. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

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.

Active solar techniques include the use of PV panels and solar thermal collectors to strap up the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties and design spaces that naturally circulate air. Solar energy has a vast area of application such as electricity generation for distribution, heating water, lightning building, crop dying etc. the sun is sending us radiation over a wide range of wavelengths at varying intensities. The electro- magnetic solar radiation impinging on the upper edge of the atmosphere is called extra- terrestrial radiation. The mean integral for the complete spectrum is 1,367 W/m^2 (the solar constant). The normal measurement of the wavelength of solar and atmospheric radiation is the nanometer and for infrared radiation is the micrometer.

2.2 Distribution of Solar Radiation:

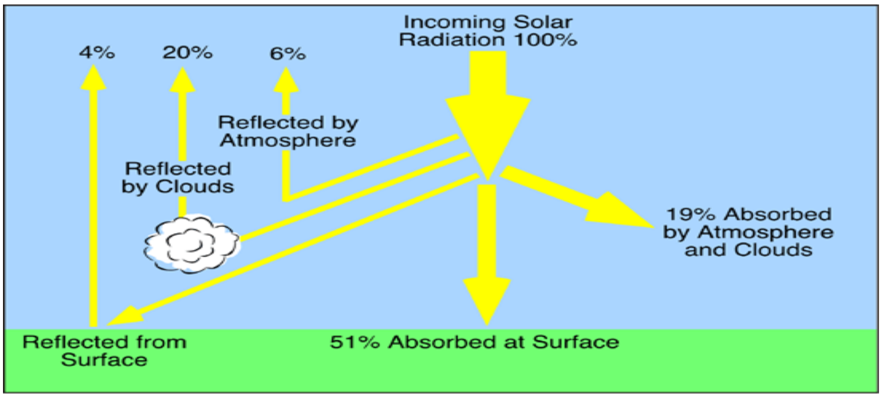


Fig 2.1: Solar Radiation Distribution

From the above Figure 2.1 of solar radiation, Earth receives 174 megawatts (PW) of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to space and only 89 pw is absorbed by oceans and land masses. The spectrum of solar light at the Earth's surface is generally spread across the visible and near-infrared reason with a small part in the near-ultraviolet. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 EJ per year.

Solar technologies are characterized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on distance from the equator. Although solar energy refers primarily to the use of solar radiation for practical ends, all renewable energies, other than geothermal power and Tidal power, derive their energy either directly or indirectly from the Sun.

2.3 Solar Radiation Reaching Earth Surface:

The intensity of solar radiation reaching earth surface which is 1369 watts per square meter is known as Solar Constant. It is important to realize that it is not the intensity per square meter of the Earth's surface but per square meter on a sphere with the radius of 149,596,000 km and with the Sun at its Centre.The sun is considered to produce a constant amount of energy. At the surface the intensity of the solar radiation is about $6.33\times10^{7}W/m^{2}$. As the sun's rays spread out into space the radiation becomes less intense and by the time the rays reach the edges of the Earth's atmosphere they are considered to be parallel.

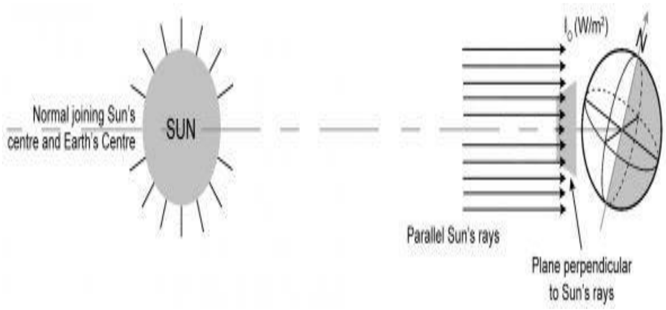


Fig2.2: The sun's rays incident on the earth

The solar constant (I_{SC}) is the average radiation intensity falling on an imaginary surface, perpendicular to the Sun's rays and at the edge of the Earth's atmosphere.The solar radiation intensity falling on a surface is called irradiance or insulation and is measured in W/m^{2}. The solar constant can be used to calculate the irradiance incident on a surface perpendicular to the sun's rays outside and Earth's atmosphere.

2.3.1 Beam radiation- It is also called direct radiation. It is used to describe solar radiation travelling on a straight line from the sun down to the surface of the earth.

2.3.2 Diffusion radiation- It is used to describe solar radiation scattered in all direction in the atmosphere and then some arrives at the plane on the earth's surface (not directional).

2.3.3 Reflected radiation: beam and diffusion radiation that hits the earth's surface and is reflected onto the plane.

The amount of energy reflected, scattered and absorbed depends on the amount of atmosphere that the incident radiation travels through as well as the levels of dust particles and water vapour present in the atmosphere.

2.4 Standard Test Conditions (STC):

A solar panel is first tested in right in the factory. As the panel comes off the production line, a worker places the panel on a "flash table" and hooks up the positive and negative lead to a measuring device. The panel is then "flashed" with fake light. The connected electronics record a number of performance values including the panel's voltage (volts), current (amps) and power (watts). These testing conditions are called "standard test conditions"

The comparison between different photovoltaic cells can be done on the basis of their performance and characteristic curve. The parameters are always given in datasheet. The datasheet make available the notable parameter regarding the characteristics and performance of PV cells with respect to standard test condition.

Standard test conditions are as
follows: TEMPERATURE
(T_n) = 25 ℃
IRRADIANCE (G_n) =
1000 W/m^2 SPECTRUM
OF X = 1.5i.e. AM

CHAPTER 3

P-V SYSTEM

3.1 Definition

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. It may also use a solar tracking system to improve the system's overall performance.

3.2 Photo-Voltaic Arrangements

3.2.1 Photo-Voltaic Cell

Photovoltaic are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons by the photovoltaic effect. PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current - that is, electricity. This electricity can then be used to power load. The operation of a photovoltaic (P-V) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

3.2.2 Photo-Voltaic Module:

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 operates 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. There are a few commercially available solar modules that exceed 22% efficiency. A single solar module can produce a limited amount of power. Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not necessary. Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels.

3.2.3 Photovoltaic Array

The power that one module can produce is not sufficient to meet the requirements of home or business. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads, lights etc. The modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current.

A Photovoltaic array is a linked collection of photovoltaic modules. A photovoltaic array is therefore multiple solar panels electrically wired together to form a much larger PV installation called PV array. A complete photovoltaic system uses a photovoltaic array as the main source for the generation of the electrical power supply. A photovoltaic array is a linked collection of photovoltaic modules.

The connection of the solar panels in a single Photovoltaic array is same as that of the PV cells in a single panel. The panels in an array can be electrically connected together in a series, a parallel, or a mixture of the two, but generally a series connection is chosen to give an increased output voltage. The electrical characteristics of a *photovoltaic array* are summarized in the relationship between the output current and voltage. The amount and intensity of solar insolation (solar irradiance) controls the amount of output current (I), and the operating temperature of the solar cells affects the output voltage (V) of the PV array. Photovoltaic panel (I-V) curves that summarize the relationship between the current and voltage are given by the manufacturers and are given as

- V_{oc}= open-circuit voltage:- This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition). This value is much higher than V_{MAX} which relates to the operation of the PV array which is fixed by the load. This value depends upon the number of PV panels connected together in series.

- I_{SC}= short-circuit current:- The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). This value is much higher than I_{MAX} which relates to the normal operating circuit current.

- P_{MAX}= maximum power point:-This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where P_{MAX}= I_{MAXX} V_{MAX}. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (W_P).

- FF = fill factor:-The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions and the product of the open- circuit voltage times the short-circuit current, (V_{OC}, I_{SC}) This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8.

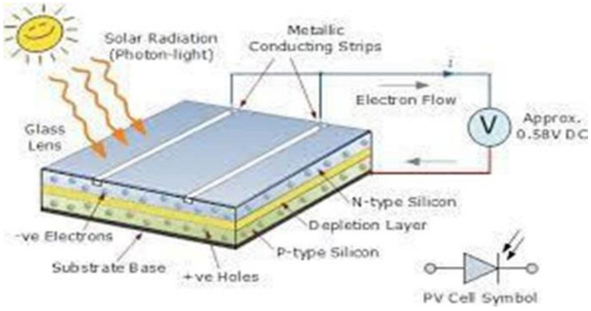


Fig 3.1 Basic Structure of PV Cell

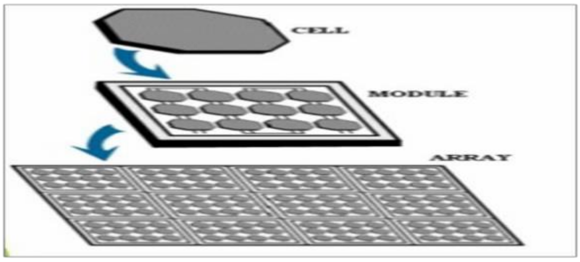


Fig 3.2 Photovoltaic System

3.3 Materials Used in P-V Cell

The materials used in PV cells are as follows:

- Single-crystal silicon
- Poly crystalline silicon
- Gallium Arsenide(GaAs)
- Cadmium Telluride(CdTe)
- Copper Indium Diselenide(CuInSe2)

3.3.1 Single-Crystal Silicon

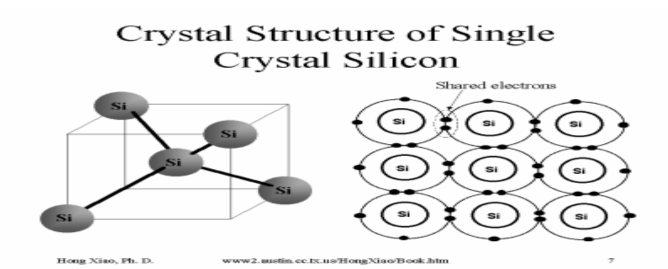


Fig3.3: Single-Crystalline Silicon Structure

Mono crystalline silicon 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. It consists of silicon in which the crystal lattice on the entire solid is continuous, unbroken to its edges, and free of any grain boundaries. Single-crystal silicon is perhaps the most important technological material of the last few decades, because its availability at an affordable cost has been essential for the development of the electronic devices on which the present-day electronics and IT revolution is based. Mono crystalline silicon used in thin-film solar cells and poly crystalline silicon. That consists of mall crystals, also known as crystallites.

3.3.2 Poly Crystalline Silicon

Poly Crystalline Silicon, also called poly silicon or poly-Si, is a high purity, polycrystalline form of silicon, used as a raw material by the solar photovoltaic and electronics industry. Poly silicon is produced from metallurgical grade silicon by a chemical purification process, called the Siemens process. This process involves distillation of volatile silicon compounds, and their decomposition into silicon at a high temperature. Poly silicon consists of small crystals, also known as crystallites, giving the material its typical metal flake effect. About 5 tons of poly silicon is require manufacturing 1 megawatt of conventional solar modules. Poly silicon is distinct from Mono crystalline silicon and amorphous silicon.

3.3.3 Gallium Arsenide

Gallium Arsenide is a compound of the elements gallium and arsenic. Gallium Arsenide is used in the manufacture of devices such as microwave frequency integrated circuits, monolithic microwave integrated circuits, infrared light-emitting diodes, laser diodes, solar cells and optical windows. It has a higher saturated electron velocity and higher electron mobility, allowing gallium arsenide transistors to function at frequencies in excess of 250 GHz. It is also used in the manufacture of Gunn diodes for the generation of microwaves. Another advantage of GAS is that it has a direct band gap, which means that it can be used to absorb and emit light efficiency. The applications of GAS are solar cells and detectors, light emit devices and spin charge converters.

3.3.4 Cadmium Telluride

Cadmium telluride is a stable crystalline compound formed from cadmium and tellurium. It is mainly used as the semiconducting material in cadmium telluride photovoltaic and an infrared optical window. It is usually sandwiched with cadmium sulfide to form of p-n junction solar PV cell. Typically, CdTe PV cells use an n-i-p structure.

CdTe is used to make thin film solar cells. The CdTe solar cell market is dominated by first solar. CdTe is used as an infrared optical material for optical windows and lenses and is proven to provide a good performance across a wide range of temperatures. CdTe is also applied for electro-optic modulators. CdTe can operate at room temperature allowing the construction of compact detectors for a wide variety of applications in nuclear spectroscopy.

3.3.5 Copper Indium Diselenide

Copper indium Diselenide is a semiconductor material composed of copper, indium, gallium, and selenium. The material is a solid solution of copper indium diselenide. CIGS is a tetrahedral bonded semiconductor, with the chalcopyrite crystal structure. It is best known as the material for CIGS solar cells a thin film technology used in the photovoltaic industry. CIGS has the advantage of being able to be deposited of flexible substrate materials, producing highly flexible, lightweight solar panels. Improvements in efficiency have made CIGS an established technology among alternative cell materials.

CHAPTER 4

P-V CELL MODELLING

4.1Photo-Voltaic Cell

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current.

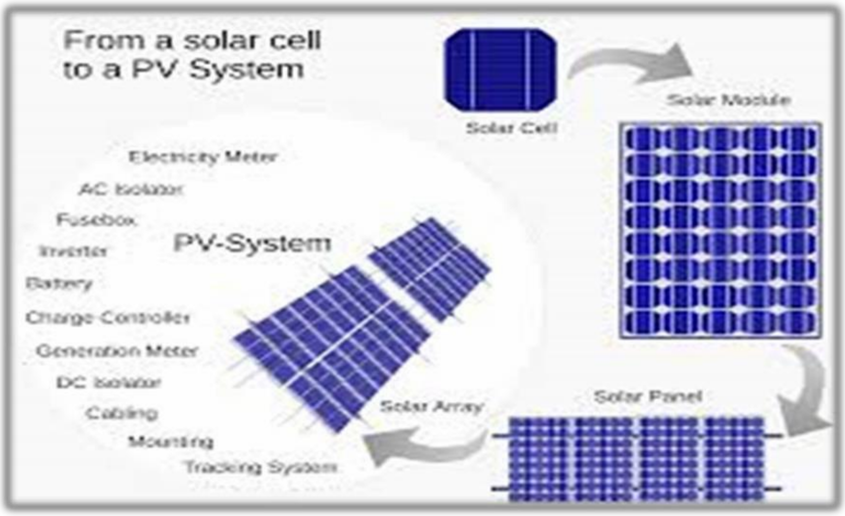


FIG 4.1: P-V Panel Operation

However a photovoltaic cell is different from a photodiode. In a photodiode light falls on n channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased.

A photovoltaic system, also P-V system or solar power system is a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline.

4.2 Solar Photovoltaic (P-V) Array under Partial Shading Condition

It is a well-documented fact that the output power capacity will be reduced by a partial shading of a photovoltaic array; however, the reduction in energy production cannot be determined in a direct method, as it is frequently not proportional to the shaded area. Some of the previous studies supposed that the decrease in power production is proportional to the shaded area and reduction in solar irradiance as well. In actuality, this concept is valid for just a single cell. The power reduction at the array level is predominantly far away from linearity with the shaded portion [2]. Numerous factors can influence the performance of a photovoltaic (PV) system. One of the most significant factors is shading. Shading indicates a shadow on the PV modules on the outer surface that will decrease the system energy yield. As a consequence, the three fundamental PV module characteristics of power, voltage, and current will be affected. With changing irradiation during the day, the array output varies in a wide range. This variation of array output is expected. However, uniform lighting concentration in a panel is not roughly satisfied due to unexpected shading effects caused by dust, clouds, trees, buildings, atmosphere fluctuation, an existence of clouds, and daily sun angle changes causing shading on cells or side of modules as shown in Figures (4.2).

Fig 4.2 Partial Shading on a PV Panel

Shade impact depends on module type, fill factor, bypass diode placement gravity of shade, and string configuration. Power loss happens from the shade as well as current mismatch within a PV string and voltage mismatch between parallel strings [5].PV solar panels are very sensitive to shading.

In PV systems, it is virtually impossible to utterly avoid shading. Looking at the electrical characteristics of PV solar panels, partial shading effect results in a distortion of the overall I-V and P-V curves of the PV solar panels. As a result, the I-V and P-V characteristics of the solar panels become more complex with existing multiple maximum power points (MPPT) under the non-uniform irradiance conditions. The total output power of a PV module will be reduced by a shadow falling on it from two mechanisms, which are reducing the energy input and increasing energy losses. Even though only one cell is shaded in the PV module, around 30% power loss will happen. The power losses will increase proportionally to the number of shaded cells. A partial shading problem results in a deformity of the overall I-V curve, and this impact can be illustrated by the mismatch between the individual modules' I-V curves [7].

4.3 Effect of Variation of Irradiance

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated.

4.4 Effect of Variation of Temperature

The temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the efficiency of the solar cell is reduced.

4.5 P-V Cell Modeling

The simple way of representing the solar cell is the single diode model. It consists of a current source in parallel to a diode. The parameters required are short circuit current (I_{sc}), open circuit voltage (V_{oc}) and the diode ideality factor. The ideality factor of a diode is a measure of how closely the diode follows the ideal diode equation.

Due to the presence of recombination losses, ideality factor other than ideal are produced. The basic model is improved for accuracy by introducing the series resistance (Rs).It does not prove to be efficient under temperature variations. To overcome this drawback, an additional shunt resistance (R_p) is included. This increases the parameters to a considerable level and the computations are increased. Although R_p is added, the model fails under low irradiation conditions. To improve the accuracy, the two diode model is introduced where another diode is in parallel to prevailing current source and diode.

Modeling of P-V Cell

The model does not take into account the internal losses of the current. Diode is connected in anti-parallel with the light generated current source. The output current (I) is obtained by Kirchhoff law:

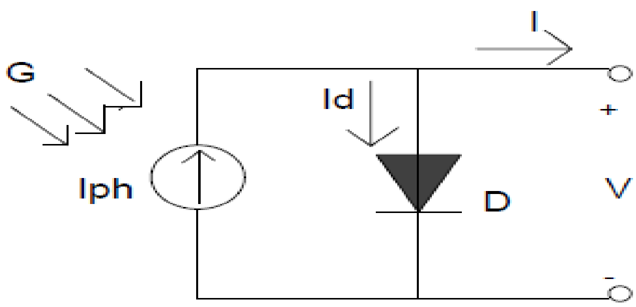


Fig 4.3 Ideal Single Diode Model of PV Cell

$I = I_{ph} - I_d$

I_{ph} is the photocurrent

I_d is the diode currents

Which is proportional to the saturation current is given by the equation

$$I_d = I_o\left[exp\left(\frac{V}{A.Ns.Vt}\right) - 1\right] \ldots\ldots (1)$$

V is the voltage imposed to the saturation current is given by the equation

$$V_t = K.\left(\frac{Tc}{q}\right) \ldots\ldots (2)$$

I_o is the reverse saturation or leakage current of the diode (A)

V_t = 26mV at 300 k for sillisium cell,

T_c is the actual cell temperature (K),

K is the Boltzmann constant 1.381×10^{-23} J/K,

Q is the electron charge (1.602×10^{-19}C)

V_t is called the thermal voltage because of its exclusive dependence of temperature.

N_s: is the number of PV cells connected in series. A is the ideality factor which depends on PV cell. It is necessary to underline that A is a constant which depends on PV cell technology. All the terms by which, V id divided in equation (2) under exponential function are inversely proportional to cell temperature and so, vary with varying conditions. In this work, this term is designed by 'a' and called the thermal voltage (V), the ideality factor, is considered constant and is chosen according to technology of the PV cell. The thermal voltage "a" is presented by equation (4)

$$A=\frac{Ns.A.K.Tc}{q} = N_s.\ A\ .V_t \ldots\ldots (3)$$

'A' is called "the modified ideality factor" and is considered as a parameter to determine,While A is the diode ideality.

In reality, it is impossible to neglect the series resistance R_S and the parallel resistance R_P because of their impact on the efficiency of the PV cell and the PV module. When R_S is taken into consideration, equation (2) should take the next form

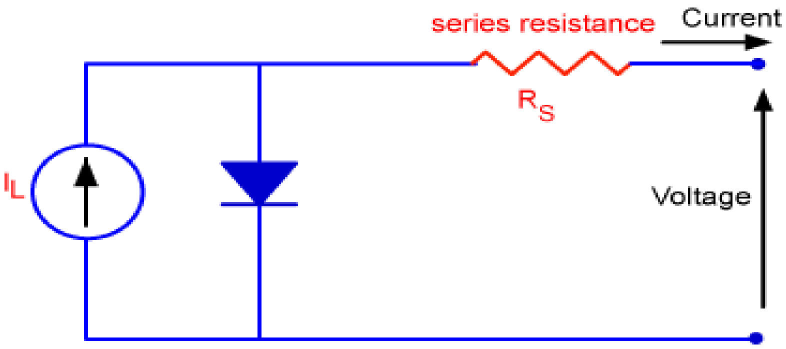


Fig 4.4 PV cell with a series resistance

$$I_d = I_o\left[exp\left(\frac{V+I.Rs}{a}\right)-1\right] \quad \ldots\ldots (4)$$

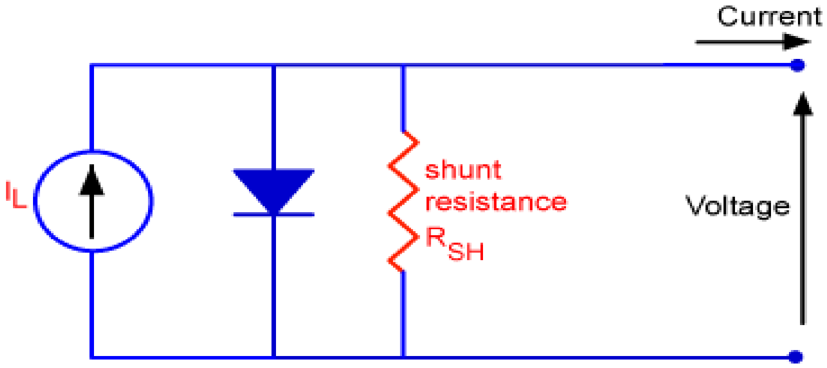


Fig 4.5: P-V cell with parallel resistance

This is the practical model representation of PV cell

By applying Kirchhoff law, current will be obtained by the equation

$$I = I_{ph} - I_d - I_p \quad \ldots\ldots (5)$$

I_p is the current leak in parallel resistor. According to this the output current of a module containing N, cells in series will be:

$$I = I_{ph} - I_o\left[exp\left(\frac{V+I.Rs}{a}\right)-1\right] - \frac{V+Rs.I}{Rp} \quad \ldots\ldots (6)$$

It is not easy to determine the parameter of this transcendental equation. But this model offers the best match with experimental values.

Determination of parameters

The number of parameters varies depending on the chosen model and on the assumptions adopted by the series searchers. It is considered that I_{ph}, I_{o}, R_{s}, R_{P} and the factor ideality are five parameters that depend on the incident solar radiation and the cell temperature. The unknown parameters are I_{ph}, I_{o}, R_{s} and Y.

Where $Y = A.N_s$

In this work the four parameters that have to be evaluated are also I_{ph}, I_{o}, R_{s}, and Rp.

Determination of I_{ph}

The output current at the standard test conditions (STC) is:

$$I = I_{ph,\,ref} - I_{o,\,ref}\left[exp\left(\frac{V}{aref}\right) - 1\right] \quad \text{.......(7)}$$

This equation allows quantifying $I_{ph,\,ref}$ which cannot be determined otherwise. When the PV cell is short-circuited:

$$I_{sc,\,ref} = I_{ph,\,ref} - I_{o,\,ref}\left[exp\left(\frac{0}{aref}\right) - 1\right] = I_{ph,\,ref} \quad \text{.......(8)}$$

But this equation is valid only in ideal case. So, the equality is not correct. And then, equation(8) has to be written as:

$$\mathbf{I_{ph,\,ref} \approx I_{sc,\,ref}} \quad \text{.......(9)}$$

The photo current depends on both irradiance and temperature:

$$I_{ph} = \frac{G}{Gref}\,(Iph,ref + \mu sc.\Delta T) \quad \text{.......(10)}$$

G= irradiance (w/m^2), G_{ref}: irradiance at STC =1000 (w/m^2)

$\Delta T = T_c - T_{c,\,ref}$ (Kelvin), $T_{c,\,ref}$: cell temperature at STC = 25+273 =298 k,

μ_{sc}: coefficient temperature of short circuit current (A/K), provided by the manufacturer, $I_{ph,ref}$: photocurrent (A) at STC.

Determination of I_o

The shunt resistance Rp is generally regarded as great, so the last term of the relationship(7) Should be eliminated for the next approximation. By applying equation (7) at the three most remarkable points at standard test condition: the voltage at open circuit (I= 0, V= $V_{oc,\ ref}$), the current at short circuit (V= 0, I= $I_{sc,\ ref}$) and the voltage ($V_{mp,\ ref}$) and current ($I_{mp,\ ref}$) at maximum power, the following equations can be written:

$$I_{sc,\ ref} = I_{ph,\ ref} - I_{o,\ ref}\left[exp\left(\frac{Isc,ref.Rs}{aref}\right) - 1\right] \text{...} (11)$$

$$0 = I_{ph,\ ref} - I_{o,\ ref}\left[exp\left(\frac{Voc}{aref}\right) - 1\right] \text{...} (12)$$

$$I_{pm,\ ref} = I_{ph,\ ref} - I_{o,\ ref}\left[exp\left(\frac{Vpm,ref+Ipm,ref}{aref}\right) - 1\right] \text{..} (13)$$

The term (-1) has to be neglected because it is very smaller than exponential term. According to equation (10) and by substituting ($I_{ph,\ ref}$) in equation (13):

$$0 = I_{sc,\ ref} - I_{o,\ ref}.\exp\left(\frac{Voc,ref}{aref}\right) \text{.......................................} (14)$$

$$I_{o,\ ref} = I_{sc,\ ref}.\exp\left(\frac{Voc,ref}{a}\right) \text{...} (15)$$

The reverse saturation current is given by:

$$I_o = DT^3\exp\left(\frac{-q\varepsilon G}{A.K}\right) \text{...} (16)$$

εG = material band gap energy (eV), (1.12eV for Si)

D = diode diffusion factor.

In order to eliminate the diode diffusion factor, equation (17) is computed twice; at a T_c and at $T_{c,\ ref}$. Then, the ratio of the two equations is written as in the next expression:

$$I_o = I_{o,\ ref}\left(\frac{Tc}{Tc,ref}\right)^3 \times \exp\left[\left(\frac{q\varepsilon G}{A.K}\right)\left(\frac{1}{Tc,ref} - \frac{1}{Tc}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

$$I_o = I_{sc,\ ref}\exp\left(\frac{-Voc,ref}{a}\right)\left(\frac{Tc}{Tc,ref}\right)^3 \times\ exp\left[\left(\frac{q\varepsilon g}{A.K}\right)\left(\frac{1}{Tc,ref} - \frac{1}{Tc}\right)\right] \ldots\ldots\ldots\ldots\ldots (18)$$

Equation (19) present I_o with some parameters provided by the manufacturers as ($V_{ref,\ Tc,\ ref,}\propto$), others, related to the technology of the PV cell, as (A, e_G) and some constants. But “a”and Tc is dependents of actual temperature. That is why; I_o has to be determined at real time.

CHAPTER 5

MPPT CONTROLLER

5.1 Maximum Power Point Tracking

Maximum Power Point Tracking is a technique used commonly with wind turbines and photovoltaic (P-V) solar systems to maximize power extraction under all conditions. MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from P-V module under certain conditions. The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

Typical P-V module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day.

The efficiency of solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whole duty cycle Is varied by using an MPPT algorithm.

P-V solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the maximum power point and MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.

5.2 WHAT IS MPPT?

The Maximum Power Point Tracking (MPPT) describes the point on a current voltage (I-V) curve at which the solar PV device generates the largest output i.e. where the product of current intensity (I) and voltage (V) is Maximum. The MPPT may change due to external factors such as temperature, light conditions and workmanship of the device.

In order to ensure maximum power output (P_{max}) of a solar PV device in view of these external factors, maximum power output trackers (MPPT) may be operated to regulate the resistance of the device.

5.3MPPT Controller

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT).This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is varied by using an MPPT algorithm.

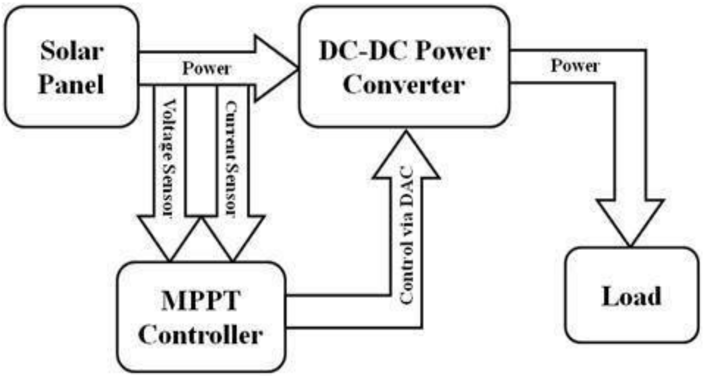


Fig 5.1: MPPT Controller.

This presents an experimental comparison of two algorithms developed in order to maximize the output power from a photovoltaic (P-V) system for the same given set of conditions. The numerical modeling of the P-V system shows the MPPT interest and then the extended MPPT algorithms are highlighted. In this a P-V system based on a boost converter as MPPT device is considered. A programmable DC electronic load is fed by two identical P-V systems in which the MPPT control converter algorithms are different. This experimental condition operates under the same conditions such as changing solar radiation and cell temperature. The experimental result shows the MPPT energy efficiency of the proposed algorithms. Temperature mainly changes the panel voltage operating point, while irradiance mainly changes the panel operating current. The maximum power point tracking (MPPT) methods proposed in this are extended by algorithms:

1. Incremental conductance method
2. Fuzzy logic method
3. Perturb and observe method
4. Fractional short circuit current
5. Fractional open circuit voltage
6. Neural networks

.

5.4 MPPT Implementation

When a load is directly connected to the solar panel, the operating point of the panel will rarely be peak power. The impedance seen by the panel derives the operating point of the solar panel. Thus by varying the impedance seen by panel, the operating point can be moved towards peak power point. Since panels are DC drives, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the order circuit (load). Changing the duty ratio of the DC-DC converter results in the impedance change as seen by panel. At particular impedance the operating point will be at the peak power transfer point. The I-V curve of the panel can vary considerably with variation in atmospheric conditions such as radiance and temperature. Therefore it is not feasible to fix the duty ratio with such dynamically changing operating conditions.

5.5 Advantages

1) MPPT solar controller is necessary for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.

2) MPPT solar controller allows users to use PV module with a higher voltage output than operating voltage of battery system.

3) MPPT solar controller reduces complexity of system while output of system is high efficiency. Additionally, it can be applied to use with more energy sources. Since PV output power is used to control DC-DC converter direct.

5.6 The Incremental Conductance Method

This method was first presented in, and it is based on the observation that in the MPPT, the following condition occurs:

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = 0$$

By accounting for the dependence of the PV current on the voltage, it is possible to express such a condition as follows:

$$I + V\frac{dI}{dV} = 0$$

So that the validity of condition is equivalent to

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

Which means that, at the MPPT, the absolute value of the conductance must be equal to the absolute value of the incremental conductance. Such a condition is the basis of incremental conductance (INC) MPPT method. Condition is verified through a repeated measure of the conductance at two different, yet closes enough, values of the PV voltage. As a consequence, the method requires the application of a repeated perturbation of the voltage value, until the following condition occurs:

$$\frac{I_k}{V_k} = \frac{I_k - I_{k-1}}{V_k - V_{k-1}}$$

where the indices k and k-1 refer to two consecutive samples of the PV voltage and current values. In an 8.4% increase in the PV power produced by a PV system equipped with the INC MPPT method is claimed with respect to the P&O method. The reason for this improvement has been mainly ascribed to the fact that the INC method is able to avoid any further oscillation of the operating point when condition () has been fulfilled. Consequently, the Inc method behaves in a way that is similar to P&O during transients, but it is able to avoid any power loss in steady-state conditions because it remains in the MPP unless any exogenous variable makes no more fulfilled.

Unfortunately, condition holds only for an ideal system, because it is almost never verified because of noises and quantization effects, related to the microcontroller by means of which the INC method is implemented. As a consequence, the method continues to check the validity of also in stationary irradiance conditions, so that the theoretical advantage of INC over P&O vanishes.

The evaluation of can be useful in order to understand on which side of the P-V curve with respect to the MPP the actual operating point lies. Indeed, we get

$$\frac{1}{V}\frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV} = G + dG$$

Where G is the conductance and dG is the incremental conductance. It results that, on the left side of the P-V curve with respect to the MPPT, dP/dV > 0: This means, according to that G+dG>0. As a consequence, if the conductance is greater than the absolute value of the incremental conductance, than the operating point is on the left side of the MPP, so that the voltage must be increased in order to move closer to the MPP. Similarly, if G+dG<0, the actual operating point is at a voltage higher than that of the MPP, so that the voltage must be reduced if the MPP has to be approached. Such information is not available if the P&O technique is used, so this is a real advantage ensured by the INC method. The new voltage at which condition () must be tested is evaluated according to the following iterative formula:

$$V_{PV}^{k+1} = V_{PV}^{k} + sign(G + dG).V$$

Where ΔV is the voltage step chosen for the perturbative phase during which the MPP is searched. The flow chart shown in below fig 5.2 puts into evidence the perturbative nature of the INC algorithm and the use of the information deriving from the comparison between the values of the conductance and the incremental conductance.

Due to the fact that the INC method is inherently based on a perturbative approach, the amplitude of the perturbation step needs to be optimized as for the P&O, regardless of whether iit acts on duty cycle or on the reference voltage. In a direct dependency of the step amplitude on the power derivative has been used, the formula proposed therein is referred to as direct control of the converter’s duty cycle.

$$D = \pm N \cdot \left| \frac{dP}{dV} \right|$$

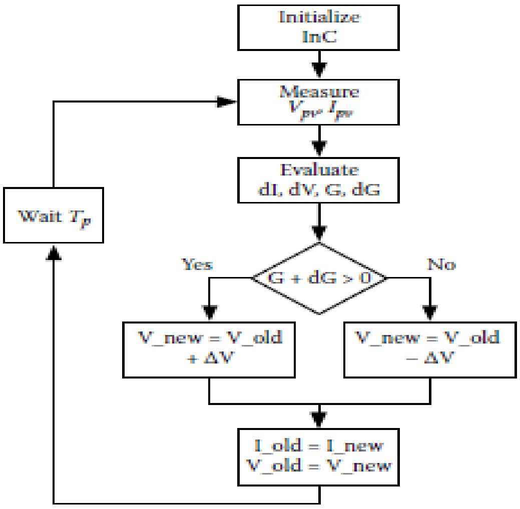


Fig.: 5.2 Flow chart of the incremental conductance method

In this way, the lower the power derivative, the closer the MPP and the smaller the duty cycle perturbation that can be settled. The authors also propose an upper bound for the value of the coefficient N, which affects the tracking performances dramatically. The inequality involves the power derivative obtained at the larger ΔD to be used, and the value thereof and its meaning are same as in.

$$N < \frac{D_{max}}{\left|\frac{dP}{dV}\right|_{fixedstep=\ D_{max}}}$$

Dynamic performances under very fast irradiation variation are claimed to be improved in, where a suitable function used for the MPP bounding is introduced. The algorithm step size modes are switched by the extreme values of a threshold function that is the product of the nth power of the PV array output power and the derivative of the same power:

$$C = P^n \cdot \left|\frac{dP}{dI}\right|$$

the parameter n being used for a closer MPP bounding. The function C has two maximum values, one of the left side and one on the right side of the MPPT. The proposed MPPT algorithm uses a variable step size mode if the PV array current falls between these two current values. Otherwise a fixed step size mode is used. This method improves both the steady state and the dynamic MPPT response.

5.7 The Perturb and Observation Method

P&O algorithms are widely used in MPPT because of their simple structure and the few measured parameters which are required. They operate by periodically perturbing (i.e. incrementing or decrementing) the array termed voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing, the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. This means the array terminal voltage is perturbed every MPPT cycle, therefore when the P&O is reached, the P&O algorithm will oscillate around it resulting in a loss of PV power, especially in cases of constant or slowly varying atmospheric conditions. This problem can be solved by improving the logic of the P&O algorithm to compare the parameters of two preceding cycles in order to check when the P&O is reached, and bypass the perturbation stage. Another way to reduce the power loss around the P&O is to decrease the perturbation step, however, the algorithm will be slow in following the P&O when the atmospheric conditions start to vary and more power will be lost.

The implementation of P&O type MPPTs with increased refresh rates of current (I)-requires two things. First, the P&O algorithm should operate with high sampling rates and the sample values of voltage and current should reflect the tendency of the output power when increasing or decreasing the reference signal for the MPPT power converter. Second, the response time of the MPPT power converter should be very fast while keeping the switching losses (frequency) low. This can be done by comparing instantaneous, instead of average, values of and Vpv and peak current control that presents one-cycle speed of response for small variations in the reference current, to further improve the performance of the system. The proposed MPPT system employs peak current control. The switch is turned on by a clock signal and turned off when the actual current reaches the reference current. Therefore, the reference current can be perturbed (increased or decreased) in every switching cycle, meaning that the perturbation cycle or refresh rate is equal to the switching cycle. In this method, a fixed perturb value is utilized to generate a reference signal for the outer control loop.

The Perturb signal is either the array reference voltage or current. The fixed perturb step is determined according to the system designer as a result of previous experience. Therefore, the solution provided by this method is not generic and system dependent. For small perturb steps, the tracking is slow but the power/voltage oscillations are minimal. In the case of large perturb step, faster tracking is achieved with increased oscillations. Hence, P&O techniques with fixed perturb suffer an inherent tracking–oscillations trade off problem. A PI/hysteresis Controller following the MPPT is utilized to control the power converter.

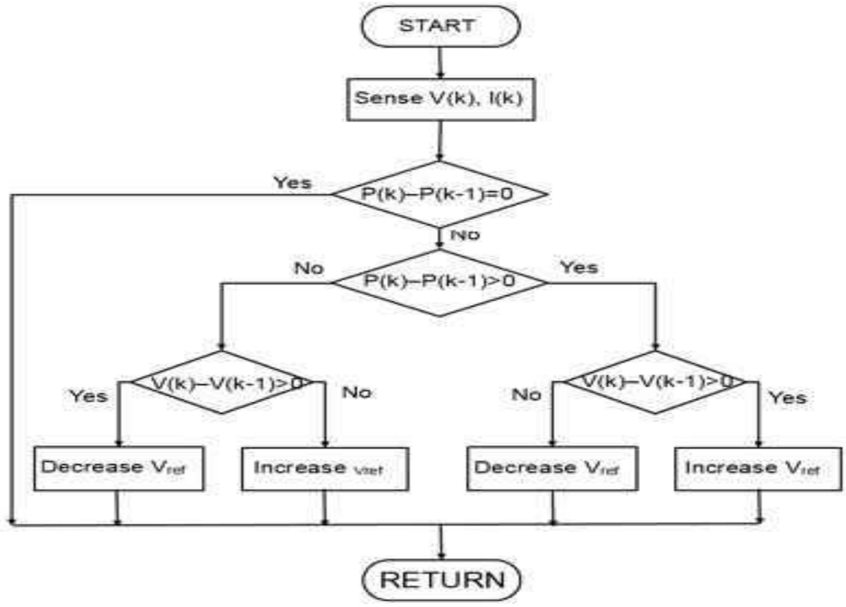


Fig.: 5.2 Flow chart of the Incremental Conductance Method

The size of the perturbation has to be chosen according to the inductor size and the switching (clock) frequency so that the switch always turns off before the next turn on signal. The perturbation and observation method (P&O), which moves the operation point of array toward the maximum power point (MPP) by periodically of any output voltage, is often used in many PV systems. It works well when the Irradiance changed very slowly, but the P&O method fails to track the MPP when irradiance changed suddenly by having slow dynamic response.

5.8 FUZZY Logic Controller

The use of fuzzy logic control has become popular over the last decade because it can deal with imprecise inputs, does not need an accurate mathematical model and can handle nonlinearity. Microcontrollers have also helped in the popularization of fuzzy logic control. The Fuzzy Logic tool was introduced in 1965, also by Lotfi Zadeh, and is a mathematical tool for dealing with uncertainty.

It has also been used in recognition of hand written symbols in Sony pocket computers, flight aid for helicopters, controlling of subway systems in order to improve driving comfort, precision of halting, and power economy, improved fuel consumption for automobiles, single-button control for washing machines, automatic motor control for vacuum cleaners with recognition of surface condition.

Additional benefits of fuzzy logic include its simplicity and its flexibility. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity.

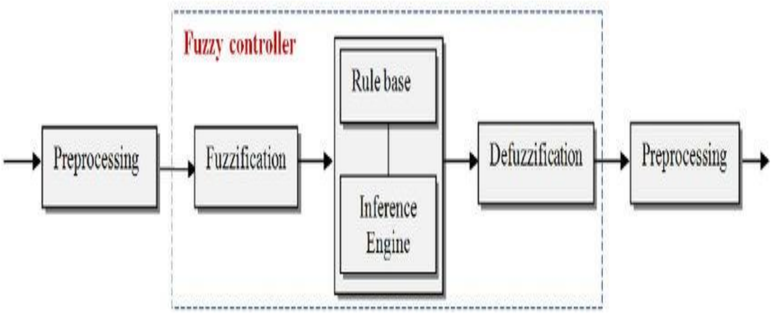


Fig5.3 Fuzzy Logic System

Fuzzy sets provide means to model the uncertainty associated with vagueness, imprecision, and lack of information regarding a problem. Linguistic variable,which represents the imprecision existing in the system. The uncertainty is found to arise from ignorance, from chance and randomness due lack of knowledge and vagueness.

$$= \begin{Bmatrix} 1, x \in A \\ 0, x \notin A \end{Bmatrix}$$

Where $X_A(x)$ is the membership of element *x* in set *A* and *A* is the entire set on the universe. This membership was extended to possess various "degree of membership" on the real continuous interval.

The Fuzzy Logic Consists of Three Stages

1. Fuzzification
2. Inference system
3. De-Fuzzification

1. Fuzzification – convert classical data or crisp data into fuzzy data or Membership Functions (MFs)

2. Fuzzy Inference Process – combine membership functions with the control rules to derive the fuzzy output

3. De-Fuzzification – use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application.

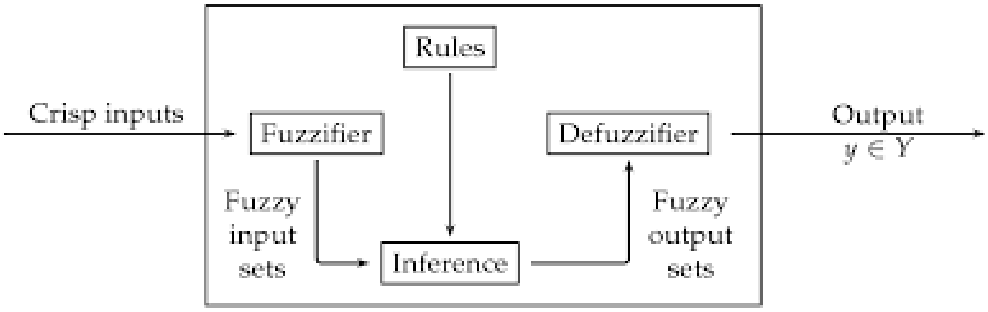


Fig 5.4 Fuggy Logic Blocks

Fuzzification comprises the process of transforming numerical crisp inputs into linguistic variables based on the degree of membership to certain sets. Membership functions, lies between (0 1) are used to associate a grade to each linguistic term. The number of membership functions used depends on the accuracy of the controller.

5.8.1 FUZZY Inference System

Fuzzy inference system consists of a Fuzzification interface, a rule base, a database, a decision-making unit, and finally a De-Fuzzification interface.

Rule base: Rule base containing a number of fuzzy IF–THEN rules.

Data base: Database which defines the membership functions of the fuzzy sets used in the fuzzy rules.

Decision-making: Decision-making unit which performs the inference operations on the rules.

5.8.2 Fuzzification:

Fuzzification interface which transforms the crisp inputs into degrees of match with linguistic values;

5.8.3 De-Fuzzification:

De-Fuzzification interface which transforms the fuzzy results of the inference into a crisp output.

In this seven fuzzy levels are used:

1. NB (Negative Big)
2. NM (Negative Medium)
3. NS (Negative Small)
4. ZERO(Zero)
5. PS(Positive Small)
6. PM(Positive Medium)
7. PB(Positive Big)

The values a, b and c are based on the range values of the numerical variable. In some cases the membership functions are chosen less symmetric or even optimized for the application for better accuracy .The inputs of the fuzzy controller are usually an error, E, and the change in the error, Delta E. The error can be chosen by the designer, but usually it is chosen as Delta P/Delta V because it is zero at the MPP. Then E and Delta E are defined as,

$$\frac{meassuredvalue - accepted\ value}{accepted\ value} * 100$$

The output of the fuzzy logic converter is usually a change in the duty ratio of the power converter, ΔD, or a change in the reference voltage of the DC link, ΔV. The rule base, also known as rule base look up table or fuzzy rule algorithm, which associates the fuzzy output to the fuzzy inputs based on the power converter used and on the knowledge of the user. Where the inputs are E and ΔE, and the output is a change in the DC-link voltage, ΔV. For example, if the operating point is far to the right of the MPP, E is NB, and ΔE is zero. Then to reach the MPPT the reference voltage should decrease, so ΔV should be NB (Negative) to move the operating point towards the MPPT.

Advantages

These controllers, besides dealing with imprecise inputs, not needing an accurate mathematical model and handling nonlinearity, are fast convergence and minimal oscillations around the MPP.

Disadvantages

In this the effectiveness depends a lot on the skills of the designer; not only on choosing the right error computation, but also in computation with an appropriate rule base.

5.9 FUZZY In MATLAB

How to Build Mamdani Systems
Using Fuzzy Logic Toolbox
Graphical User Interface Tools

This example shows how to build a Fuzzy Inference System (FIS) for the tipping example using the Fuzzy Logic Toolbox graphical user interface (GUI) tools. You use the following graphical tools to build, edit, and view fuzzy inference systems:

- **Fuzzy Inference System (FIS) Editor** to handle the high-level issues for the system—How many input and output variables? What are their names? Fuzzy Logic Toolbox software does not limit the number of inputs.

However, the number of inputs may be limited by the available memory of your machine. If the number of inputs is too large, or the number of membership functions is too big, then it may also be difficult to analyze the FIS using the other GUI tools.

- **Membership Function Editor** to define the shapes of all the membership functions associated with each variable

- **Rule Editor** to edit the list of rules that defines the behavior of the system.

- **Rule Viewer** to view the fuzzy inference diagram. Use this viewer as a diagnostic to see, for example, which rules are active, or how individual membership function shapes influence the results.

- **Surface Viewer** to view the dependency of one of the outputs on any one or two of the inputs—that is, it generates and plots an output surface map for the system.

These GUIs are dynamically linked, in that changes you make to the FIS using one of them, affect what you see on any of the other open GUIs. For example, if you change the names of the membership functions in the Membership Function Editor, the changes are reflected in the rules shown in the Rule Editor.

You can use the GUIs to read and write variables both to the MATLAB workspace and to a file (the read-only viewers can still exchange plots with the workspace and save them to a file). You can have any or all of them open for any given system or have multiple editors open for any number of FIS systems..

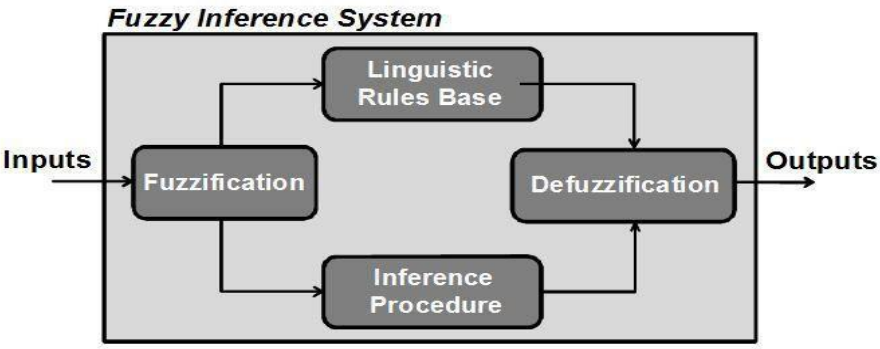


Fig 5.5 Fuzzy Interface System

The FIS Editor

The FIS editor displays information about a fuzzy inference system. To open the FIS Editor, type the following command at the MATLAB prompt: fuzzy The FIS Editor opens and displays a diagram of the fuzzy inference system with the names of each input variable on the left, and those of each output variable on the right, as shown in the next figure. The sample membership functions shown in the boxes are just icons and do not depict the actual shapes of the membership functions.

In The FIS Editor:-

1 Select Edit >Add variable >Input.

A second yellow box labeled input2 appears.

2 Click the yellow box input1. This box is highlighted with a red outline.

3 Edit the Name field from input1 to service, and press Enter.

4 Click the yellow box input2. This box is highlighted with a red outline.

5 Edit the Name field from input2 to food, and press Enter.

6 Click the blue box**o**utput1.

7 Edit the Name field from output1 to tip, and press Enter.

8 Select File >Export >To Workspace.

9

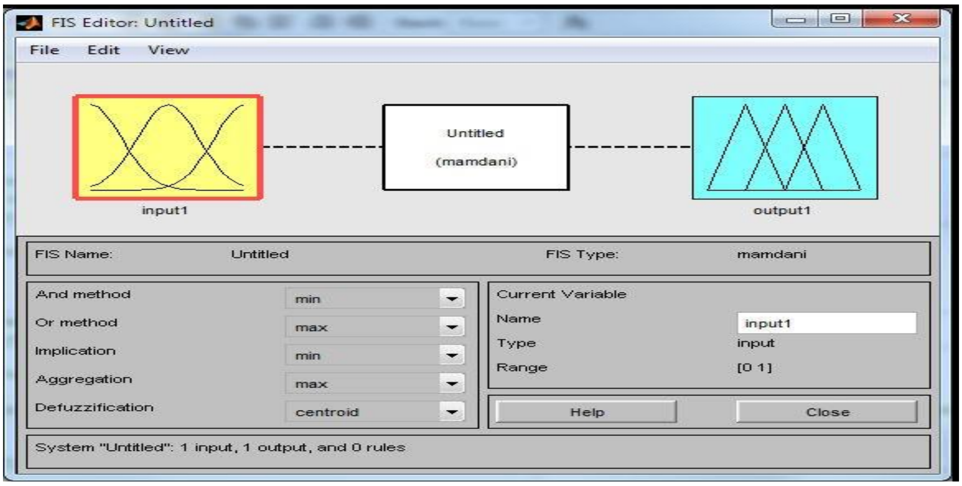


Fig5.6: FIS Editor

The Membership Function Editor

The Membership Function Editor is the tool that lets you display and edits all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system. The Membership Function Editor shares some features with the FIS Editor, as shown in the next figure. In fact, all of the five basic GUI tools have similar menu options, status lines, and Help and Close buttons.

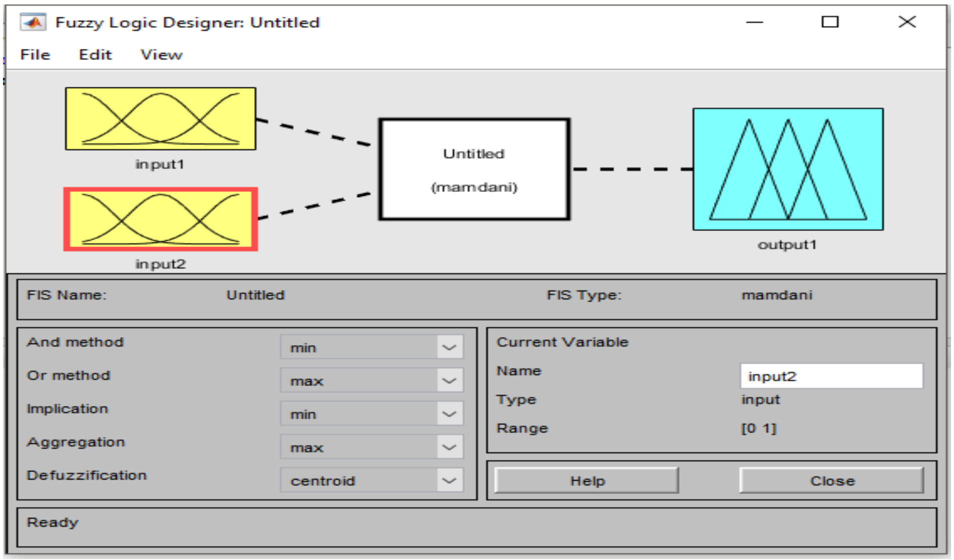


Fig 5.7: Mamdani Representation of Fuzzy Logic Controller

ΔP \ ΔV	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig 5.8: Fuzzy Rule Table

The proposed output from FLC is Δ which correspond to the modulation signal which is applied to the PWM modulator in order to produce the switching pulses. The input variables are defined as in below. During fuzzification, the numerical input variables are converted into linguistic variables based on the membership functions. In Figure 5.8 Figures 1, 2 and 3 show the membership of Δv, ΔP and Δu respectively. Seven fuzzy levels are used for all the inputs and outputs variables: NB (negative big),NM (negative medium) NS (negative small), ZE (zero), PS (positive small), PM (positive medium) and PB (positive big).

$$\Delta V=V(K)-V(K-1) \quad ; \qquad \Delta P=I(K)-P(K-1)$$

The theoretical design of the rules based on the fact that if the change in the voltage causes the power to increase, the moving of the next change is kept in the same direction otherwise the next change is reversed. After the theoretical design, all the MFs and the rules were adjusted by the trial and error to obtain the desired performance.

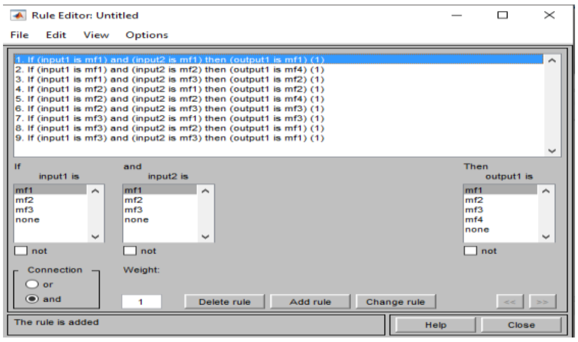


Fig 5.9: Fuzzy Rule Editor

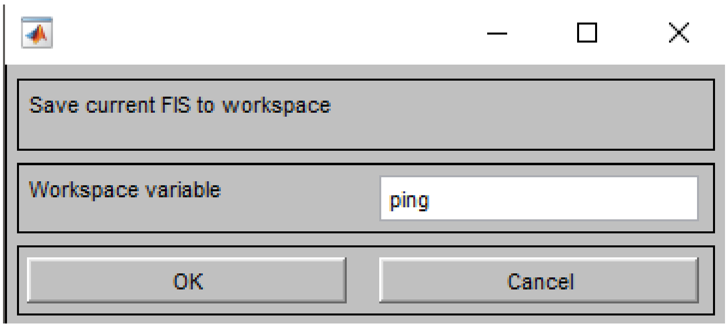
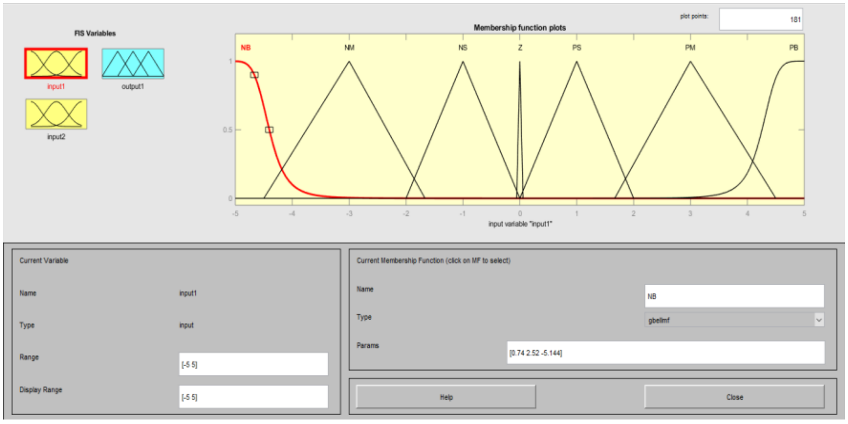
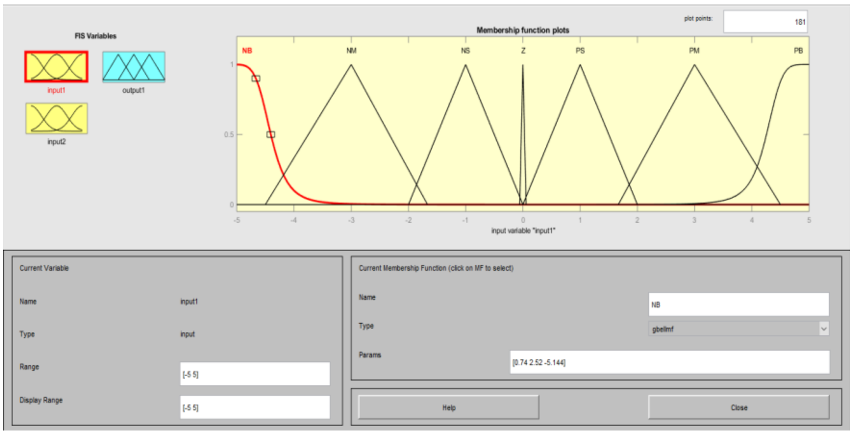


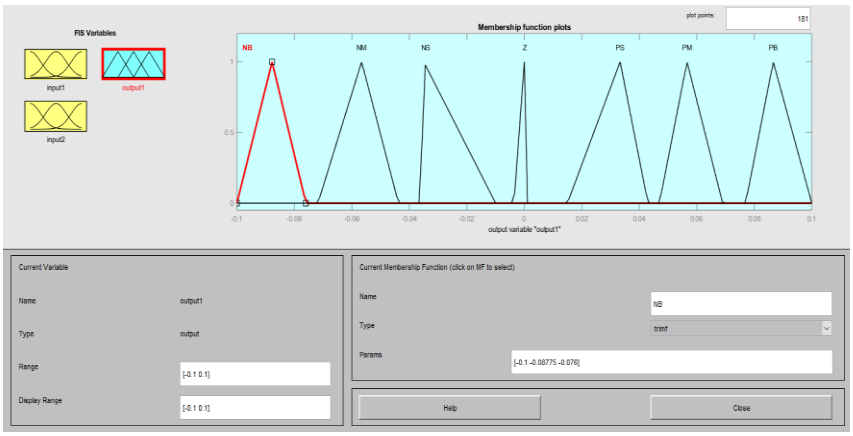
Fig 5.10: Save to Work Space



1. Input 1 membership function of Δv



2. Input 2 membership function of ΔP



3. Output membership function ΔU change in Error

Fig .5.11: Membership Functions of Fuzzy Logic Controller

CHAPTER 6

BOOST CONVERTER

6.1 DC-DC 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 V_C 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 V_{CR}. The PWM control signal for the dc converter is generated by comparing V_{CR} with a saw tooth voltage V. There are four topologies for the switching regulators: buck converter, boost converter, buck-boost converter. However my project work deals with the boost regulator and further discussions will be concentrated towards this one.

DC to DC converters are used in portable electronic devices such as a cellular phones and Laptops, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored energy is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

Most DC to DC converter circuits also regulate the output voltage. Some exceptions include high-efficiency, LED power sources which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the output voltage.DC to DC converters developed to maximize the energy harvest for photo voltaic systems and for wind turbines are called power optimizers.

6.2 Boost Converter:

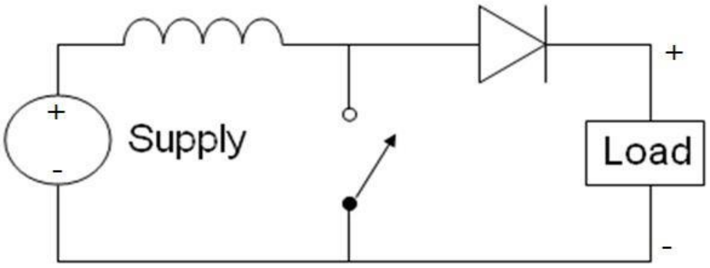


Fig 6.1: Boost converter basic circuit

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinate manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change.

6.3 Principle Of Operation of Boost Converter

The main working of boost converter is that the inductor is the main circuit resists sudden variations in input current. When the switch is OFF the inductor stores the energy in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. The large time constant compared to switching period ensures a constant output voltage.

6.4 Boost Converter and its Operation

The figure below shows a step up or PWM boost converter. It consists of a dc input voltage source Vg; boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

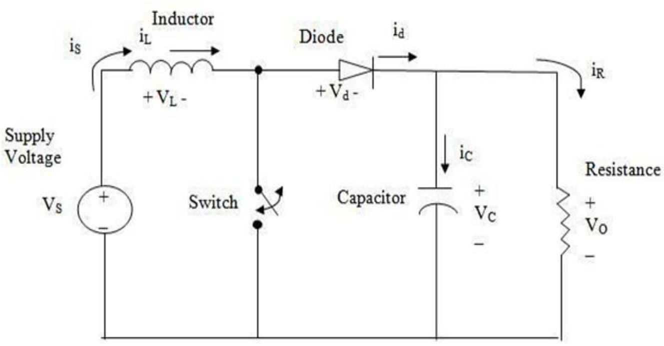


Fig 6.2: Boost Converter Circuit

6.4.1 Modes of Operation

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation.

In ON stage, switch is closed resulting in an increase in the inductor current. In OFF stage, switch is opened resulting in decrease in the inductor current.

6.4.2 Charging Mode

This mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

6.4.3 Discharging Mode

In this mode of operation; the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

6.5 Steady State Analysis of the Boost Converter:

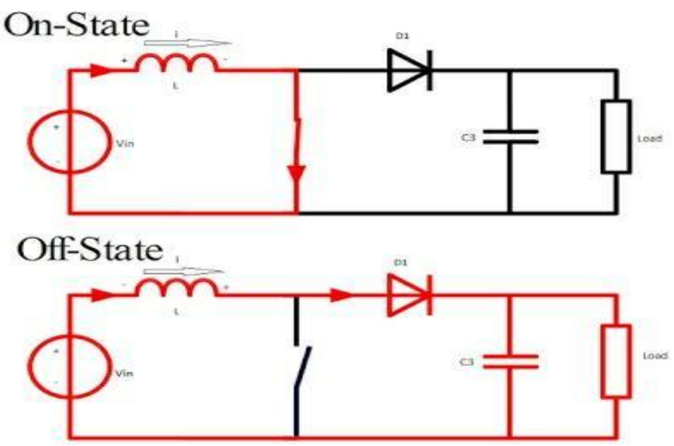


Fig6.3: ON-OFF State of Boost Converter

(a) Off State

In the OFF state, the circuit becomes as shown above fig: 6.3

When the switch is off, the sum total of inductor voltage and input voltage appear as the load voltage.

(b) On State

In the ON state, the circuit diagram is as shown above fig: 6.3

When the switch is ON, the inductor is charged from the input voltage source V_g and the capacitor discharges across the load. The duty cycle, $D= T_{ON}/T$ where $T=1/f$.

Continuous Mode

When a boost converter operates in continuous mode, the current through the inductor never falls to zero. Below figure shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behavior) operating in steady conditions. During the On-state, the switch S is closed, which makes the input voltage (Vi) appear across the inductor, which causes a change in inductor current value.

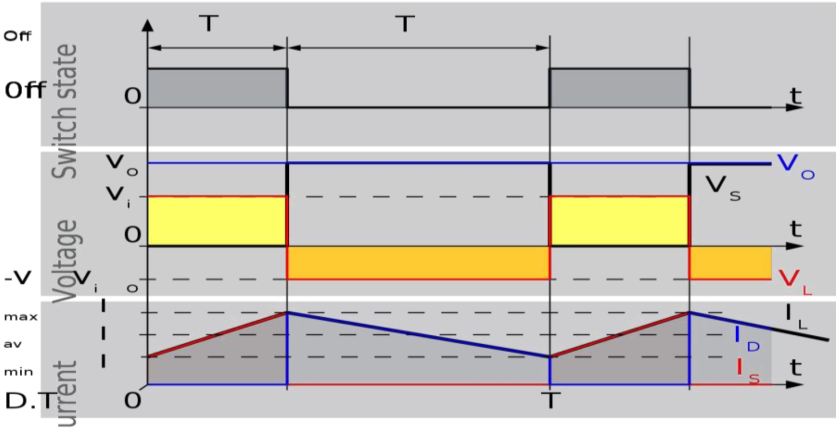


Fig 6.4: Continuous Mode of Boost Converter

Discontinuous Mode

The discontinuous conduction mode usually occurs in converters which consist of single-quadrant switches and may also occur in converters with two-quadrant switches. Two- level DC buck, and boost and buck-boost converters will be discussed further in this article. There are two levels indicated here towards the two-voltage level for the inductor voltage.

The energy stored in the inductor is proportional to the square of the current flowing through it. Having the same power through the converter, the requirement of the inductor current is higher in the case of the discontinuous conduction as compared to the continuous conduction mode. This causes more losses in the circuit of the discontinuous conduction. As the energy stored is not yet released to the output in the discontinuous conduction, the output gets affected by the ringing.

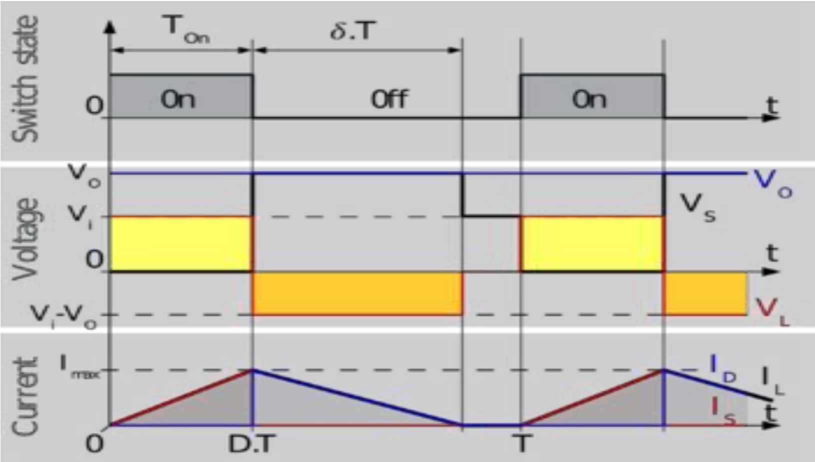


Fig 6.5: Discontinuous mode of Boost Converter

From the inductor voltage balance equation, we have,

$V_g(DT_g) + (V_g\text{-}V_o)\ (1\text{-}D)\ T_g\text{=}0$

$Vg\ (DTs) – V_g(DT_g) – V_gT_g\text{+ VoDTg -VoTg= 0}$

$V_0\text{= }V_g\text{/ (1-D)}$

Conversion ratio, $M = V_o/V_g\text{= 1/ (1-D)}$

From inductor current ripple analysis, change in inductor current,

$$\Delta I1 = (\mathrm{I}max - \mathrm{I}min)$$

$$\Delta IL = (Vg/L) * (DTg)$$

$$\Delta Il = (VgD)/\ (fgL)$$

$$L = V_gD\ /\ f_g\ (\Delta I1)$$

The boost converter operates in CCM (continuous conducting mode) for L> Lg

$$L_b\text{=} \frac{(1-D)2DR}{2f}$$

The current supplied to the output RC circuit is discontinuous. Thus a large filter capacitor is used to limit the output voltage ripple. The filter capacitor must provide the output dc current to the load when the diode D is off.

The minimum value of the filter capacitance that results in the voltage ripple V_r is given by

$$C_{min} = \frac{DV_o}{V_o R f}$$

6.6 Advantages

- Gives the high output voltage
- Low operating duty cycles
- Lower voltage on MOSFET.

6.7 Applications of Boost Converters

1. They are used in regulated power supplies.
2. They are used in regenerative breaking motors
3. Low power boost converters are used in portable device applications.
4. Boost converters are used in battery powered applications where there is space constraint to stack more number of batteries in series to achieve higher voltage.
5. As switching regulator circuit in highly efficient white LED drives

6.8 Design of the Boost Converter

(1) Current Ripple Factor(CRF)

According to IEC harmonic standard, CRP should be bounded within 30%

$$\frac{\Delta I_o}{I_o} = 30\%$$

(2) Voltage Ripple Factor(VRF):

$$\frac{\Delta V_o}{V_o} = 50\%$$

(3) Switching Frequency (f_s):

F_s= 100 KHZ

Step 1: calculation of duty cycle (D):

The first step to calculate the switch current is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

$$D = \frac{Vout - Vin}{Vout}$$

V IN(min) = minimum input voltage
VOUT = desired output voltage
η = efficiency of the converter, e.g. estimated 80%

Step 2: calculation of ripple current (ΔI_L):

The next step to calculate the maximum switch current is to determine the inductor ripple current. In the converters data sheet normally a specific inductor or a range of inductors is named to use with the IC. If none is given in the data sheet, the one calculated in the Inductor Selection section of this application note.

$$\Delta I_L = \frac{V_{IN(min)} \times D}{f_S \times L}$$

$V_{IN(min)}$ = minimum input voltage
D = duty cycle calculated in Equation 1
f_S = minimum switching frequency of the converter
L = selected inductor value

Step 3: calculation of inductor value

It is recommended to choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current.. Note that the inductor must always have a higher current rating than the maximum current increases with decreasing inductance.

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}}$$

V_{IN} = typical input voltage
V_{OUT} = desired output voltage
f_S = minimum switching frequency of th
ΔI_L = estimated inductor ripple current,

Step 4: calculation of capacitance value

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

CHAPTER 7

SIMULATION CIRCUITS AND RESULTS

7.1 P-V Cell Modeling

Here the PV cell is taken directly prom the Simulink blocks as shown in below figure containing the total PV cell

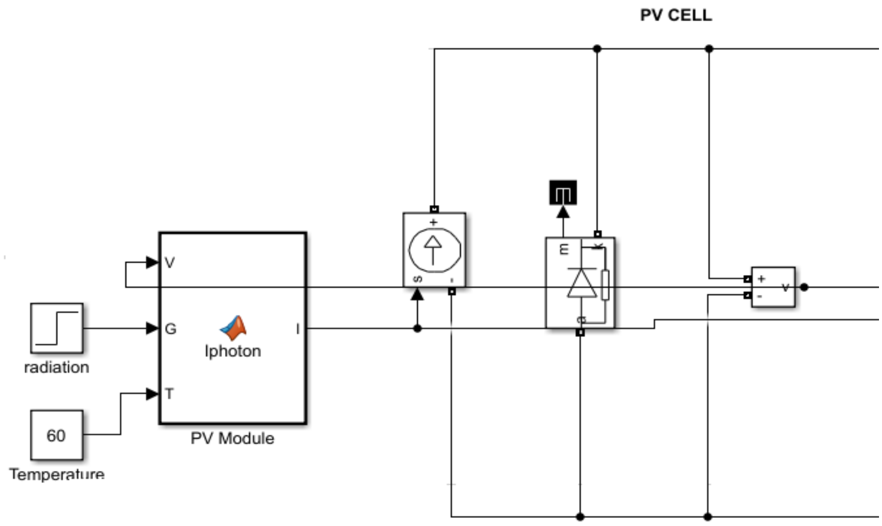


Fig 7.1 Subsystem of PV Cell

7.2 Boost Converter

The purpose of boost converter is to step up the dc voltage of PV cell. Because V_{oc} of PV cell is very low this cannot be used for driving the other loads.

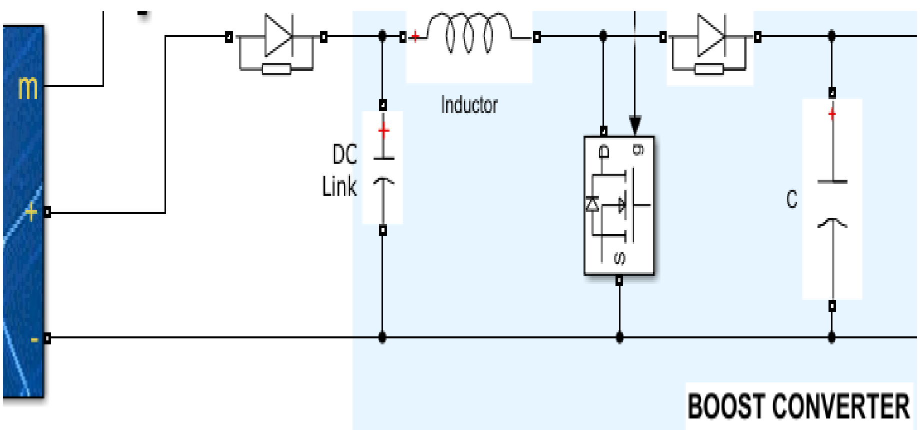


Fig 7.2 Subsystem of Boost converter

7.3 Characteristics of PV Cell

Plot of PV panel Voltage (V) Vs. Time (SEC)

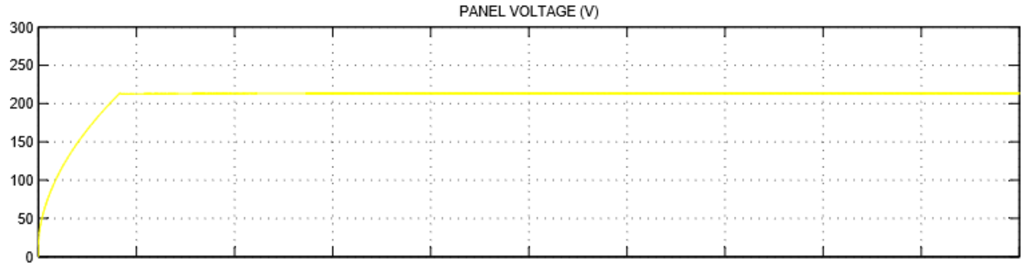


Fig 7.3: Voltage Vs. time of solar panel

Plot of PV panel Current (A) Vs. Time (SEC)

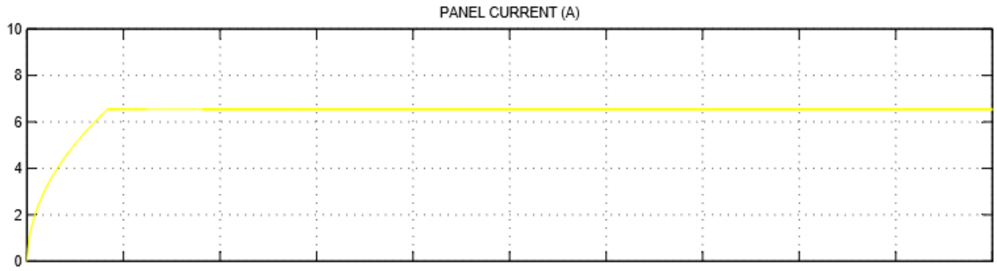


Fig 7.4: Current Vs. time of solar panel

7.4 Perturb and Observation Method

Proposed Simulink model of Perturb and Observe method is as follows.

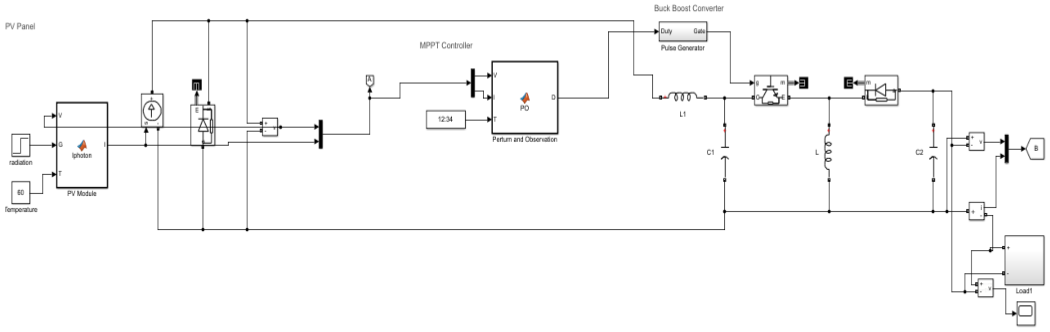


Fig 7.5: Simulink Model of Perturb and Observation Method

7.4.1 Result of Perturb and Observation Method

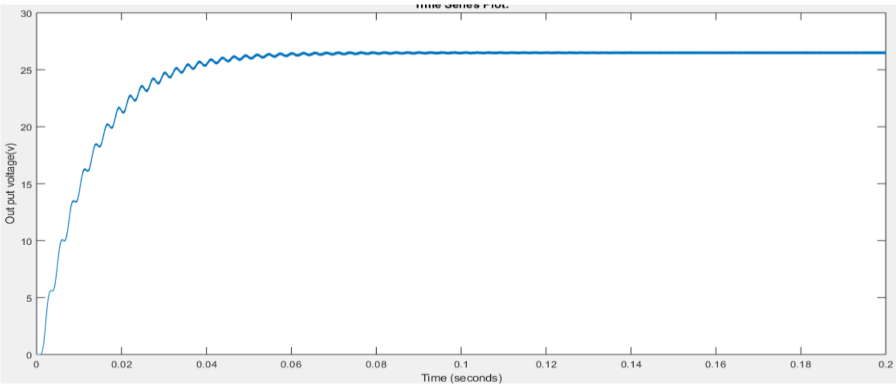


Fig 7.6: Plot of Output Voltage using P&O Vs. time

7.5 Incremental Conductance Technique

Proposed Simulink model of Incremental Conductance technique is as follows.

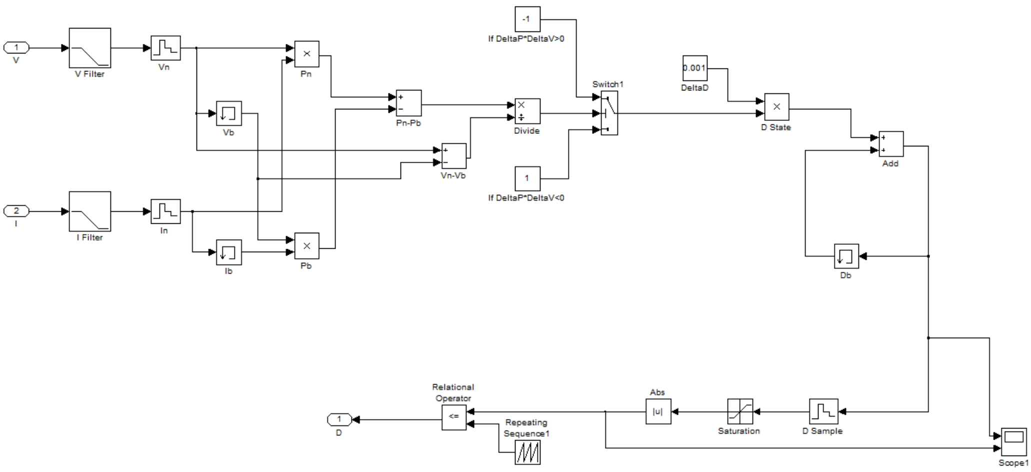


Fig 7.7: Simulink model of Incremental Conductance method

7.5.1 Result of Incremental Conductance Technique

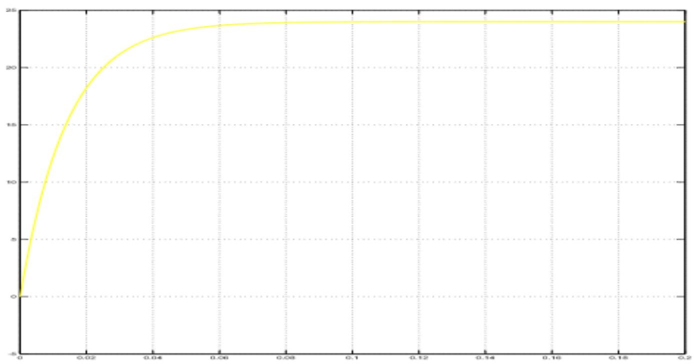


Fig 7.8: Plot of Output Voltage using INC Vs. time

7.6 Fuzzy logic controller

Proposed Simulink model of MPPT technique with Fuzzy logic controller method is as follows.

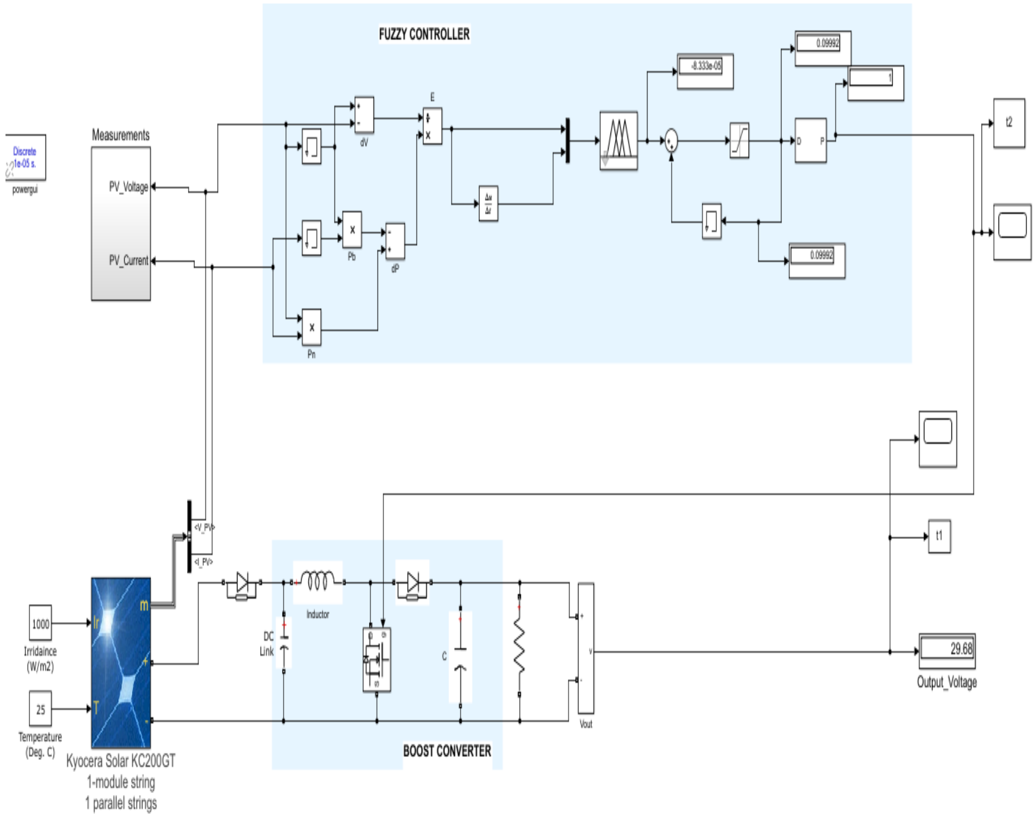


Fig 7.9: Simulink model of Fuzzy logic controller method

7.5.1 Result of Incremental Conductance Technique

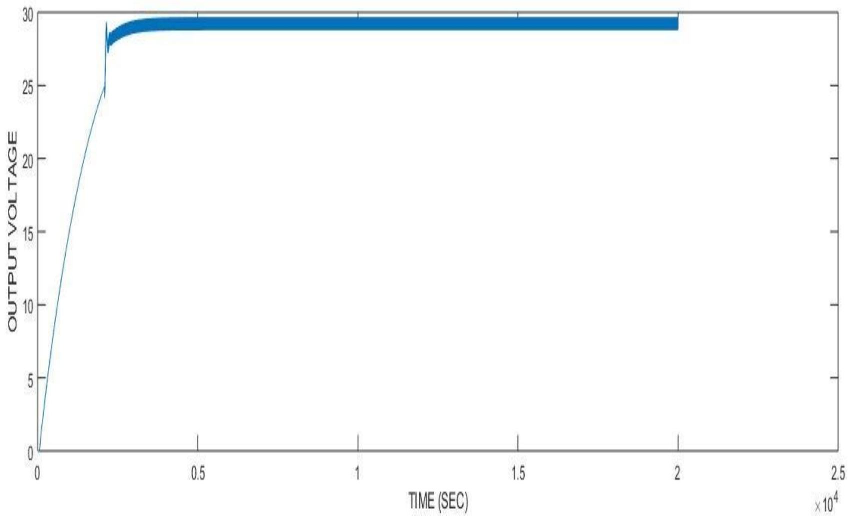


Fig 7.10: Plot of Output Voltage using Fuzzy controller Vs. time

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 Conclusions

In the present investigation study, the simulation and experimentation analysis of two mostly preferred existing (conventional) methods of maximum power point tracking control in solar photo-voltaic system has been carried out and one new MPPT control methods have been proposed. Design, modeling and development of three MPPT controllers (viz. perturb and observe, incremental conductance, fuzzy logic based, based MPPT controllers) for a stand-alone photo-voltaic system have been carried out.

Incremental conductance (INC), Perturb and Observe and Fuzzy logic based, MPPT controllers have been modeled and investigated using simulated analysis. P&O MPPT controller has better tracking and has been seen for step and ramp change in radiation. Responses to the step change in load resistance of INC to the Perturb and Observe MPPT controller have been found to be slow. Hence simulation results say that Perturb and Observe results better and faster when compared to the INC.

Fuzzy logic based MPPT controller has been designed and simulated with two inputs and one output. The steady-state oscillations have been greatly reduced using fuzzy logic based MPPT as compared to the P&O and INC based MPPT controllers. Better tracking has been seen for step and ramp changes in radiation but little spikes have been observed in its steady-state response. Its response for step change in load resistance has been found to be better and faster to that of the P&O and INC MPPT controllers.

8.2 Scope for Future Work

We identify following areas in which the research can be extended:

1. Simulation and experimental analysis of the proposed MPPT controllers for grid connected solar PV system with multilevel inverter can also be carried out.

2. A hybrid system can be developed with combination of mechanical sun tracking system and the proposed MPPT controllers for stand-alone solar PV system and its efficency analysis can be carried out.

3.The smaller ripples still can be nullified by connecting a suitable conventional controllers (i.e. P, PI and PID) with fine tunning.

PUBLICATIONS

ANNEXURE

1.Code for Photo Voltaic Module

```
function I = Iphoton(V, G, T)
% I - output current (ampere)
% V - output voltage (volt)
% G - operating solar irradiation (kW m-2)
% T - operating temperature (C)
% k - boltzmann's constant (J/K or m2 kg s-2 K-1)
% q - electron charge (coulomb)
% n - ideal factor dependent of the PV characteristics
% ki - short-circuit current temperature coefficient(A/K)
% Eg - band gap energy of semiconductor used in a cell (eV)
% Ns - number of cell in series
% Np - number of cell in parallel
% Tr - reference temperature at STC (K)
% Voc - open circuit voltage (volt)
% Iph - photo current (ampere)
% Isc - short circuit current (ampere)
% Is - cell saturation current (ampere)
% Ir - cell reverse saturation current (ampere)
% Rs - Series Resistance (ohm)
% Rsh -Shunt Resistance (ohm), here it is inf

k = 1.3806488e-23;
q = 1.6021766e-19;
n = 1.3;            % 1.3 for poly crystalline solar cell (1<n<2)
ki = 1.33e-3;       % 0.065A/C
Eg = 1.12;          % Si-1.12, GaAs-1.42
Ns = 10;
Np=6;
Tr = 273.15+25;     % 25C  0C=273.15K

Voc = 37.51/Ns;
Isc = 8.63/Np;
Tk = 273.15+T;
Vc = V/Ns;
Vt = (n*k*Tr) / q;
Vta = (n*k*Tk) / q;
b = (Eg*q) /(n*k);

% photo current at operating temperature
Iss = Isc * (1 + (ki * (Tk - Tr)));
% photo current at operating irradiation
Iph = G * Iss;

% Tinh toan dong bao hoa Io
Ir = Isc / (exp(Voc / Vt) -1);
Is = Ir * (Tk/Tr)^(3/n) * exp(b * (1/Tr - 1/Tk));

% calculation for Rs using slope of  I-V curve
dVdI = -2.0/Ns;  % Take dV/dI at Voc from I-V curve of datasheet
Xv = Ir / Vt * exp(Voc / Vt);
Rs = - dVdI - 1/Xv;
```

```
% I = Iph - Is * (exp((Vc + I * Rs) / Vta) -1)
% f(I) = Iph - I - Is * ( exp((Vc + I * Rs) / Vta) -1) = 0
% Solve for I by Newton's method: Ia2 = Ia1 - f(Ia1)/f'(Ia1)
% Initialize I with zeros
I = zeros(size(Vc));
for j=1:5;
    I = I - (Iph - I - Is .* ( exp((Vc + I .* Rs) ./ Vta) -1))...
        ./ (-1 - Is * (Rs ./ Vta) .* exp((Vc + I .* Rs) ./ Vta));
end
I=I*Np;
End
```

2.Code for obtaining MPPT in P V module

```
function D   = PO(V, I, T)

persistent Pn  Po  dP d dd n;

if isempty(V)
    V=20;
end
if isempty(I)
    I=0;
end
if isempty(Po)
    Po=0;
end
if isempty(Pn)
    Pn=0;
end
if isempty(dP)
    dP=0;
end
if isempty(d)
    d=1;
end
if isempty(dd)
    dd=0;
end
if isempty(n)
    n=1;
end

if  (T>n*0.02)
    n=n+1;
    Po=Pn;
    Pn=V*I;
    dP=Pn-Po;

if (dd==0)                 % to avoid dP/dd=inf
if dP>1
dd=0.01;
d=d+dd;
else
if (dP<-1)
dd=-0.01;
d=d+dd;
```

```
else
dd=0;
end
end
else
if ((dP<1)&&(dP>-1)) % leave little margin
dd=0;
d=d+dd;
else
if ((dP/dd)>0)  % positive slop
dd=0.01;
d=d+dd;
else            % negative and zero slop
dd=-0.01;
d=d+dd;
end
end
end
end

D=d/(d+1);  % calculate duty

% code to avoid duty less than 0.1 and more than 0.9
if (D<0.1)
D=0.1;
d=D/(1-D);
else
if (D>0.9)
D=0.9;
d=D/(1-D);
else
end
end
end
```

REFERENCES

1. B. Subudhi and R. Pradhan, "A comparative study of maximum power point tracking techniques for photovoltaic system", IEEE Trans. On sustainable energy, vol. 4, no.1, pp.89-98, 2013.

2. Trishan Esram, Patrick L. Chpman, "comparison of photovoltaic array Maximum power point tracking techniques", IEEE Transaction on Energy conversion, vol. 22, no.2, pp. 439-448,2007.

3. R. Pradhan and Subudhi , 'A New Digital Double Integral Sliding Mode Maximum Power Point Tracker for Photovoltaic Power Generation Application", 3rdIEEE International Conference on Sustainable Energy Technologies, IEEE ICSET 2012, Kathmandu, Nepal, 24-27 Sep2012.

4. Elawila, M. And ZHAO, Z. (2013) MPPT Techniques for Photovoltaic Applications. Renewable and Sustainable Energy. Reviews, 25,798-813.

5. Guenounoua, O., Boutaib, D. And Ferhat, (2013) Adaptive Fuzzy Controller Based Maximum Power Point Tracking for Photovoltaic System. Energy Conversion and Management, 78,843-850.

6. Renewable Energy Resources Text Book John Twidell, Tony Weir Anthony D. Weir

7. M. A. Eltawil and Z. Zhao, "MPPT techniques for photovoltaic applications," Renewable and Sustainable Energy Reviews, vol. 25, pp. 793–813, 2013