Project on

NOVEL MAXIMUM POWER POINT TRACKING TECHNIQUE BASED ON FUZZY LOGIC FOR PHOTOVOLTAIC SYSTEMS

Submitted In Partial Fulfillment
Of the Requirements for the Award Of

Degree of Bachelor of Technology

In

Electrical and Electronics Engineering

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CERTIFICATE

This is to certify that a project report entitled as “NOVEL MAXIMUM POWER POINT TRACKING TECHNIQUE BASED ON FUZZY LOGIC FOR PHOTOVOLTAIC SYSTEMS” is a bonafide report submitted by

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DECLARATION

We hereby declare that the project entitled – "**NOVEL MAXIMUM POWER POINT TRACKING TECHNIQUE BASED ON FUZZY LOGIC FOR PHOTOVOLTAIC SYSTEMS**", which is being submitted as Major project of 8th semester in ELECTRICAL AND ELECTRONIC ENGINEERING to SRI VENKATESWARA COLLEGE OF ENGINEERING (A.P) is an authentic record of our genuine work.

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ABSTRACT

Raising energy needs and a concern to produce energy in a cleaner way is an important need for the coming years. Solar energy being the most reliable sources of all the renewable resources, where solar energy is converted into electrical energy directly by employing photovoltaic cells which work on the principle to photovatic effects. The efficiency of the PV system can be improved by operating the system at its maximum power point. Hence it becomes necessary to operate the solar cell at MPP to yield better outputs.

As Maximum power point tracking (MPPT) techniques are considered a crucial part in photovoltaic system design to maximize the output power of a photovoltaic array. Whilst many different techniques has been designed, Perturb and Observe (P&O) is widely used for MPPT due to its simple implementation and low cost. Fuzzy logic (FL) is another general technique that achieves vastly improved performance of MPPT technique in terms of response speed and low fluctuation about the maximum power point. But, the drawbacks of conventional FL-MPPT are drift problem associated with changing irradiance and the implementation becomes complicated when compared with the P&O-MPPT. In this project, a novel MPPT technique based on FL control and P&O algorithm is presented.

The proposed method incorporates the advantages of the P&O-MPPT to account for slow and fast changes in solar irradiance and the reduced processing time for the FL-MPPT to address complex engineering problems when the membership functions are less. To evaluate the performance, the P&O-MPPT, FL-MPPT and the proposed method are simulated in MATLAB-SIMULINK model for a grid-connected PV system. Later the results are compared, the simulation results shows that the proposed method accurately tracks the maximum power point and avoids the drift problem, whilst achieving greater power with medium oscillations near the MPP.

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LIST OF ABBREVIATIONS:

- **I_{ph} –** photo current.
- **I_d –** diode current.
- **I_{sh} –** diode reverse saturation current.
- **I_S –** load current.
- **I_{ph} -** The photocurrent.
- **V_t** - Is the thermal voltage, kT/q.
- **N** - Is the quality factor (diode emission coefficient) of the first diode.
- **K** - Is the Boltzmann constant.
- **T -** Is the Device simulation temperature parameter value.
- **q** - Is the elementary charge on an electron.
- **N_2 -** is the quality factor (diode emission coefficient) of the second diode.
- **V** - Is the voltage across the solar cell electrical ports.
- **I_m** - Current at Maximum Power Point.
- **P_m**- maximum power
- **P_{max}** - is its theoretical maximum power
- **V_m**- voltage at Maximum Power Point
- **R_s** - Series resistance is the bulk resistance of semiconductor material and interconnections.
- **A** - area
- **I_L** - is the light generated current.
- **G** - Is the solar irradiance.

- **I_{SC}** - is the PV short circuit current.
- **T_{STC}** - is the temperature operation for the PV cell under standard test conditions (STC).
- **T** - Is the temperature operation.
- **V_d** - Is the Voltage across diode.
- **I_{PV}** - Is the PV output current of PV cell.
- **V_{pv}** - Is the PV output voltage of PV cell.
- **STC** - standard temperature conditions.
- **MPP** - maximum power point.
- **V_o** - is the output voltage DC-DC boost converter.
- **V_i** - is the input voltage DC-DC boost converter.
- **D** - is the duty cycle of DC-DC boost converter.
- **FL** - Fuzzy logic.
- **MPPT** - Maximum power point tracking.
- **P&O** - Perturb and observation method algorithm for MPPT.
- **PV** - Photovoltaic.
- **e(k)** - is the change of slope P-V curve.
- Δ**e** – change in the slope.
- **W_i** - is the minimum number of membership functions of the i^{th} rule.
- **C_i** - is the center value of the output membership functions of the i^{th} rule.
- Δ**G** - is the historical change in solar irradiance.
- **EN 50530 standard test** – European 50530 standard test.
- Δ**P** - is the historical change in PV power.
- **P** - is the previous iteration for PV power.
- **D_{k-1}** - previous iteration for the duty cycle respectively.
- **D_k** - next iteration for the duty cycle respectively.

- **ΔD** - incremental increase duty cycle.
- **IC** - incremental conductance method for achieving MPPT.
- **PSO** - particle swam optimism.
- **NN** - Neural Networks.
- **GA**s - genetic algorithms.

CHAPTER 1: INTRODUCTION

1. INTRODUCTION:

1.1. motivation

1.1.1) Energy

Energy is the primary and most universal measure of all kinds of work by human beings and nature. Everything what happens in the world is the expression of flow of energy in one of its forms. Most people use the word energy for input to their bodies or to the machines and thus think about crude fuels and electric power. The energy sources available can be divided into three types:

i. primary energy sources

Primary energy sources can be defined as sources which provide a net supply of energy. Coal, oil, uranium etc. are examples of this type. The energy required to obtain these fuels is much less than what they can produce by combustion or nuclear reaction. Their energy yield ratio is very high.

ii. Secondary fuels

Secondary fuels produce no net energy. Though it may be necessary for the economy, these may not yield net energy. Intensive agricultural is an example wherein terms of energy the yield is less than the input.

iii. Supplementary

Supplementary sources are defined as those whose net energy yield is zero and those requiring highest investment in terms of energy insulation (thermal) is an example for this source.

1.1.2) Energy Sources and their Availability

Today, every country draws its energy needs from a variety of sources. We can broadly categorize these sources as commercial and non- commercial. The commercial sources include fossil fuels (coal, oil and natural gas), hydroelectricity power and nuclear power. In an industrialized country like, U.S.A, most of the energy requirements are met from commercial sources, while in a country like India, the use of commercial and non-commercial sources are about equal.

1.1.3) The need for Renewable Energy

While fossil fuels will be the main fuels for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore other systems based on non-conventional and renewable sources are being tried by many countries. These are solar, wind, sea, geothermal and biomass.

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible, unlike dwindling conventional fossil fuels. The global energy crunch has provided a renewed impetus to the growth and development of Clean and Renewable Energy sources. Clean Development Mechanisms (CDMs) are being adopted by organizations all across the globe. Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts.

Solar energy can be a major source of power. Its potential is 178 billion MW which is about 20,000 times the world’s demand. But so far it could not be developed on a large scale. Sun’s energy can be utilized as thermal and photovoltaics. The former is currently being used for steam and hot water production.

1.1.4) Solar energy

Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy could be used, it will be one of the most important supplies of energy especially when other sources in the country have depleted.

Energy comes to the earth form the sun. This energy keeps the temperature of the earth from the earth above that in colder space, causes current in the atmosphere and in ocean, causes the water cycle and generate photosynthesis in the plants.

1.1.5) Photovoltaic (PV) power systems and solar power Generation

i. Solar power generation:

When sunlight strikes on photovoltaic solar panels solar electricity is produced as shown in **Fig.1.1:**. That is why this is also referred to as photovoltaic solar, or PV solar.

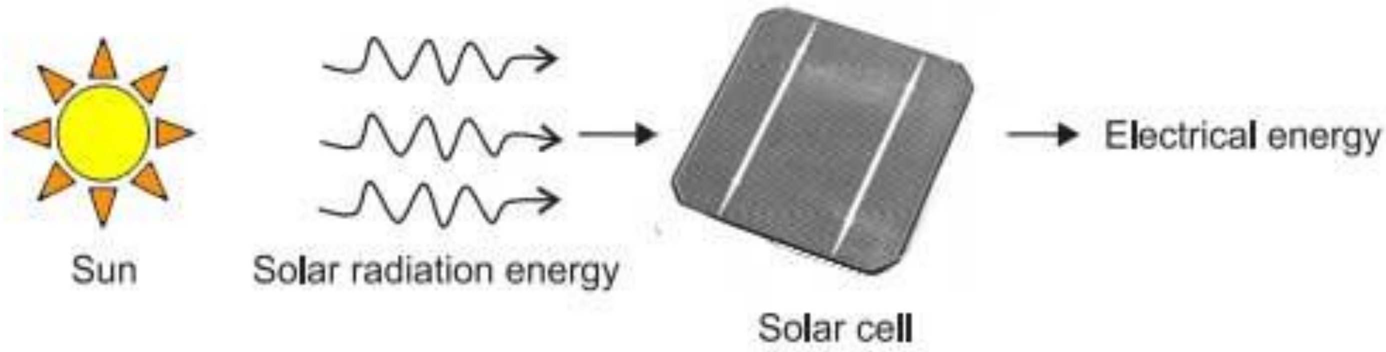

Fig.1.1: Working of solar panel

Principles of Solar Electricity

Generation of electricity by using solar energy depends upon the photovoltaic effect in some specific materials. There are certain materials that produce electric current when these are exposed to direct sun light. This effect is seen in combination of two thin layers of semiconductor materials. One layer of this combination will have a depleted number of electrons. When sunlight strikes on this layer it absorbs the photons of sunlight ray and consequently the electrons are excited and jump to the other layer. This phenomenon creates a charge difference between the layers and resulting to a tiny potential difference between them. The unit of such combination of two layers of semiconductor materials for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as the semiconductor material for producing such solar cell. For building cell silicon material is cut into very thin wafers. Some of these wafers are doped with impurities. Then the un-doped and doped wafers are then sandwiched together to build solar cell. Metallic strip is then attached to two extreme layers to collect current. Conductive metal strips attached to the cells take the electrical current. One solar cell or photovoltaic cell is not capable of producing desired electricity instead it produces very tiny amount of electricity hence for extracting desired level of electricity desired number of such cells are connected together in both parallel and series to form a solar module or photovoltaic module which is shown in **Fig.1.2:**.

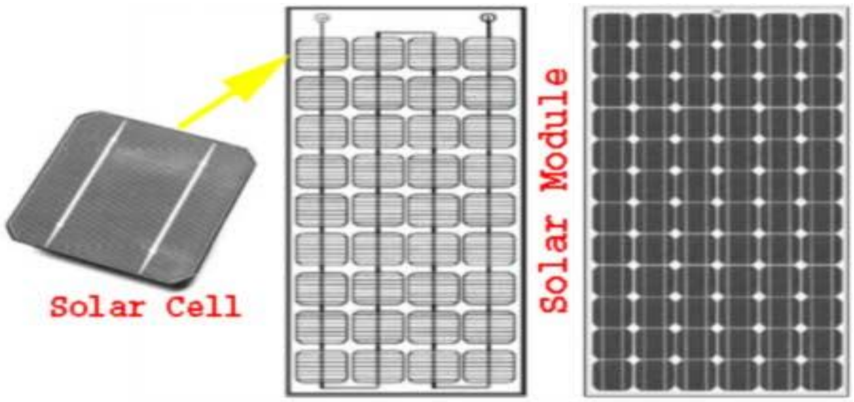

Fig.1.2: **Solar cell and solar module**

ii. Application of Solar Electricity

Solar electric power generation system is useful for producing moderate amount of power. The system works as long as there is a good intensity of natural sunlight. The place where solar modules are installed should be free from obstacles such as trees and buildings otherwise there will be shade on the solar panel which affects the performance of the system. It is a general view that solar electricity is an impractical alternative of conventional source of electricity and should be used when there is no traditional alternative of conventional source of electricity available. But this is not the actual case. Often it is seem that solar electricity is more money saving alternative than other traditional alternatives of conventional electricity.

1.2. LITERATURE SURVEY

Souza NSD, Lopes LAC, Liu X, Proposed **[1]** that use of Fuzzy logic and non-switching zone schemes for implementing variable size perturbations for improved transient and steady-state responses. The best performance is achieved with a new strategy called non-switching zones in the VPV×IPV plane. The duty cycle (D) equal to 0 or 1, depending on which non-MPP region the system operates, pushing the operating point the fastest towards the MPP region, for improved transient response. At the MPP region, a reduced Fuzzy P&O MPPT algorithm optimized for small variations around the MPP is used for reduced oscillations and increased power yield in the steady-state.

Koad RBA, Zobaa AF, El-Shahat A, explains about **[2]** a new maximum-power-point-tracking method for a photovoltaic system based on the Lagrange Interpolation Formula and proposes the particle swarm optimization method. The proposed control scheme eliminates the problems of conventional methods by using only a simple numerical calculation to initialize the particles around the global maximum power point. Hence, the suggested control scheme will utilize less iteration to reach the maximum power point.

A supposed bother and watch (P&O) technique is considered here by **Piegari L, Rizzo R, [3]**. This strategy is generally easy and simple to use. At the point when climatic conditions are consistent or change gradually, the P&O strategy sways near MPP. But when weather changes are rapid this algorithm fails to follow MPP. A versatile P&O technique is proposed in this examination that has quicker elements and improved steadiness contrasted with the conventional P&O. The MPPT calculation was set up and approved by methods for numerical reproductions and trial tests, affirming the viability of the technique.

. A modified method is proposed and evaluated by **Kamala Devi V, Premkumar K, Bisharathu Beevi A, Ramaiyer [4]**. Perturb & Observe (P&O) method is selected for analysis. A Modified P&O method using directional step size is suggested here that can effectively tackle steady state variations around maximum power point and dynamic variations in environmental conditions of temperature and solar radiation. This is achieved by determining a step size that switches to ‘zero’ during the above conditions. Thus, the proposed method provides a stable PV voltage.

Ali AIM, Sayed MA, Mohamed EEM [5], proposed an adjusted productive variable advance P&O (VSPO) calculation as an endeavor to tackle the quickly evolving insolation issue. The VSPO procedure partitions the PV-cluster activity area into four working areas. With the assistance of these four areas, the progression size is changed by how the part a long way from the MPP. The exhibition of the regular and variable advance calculations P&O procedures is looked at. . Three-stage matrix tie inverter (GTI) is utilized to interface the framework to the utility lattice.

J. Ahmad, describes **[6]** the PV array voltage corresponding to the maximum power exhibits a linear dependence with respect to array open circuit voltage for different irradiation and temperature levels. This method is the simplest of all the MPPT methods. The main disadvantage is that the PV array is disconnected from the load after regular intervals for the sampling of the array voltage. J. Ahmad uses a MPPT circuit in which the sampling interval of the PV array voltage, and the sampling period have been shortened. The sample and hold circuit, which samples and holds the MPP voltage, has also been simplified.

Seyedmahmoudian M, Horan B, Soon TK, Rahmani R, Than AM, Mekhilef [7], reviews AI-based techniques proven to be effective and feasible to implement and very common in literature for MPPT, including their limitations and advantages. In order to support researchers in application of the reviewed techniques this study is not limited to reviewing the performance of recently adopted methods, rather discusses the background theory, application to MPPT systems, and important references relating to each method. It is envisioned that this review can be a valuable resource for researchers and engineers working with PV-based power systems to be able to access the basic theory behind each method, select the appropriate method according to project requirements, and implement MPPT systems to fulfill project objectives.

Kollimalla SK, Member S, Mishra MK, Member S. proposed **[8]**, a short-circuit current-based adaptive perturb and observe maximum power point tracking algorithm is proposed to extract the maximum power from photovoltaic (PV) panel under sudden changes in the irradiance. This scheme is divided into two algorithms: 1) current perturbation algorithm; and 2) adaptive control algorithm. The current perturbation algorithm makes the PV panel operate at maximum power point. The adaptive control algorithm identifies the operating limit violation and sets a new operating point nearer to maximum power point.

Patcharaprakiti N, Premru deepreecha charn S. Proposed **[9]** a method of maximum power point tracking using adaptive fuzzy logic control for grid connected photovoltaic system. The system composed of boost converter single-phase inverter connected to utility grid. The maximum power point tracking control is based on adaptive fuzzy logic to control MOSFET switch of boost converter and single phase inverter uses predicted current control to control four IGBTs switch for grid-connected control.

Topaloglu N. In this work **[10],** fingerprint classification based on the Gray-Level Fuzzy Clustering Co-Occurrence Matrixes proposed. Using Gray-Level Fuzzy clustering co-occurrence matrices provide representing the fact that a fingerprint image is composed of regular texture regions. Firstly extracting the features using certain characteristics of the Fuzzy Clustering co-occurrence matrix was performed, these features were trained and classified into four common classes using neural network at the next step.

Elgendy MA, Zahawi B, Member S, Atkinson DJ. They proposed **[11]** that presents an experimental evaluation of the incremental conductance MPPT algorithm when employed by a standalone PV pumping system, using an experimental installation comprised of a 1080-Wp photovoltaic array connected to a 1-kW permanent magnet dc motor-centrifugal pump set. Particular focus is given to the evaluation of the two commonly utilized implementation techniques: reference voltage perturbation and direct duty ratio perturbation.

Bechouat M, Soufi Y, Sedraoui M, Kahla S. Proposes **[12]**, a comparison between GAs and PSO Approaches is considered to select and generate an optimal duty cycle which varies with photovoltaic parameter in order to extract the maximum Power from Photovoltaic System using real values of temperature and insolation.

B. N. Alajmi, K. H. Ahmed, S. J. Finney and B. W. Williams. Proposes **[13], a** new fuzzy-logic controller for maximum power point tracking of photovoltaic (PV) systems is proposed. PV modeling is discussed. Conventional hill-climbing maximum power-point tracker structures and features are investigated. The new controller improves the hill-climbing search method by fuzzifying the rules of such techniques and eliminates their drawbacks. Fuzzy-logic-based hill climbing offers fast and accurate converging to the maximum operating point during steady-state and varying weather conditions compared to conventional hill climbing. Simulation and experimentation results are provided to demonstrate the validity of the proposed fuzzy-logic-based controller.

Gupta, Nikita & Garg, Rachna & Kumar, Parmod. Proposes **[14]** asymmetrical fuzzy logic control (AFLC) for PV module connected micro grid. PV module connected micro grid is considered as two stages control, (i) maximum power point tracking control, and (ii) three phase PWM voltage source control. Voltage source converter (VSC) is used for interfacing solar energy with the micro grid and the dc link voltage is regulated using conventional and intelligent controller. During load change transients, there is considerable variation in dc link voltage in case of conventional controller whereas with asymmetrical fuzzy logic control, transient performance is improved considerably.

Sadeq D. Al-Majidi, Maysam F. Abbod, Hamed S. Al-Raweshidy Proposes **[15]** a novel MPPT technique based on FL control and P&O algorithm. The proposed method incorporates the advantages of the P&O-MPPT to account for slow and fast changes in solar irradiance and the reduced processing time for the FL-MPPT to address complex engineering problems when the membership functions are few.

1.3. Problem Formulation

1.3.1) Solar radiation and intermittent nature of irradiation

In general, the energy produced and radiated by the sun, more specifically the term refers to the sun's energy that reaches the earth. Solar energy, received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat and electricity, which can be utilized by man. Since the sun is expected to radiate at essentially constant rate for few billion years, it may be regarded as an in- exhaustible source of useful energy. The major drawbacks to the extensive application of solar energy are:

1. The intermittent and variable manner in which it arrives at the earth's surface and
2. The large area required to collect the energy at a useful rate.

Experiments are underway to use this energy for power production, house heating, air conditioning, cooking and high temperature melting of metals.

The solar power where sun hits atmosphere is 10^{17} watts, whereas the solar power on earth's surface is 10^{16} watts. The total world – wide power demand of all needs of civilization is 10^{13} watts. Therefore, the sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require. The energy radiated by the sun on a bright sunny day is approximately 1 kW/m^2, attempts have been made to make use of this energy in raising steam which may be used in driving the prime movers for the purpose of generation of electrical energy. However on account of large space required, uncertainty of availability of energy at constant rate, due to clouds, winds, haze etc., there is limited application of this source in the generation of electric power.

In recent years, the global demand for energy has increased dramatically due to population growth. In addition, the phenomenon of global warming has been intensified owing to the CO_2 emissions from fossil fuels. To solve this complex challenge, many studies have called for the use of renewable energies to face the issue of lack of energy in future years and to minimize the side effects of burning fossil fuels. Hence, developing renewable energies has been become a worthy research topic in the last decade. A solar photovoltaic (PV) systems, wind turbines, hydropower, biomass and geothermal power are the major renewable energy resources. The solar PV arrays are considered one of the most attractive renewable energy resources due to their provision of sustainable, clean and safe energy **[16].** However, the efficiency of a PV system is low, because the output power of a PV array is dependent on irradiance and temperature, i.e. weather conditions, which is intermittent in nature and can result in a loss of energy of up to 25% **[16].**

1.4. Objective of Project

1.4.1) Maximum Power Point Tracker (MPPT)

The most effective way to improve the efficiency of a PV system is to employ a maximum power point tracking MPPT technique with it, thereby achieving maximum power production under varying weather conditions.

Basically, The MPPT technique is an electronic system, which feeds an appropriate duty cycle (D) to a power conversion system for the output and/or input of the PV module to achieve continuous maximum power production.

The P&O-MPPT is a popular method for PV-MPPT owing to its low cost and simple implementation. However, it poses many challenges, such as lower converging speed, high oscillation around a maximum power point MPP, and a drift problem associated with rapidly changing irradiance. Several modifications have been introduced based on a Power (P) - Voltage (V) curve, but they are considered as insufficient solutions for addressing all of these problems. Consequently, artificial intelligent techniques based on MPPT have been proposed to solve the significant problems of the classical MPPT methods.

In addition, these techniques do not need accurate parameters or complex mathematics when managing the system. In particular, the FL-MPPT technique is one of the most powerful controllers for a PV system due to its high converging speed and low fluctuation around the MPP.

Moreover, it does not require training data, thus resulting in its working for various types of PV module with the same MPPT design. However, the main disadvantages are the aforementioned drift problem associated with changing irradiance and complex implementation when compared with the classical MPPT methods.

1.4.2) Solution for the problem

In this project, a novel FL-MPPT technique based on a modified P&O algorithm is designed. The proposed design takes into account two key issues. First, whilst the conventional P&O-MPPT is a suitable method for the PV system under a slow change of irradiance, it faces significant challenges under a fast one. The second issue, is that the complex engineering problems of a fuzzy system become diminished when the designed membership functions are few. The fuzzy rules of the proposed method are obtained from a modified P&O-MPPT algorithm. The proposed technique accurately tracks the maximum power point and avoids the drift problem. Moreover, our simplified FL-MPPT method, when applied to a grid-connected PV system, achieved efficiencies greater than 99.6% under the EN 50530 standard test **[15]**.

1.5. Organization of project

The rest of this project is organized as follows.

Chapter-2

Covers the basic modelling of a solar PV cell and basics of MPPT finishing with explaining the conventional P&O method.

Chapter-3

Explains about the basics of Fuzzy Logic system, whilst later Sections explains about the conventional Fuzzy Logic controller (FLC) method and continued with discussion of Proposed FLC method and its membership functions.

Chapter-4

is about designing of the Proposed FLC method model, solar cell modelling and Power conversion system explain the workings of a power conversion system, respectively.

Chaprter-5

Gives the simulation results of the proposed method and whilst the section result analysis discusses about the comparison between the conventional P&O, conventional FLC method and the proposed method. Finally concluding with presenting with conclusion, future scope and references.

CHAPTER 2:

SOLAR CELL AND MAXIMUM POWER POINT TRACKER

2. SOLAR CELL

The name “solar cell” means that it is a cell or a plate which converts solar energy into the useful electrical energy. The energy which we get from sun is enormous and it is a great source of energy. Its energy will never finish so this is also known as the main source of renewable energy. With the scarcity of non-renewable energy it is of utmost importance to find a way out to solve the energy problem by some means within a very short period of time. So there is a way out which is now developing. That is we are now able to convert the sun energy to electrical by some means and that is why the importance of solar cell comes into play. Though it is developing but if it is developed completely, then every household may produce the energy of its own. The solar cell is a device which is made of p-n junction diode which effect photovoltaic effect to convert light energy into electrical energy.

2.1. Working Principle of Solar Cell

When light reaches the p-n junction, electron is excited to the valance band under the condition that light energy is higher than the band gap energy; it generates the electron and holes which are equal in number in the valance and conduction band respectively which is shown in the **Fig.2.1:**. These electron hole pairs move in opposite directions to the barrier field. Electrons move towards the n-side and the hole is moved towards the p-side. So a voltage is set up which is known as photo voltage and when a load is connected, the current flows. The typical characteristics of a solar cells when connected in to from an array is given in **Fig.2.2:**.

2.2. Construction of Solar Cell

The junction diode is made of SI or GaAs. A thin layer of p-type is grown on the n-type semiconductor. As in **Fig.2.1:**, top of the p-layer is provided with a few finer electrodes which leaves open space for the light to reach the thin p-layer and it under lays p-n junction. Bottom of the n-layer is provided with a current collecting electrode.

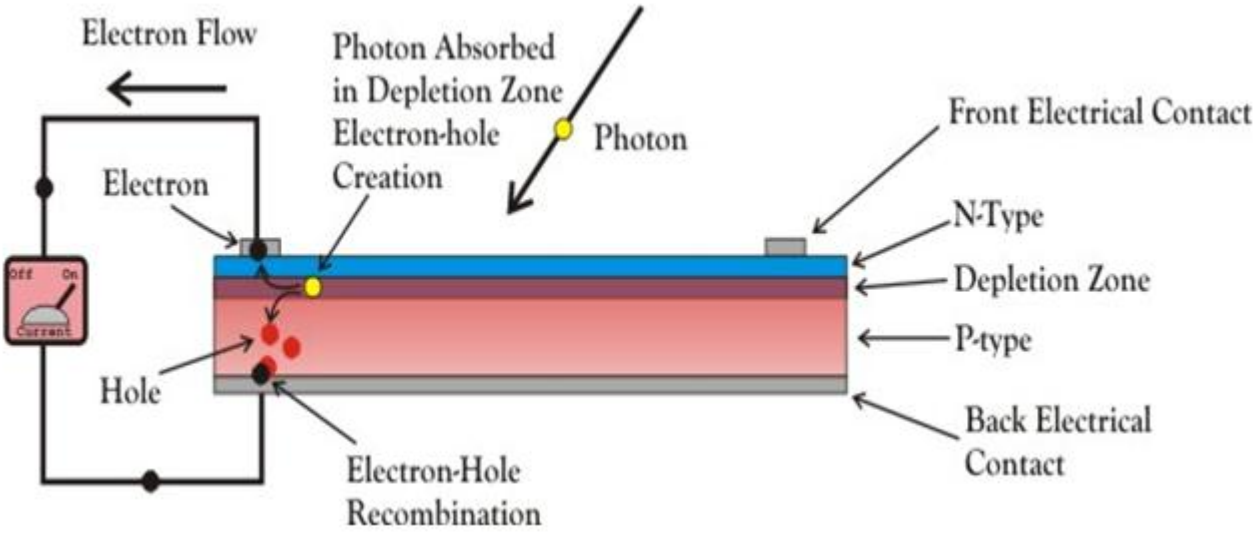

Fig.2.1: Junction diagram of solar cell

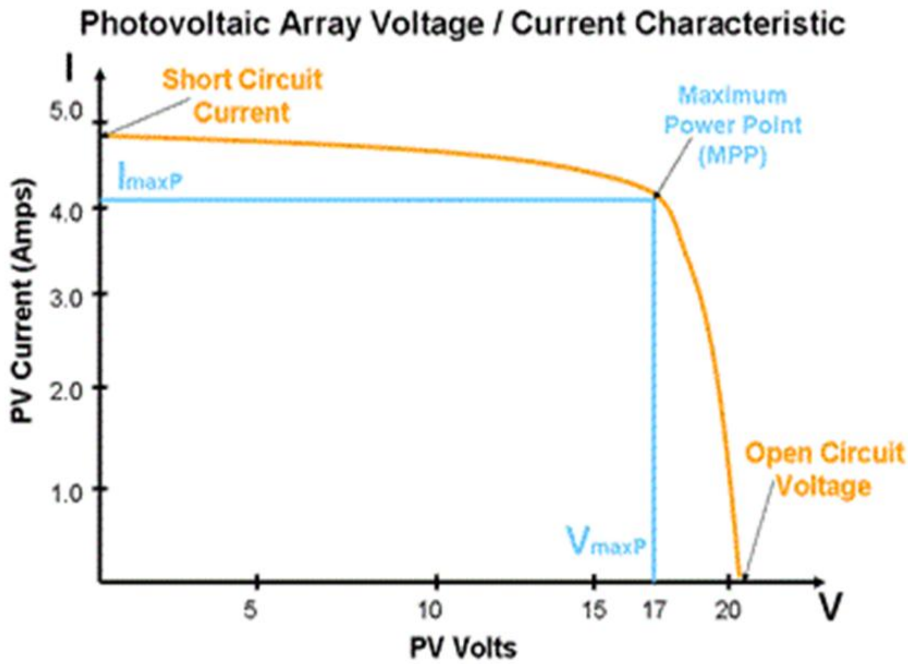

Fig.2.2: I-V curve of a solar photovoltaic array

2.2.1) Advantages and disadvantages of Solar Cell

a) Advantages of Solar Cell

1. No pollution associated with it.

2. It must last for a long time.

3. No maintenance cost.

b) Disadvantages of Solar Cell

1. It has high cost of installation.

2. It has low efficiency.

3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

2.3. Characteristics and Parameters of a Solar Cell

Solar cell is the basic unit of solar energy generation system where electrical energy is extracted directly from light energy without any intermediate process. The working of a solar cell solely depends upon its photovoltaic effect hence a solar cell also known as photovoltaic cell. A solar cell is basically a semiconductor device. The solar cell produce electricity while light strikes on it and the voltage or potential difference established across the terminals of the cell is fixed to 0.5 volt and it is nearly independent of intensity of incident light whereas the current capacity of cell is nearly proportional to the intensity of incident light as well as the area that exposed to the light.

2.3.1) Short Circuit Current of Solar Cell

It is the maximum current that a solar cell can deliver without harming its own constriction. It is measured by short circuiting the terminals of the cell at most optimized condition of the cell for producing maximum output. The term optimized condition I used because for fixed exposed cell surface the rate of production of current in a solar cell also depends upon the intensity of light and the angle at which the light falls on the cell. As the current production also depends upon the surface area of the cell exposed to light, it is better to express maximum current density instead maximum current. Maximum current density or short circuit current density rating is nothing but ration of maximum or short circuit current to exposed surface area of the cell.

$$J_{sc} = \frac{I_{sc}}{A} \qquad \textbf{(2.1)}$$

Where, I_{SC} is short circuit current, J_{SC} maximum current density and 'A' is the area of solar cell.

2.3.2) Open Circuit Voltage of Solar Cell

It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volts. It is normally denoted by V_{oc}.

2.3.3) Maximum Power Point of Solar Cell

The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the V-I characteristics of a solar cell maximum power will occur at the bend point of the characteristic curve. It is shown in **Fig.2.3:,** the V-I characteristics of solar cell by P_m.

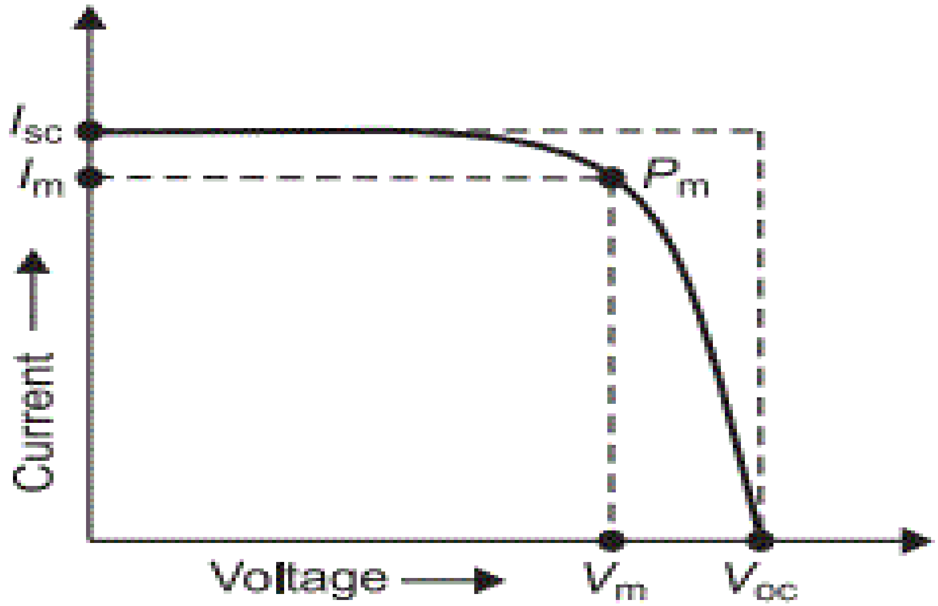

Fig.2.3: Maximum power point on I-V curve

2.3.4) Current and voltage at Maximum Power Point

The current at which maximum power occurs is called maximum current on the characteristics. Current at Maximum Power Point is shown in the V-I characteristics of solar cell by I_m, and voltage at maximum power by V_m. Voltage and current at Maximum Power Point is shown in the **Fig.2.3:**, V-I characteristics of solar cell.

2.3.5) Efficiency and Fill Factor of Solar Cell

The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell is called fill factor.

$$Fill\ Factor = \frac{P_m}{I_{sc} \times V_{oc}} \qquad \textbf{(2.2)}$$

It is defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage. It is considered that the radiation power on the earth is about 1000watt/square meter hence if the exposed surface area of the cell is 'A' then total radiation power on the cell will be 1000*A watts. Hence the efficiency of a solar cell may be expressed as

$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000A} \quad \textbf{(2.3)}$$

2.4. Modeling of solar PV cell

2.4.1) Single diode model

Solar cell is an electrical device that converts the light energy into electricity by the photovoltaic effect. In ideal PV cell, parallel and series resistances are not present but in practical case they are included due to leakage current and ohmic resistances as shown in **Fig.2.4:**. While major contributor to the shunt resistance Rsh is that a pen junction of PV diode is non-optimal, the series resistance Rs is the bulk resistance of semiconductor material and interconnections.

When PV cell is supplied solar irradiance the output current from the solar PV cell can be found using Kirchhoff's law, as shown in Eq. (2.4):

$$I_{PV} = I_L - I_d - I_{sh} \quad \textbf{(2.4)}$$

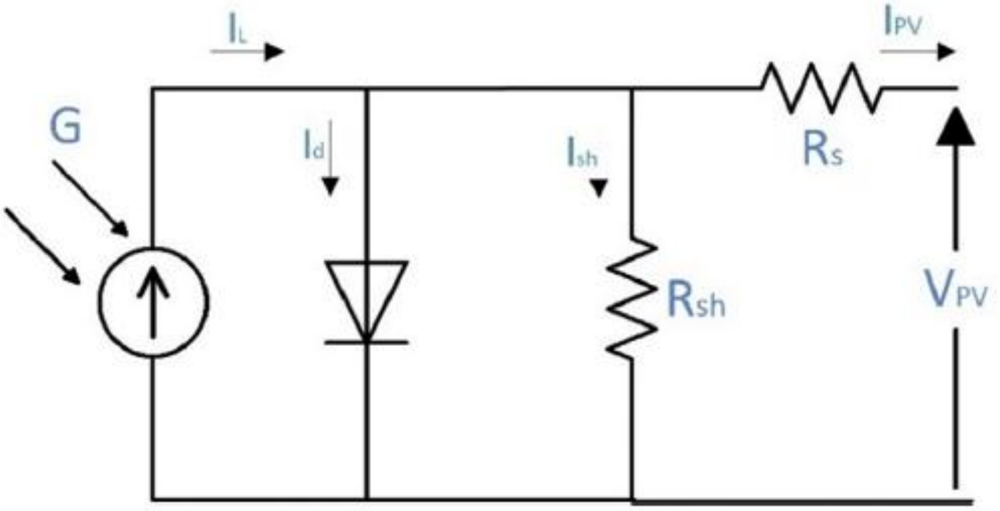

Fig.2.4: Single diode model of solar cell or 5 parameter model of solar cell

Where I_L is the light generated current and given as in Eq. (2.5):

$$I_L = G\{I_{SC}[1 + a(T - T_{STC})]\} \qquad \textbf{(2.5)}$$

where, G is the solar irradiance, I_{SC} is the PV short circuit current, a is the temperature coefficient of short circuit current, T is the temperature operation, T_{STC} is the temperature operation for the PV cell under standard test conditions (STC).

And Id is the diode current and given as Eq. (2.6):

$$I_d = I_0\left\{\exp\left(\frac{qV_d}{nkT}\right) - 1\right\} \qquad \textbf{(2.6)}$$

Where Io is the reverse saturation current of the diode, and V_d is the Voltage across diode, q is the electron charge (1.69 x 10^{19} C), k is the Boltzmann's constant (1.38 x 10^{23} J/ K), and n is the diode idealist factor.

A general equation that describes the I-V characteristic curve of the PV cell is shown in Eq. (2.7) [1]:

$$I_{PV} = I_L - I_0\left[\exp\left(\frac{q(V_{PV} + I R_S)}{nkT}\right) - 1\right] - \left[\frac{V_{PV} + I R_S}{R_{sh}}\right] \quad \textbf{(2.7)}$$

Where I_{PV} is the PV output current, and V_{PV} is the PV output voltage of PV cell. Solar cells are connected in parallel and series to obtain desired current and voltage respectively for the solar panel, and then the solar panels are connected in series and/or parallel to give different configurations of PV array. These models is connected in series or in parallel of suitable configurations. Hence P – V curves for Irradiation at 1000, 800, 600, 400 (kW/m^2) and temperature at 25 degree centigrade is obtained shown in **Fig.2.5:.** And obtain curves for Temperature at 0, 25, 45, 65 degree centigrade and irradiation at 1000 (kW/m^2) as shown in **Fig.2.6:**.

There is unique point on the P-V curve of the PV array, which is known as the maximum power point (MPP) and this depends on solar irradiance and temperature. The voltage operation of PV array also depends upon the impedance of the load. When PV array is connected to the load it drops to a new operating point. To address those issues, power conversion system and MPPT technique are connected between PV array and the load or invertor.

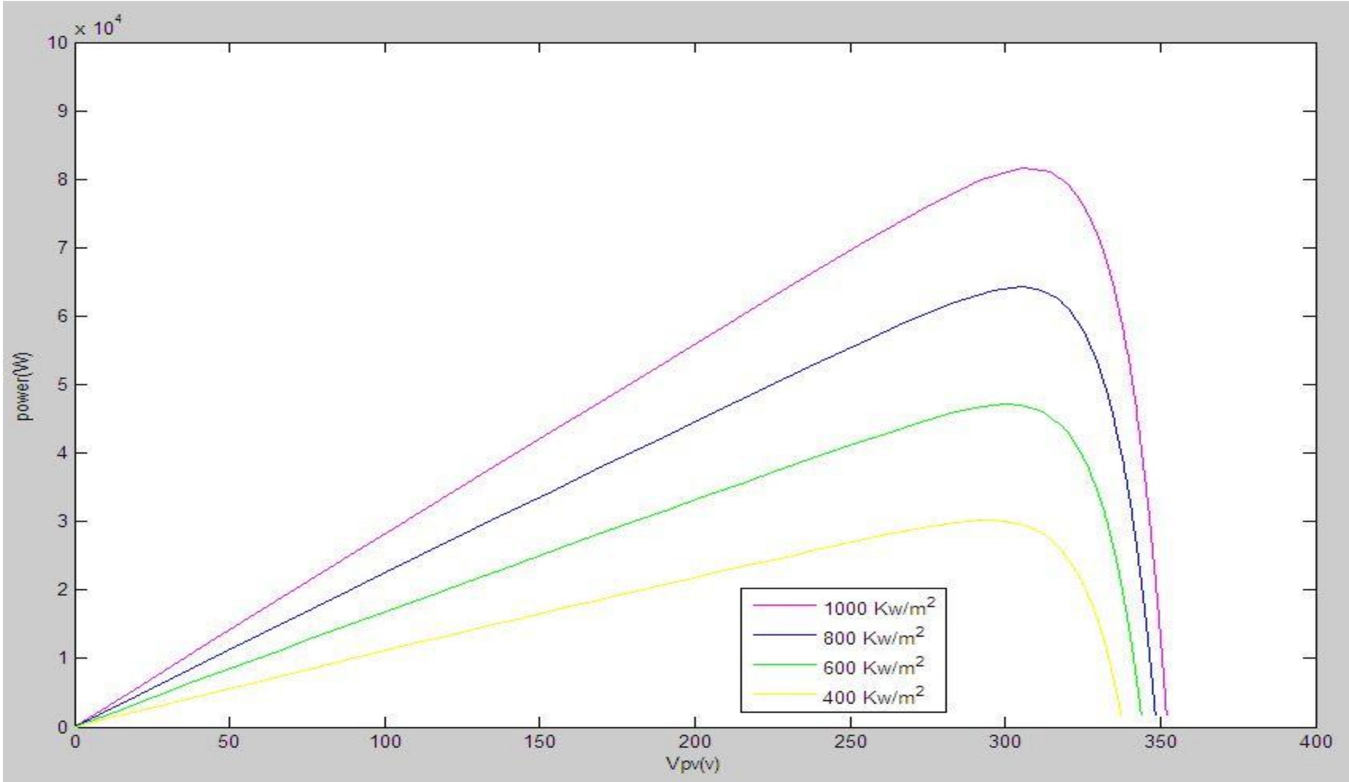

Fig.2.5: **P-V curve of a PV array under: various values of irradiance at a temperature of 25º C.**

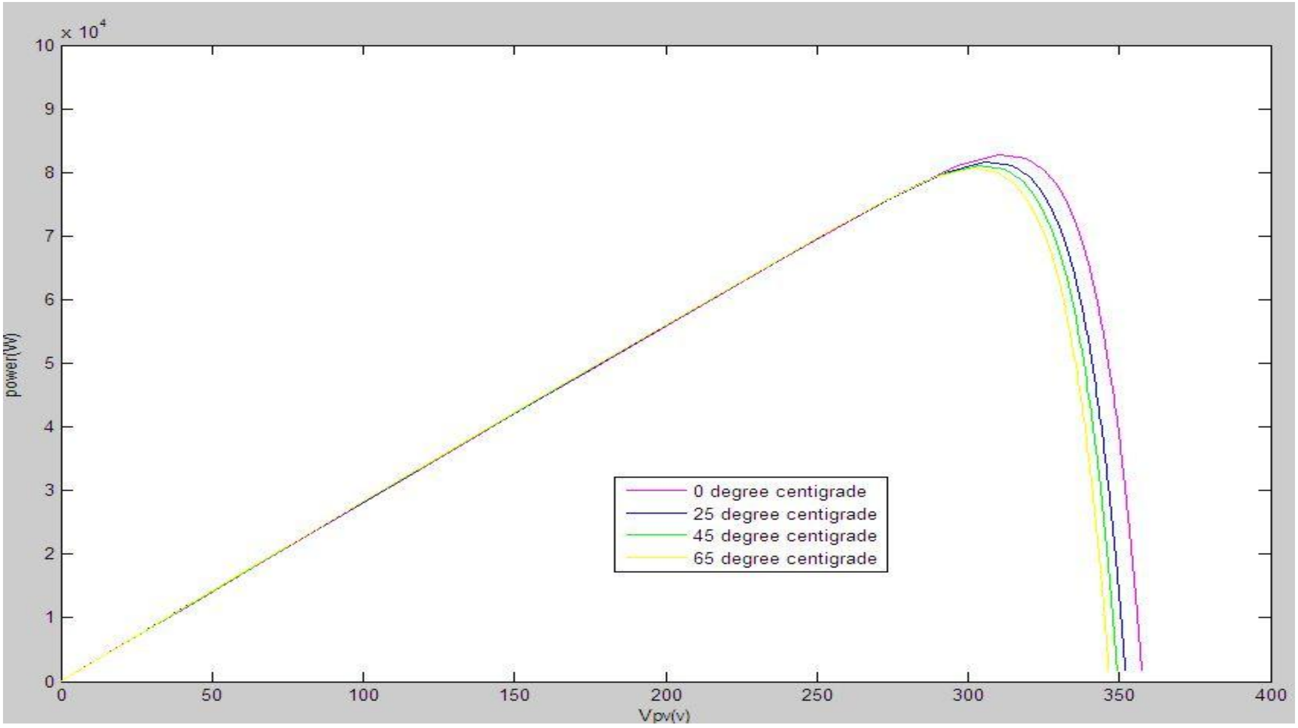

Fig.2.6: **P-V curve of a PV array under: various values of temperature at an irradiance of 1000 W/m2.**

2.5. Maximum Power Point Tracker (MPPT)

The most effective way to improve the efficiency of a PV system is to employ a maximum power point tracking MPPT technique with it, as shown in **Fig.2.7:**, thereby achieving maximum power production under varying weather conditions.

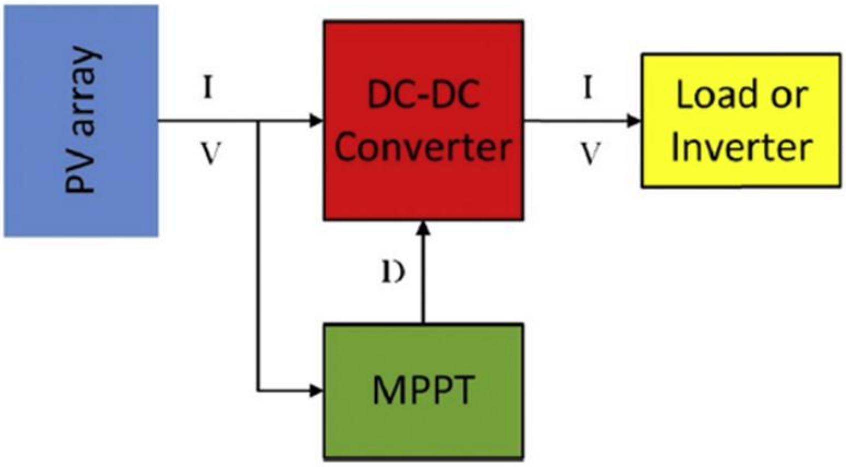

Fig.2.7: Diagram of PV system based MPPT.

MPPT is the process of finding and keeping the load characteristic at *maximum power point* (MPP). 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.

Thus by varying the impedance seen by the panel, the operating point can be moved towards peak power point. Since panels are DC devices, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the other circuit (load). Changing the duty ratio of the DC-DC converter results in an impedance change as seen by the panel. At a particular impedance (i.e. duty ratio) the operating point will be at the peak power transfer point.

MPPT implementations utilize algorithms that frequently sample panel voltages and currents, then adjust the duty ratio as needed. Microcontrollers are employed to implement the algorithms. Modern implementations often utilize larger computers for analytics and load forecasting.

In general, there are several issues that are key when aiming to design the best MPPT technique for a PV system, including cost, efficiency, lost energy, and type of implementation. As already mentioned in chapter -1, many types of MPPT methods have been developed for PV systems, which can be divided into two types: classical methods, such as Perturbation and Observation (P&O), Incremental Conductance (IC), and Fractional Open Circuit Voltage; and artificial intelligent techniques, for instance, Neural-fuzzy ANFIS, Fuzzy Logic (FL), genetic algorithms (GAs), particle swam optimism (PSO), sliding mode and Neural Networks (NNs).

The P&O-MPPT is a popular method for PV-MPPT owing to its low cost and simple implementation. However, it poses many challenges, such as lower converging speed, high oscillation around a maximum power point MPP, and a drift problem associated with rapidly changing irradiance

Several modifications have been introduced based on a Power (P) - Voltage (V) curve, but they are considered as insufficient solutions for addressing all of these problems. Consequently, artificial intelligent techniques based on MPPT have been proposed to solve the significant problems of the classical MPPT methods.

2.5.1) Perturb and observe method (P&O)

The P&O algorithm is widely used for PV-MPPT due to its low cost and simple implementation. As shown in **Fig.2.8:**, the principle work of this algorithm calculating the PV power by using the sensed values of the voltage and current of the PV module. These are then compared with the previous power and voltage, with the direction of the algorithm being adjusted accordingly and the duty cycle of the boost converter being adjusted as in Eq. (2.8):

$$D_{k+1} = D_k \pm \Delta D \quad \textbf{(2.8)}$$

Where D_k and D_{k+1} are the previous and next perturbation of duty cycle respectively, and ΔD is the constant width of the step size. Basically, if the tendency of change in PV voltage and PV power increase regarding to an increase in the duty cycle, the control system moves in the same direction; otherwise the operating point moves in the opposite direction. The process is continued until it reaches to the MPP and then it oscillates around the optimal MPP.

The probabilities of the direction P&O-MPPT algorithm are explained in **table.2.1:.** In general, there are three main issues facing its operation: a long convergence time, high oscillation around the MPP and a drift problem associated with irradiance changing rapidly. To solve these drawbacks, variable step size and an adaptive P&O-MPPT algorithm have been developed. However, they are considered insufficient solutions to address all of these issues. Consequently, artificial intelligence techniques based on PV-MPPT have been proposed to overcome the limitations of the classical P&O-MPPT method.

TABLE.2.1: PROBABILITIES OF THE DIRECTION P&O ALGORITHM

ΔP (change in power)	**ΔV (change in voltage)**	**Direction of perturbation**
Positive	**Positive**	**Positive**
Positive	**Negative**	**Negative**
Negative	**Positive**	**Negative**
Negative	**Negative**	**Positive**

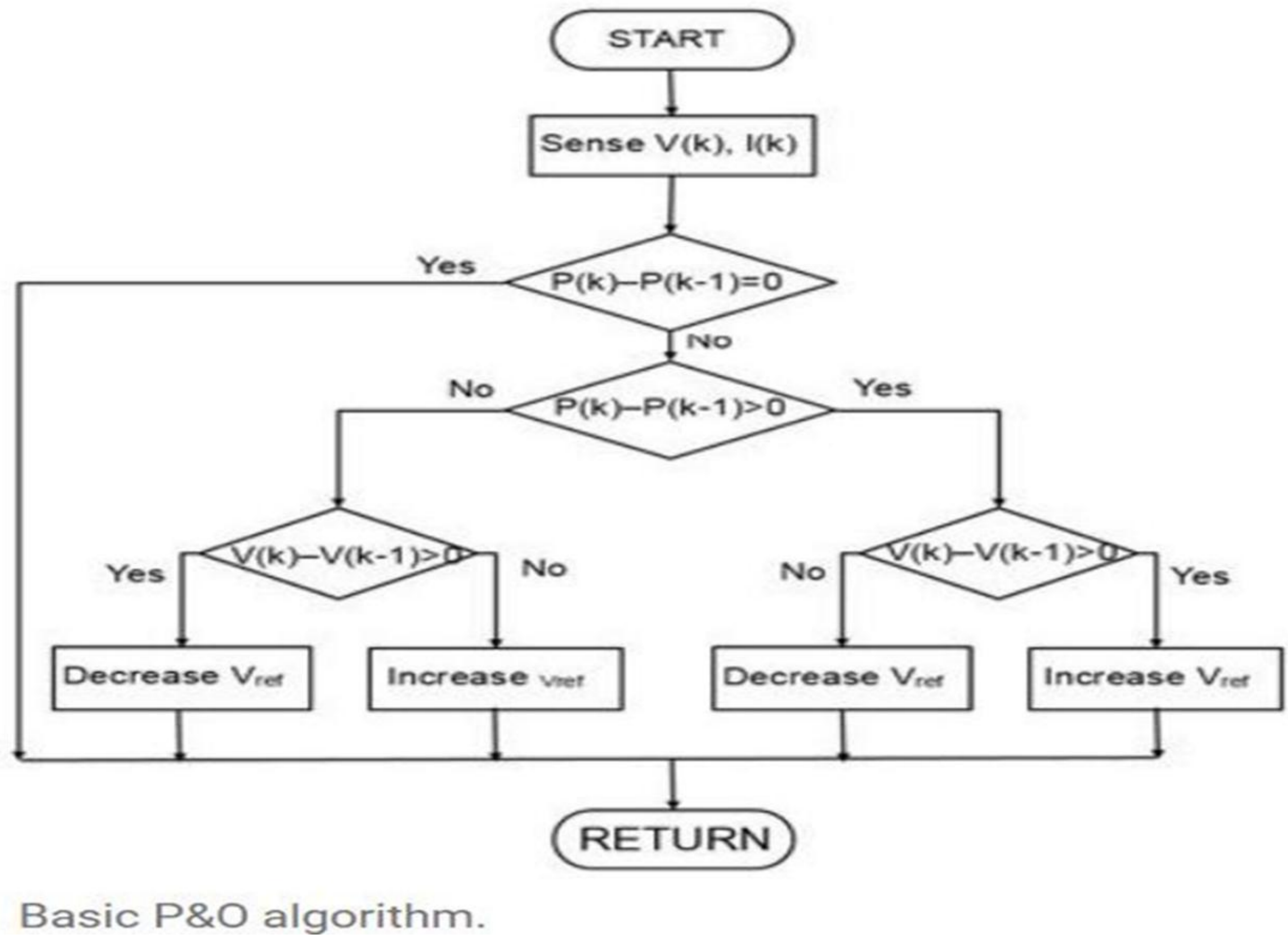

Fig.2.8: Flowchart of a conventional P&O method.

2.6. SUMMARY

Solar cells, can be modelled using diodes, resistors and current sources. There are many types of model such as Single Diode Model and Double Diode Model. Single Diode Model is used in this chapter and used to model solar cell in chapter 4.

MPPT is a technique to achieve maximum power point through adjusting the impedance seen by the solar panel, which is done through adjusting the change in duty cycle of converter. There are many algorithms to achieve MPP, but the most simple and easy to implement is P&O algorithm. But P&O algorithm oscillates around the MPP, and is not effective during rapid changes in the weather conditions.

CHAPTER 3:

FUZZY LOGIC AND FL – MPPT TECHNIQUES

3. FUZZY LOGIC

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. This section contains a basic overview of the principles of fuzzy logic.

3.1. Fuzzy Logic System

Today control systems are usually described by mathematical models that follow the laws of physics, stochastic models or models which have emerged from mathematical logic. A general difficulty of such constructed model is how to move from a given problem to a proper mathematical model. These complex systems can be simplified by employing a tolerance margin for a reasonable amount of imprecision, vagueness and uncertainty during the modeling phase.

Fuzzy logic allows to lower complexity by allowing the use of imperfect information in sensible way. It can be implemented in hardware, software, or a combination of both. In other words, fuzzy logic approach to problems control mimics how a person would make decisions, only much faster.

The fuzzy logic analysis and control methods shown in **Fig.3.1:,** can be described as:

1. Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analyzed or controlled.
2. Processing all received inputs according to human based, fuzzy ”if-then” rules, which can be expressed in simple language words, and combined with traditional non-fuzzy processing.
3. Averaging and weighting the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzified value. This is Fuzzy Logic Control/Analysis Method shown in **Fig.3.1:**.

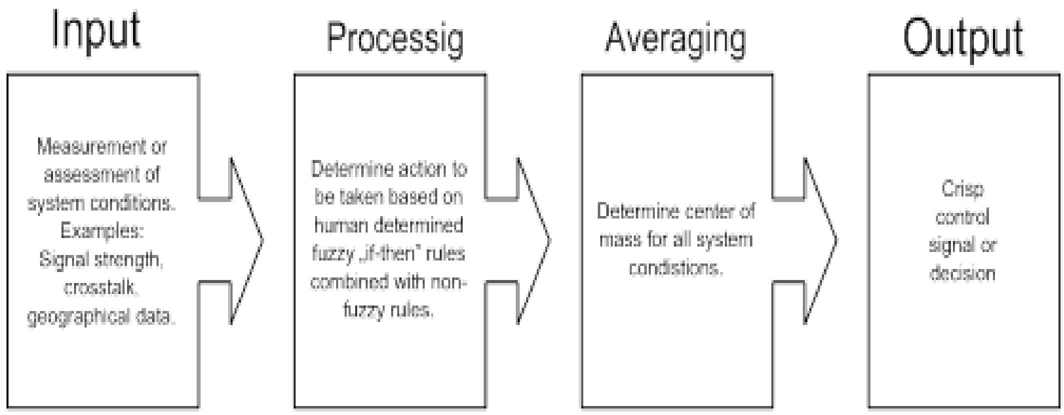

Fig.3.1: The Fuzzy logic Control - Analysis Method

In order to operate fuzzy logic needs to be represented by numbers or descriptions. For example, speed can be represented by value 5 m/s or by description “slow”. Term “slow” can have different meaning if used by different persons and must be interpreted with respect to the observed environment. Some values are easy to classify, while others can be difficult to determine because of human understanding of different situations. One can say “slow”, while other can say “not fast” when describing the same speed. These differences can be distinguished with help of so-called fuzzy sets. Usually fuzzy logic control system is created from four major elements presented on **Fig.3.2:**, fuzzification interface, fuzzy inference engine, fuzzy rule matrix and defuzzification interface. Each part along with basic fuzzy logic operations will be described in more detail below.

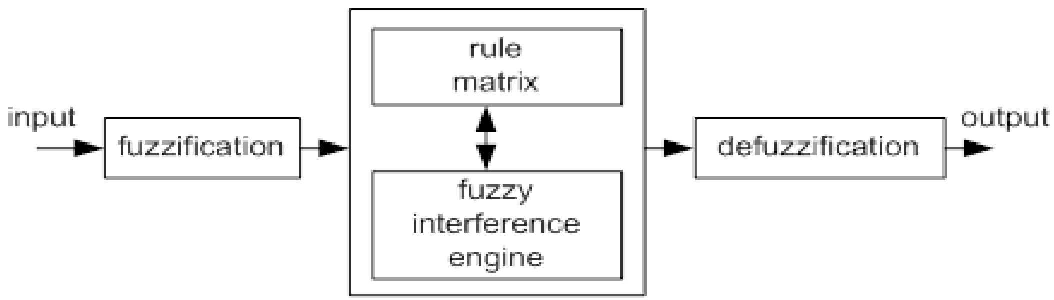

Fig.3.2: Fuzzy logic controller

3.1.1) Membership Function

It is a graphical representation of fuzzy sets, $\mu_F(x)$.

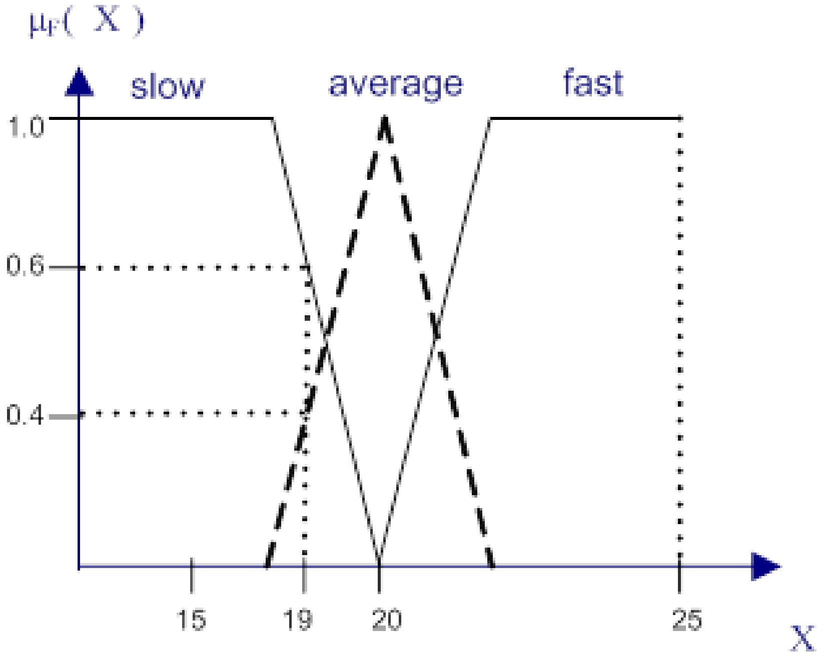

Fig.3.3: An example of fuzzy logic membership function

Fig.3.3:, shows the membership functions of three fuzzy sets, “slow”, “average”, and “fast”, for a fuzzy variable Velocity. The universe of discourse creates all possible values of Velocity, i.e., X = 19. For Velocity value 19 km/h, the fuzzy set “slow” has the membership value 0.6. Hence, $\mu_{slow}(19) = 0.6$. Similarly, $\mu_{average}(19) = 0.4$, and $\mu_{fast}(19) = 0$.

3.1.2) Fuzzification Method

First phase of fuzzy logic proceeding is to deliver input parameters for given fuzzy system based on which the output result will be calculated. These parameters are fuzzified with use of pre-defined input membership functions, which can have different shapes. The most common are: triangular shape, however bell, trapezoidal, sinusoidal and exponential can be also used. The only condition a membership function must meet is that it must vary between zero and one. The value zero means that input variable is not a member of the fuzzy set, while the value one means that input variable is fully a member of the fuzzy set.

3.1.3) Rule Matrix

The rule matrix is used to describe fuzzy sets and fuzzy operators in form of conditional statements.

The rule matrix is a simple graphical tool for mapping the fuzzy logic control system rules. It accommodates two or more input variables and expresses their logical product (AND or OR) as one output response variable. The degree of membership for rule matrix output can take value of maximum, minimum of the degree of previous of the rule.

3.1.4) Inference Mechanisms

Inference mechanism allows mapping given input to an output using fuzzy logic. It uses all pieces described in previous sections: membership functions, logical operations and if-then rules. The most common types of inference systems are Mamdani and Sugeno. They vary in ways of determining outputs.

3.1.5) Defuzzification Mechanisms

Defuzzification task is to find one single crisp value that summarizes the fuzzy set. There are several mathematical techniques available: centroid, bisector, mean, maximum, maximum and weighted average. **Fig.3.4:** demonstrate illustration of how values for each method are chosen.

Centroid defuzzification is the most commonly used method, as it is very accurate. It provides center of the area under the curve of membership function. For complex membership functions it puts high demands on computation. Bisector defuzzification uses vertical line that divides area under the curve into two equal areas.

Mean of maximum defuzzification method uses the average value of the aggregated membership function outputs.

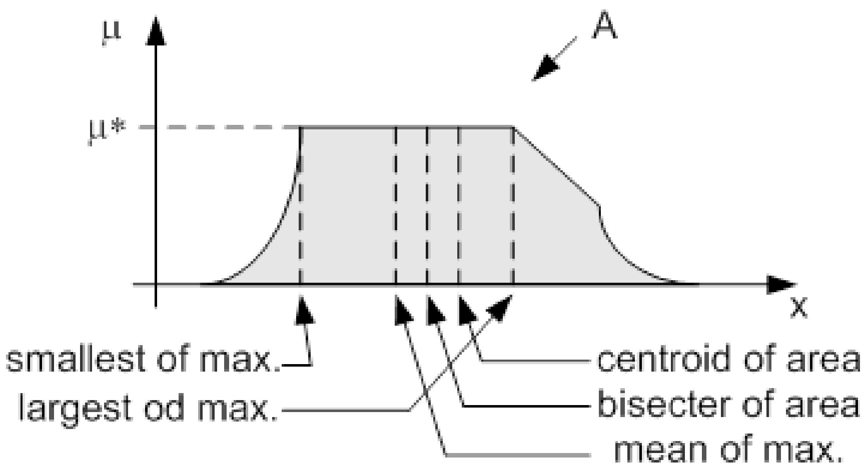

Fig.3.4: Graphical demonstration of defuzzification methods

Smallest of maximum defuzzification method uses the minimum value of the aggregated membership function outputs. Largest of maximum defuzzification method uses the maximum value of the aggregated membership function outputs. Weighted average defuzzification method, based on peak value of each fuzzy sets, calculates weighted sum of these peak values.

3.2. Conventional FL-MPPT

Nowadays, FL control based on an MPPT technique has become a popular method for PV systems. The structure of FL control includes three stages: fuzzification, fuzzy rules and defuzzification. A block diagram of this technique is shown in **Fig.3.5:**. In first stage, the input variables are converted into linguistic variables based on many defined membership functions.

In next stage, these linguistics variables get manipulated, according to rules based on the "if-then" concept that are guided by the desired behavior of the system. In the last stage, the FL control converts the linguistic variables into numerical variables using the output of membership functions.

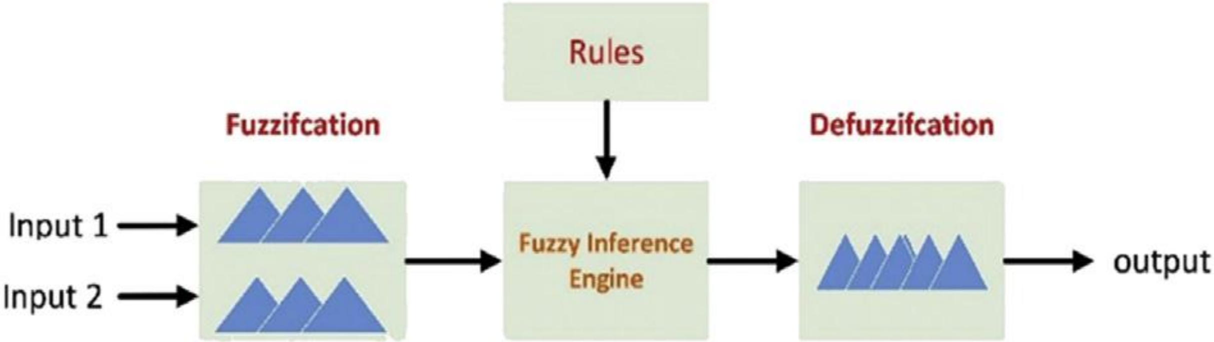

Fig.3.5: A general diagram of the fuzzy logic system.

In general, the quantity of membership functions is considered an important aspect of the design as it determines the speed and accuracy of the FL system. If the system has more membership functions. The implementation problem becomes over complex, resulting in an accurate system but with an excessive processing time. In contrast, if the system has few membership functions, then it is simple and whilst there is a faster processing system time and there is a high acceptable diversity of outcomes.

The conventional FL- MPPT has two inputs and one output, as shown in **Eqs. (3.1) and (3.2)**:

$$e(k) = \frac{\Delta P}{\Delta V} = \frac{P_{(k)} - P_{(k-1)}}{V_{(k)} - V_{(k-1)}} \qquad \textbf{(3.1)}$$

$$\Delta e = e_{(k)} - e_{(k-1)} \qquad \textbf{(3.2)}$$

Where e(k) is the change of slop P-V curve, and Δe is the change in its value of slop P-V curve.

The output is the change of duty cycle ΔD, which adjusts the performance of DC-DC converter as through Eq. (3.3):

$$\Delta D = \frac{\sum_i^n W_i \, C_i}{\sum_i^n W_i} \qquad \textbf{(3.3)}$$

Where W_i is the minimum number of membership functions of the i^{th} rule and C_i is the center value of the output membership functions. The conventional FL-MPPT examines the first input and increases or decreases the incremental change in duty cycle based on whether the input is greater than or less than zero, until the optimal value is reached. The second input is then used to reduce the oscillation in the duty cycle effectively. The quantity of membership functions of the conventional FL-MPPT method is divided into five values: negative big (NB), negative small (NS), Z, Zero (ZZ), positive small (PS), and positive big (PB) and 25 fuzzy rules. For example, if the value of the error is NB and changing error also negative big PB, the predefined rules assign the next variable duty cycle as ZZ, with process continuing until the optimal MPP is reached. All the rules of the FL-MPPT algorithm are provided in **table.3.1:**.

In general, FL - MPPT is considered one of the efficient controllers for a PV system due to its smooth fluctuation, and high accuracy in reaching the MPP and it does not require training data and thus works on different types of PV module the same MPPT design. But, implementation of this method is complex compared with the classical MPPT methods. The main challenge of this method is the drift phenomenon happens when weather conditions change, which **Fig.3.6:** explains.

If Point A (low point), represents the MPP at a low solar irradiance level is moving to B (high point) due to a rapid increase in solar irradiance, the right direction of the fuzzy tracker is moving far away from the new MPP, according to the rule base of the conventional FL-MPPT algorithm, as show in **table.3.1:**. To solve this issue. Many modifications have been proposed, such as an adaptive and optimized membership function of the conventional FL-MPPT algorithm. However, in this case the implementation becomes much more complex.

TABLE.3.1: FUZZY RULES THAT ARE USED IN THE CONVENTIONAL FL-MPPT

Δe (Change in error)	**e (error)**				
	NB	**NS**	**ZZ**	**PS**	**PB**
NB	ZZ	ZZ	NB	NB	NB
NS	ZZ	ZZ	NS	NS	NS
ZZ	NS	ZZ	ZZ	ZZ	PS
PS	PS	PS	NS	ZZ	ZZ
PB	PB	PB	NB	ZZ	ZZ

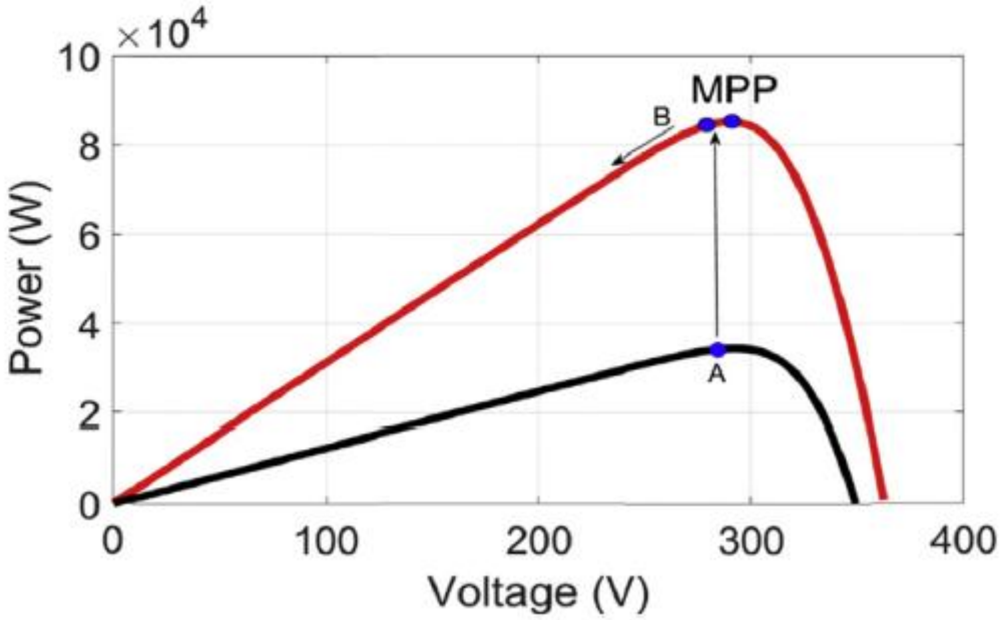

Fig.3.6: **P-V curve for a rapid irradiance change from A (low point) to B (high point), thus illustrating the drift problem in the FL-MPPT algorithm.**

3.3. Proposed method

The proposed method is designed to incorporate the advantages of the FL-MPPT and P&O-MPPT algorithms, whilst eliminating their drawbacks. Many studies provided evidence that the P&O algorithm is a suitable method for a PV-MPPT system when solar irradiance changes slowly from 1 to 10 W/m^2/s. However, this method is flawed when the changing irradiance is quicker than this.

Therefore, the irradiance is classified into two types: fast change and slow change, as shown by **Eqs. (3.4)** and **(3.5)**.

$$\Delta G > 10\ W/m^2/s \quad \textit{fast change} \tag{3.4}$$

$$\Delta G < 10\ W/m^2/s \quad \textit{slow change} \tag{3.5}$$

Where ΔG is the historical change in solar irradiance. The standard test condition (STC) of G=1000W/m^2/s. Substituting value of G into **Eqs. (3.4)** and **(3.5)**, the following is obtained:

$$\frac{\Delta G}{G} > 0.01 \quad \textit{fast change} \tag{3.6}$$

$$\frac{\Delta G}{G} < 0.01 \quad \textit{slow change} \tag{3.7}$$

As proved in Ref. [15], the normalized change in PV Power is equal to the normalized change in the solar irradiance, as shown in **Eq. (3.8):**

$$\frac{\Delta P}{P} = \frac{\Delta G}{G} \tag{3.8}$$

Substituting **Eq. (3.8)** into **Eqs. (3.6) and (3.7),** then:

$$\frac{\Delta P}{P} > 0.01 \quad \textit{fast change} \tag{3.9}$$

$$\frac{\Delta P}{P} < 0.01 \quad \textit{slow change} \tag{3.10}$$

Where ΔP is the historical change in PV power and P is the previous iteration for PV power. If the value of P is changed due to a solar irradiance change, the value of DP also changes in the same direction. Consequently, the value of $\Delta P/P$ is almost constant during varying weather conditions. This value is used in the fuzzy rules to detect the drift problem early. Defining the input and output of membership functions is considered an important step in the fuzzy logic design and those for the proposed system are selected as follows:

$$\frac{\Delta P}{\Delta V} = \frac{P_{(k)} - P_{(k-1)}}{V_{(k)} - V_{(k-1)}} \quad \textbf{(3.11)}$$

$$\frac{\Delta P}{P} = \frac{P_{(k)} - P_{(k-1)}}{P_{(k-1)}} \quad \textbf{(3.12)}$$

Where the **Eq. (3.11)** represents the historical change in PV power relative to the historical change in PV voltage, whilst the **Eq. (3.12)** pertains to the historical change in PV power relative to the previous iteration for it and the output of proposed fuzzy system is:

$$D_k = D_{k-1} + \Delta D \quad \textbf{(3.13)}$$

Where D_{k-1} and D_k are the previous and next iteration for the duty cycle respectively, and ΔD its incremental increase, which is the output of the fuzzy controller. The principle work of this proposal is to examine the first input. If this value is greater than zero the incremental change of the duty cycle increases until the MPP is reached, whilst if it is less than zero the opposite occurs also until the optimal value is reached. The second input is then used to address the drift problem. The variable inputs and output are divided into four fuzzy subsets: positive big (PB), positive small (PS), negative big (NB), and negative small (NS), as show in **Fig.3.7:, Fig.3.8: and Fig.3.9:**. The variable second input (ΔP/P) is adjusted according to **Eqs. (3.11) and (3.12).** The fuzzy rules of the proposed system are based on the P&O-MPPT algorithm, with there being a total of 16. If the value of (ΔP/ΔV) is NB and (ΔP/P) is also NB, then so too is the duty cycle is NB. The process is continued until the optimal MPP is reached and then it oscillates around the optimal MPP.

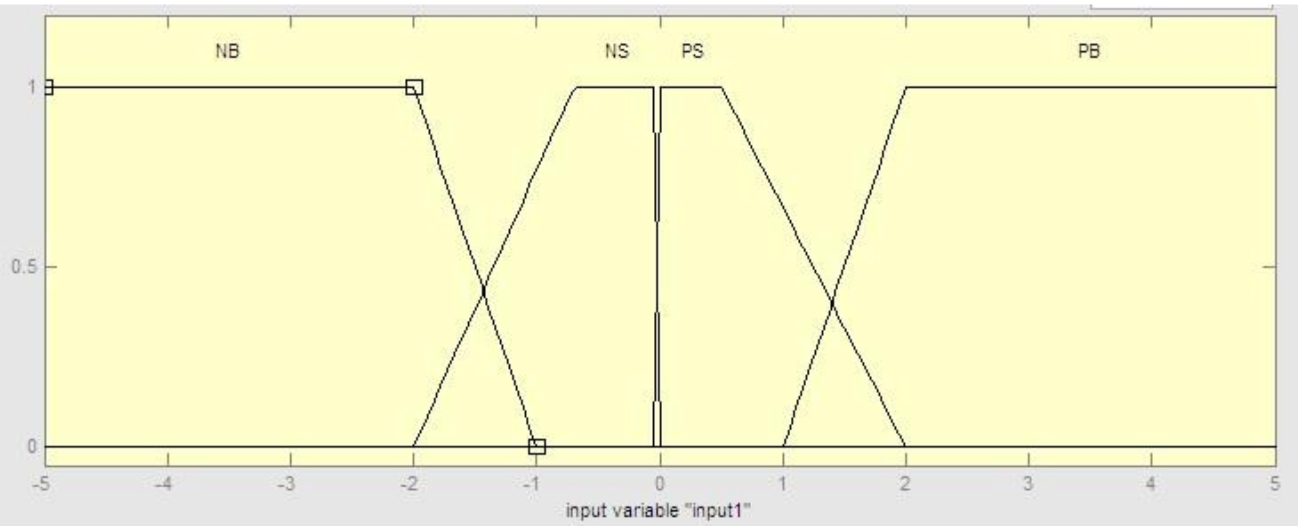

Fig.3.7: Input - 1 member function plots

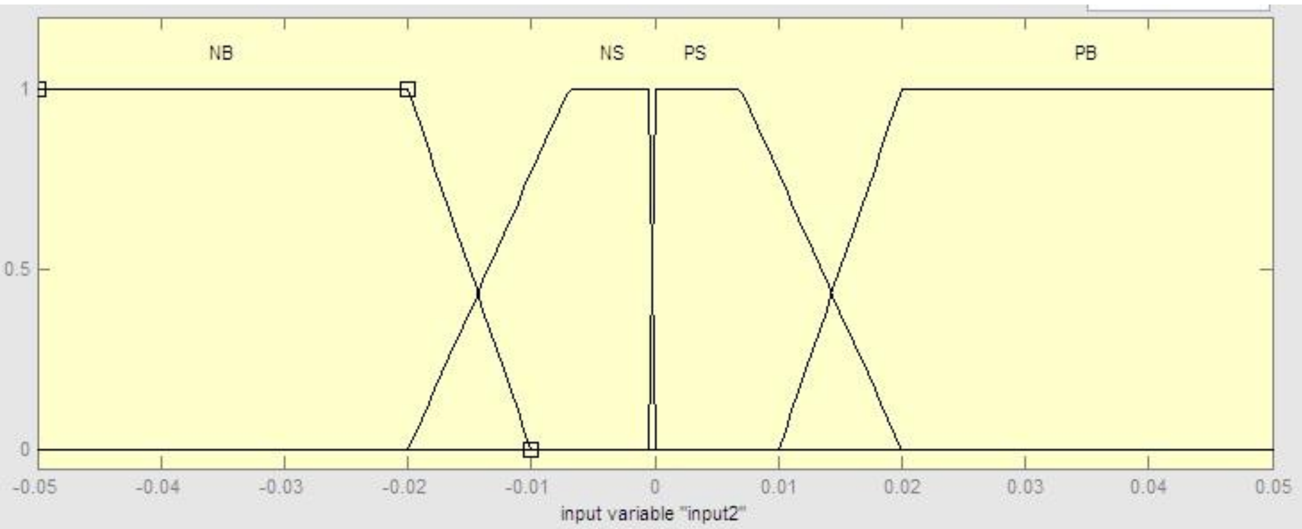

Fig.3.8: Input - 2 member function plots

To avoid the drift problem associated with positive fast change in solar irradiance, the fuzzy rules are changed in a reverse direction when ($\Delta P/P$) > 0.01, which is equal to the PB in the second input. All the fuzzy rules of the proposed MPPT method are provided in **table.3.2:**. The output of proposed system is the variable duty cycle ΔD, which is added to the previous iteration for the duty cycle, as show in **Eq. (3.13).**

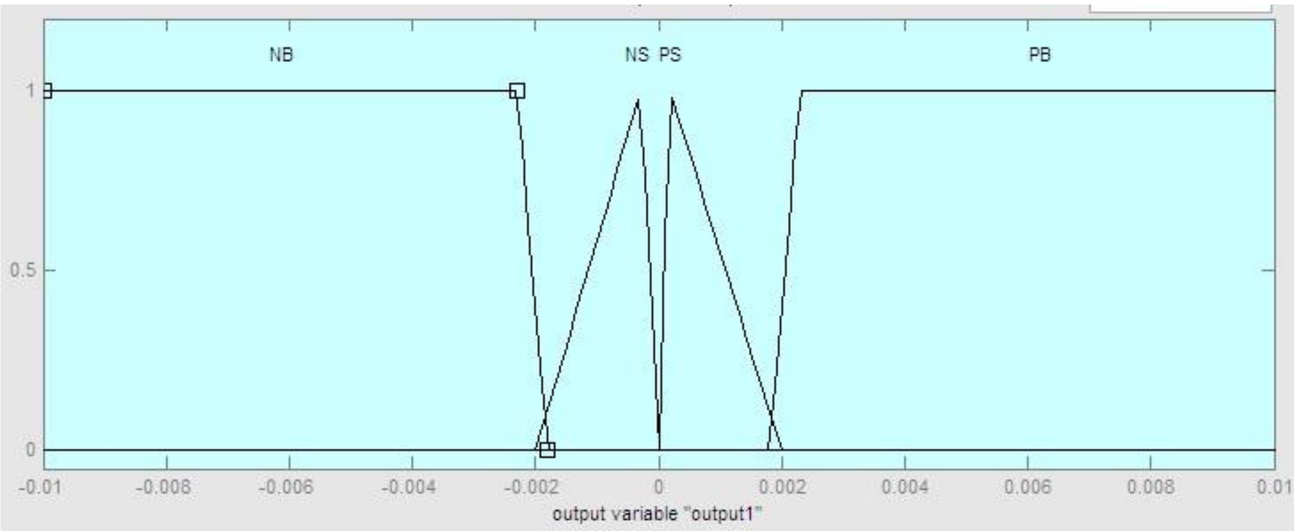

Fig.3.9: output member function plots

As a result, the step size of the duty cycle is large when the operational point is far from the MPP, and it automatically becomes tiny, when the operational point closes in on it.

Consequently, the proposed system increases the speed of MPPT tracking when the weather conditions change rapidly. In addition, it reduces the oscillation around the MPP for steady-state conditions. Moreover, what is proposed is more accurate for addressing the new MPP when the irradiance changes owing to the adaptive rules of the fuzzy system according to weather conditions. Furthermore, the proposed system provides less complex implementation, minimum processing time and more delivery compared with the conventional FL-MPPT, because of its lesser number of fuzzy rules.

TABLE.3.2: THE FUZZY RULES THAT ARE USED IN THE PROPOSED METHOD

ΔP/P (change in PV power relative to the previous iteration power)	ΔP/ΔV (change in PV power relative to the change in PV voltage)			
	NB	**NS**	**PS**	**PB**
NB	NB	NS	PS	PB
NS	NB	NS	PS	PB
PS	NB	NS	PS	PB
PB	PB	PS	NS	NB

3.4. SUMMARY

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state. This mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra.

Conventional FL-MPPT, is P&O algorithm with Fuzzy Logic controller. This uses 25 rules and 5 membership functions which achieves MPP, but as a disadvantage of complex implementation compared to P&O and drift problem associated with rapid changing irradiance. Proposed method uses Fuzzy logic with P&O algorithm with less number of rules that is 16 and membership functions to reduce the complexity and processing time.

CHAPTER 4:

DESIGNING AND MODELLING OF THE PROPOSED MPPT TECHNIQUE

4. DESIGNING AND MODELLING OF THE PROPOSED NOVEL MPPT TECHNIQUE

To test the performance of the proposed method, a MATLABSIMULINK model for the PV system has been developed. The PV system used in this simulation consists of a PV array, DC-DC boost converter with MPPT controller and a grid, as shown in **Fig.4.1**:.

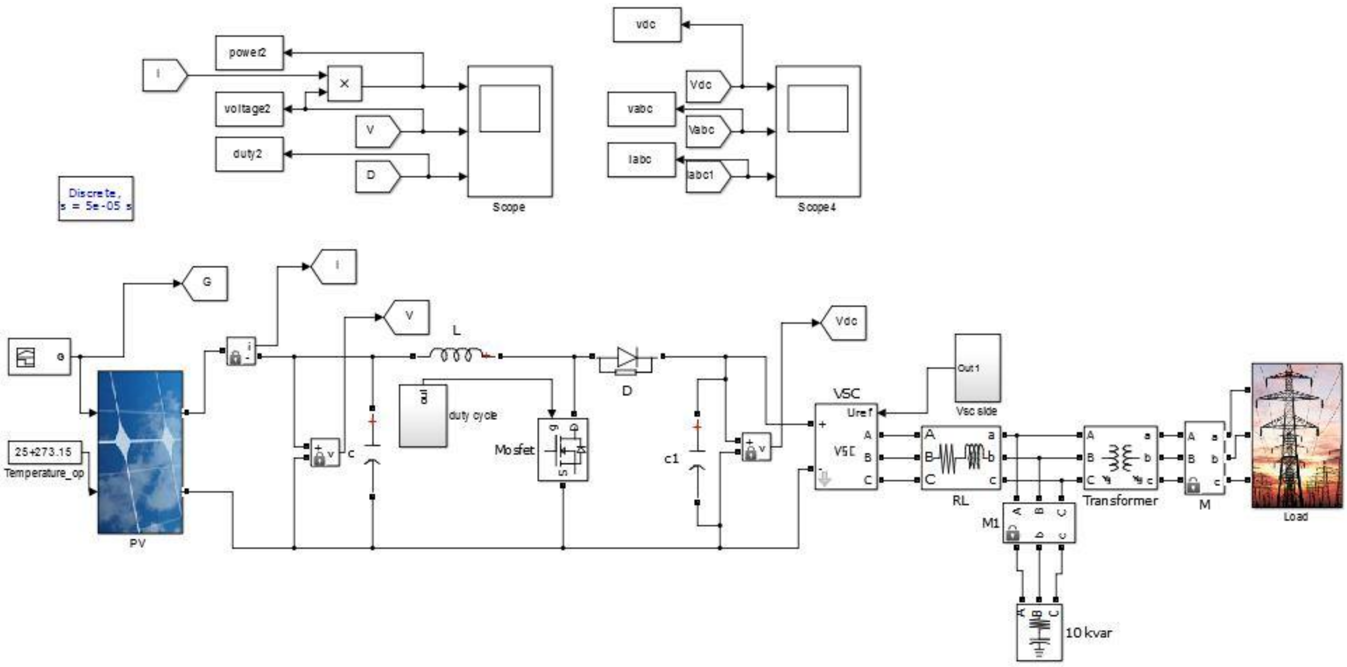

Fig.4.1: Simulink Model of PV system

4.1 Modeling of solar PV array

Basically the solar cell is modelled using the equivalent circuit and equations as given in the chapter - 2, that is equations from **Eq.2.4 to 2.7.** Practically the output of the solar cells are very low with voltages ranging about 0.5 volts. Hence a desired number of cells are connected in series to form a string, which is then later such strings are used for connecting in parallel to form a solar array of required output voltage and current.

Further multiple panels are connected together both in parallel and series to achieve higher current and higher voltage. The parameters of the solar panel used in model has a open circuit voltage of 320 V and short circuit current of 390 A. the solar panel is shown in **Fig.4.1:** connected to the boost converter and its PV curve for variable irradiance and temperature given in **Fig.4.2: and Fig.4.3:**.

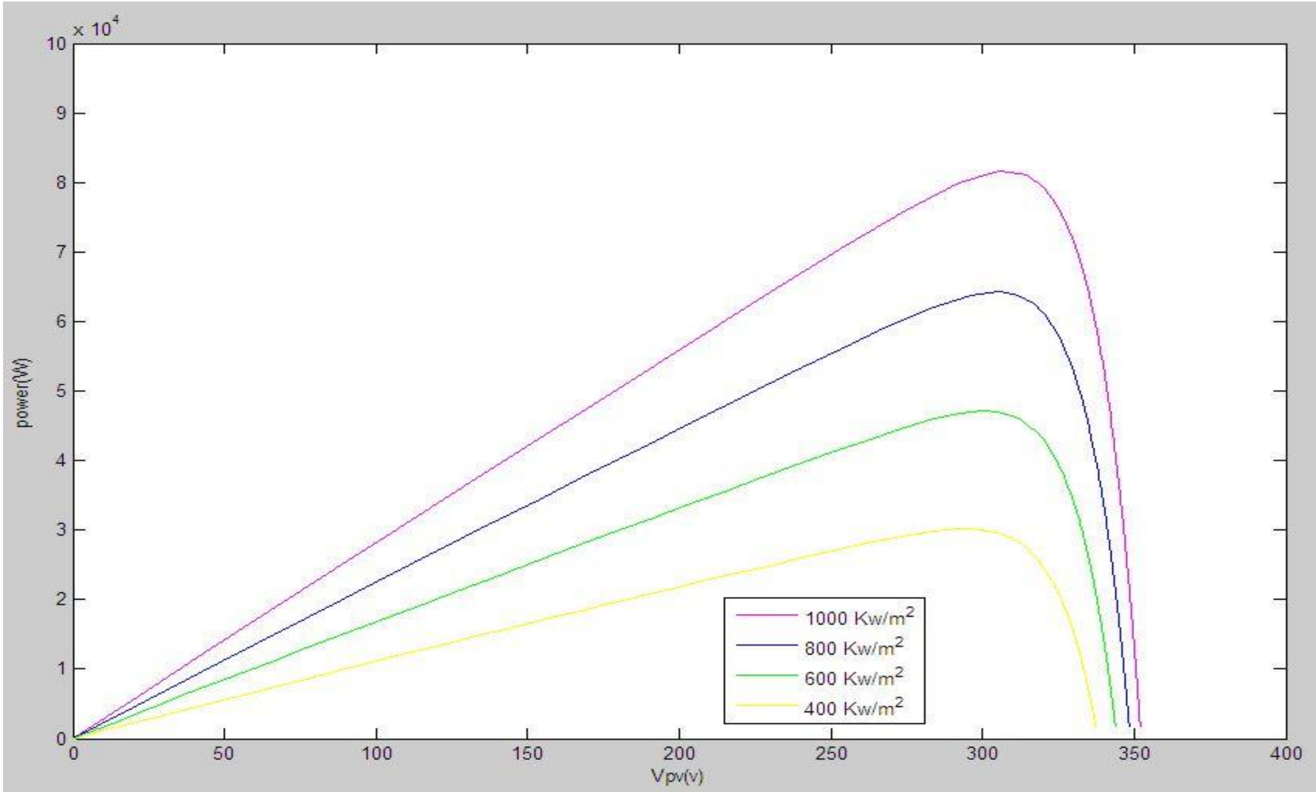

Fig.4.2: P-V curve of a PV array under: various values of irradiance at a temperature of 25° C.

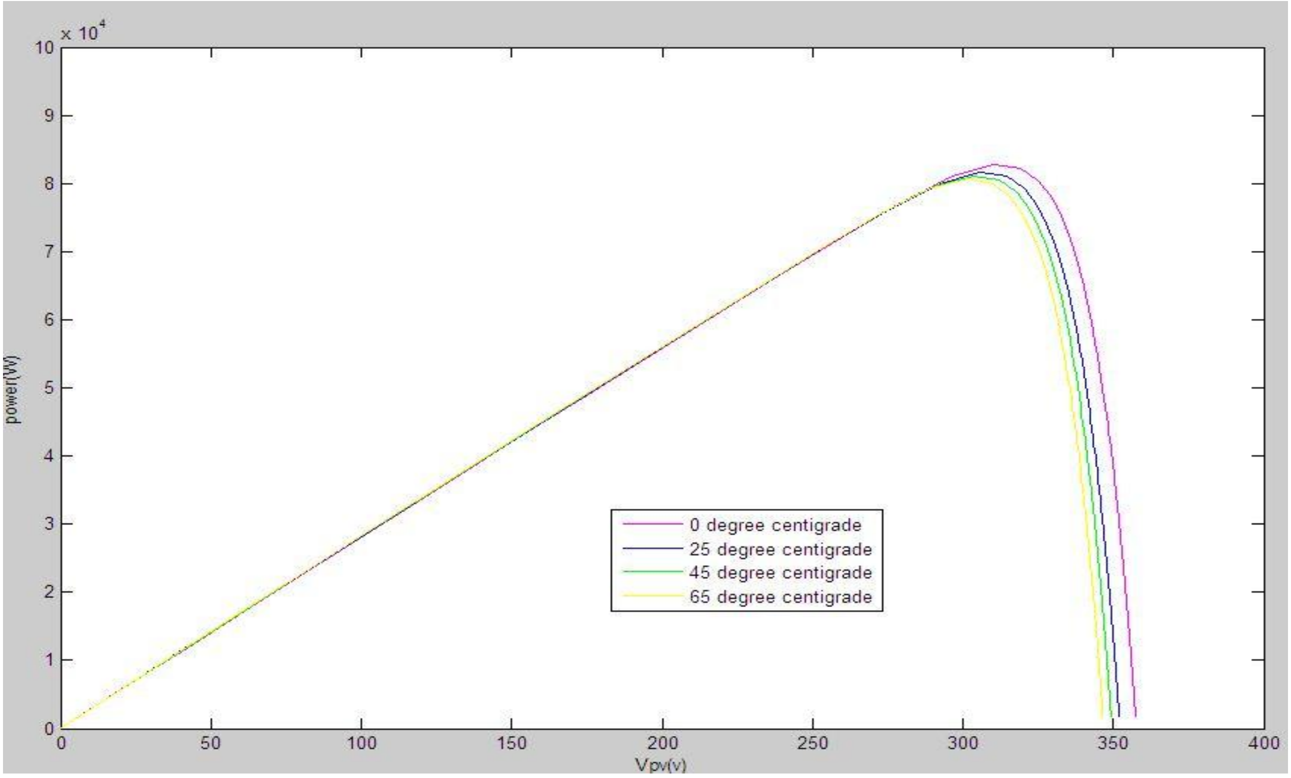

Fig.4.3: **P-V curve of a PV array under: various values of temperature at an irradiance of 1000 W/m2.**

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4.2 Power conversion system

To improve the stability, reliability and quality of the output of PV system generation, a power conversion system is employed. There are two types for PV power conversion system; single stage and double stage. Although the single stage-power conversion system is lower in cost due to its fewer part count, it suffers from several drawbacks such as hot-spots during partial shading conditions of the PV array, increased probability of leakage current through the parasitic capacitance between the PV array and the ground system, and reduced safety. Those issues occurred in grid-connected PV system due to a large change in DC voltage of PV array. Therefore, the first stage is used to boost the MPP voltage and track the maximum power, and the second stage converts this DC power into high quality AC power.

4.2.1) DC-DC BOOSTER converter

In first stage, a DC-DC boost converter is widely used for the PV generated system due to its high efficiency and easily adapted MPPT controller. It is used to provide and regulate an appropriate the output voltage that has level which is considerably more than the input voltage. As shown in **Fig.4.4:**, the heart of the DC-DC boost converter is a transistor, which regulates the amplified processing by a controller. The MOSFET transistor is usually used for this kind of converter. The voltage gain of the circuit is given as in Eq. (4.1):

$$G_n = \frac{V_o}{V_i} = \frac{1}{(1-D)} \qquad \textbf{(4.1)}$$

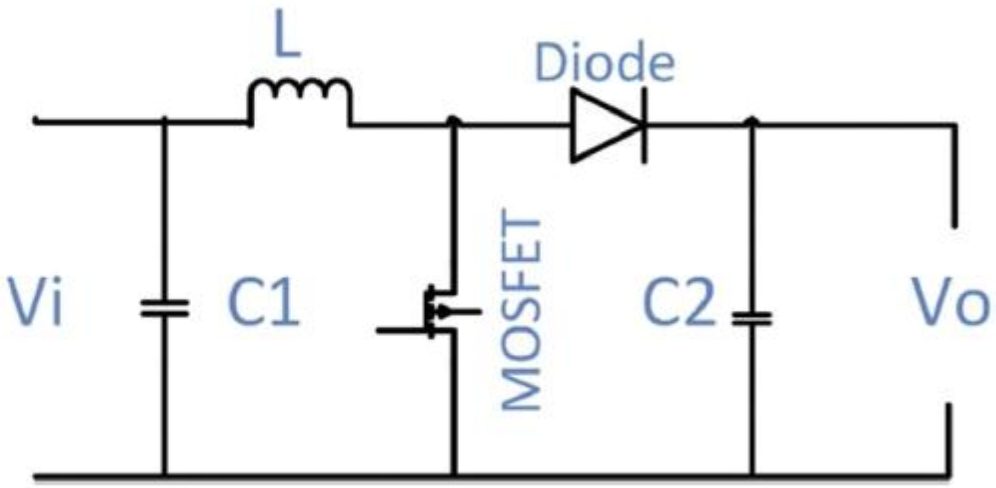

Fig.4.4: Circuit diagram of a DC-DC boost converter.

Where V_o is the output voltage, V_i is the input voltage, and D is the duty cycle of DC-DC boost converter, which is converted to a control signal by a gate driver circuit. The principle work of this converter divides into two states, first, when the MOSFET is switched ON; the current flows through an inductor (L) in a reverse direction and the inductor stores the energy by generating a magnetic field, while the output capacitor (C2) transfers its energy to the load or invertor. In state two, when the transistor is switched OFF, the energy stored and main source will be in series, which leads to a higher output voltage. In the grid-connected PV system, the DC-DC boost converter plays a crucial role in maintaining a constant DC voltage system for a DC-AC inverter.

Design of the boost converter involves calculation inductor and capacitor values from the given formulas below.

$$\text{Duty Cycle (D)} = 1 - \frac{V_s}{V_o} \qquad \textbf{(4.2)}$$

V_S = Input Voltage

V_O = Output Voltage

D = Duty cycle

Duty cycle D = 0.8, is obtained from **Eq.4.2.**

INDUCTOR:

$$L = \frac{V_S \times D}{f_S \times \Delta I_O} \qquad \textbf{(4.3)}$$

Here, L = Inductance, V_S= input voltage, f_S = Switching frequency = 5 KHz and ΔIo = Ripple current.

The ripple current is considered equal to 20% to 40% of the inductor current I_L, the thumb rule is that, if the value of ripple current is considered below 20% of I_L, then the system may become unstable operation. And if the value of ripple current is considered more than 40% of I_L, then the system becomes more sensitive to EMI (Electro Magnetic Interference).Thus the range for ripple current value is taken in between 20% to 40% of I_L. The inductor value is taken just higher than the inductor value obtained from the above equation.

CAPACITOR:

$$\Delta \mathbf{V} = \text{ESR}\ \left(\frac{I_o}{1-D} + \frac{\Delta I_{L_{new}}}{2}\right) \qquad \mathbf{(4.4)}$$

$$\text{C} = \frac{I_o \times D}{f_S \times \Delta V_o} \qquad \mathbf{(4.5)}$$

$$\text{Ripple Voltage } (\Delta \mathbf{Vo}) = \frac{I_o \times D}{f_S \times C} \qquad \mathbf{(4.6)}$$

Where, C = Capacitance and I_O = Output current

The ripple voltage should be as low as possible to make a system efficient and to reduce unwanted voltage variations in the output of the booster converter. The ripple voltage is considered of value between 1% to 5% of capacitor voltage or load voltage. If the ripple voltage is considered below 1% of V_{OUT}, then the size and cost of capacitor will increase and not economical.

The inductor value of 5 mH and capacitor value of 1μF obtained through equations **Eq.4.2 to 4.6.**

4.2.2) DC – AC converter

The second stage of the power conversion system is a voltage source converter, built using Universal bridge block from simulink which is shown in **Fig.4.5:**, as simulink block. This converter is controlled by a controller. Controller acts by providing the Uref to the bridge.

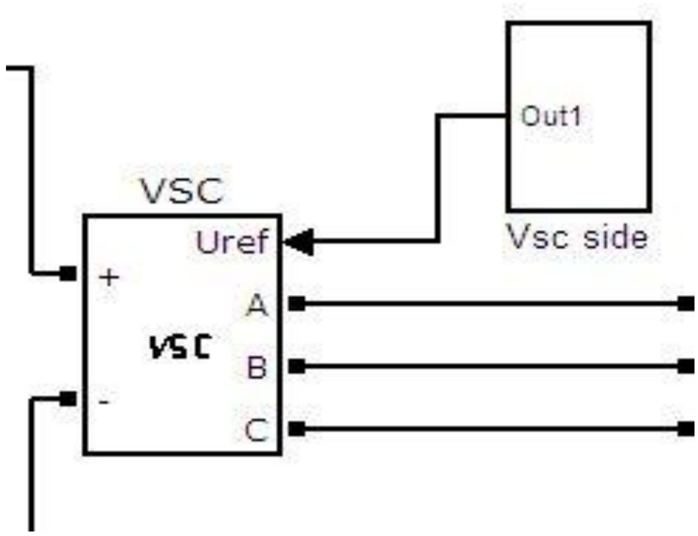

Fig.4.5: DC – AC converter simulink block

The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box. Series RC snubber circuits are connected in parallel with each switch device. For most applications the internal inductance Lon of diodes and thyristors should be set to zero.

A three arm bridge converter was modelled for 3- phase conversion with the DC input from the DC-DC booster converter through DC link.

4.3 SUMMARY

The solar cell is modelled through single diode model. It was formed by the equation as given in chapter 2 about modelling of solar cell. The DC-DC booster and the inverter together is called the power conversion system, by using the equation of boost converter and inductor and capacitor values were obtained. The switching frequency of the IGBT is 5000 Hz.

Inverter used to connect to the grid is obtained by using the universal bridge block in the MATLAB/SIMULINK, 3 arm or 6 pulse converter was realized to convert DC to 3 phase current and voltages, the also contains snubber resistances and capacitance.

CHAPTER 5:

SIMULATION RESULTS

5. SIMULATION RESULTS

5.1 P&O WITH PROPOSED FUZZY LOGIC CONTROLLER METHOD

Above **Fig.4.1:**, shows the simulink model for P&O with proposed Fuzzy Logic controller implementation. The duty cycle block produces the duty cycle to IGBT for achieving MPPT at the output.

The subsystem inside the duty cycle block is shown below in **Fig.5.1:**. initially P&O algorithm is used with inputs of voltage, current and irradiance, whose output is error E and change of error ΔE (CE), these are feed to Fuzzy Logic block system producing a ΔD value which is suitable to adjust the actual duty cycle such that the PV-MPPT system reaches the maximum power point (MPP) with reduced and medium oscillations around the MPP with low complexity compared to conventional FL-MPPT method.

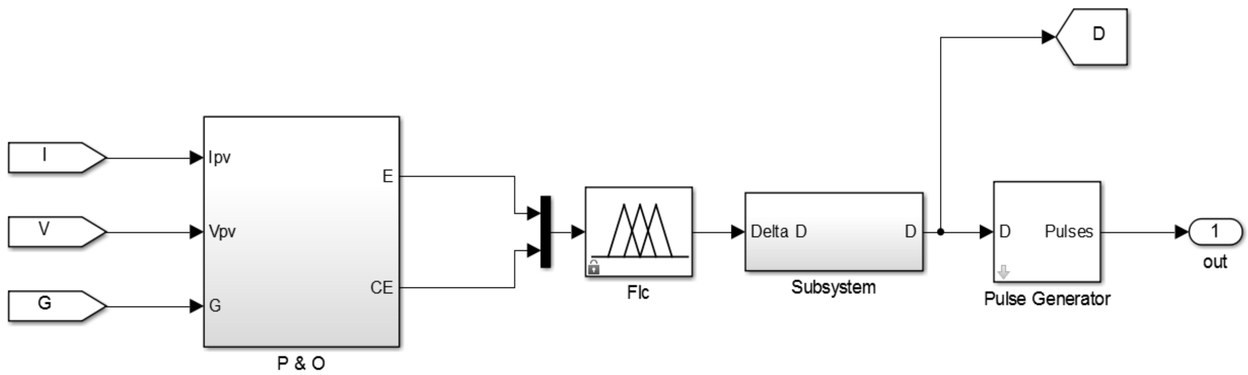

Fig.5.1: Simulink Function block implementing P&O with proposed FLC method

When the input solar irradiance was rapidly increased from 400 to 1000 W/m^2 at 1 to 2 s, and the temperature was kept at a constant value of 25^0 C Output of the above model that is power, voltage and duty cycle is shown below from **Fig.5.1: to Fig.5.4:,** with respect to time, respectively.

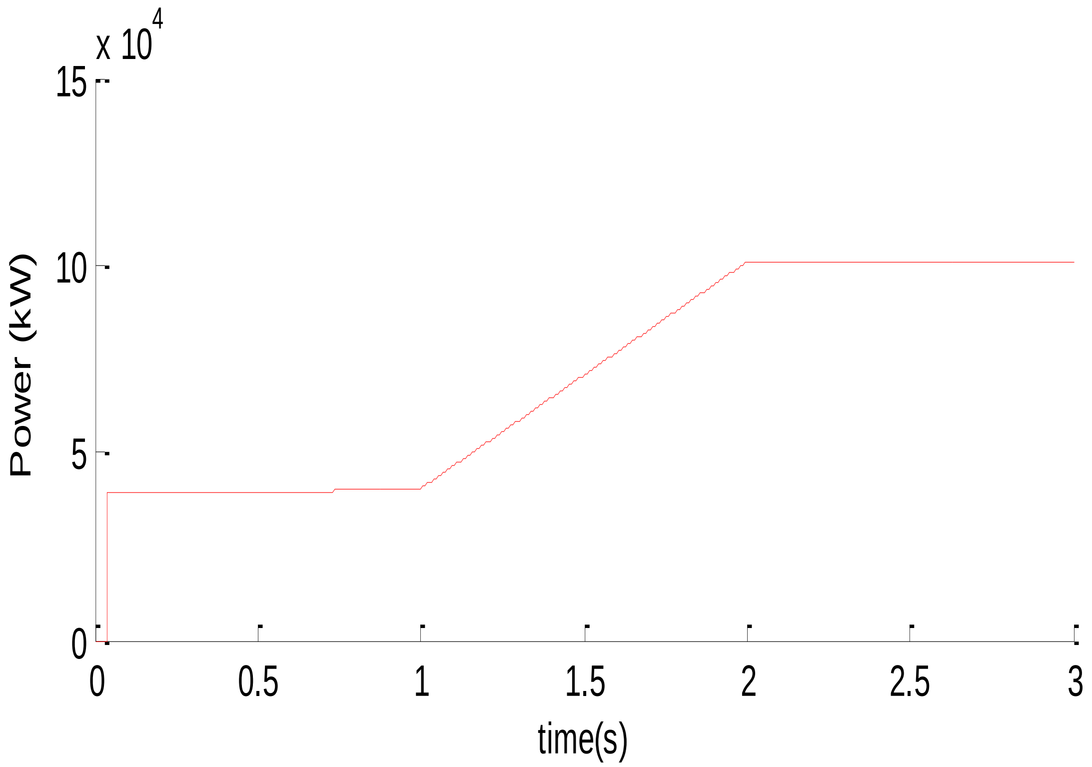

Fig.5.2: Power of solar panel in proposed FL method.

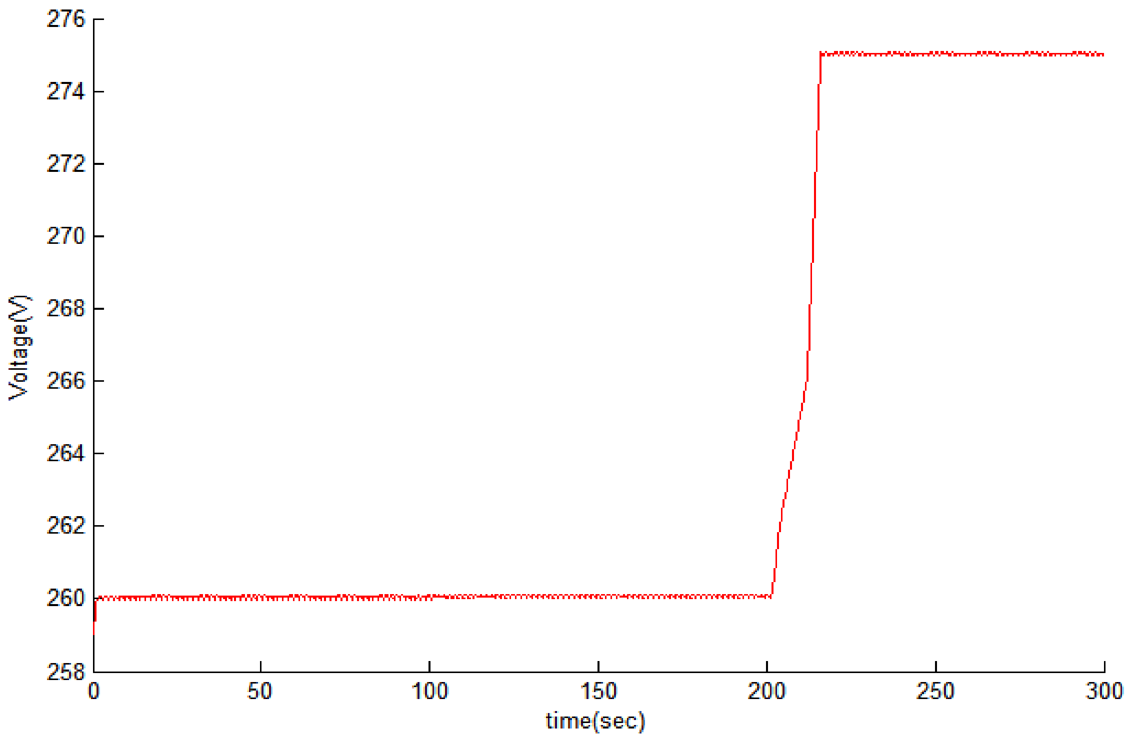

Fig.5.3: Output voltage of solar panel in proposed FL method.

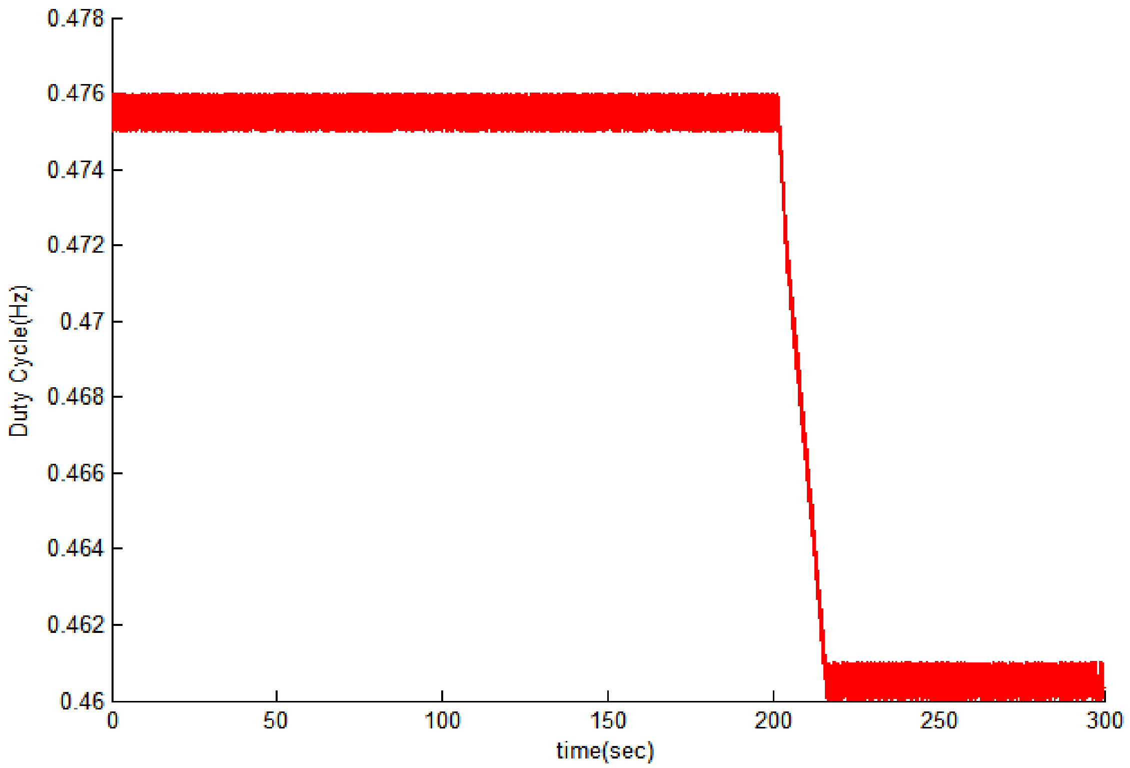

Fig.5.4: dutycycle in proposed FL method.

5.2 RESULT ANALYSIS:

5.2.1) P&O with Proposed FLC Vs only P&O method and conventional FLC

The simulation was divided into two scenarios. First, the proposed method and conventional P&O were simulated. The input solar irradiance was rapidly increased from 400 to 1000 W/m^2 at 1 to 2 s, and the temperature was kept at a constant value of 25º C. As shown in **Fig.5.5:**, the power tracking of the proposed method turned out to be fast and accurate in finding the right direction, whilst that of the conventional P&O algorithm was lost when the solar irradiance changed rapidly. As a result, the latter method takes a longer time than the proposed one to address the phenomenon of the drift problem, as shown in **Fig.5.5:, Fig.5.6: and Fig.5.7:**.

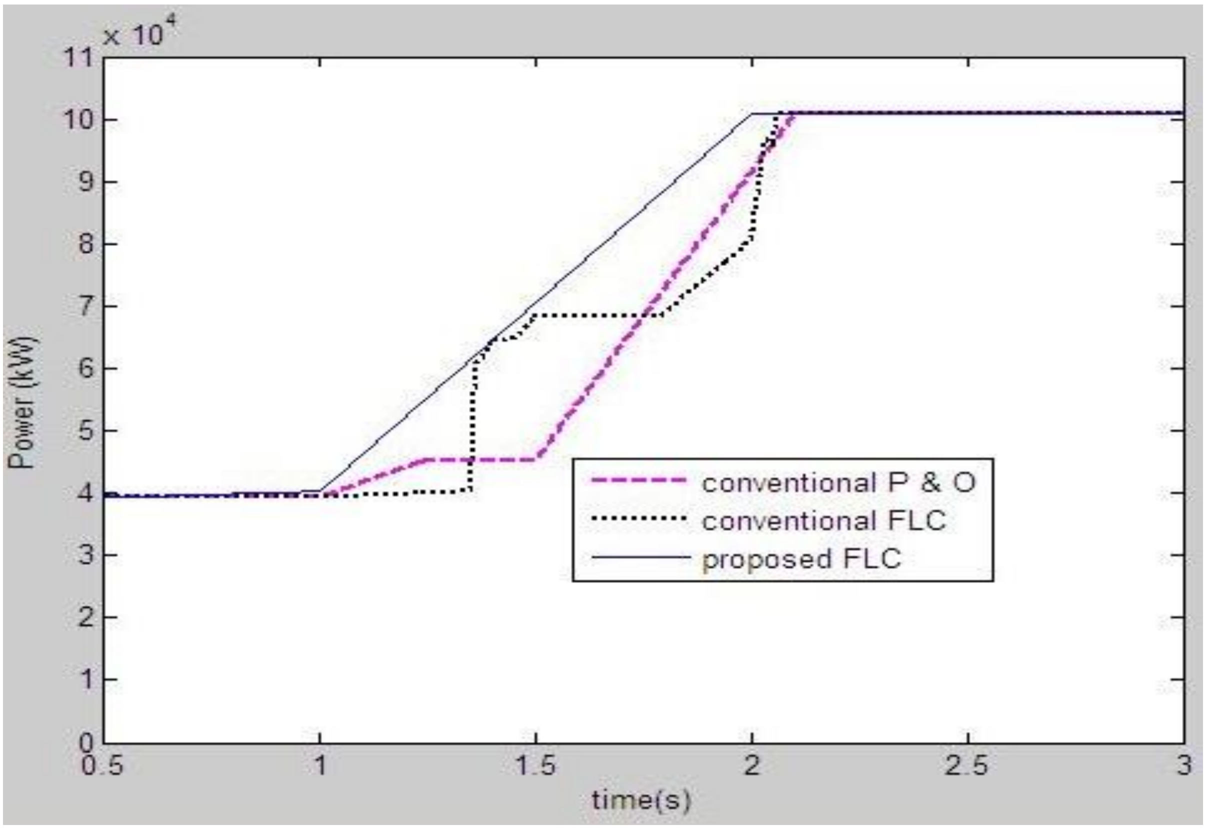

Fig.5.5: Power Comparison between Proposed FLC method, P&O method and conventional FLC method

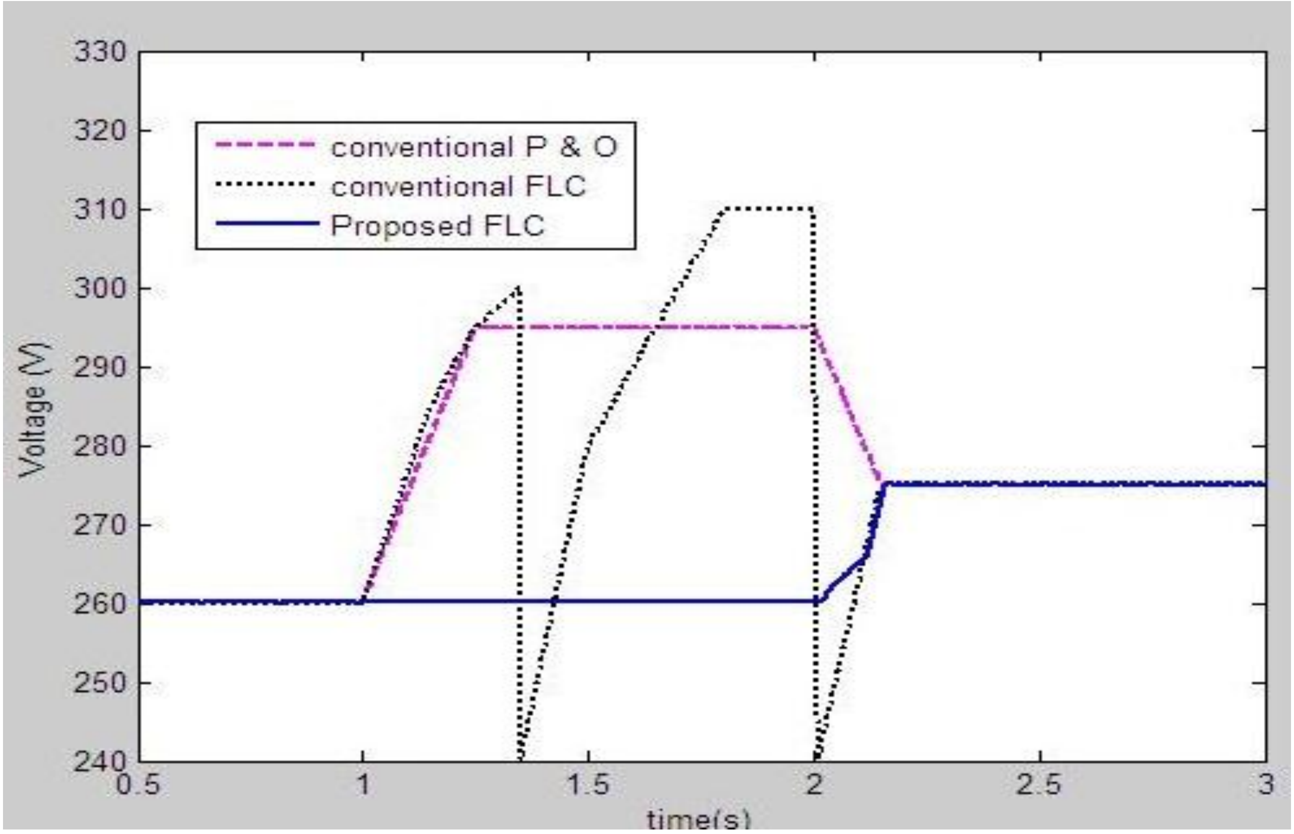

Fig.5.6: Voltage comparison between proposed FLC method, P&O method and conventional FLC method

The proposed method and the conventional FL-MPPT algorithm were simulated under the same weather conditions as previously. The simulation results again proved that the proposed method avoids the system experiencing the drift problem. In addition, it gives a fast response to finding the new MPP during a high change in solar irradiance, whereas the FL-MPPT continues to suffer from the drift problem, as shown in **Fig.5.5:, Fig.5.6: and Fig.5.7:**.

Whilst the fluctuations of the MPPT tracker around the MPP steady state conditions are higher in the proposed method when compared with the conventional FL-MPPT, as shown in the **Fig.5.7:** the output PV power of the conventional FL-MPPT is lower due to it having more membership functions, thus resulting in a longer computation time.

In addition, the duty cycle of the proposed method is more accurate in finding the new MPP after solar irradiance changes, and it has a smooth oscillation around this value for steady-state conditions when compared with the conventional P&O-MPPT, as shown in the **Fig.5.6:**.

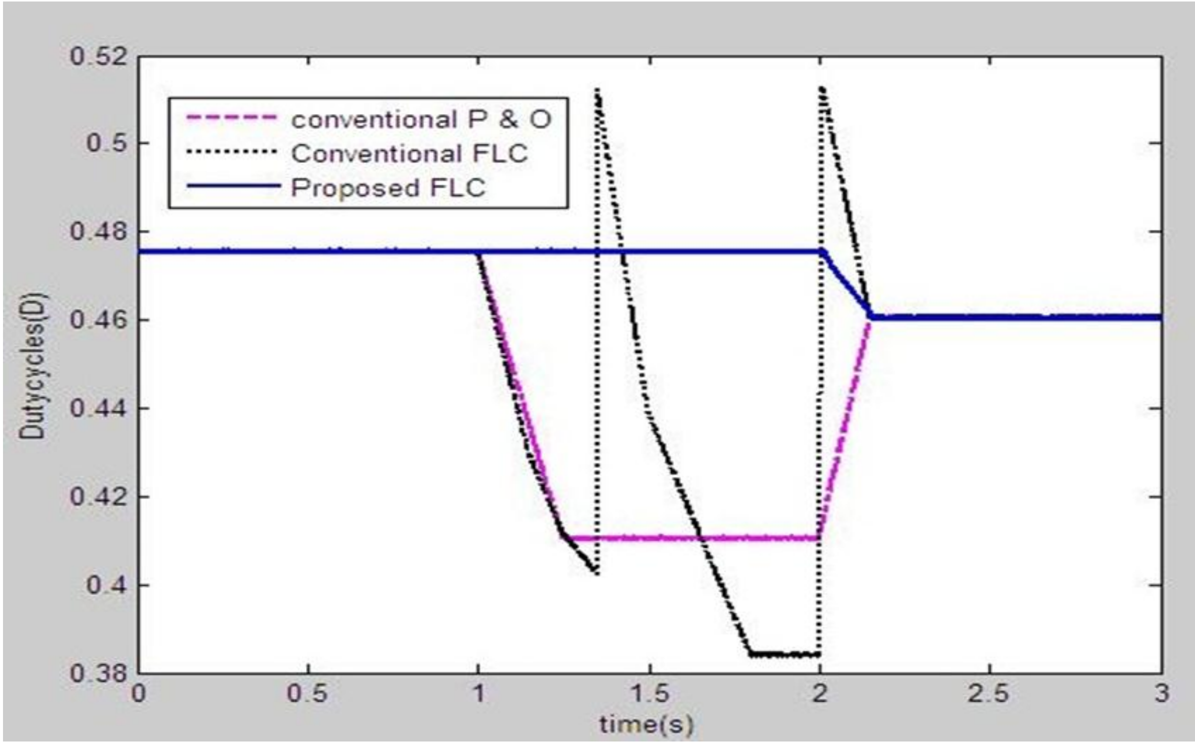

Fig.5.7: Duty cycle comparison between proposed FLC method,P&O method and conventional FLC method

Consequently, the output power of conventional P&O-MPPT and the proposed method at the steady-state condition, after they reach to the MPP, are 100.722 kW and 100.724 kW, respectively, as shown in **Fig.5.5:**.

To validate the accuracy of the proposed MPPT tracker for the grid-connected PV system, DC voltage, injected current and grid voltage, before and after the weather conditions change, were simulated. As shown in the **Fig.5.8:**, the output voltage of the DC-DC boost converter is stable even during rapid weather conditions change as the one cycle at 1.1 s. Hence, the injected current and the grid voltage of the grid-connected PV system is stable at all times, as shown in **Fig.5.8:**. As a result, the proposed method is more effective for working with the grid-connected PV system under varying weather conditions. To assess further the proposed MPPT technique, **table.5.1:** compares its properties with the conventional P&O-MPPT and FL-MPPT methods. As can be seen, the proposed MPPT method has a medium oscillation around the MPP point under the steady state condition, less number of fuzzy rule subsets, simple implementation and the highest output power. Moreover, according to the simulated results, the proposed technique accurately tracks the MPP and avoids the drift problem.

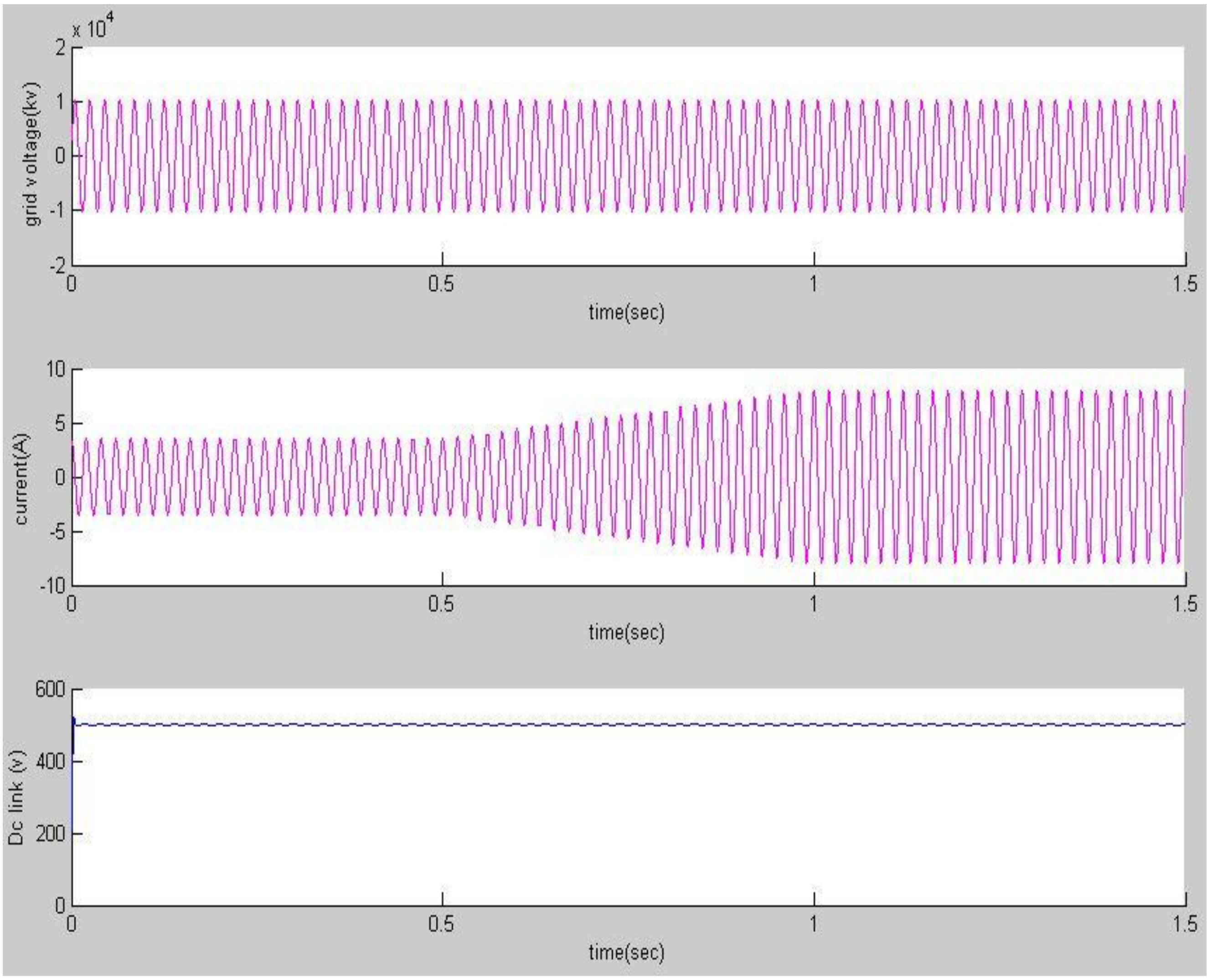

Fig.5.8: Grid-connected PV system using the proposed MPPT method:,the grid voltage the injected current to the grid and the DC voltage.

TABLE.5.1: A COMPARISON OF PROPERTY OF PROPOSED METHOD, CONVENTIONAL P&O AND CONVENTIONAL- FL METHODS.

MPPT	***Number fuzzy rules***	***Oscillation***	***Implementation***	***Output power (kW)***
Proposed method [15]	16	Medium	Simple	100.724
Conventional FL [15]	25	Low	Complex	100.723
Perturbation and Observation (P & O)	–	High	Simple	100.722

CONCLUSIONS:

- A novel maximum power point tracking technique based on fuzzy logic for a grid-connected PV system has been presented, which has the ability to track the MPP when there are big fluctuations of irradiation.

- The advantages and disadvantages of the FL-MPPT and P&O-MPPT have been discussed. The designed membership functions of FL the controller where tuned based on modified a P&O algorithm to incorporate the advantages of the P&O-MPPT and the FL-MPPT as well as to eliminate their drawbacks.

- A MATLAB-SIMULINK model for the grid-connected PV system was developed. The P&O-MPPT, FL-MPPT, and proposed method were simulated, being then compared, according to their common features.

- The simulation results have revealed that the proposed technique exhibits higher output power of 100.724 kW compared to conventional FL and P&O method as shown in **table.5.1:**, medium oscillation around the MPP point under the steady state condition and no divergence from the MPP during varying weather conditions regardless of the speed of change. With reduced complexity and reduced (i.e 16) membership functions.

- That is, the proposed concept has been demonstrated to be highly effective for working with a grid-connected PV system, achieving higher efficiencies. Finally, this modification has been shown to be simple to implement.

FUTURE SCOPE

The proposed Fuzzy Logic control method implemented with P&O, as explained and simulated in this project is one of the efficient methods for achieving MPP. This project can be further expanded by implementing Artificial Intelligence through Fuzzy Logic system for improved performance during rapid changes in the environment such as partial shading conditions (PSC). P&O MPPT method is the easiest method and simple implementation, but it has drawbacks of wrong tracking during rapid change in weather conditions and other disadvantages, negative effects associated to such a drawback can be greatly reduced if the Artificial Intelligence (AI) concepts are used to improve P&O algorithm. They are designed to track global maximum power point (GMPP) instead of local MPP in alleviating the effects of PSC.

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