Geographical Parameter Based Maximum Power Point Tracking Using Fuzzy Logic for Isolated PV system

A Thesis submitted in partial fulfillment of the requirements for the degree
Of Master of Technology
In
Electrical Engineering (Control and Automation)

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Under the Supervision of
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Dedicated to my family and friends

CERTIFICATE

This is to certify that the thesis entitled, **"Geographical Parameter based Maximum Power Point Tracking using Fuzzy Logic for Isolated PV system"** submitted by **Karmila Soren** in partial fulfillment of the requirements for the award of Master of Technology degree in **Electrical Engineering** with specialization in **Control and Automation** during 2013-2015 at the National Institute of Technology, Rourkela is an authentic work carried out by her under our supervision and guidance.

To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other university / Institute for the award of any degree or diploma.

Date………………….

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Abstract

In the run of non-conventional energy resources, it beneficial to optimize the resources for the operation. One can look for fetching maximum power from the source such as PV system. So the photovoltaic MPPT system is developed by combining the models established of solar PV module and DC-DC boost converter. MPPT technique has a quick response and can track the peak power generated in any weather condition. As a result, MPPT strategies should be deployed to ensure the tracking of the MPP of nonlinear PV characteristics. To achieve the objective, conventionally numerous algorithms have been applied in the literature. However, such algorithm ignored the environmental effect such as weather, dust factor, which dynamics is difficult to construct.

The effect of various geographical parameters on the efficiency and the performance of photovoltaic cells. To overcome this problem, Fuzzy logic can be applied to achieve the goal. As fuzzy logic is operator rule base platform, one needn't to depend upon system model. In this work, fuzzy logic is applied to operate at maximum power point of PV system. It had observed that fuzzy logic based maximum power point tracker works more efficiently when environmental factors considered along with electrical parameters. Here consider 3 cases to track the maximum power of PV system, such as case-1(radiation and temperature), case-2 (radiation, temperature and change in power) and case-3 (radiation, temperature, and change in power and dust factor). The above three cases affect to design the solar cell and taken into consideration.

Acknowledgement

There are many people who associate with this project directly or indirectly whose help, and timely suggestions are highly appreciable for completion of this project. First of all, I would like to thank Prof. A. K. Panda, Head of Department of Electrical Engineering for his kind support and constant encouragements, valuable discussions that are highly commendable.

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Lastly, I would also like to thank my parents for their love and affection and especially their courage that inspired me and made me believe in myself.

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List of Abbreviation

PV	Photovoltaic
MPPT	Maximum power point tracking
MPP	Maximum power point
BOS	Balance of system
P&O	Perturb and Observe
INC	Incremental conductance
I_{pv}	Current generated by the incident light (A)
I_{ph}	Module photocurrent (A)
I_d	Shockley diode
I_0	Reverse saturation and leakage current (A)
V_{oc}	Open-circuit voltage (V)
I_{sc}	Short-circuit current (A)

List of Symbols	Description	Values
Q	Charge of Electron	$1.6 * 10^{-19}$ C
K	Boltzmann Constant	$1.3805 * 10^{-23}$ J/K
A	Ideality factor	1.6
P_{mpp}	Maximum Power (W)	37.08 W
V_{mpp}	Maximum voltage (V)	16.56 V
I_{mpp}	Maximum Current (A)	2.55 A
K_I	Temperature coefficient of I_{sc} (℃)	0.0017 A/℃
T_j	Reference temperature (℃)	298 K
T_{jref}	Operating temperature (℃)	20℃ − 60 ℃
N_S	Number of cells in Series	36
N_P	Number of Cells in Parallel	1

Chapter-1

Introduction to Solar Photovoltaic System

Use of renewable energy sources has increased rapidly due to environmental problems created by conventional sources such as pollution, rising temperatures around the Earth and depleting fossil fuel. The only emissions produced with photovoltaic power generation are from the production of its components. The renewable energy conversion technology was developed to curb environmental problems; one of them is solar PV technology. PV conversion is the modern renewable source because of its merits such as availability, low maintenance, and environment friendliness. However, current solar panels exhibit low power efficiency e.g. up to 20%. The primary reason for the low conversion efficiency is the non-linear voltage-current (V-I) characteristics, which depend on the solar insolation and panel temperature [1].

Photovoltaic (PV) transforming the solar light into electric energy by considering the semiconductor devices named photovoltaic cells. The solar panel itself constituted of an association of series and parallel of the necessary number of modules to get the requisite energy. PV systems divided into three categories: stand-alone, grid-connection and hybrid systems. For places that are far from a conventional power generation system, Stand-alone PV power supply systems have been considered a suitable alternative [2; 3].

A PV system generates electricity by direct conversion of Sunlight into electricity that does not produce heat. The primary device for a PV system is the solar cell. Solar cells may be grouped to form modules, panels, and arrays [4]. Solar cells are a constituent of a PV array. These are made up of semiconductor materials like silicon, GA As, CdTe, etc. A thin semiconductor layer is specially treated to form an electric field, positive on one side and negative on the other. It can be circular or square in shape. Solar PV and solar-thermal plants are expected to fulfill most of the world's electrical power demand by 2060. By the same year, half of all energy needs with the wind, hydropower and biomass plants supplying much of the remaining generation [5].

1.1 PV System and Characteristics

A solar PV module is used to convert solar energy into electricity. The use PV module has emerged as an alternative renewable energy, energy conservation, and demand-side management. Initially having high costs, PV modules have not yet been an entirely attractive alternative for electricity users who can buy cheaper electrical energy from the utility grid. So researchers are focused on evolving a simpler technology with cost reduction. On cost analysis of various PV configurations, it is found that storage batteries resolve the most PV system failures and give significantly to both the initial and the conditional replacement cost.

Solar electricity is used where an appropriate voltage or current values for their operation, some solar cells are connected to form a solar panel, as shown in Figure 1. The output power depends on the amount of energy that is incident on the cell surface and operating temperature. Modules are designed to supply electricity at certain DC voltages such as 12, 24 or 48 volts. The current directly depends on the module. For a large-scale generation of solar electricity, the large numbers of solar panels are connected to a solar array [6; 7].

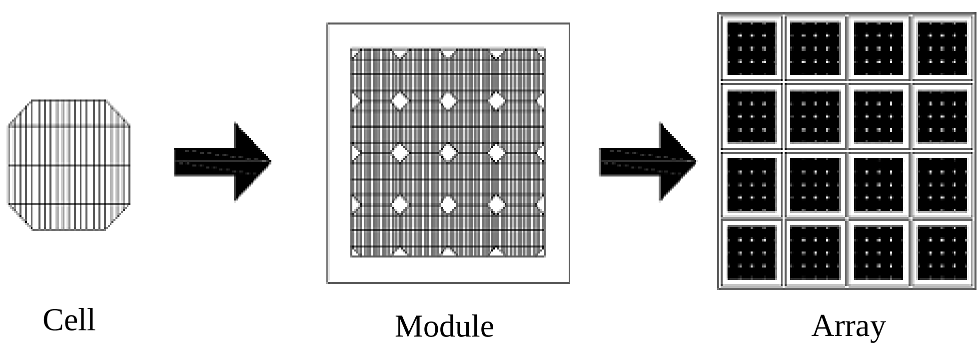


Figure 1 Solar cell to PV Array

There are some factors like radiation, temperature, partial shading, affect the power characteristics of PV system and hence the connected load. A fluctuation in these factors prohibits achieving maximum power extraction from the solar energy system. For example, change in solar insolation caused changes in current–voltage (I-V) characteristics and voltage (P-V) characteristics of PV system as shown in Figure 2 [7].

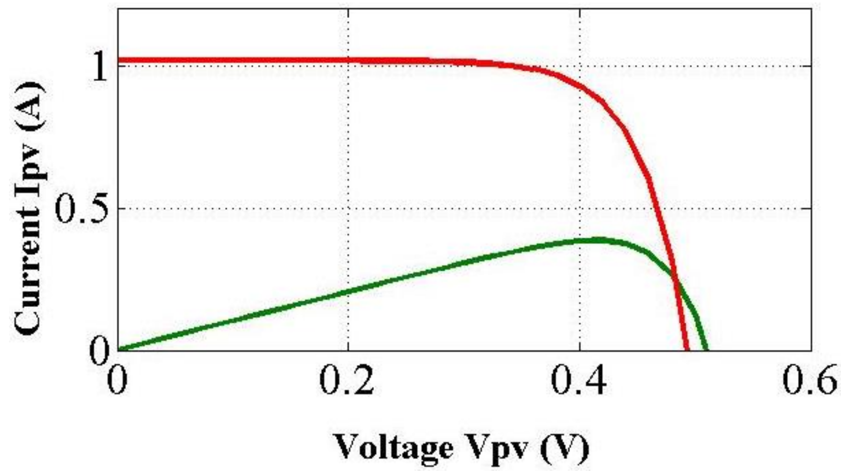


Figure 2 Current-Voltage Characteristics of Solar Cell

1.2 Balance of System

In a typical PV system, there are several components requires to make solar energy to electrical energy conversion possible. The group of assistive components used in the system are considering as Balance of System (BOS). BOS combines all components of PV systems like one or many solar inverters, battery charger, MPPT, solar irradiance sensors. The BOS components categorized into the following categories based on their primary functions as shown in Figure 3 [8].

1.2.1 Mounting Structure

The mounting structure is the support system on which the PV modules are in rest. It should be designed like that it can withstand the weather conditions. The common mistakes found in the selection of the mounting structures are as follows: the period of the design, array shading, Orientation, Tilt angle. The backup function denotes the mounting structure provides a tilting structure that tilts the PV arrays at an angle describe by the latitude of the particular site location, to maximize the solar radiation inclined to the PV system. The position of the sun varies every day, the highest tilt angle required to maximize the solar insolation changes with it.

1.2.2 Cables and Protection Devices

The cabling is the main purpose to allow a safe way for current, determined by a particular voltage to travel through a conductive medium. Exact cable sizing allows the current to be transferred within an acceptable loss limit, ensuring optimum system performance. The solar PV module, charge controller, battery, etc. are used to connected to the cable of PV system. In general, the sizing of the cable depends on the transmission length, voltage, flowing current and the conductor [9].

1.2.3 Battery

The rechargeable battery is the obvious way of storing the electrical power output from the PV panels. The batteries are mainly used for backup the purpose of supplying power to the load during non-shining hours, as well as PV configuration system. Batteries are one of the most sensitive components and need maintenance. In some applications, when used in locations with extreme climate conditions [10].

1.2.4 Charge Controller

The solar charge controller primary task is to charge the battery and to protect it from deep discharging. Overcharging and deep discharging causes damage the battery or even its destruction. Batteries are connected to the load when PV output power is less. Batteries used in that place where prevent it from overcharging to preserve the life and to get the good performance. Some of them could used in both 12 V and 24 V DC systems [11].

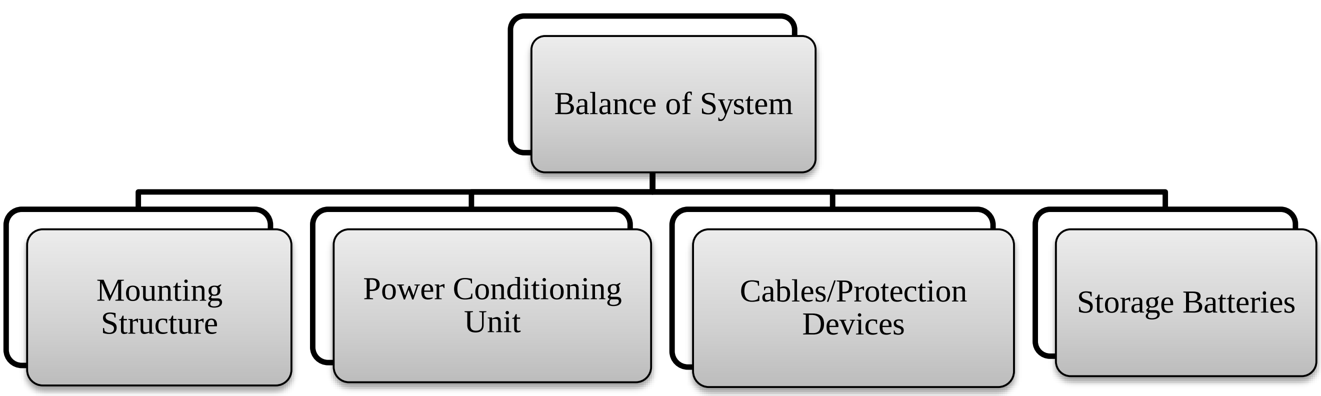


Figure 3 Balance of System components

1.3 Need of Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is an electronic system operating the PV modules to produce all the power producible to maximize efficiency [12]. The PV plant depends on inverter efficiency, MPPT algorithm, and the efficiency of PV panel. Increasing efficiency of PV panel is difficult due to technology and cost consideration. On the other hand, enhancing algorithms of MPPT is inexpensive and can be implemented on existed PV system [13].

MPPT needed to maintain the PV array's operating point at its MPP. MPPT technique has a quick response and can track the peak power generated in any weather condition. As a result, MPPT strategies should be deployed to ensure the tracking of the MPP of nonlinear PV characteristics. MPPTs find and maintain operation at the MPP, using an MPPT algorithm. PV MPPT system is developed by combining the models established of solar PV module and DC-DC boost converter.

1.4 Comparisons of Different MPPT Algorithms

MPPT algorithms are essential as PV arrays have a nonlinear voltage-current characteristic at MPP point. MPP point depends on the temperature of the panel and the irradiance conditions. Both the conditions change during the day and season. Radiation can change rapidly due to changing atmospheric conditions such as clouds, dust factor. It is crucial to track the MPP accurately under all possible conditions to obtain the maximum available power. There are different kinds of algorithms, such as perturb and observe, incremental conductance, curve fitting method, artificial neural network, open circuit voltage and short circuit current [14]. Conventional MPPT algorithms like perturb and observe, use a fixed rigid algorithm causing difficulty to respond quickly and appropriately to changing weather pattern.

1.4.1 Perturb and Observe Technique

Perturb and Observe algorithm as shown in Figure 4 is one of the simplest and widely used MPPT algorithms. Perturb and observe method works by perturbation of the system and observing the impact on the power output of PV module. Here small disturbance is generated in the panel voltage. The voltage is an increase or decreases according to the situation. The disturbances power before and after calculated using a feedback loop in the system. P&O is simple MPPT method that does not require pre-knowledge of the photovoltaics characteristics. The overall tracking efficiency is 99.33%.

Its disadvantages are in steady state conditions; working power oscillates about the MPP, which gives energy loss. When there are sudden changes in radiation, this method fails to get the optimum MPP. When there are small changes in voltage, at that instant radiation jump higher value, to get the increased power. Because of the wrong feedback, the voltage gets further reduced. This problem is observed when there is a fast change in the radiation [15].

1.4.2 Incremental Conductance

The Incremental Conductance algorithm, as shown in Figure **5**, is based on the following logic: the slope of the curve (P-V) and (I-V) i.e. power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) to the left of it, and negative (positive) on the right [15]. This method, MPP is tracked by matching the PV array impedance of the converter reflects across the display terminal. Then later tune the value of duty cycle by increasing or decreasing. This method tracks rapidly under vary radiation conditions more accurately than P&O method. The disadvantages of the system are too complex and require high calculation capacity, which increases the system control period. The overall tracking efficiency is 99.4%. It has reduced efficiency under cloudy conditions as compared to P&O technique. The primary advantage of this method is calculated the actual direction in which to perturb the array's operating point to reach the MPP. Thus, under rapidly changing conditions, it should not track in the wrong direction unlike in the case of P&O [16].

1.4.3 Look-up Table Method

In this method, the measured values of the PV array voltage and current are compared with the stored control system, which correspond to the operation at the maximum point, under specific climatological conditions. Then, this algorithm has as the disadvantage is that a large capacity of memory requires for storage of the data. Also, it is difficult to record and store all possible system conditions [17].

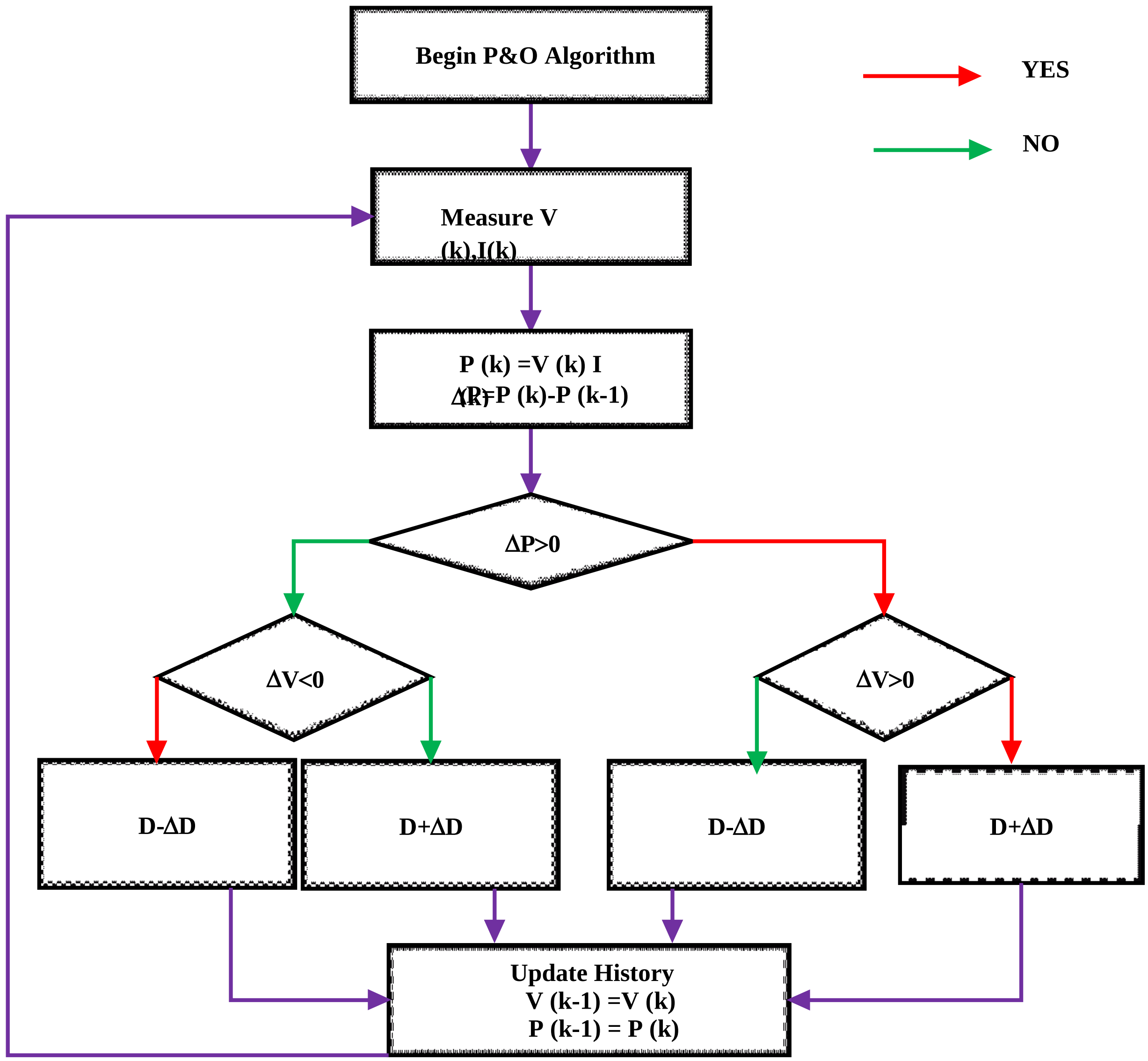


Figure 4 Flowchart of the Perturb and Observe Algorithm

1.4.4 Curve-Fitting Method

Curve-fitting is a complicated method used where the nonlinear characteristics of PV system are modeled using mathematical equation. The requirement of data storage is the major disadvantage of the curve-fitting method. Mostly this method is not found to track the MPP as its resolution is very difficult to obtain by conventional digital control method. This method never used for the meteorological variations. The optimum voltage value corresponds to the MPP, is calculated from the following equation:

$$\mathbf{P_{pv} = a * V_{pv}^3 + b * V_{pv}^2 + c * V_{pv} + d} \quad \ldots\ldots \quad 1$$

$$\mathbf{V_{MPP} = \frac{-b + \sqrt{b^2 - 3ac}}{3a}} \quad \ldots\ldots \quad 2$$

1.5 Fuzzy Logic Algorithm

Fuzzy logic is human thinking based algorithm offers a universal method to express linguistic rules. Fuzzy logic is a well-known artificial intelligent tool that is used to compute output based on expert knowledge. Fuzzy Logic Controller algorithm based on three steps: expert knowledge, fuzzification and inference diagram, and defuzzification [18] and shown in Figure 6. In fuzzification, membership functions defined on input variables are applied to their actual values so that the degree of truth of each rule can be determined. Fuzzy statements in the antecedent resolve to a level of membership between 0 and 1.If there is only one part of the antecedent, then this is the level of support for the rule.

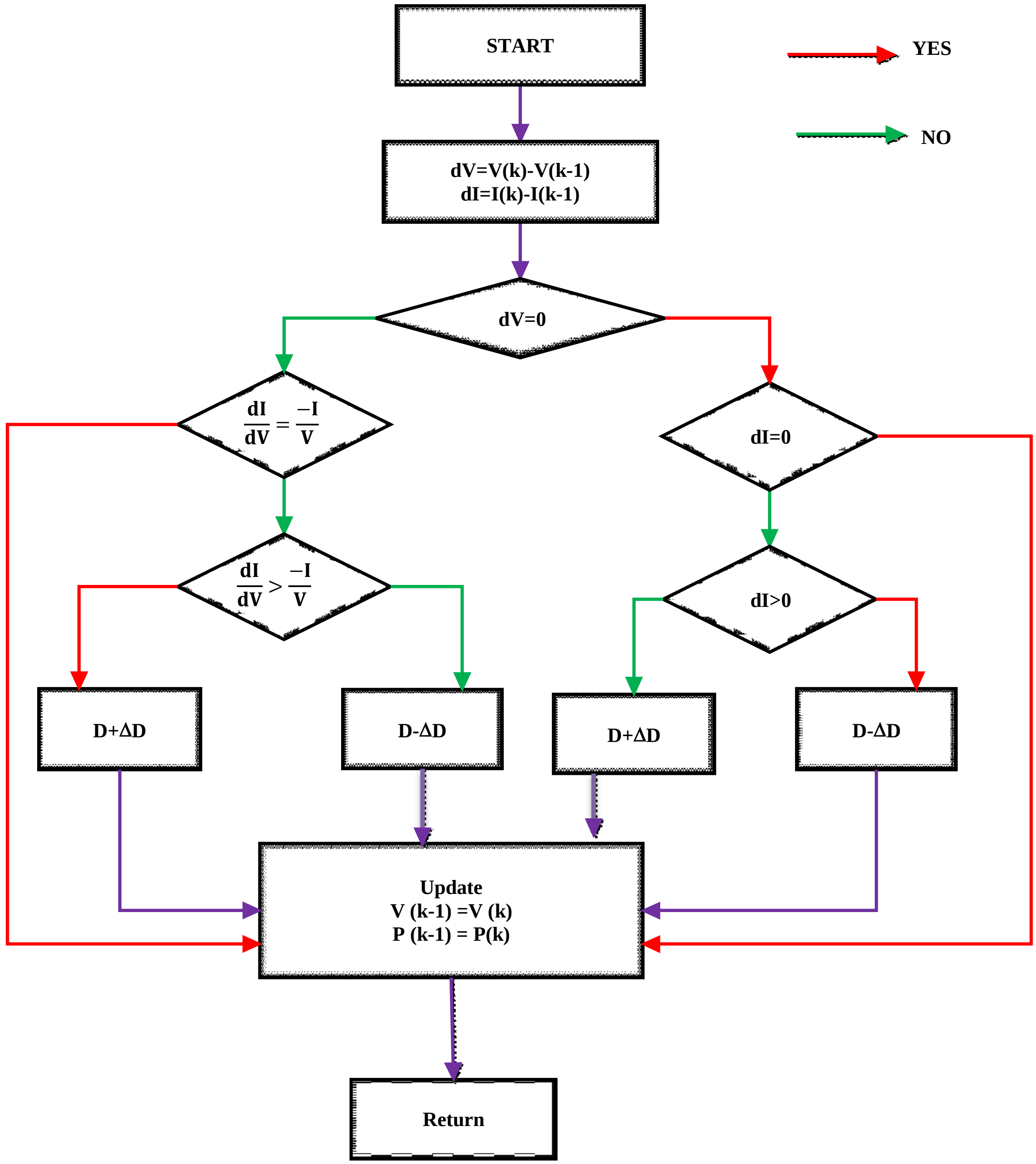


Figure 5 Flowchart of the Incremental Conductance Algorithm

Fuzzy Rules refer to a set of pre-defined instructions that link the different values of crisp variables with different subsets of the fuzzy output space. The fuzzy rule base control system uses operator experiences to work effectively in the absence of an accurate mathematical model. By adding primary geographical parameters such as temperature and radiation as an input variable, the performance of MPPT enhance significantly. Defuzzification is the method of finding final linguistic to numerical in fuzzy output. The values of membership functions determine the weight of different subsets of fuzzy output universe [19].

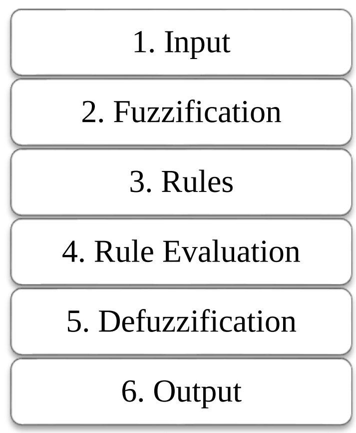


Figure 6 Flow Chart of Fuzzy Logic Control System

P&O method simple to implement but the major drawback is the periodic difference in case of rapidly changing atmospheric conditions. Environmental factors are changing continuously, so P&O and INC methods have some limitations such as severe control accuracy and sophisticated algorithm. Therefore, there is great need to attempt to optimize the maximum power point tracking method. FLC based controllers overcome the disadvantages of classical methods in tracking maximum power point. Fuzzy Logic based controller is simple to implement gives better convergence speed and improves the tracking performance with minimum oscillations. The Mathematical model cannot represent nonlinear characteristics of photovoltaic cells, can't accurately demonstrate the changes caused by the light intensity and environmental temperature. So for greater complexity and uncertainty of the system, we consider the fuzzy control algorithm to achieve the maximum power point tracking [20; 21].

1.6 Review of Fuzzy Logic

The basic ideas soft computing in the current scenario have links to many earlier influences, among them are Zadeh's (1965), his paper described on fuzzy sets. He proposed to use the generalized theory of uncertainty. Zadeh further extended the concept of fuzziness to algorithms. The progress of the algebraic theory of fuzzy automata and fuzzy formal languages can see by the amount of new research that observed over the years [22]. Assilian and E. Mamdani (1974), they described a fuzzy logic controller for a steam engine in which non-numeric linguistic statements about appropriate control strategies are converted directly into a fuzzy control [23].Royes and Bastos (1988), used the fuzzy concepts to build a fuzzy expert system based on the vagueness and imprecision of the statement [24].

Li-Xin Wang and J. M. Mendal (1992), fuzzy also helps to solve different real world due to its systematic rule depended on the concept. His method is the general way to combine both numerical and linguistic information and give a brief description of chaotic time-series prediction problem. Theory of rough set discussed the different kind of formulation and interpretations [25]. Samuel O. Russell and Paul F. Campbell (1996), they worked on Reservoir Operating Rules with Fuzzy Programming. Fuzzy logic offers a way to improve on existing operating practices, which is relatively easy to explain and understand. Operation of the fuzzy system is simulated using both fuzzy logic programming and rules defining [26]. Dimitrov (1997) has done research in the primary role to provide the importance of FL in the social sector. He gave the practical view of fuzzy logic to deal with paradoxical and chaotic nature of the social system [27].

Jin M. Won, Y. Park, Jin S. Lee (2002) explained the about the Takagi–Sugeno–Kang (TSK) fuzzy system shows the output of the TSK fuzzy system is monotonic with respect to its input. The output of the TSK fuzzy system is first differentiated w.r.t its information and the parameter conditions are derived to make the derivative nonnegative. The setting conditions developed for both single-input and multi-input (TSK) are fuzzy systems, where the involved fuzzy membership functions are differentiable everywhere or bar some finite points [28].

Zhiyi (2004) coined the formula based Mamdani type FIS to assess compost maturity and stability. Zhiyi explained how multi-decision making system formulated with the help of fuzzy. The concept was fabricated formula based [29]. Wang and Elhag (2007) described a fuzzy group decision-making approach for bridge risk assessment. They used bridge risk factors using linguistic terms such as Certain, Very High, High, Slightly High, Medium, Slightly Low, Low, Very Low rather than numerical values. Allows them to express their opinions, also provides two alternative algorithms to aggregate the assessments of multiple bridge risk factors, one is a rapid assessment, and the other is an exact evaluation [30].

M. Z. Shafiq et al. (2008) has explained the importance of Fuzzy Inference System with respect to Fuzzy, Neural and Neuro-Fuzzy Inference System (NFIS) are there to empower the importance [31]. Lius Teran (2011) introduced web-based Voting Assistance Application (VAA) used to aid voters to find the election party or candidate that is most in line with their choice. [32]**.** Ahd. M. Abdelrhman, M. Salman Leong, Somia Alfatih M. Saeed and Salah M. Ali Al-Obiadi (2012) introduced the vibration based methods for turbine blade faults. This method typically involved analysis frequency analysis, wavelet analysis, neural networks and fuzzy logic and model-based analysis [33].

1.7 Effects of Geographical Parameters

To reduce all the unwanted effects, it is continuously desirable to shift towards the use of environmentally friendly, clean and renewable energy resources, especially, the solar power alternatives. The use of conventional energy resources such as oil, coal and natural gas will continue at reduced rates with the replacement of renewable sources to a certain increasing rate. It is necessary to take the appropriate measures and developments toward more using of solar and other renewable energy alternatives by the advancement in the research and technological progress. Sustainable development within a society demands a sustainable supply of energy also to an effective and efficient utilization of energy resources. There are different kinds of conventional algorithms, such as perturb and observe, incremental conductance and curve fitting method. Modern algorithms are fuzzy logic and artificial neural network. Classical MPPT algorithms use a fixed rigid algorithm causing difficulty to respond quickly and appropriately to changing weather pattern. The fuzzy logic algorithm has a fast transient response, but it faces the problem of oscillating around the MPP under steady state condition. In this paper, geographical parameters like temperature, radiation, dust and cloud factor controlling the performance of the isolated solar panel is presented. Their particular problem, fuzzy logic use where nature's randomness has a significant effect on maximum power point. Proposed Fuzzy Logic based

Maximum Power Point considers the dynamics of geographical parameters along with electrical parameters to improve the tracking [34].

Power output from the panel is directly proportional to the incident radiation. The decrease in temperature reduces the open circuit voltage reducing the output of the panel. With a large number of clouds and frequency of appearance of clouds passing over the panel location, there is a variation indirect and diffused sunlight throughout a day. Cloudy sky decreases the average power output of the panel because of shadowing. The presence of dust on the board surface sharply reduces the energy production, which results in a significant economic loss. Nature and amount of dust getting deposited in the group depends on the temperature, type of soil, and wind speed. The problem of soiling in regions like the desert is prominent. The amount of dust varies as per season e.g. in the summer dust amount is more since it is less in a rainy season. Due to the nature of parameters considered such as imprecision, the absence of an accurate mathematical model, and nonlinear nature, FLC is used for the decision-making process [35].

1.8 Objective of Thesis

The aim of this project is to establish an electrical circuit based PV module with fuzzy logic MPPT algorithm using Simulink/MATLAB environment rule base. Use of different renewable energy sources have increased rapidly due to environmental problems due to such as pollution, rising temperatures around the Earth and depleting fossil fuel but an important one, is the solar energy. The concepts of a PV model and its characteristics have been studied and draw its characteristic equation. Boost converter has been considered and combined it with PV cell and get the P-V, I-V curves have obtained with varying radiation and temperatures levels. The aim of this paper is to implement a PV model that becoming to model the different types of PV cells, arrays, and modules and comparing its performance with a practically available module. Moreover, the simulated model is in the form of Simulink block, with a user-friendly icon and MATLAB/Simulink block libraries or other component-based electronics simulation software packages. This Simulink block can easily used in circuits involving PV systems. The proposed model been verified by comparing its performance with different modules and results exhibited a good the simulation results. The suggested model is expected to serve as the basis model for carrying out the study by the researchers in the field of the geographical parameter based MPPT using FLC technique. To validate the MATLAB/Simulink model, an experiment has performed under different conditions. The fuzzy rule base control system uses operator experiences to work effectively in the absence of an accurate mathematical model. By adding primary geographical parameters such as temperature and radiation as an input variable, the performance of MPPT enhanced significantly. Considering location-centric parameters, an FLC based MPPT model, is to develop in Matlab / Simulink environment rule base. This FLC based MPPT works on electrical parameter along with geometrical parameter. Considering dust factor and cloud factor as membership function, more accurate MPP can be determined.

Chapter-2

Modeling of PV system

In order to view the behavior of PV system, it is necessary to design the model the system in terms of electrical parameters, geographical parameters and then realize it into Simulink model. After that, the models help to test and evaluate the performance of the system. Different configurations of PV cell can be used to illustrate the V-I curves such as single diode model, two diode models, and Rs-Rp model. Extra diode is used to represent the effect of the recombination of carriers. But among them due to degree of accuracy and simplicity single diode model has been used in a number of previous works. The next chapter discusses the modelling of a PV array.

2.1 Modeling of PV Module

The PV module is a combination of solar cells which is a photoactive semiconductor PN junction diode. The PV cell takes in solar energy and converts it into electricity. The complete solar photovoltaic is a power electronic conversion system in a circuit-based simulation model to simulate the electrical behavior of the PV systems. A single diode standard template of the PV panel use for the simulation study carried out using MATLAB software under different operating conditions, and load has conducted. The use of equivalent electric circuits and mathematical equations make it possible the model of the characteristics of a PV cell and simulate it. It is important to build an observed model that makes suitable for scaling at all levels of the model, i.e. the PV cell and module. A generalized PV model has hence been developed using MATLAB/Simulink to feature and verifies the nonlinear I-V and P-V output characteristics of PV module. To make the generalized model easy to identify and understand, a masked model is designed to have a dialog box, in which the parameters of PV module can configure in the same way as the standard Simulink block libraries. General mathematical description of I-V output characteristics for a PV cell has studied, and the solar cell represented by the electrical model shown in Figure **7** [36]**.**

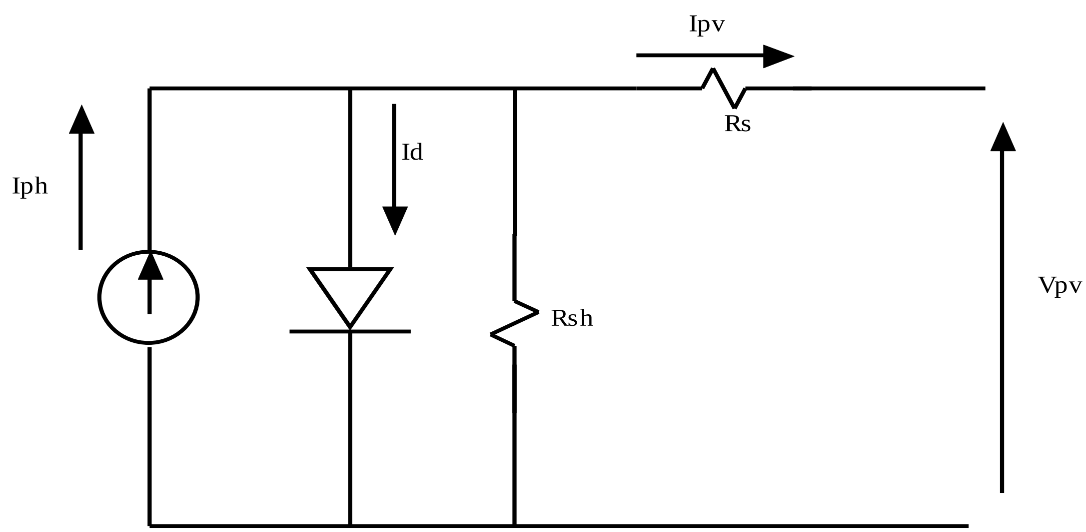


Figure 7 Single Diode Equivalent Circuit for modeling Solar Cell Model

2.2 PV Module Performances

The following performances give PV module performance:

1. *Short-circuit Current:* It is the current through the solar cell when the voltage across the cell is zero. It is due to the generation and collection of light-generated carriers. It mainly depends on the band gap energy. Hence, the short-circuit current is increased with the band gap energy.
2. *Open Circuit Voltage:* It is the voltage through the solar cell when current across the cell is zero. The band gap energy of the material is higher than the open circuit voltage of the solar cell.
3. *Fill Factor:* The Fill Factor (FF) is used to measure the quality and mainly related to the resistive losses of the solar cell. Its value is always 100%. It is calculated by comparing the maximum power to the theoretical power that would be output at both the open circuit voltage and short circuit current together. FF also represent the ratio of the rectangular areas and shown in Figure 8.

$$FF=\frac{P_{MAX}}{P_T}=\frac{I_{MAX}*V_{MAX}}{I_{SC}*V_{OC}} \quad \ldots\ldots 3$$

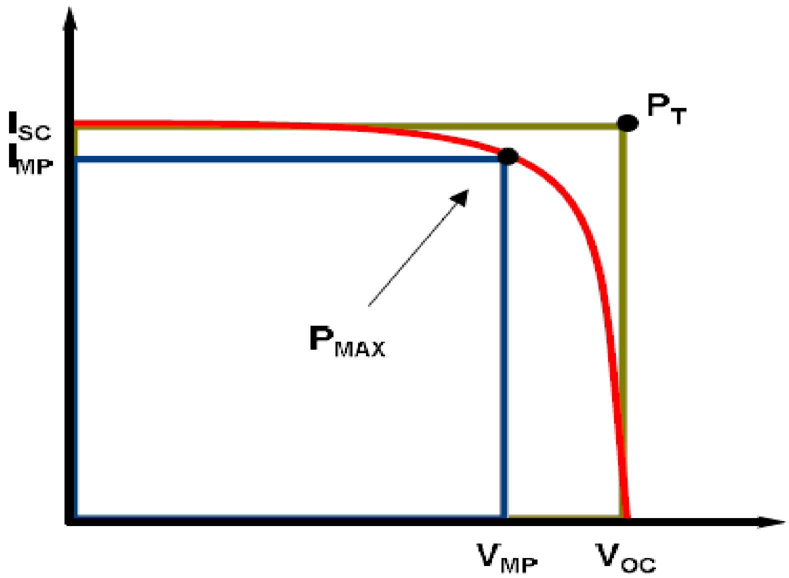


Figure 8 Getting the FF from the I-V Characteristics Curve

4. *Efficiency:* The ratio of the output power (P_{out}) to the solar input power (P_{in}), called the efficiency of Solar Cell.

$$\eta = \frac{P_{OUT}}{P_{IN}} \ldots\ldots\ldots 4$$

Its current-voltage characteristic expressed from equation 7 to equation 12 solved for obtaining the current and power delivered by the panel for different geographical parameters.

$$\mathbf{I_{pv} = I_{ph} - I_d - I_{sh}} \ldots\ldots\ldots 5$$

$$\mathbf{I_d = I_s(\exp\left(\frac{q*V_{oc}}{A*K*Tj}\right) - 1} \ldots\ldots\ldots 6$$

$$\mathbf{I_{ph} = \left[I_{sc} + K_i\left(T_j - T_{jref}\right)\right] * \frac{G}{G_{ref}}} \ldots\ldots\ldots 7$$

$$\mathbf{I_{rs} = \frac{I_{sc}}{[\exp\left(\frac{q*V_{oc}}{N_s*K*A*Tj}\right)-1]}} \ldots\ldots\ldots 8$$

$$\mathbf{I_0 = I_{rs}[\frac{T_j}{T_{jref}}]^3 exp[\frac{q*E_{g0}}{A*K}\left(\frac{1}{T_j} - \frac{1}{T_{jref}}\right)]}$$ ……………………………………………………………………………9

$$\mathbf{I_{pv} = N_p * I_{ph} - N_p * I_s \left[exp\left(\frac{q*(V+I_{pv}*R_s)}{N_s*K*A*T_j}\right) - 1\right] - \frac{V+I_{pv}*R_s}{R_{sh}}}$$ ……………………………………….....10

The solar PV modules rated in terms of maximum output power. The users and manufacturers widely accept the module rating under STC (standard test condition). For the simulation, panel parameters borrowed from the datasheet of SOLKAR 36W PV specified at $25^0 C$, $1000 W/m^2$ in STC and are tabulated in Table 1 [37].

Table 1 Electrical characteristics of SOLKAR 36W solar at 25℃, 1.5 AM, 1000 W/ m^2 [37]

Parameters	Value	Parameters	Value
Maximum Power P_{max}	37.08 W	Short circuit current I_{sc}	2.55 A
Voltage at maximum power V_{max}	16.56 V	Temperature coefficient of $I_{sc}(K_I)$	0.0017 A/℃
Current at maximum power I_{max}	2.25 A	Total no. of cells in series (N_s)	36
Open circuit voltage V_{oc}	21.24 V	Total no. of cells in parallel (N_P)	1

2.2 Effect of Geographical Parameters on PV characteristics

It has observed that the PV characteristics vary with the change in solar radiation, temperature, and some geographical parameters. Solar irradiance and cell temperature are affecting the PV cell output to a much greater range than the other conditions. The extracted amount of power from a PV system is a function of the PV array voltage and current set point. Due to these reasons, it is crucial to maximizing the output power available from the PV cell. The solar PV cell has nonlinear I-V and a P-V characteristic that depends on the irradiance and the operating temperature also in load condition. The presence of dust on the board surface sharply reduces the energy production, which results in a significant economic loss.

2.2.1 Radiation Effect

The solar PV, solar collectors, and solar thermal devices based on solar radiation. The economic and technical performances depend on the amount of sunlight falling at given location. The amount of radiation incepted by the earth varies inversely with the square of the distance between the sun and the earth. The sun and earth are two types of motion; both involved with each other. The rotation of the earth inclined towards the polar axis w.r.t. The elliptical plane may cause radiation variation. The sun and earth distance is not constant, but the amount of radiation incepted by the earth varies. So the variation of radiation is not giving any response to different seasons. Solar radiation is at the upper atmosphere of the earth. When the sunlight passes through the Earth atmosphere, it interacts with some gaseous molecules such as absorption and scattering. An absorption interaction of solar radiation is contact with air with gaseous particles, this cause's solar radiation loss. The amount of sunlight falling on an object and value of angle of incidence should be known. Due to economic reason, it is not possible to measure all the locations. Therefore, they used parameters based on meteorological data. By using this easily calculate on hourly, monthly and daily basis data, whichever needed.

Solar radiation depends on the sun-moon movement that includes declination angle, it varies between the earth polar axis and revolves around the sun. The value if declination angle is positive in the northern hemisphere and negative in the southern hemisphere. To calculate the declination angle expressed equation mathematically as given below:

$$\boldsymbol{\delta = 23.34 \sin\left(\frac{360}{365}(284 + n)\right)} \quad \ldots\ldots \quad 11$$

Where δ is declination angle, n is the starting day, radiation changes with changing the declination angle due to the position of the earth, that varies during summer and winter. Now to check the location of the sun changes over the day. The apparent motion depends on the latitude that is tilted, in that way radiation also change. The latitude is changes due to the sun position movement also varies in the morning and evening time. Solar altitude is minimum in winter season and maximum in the summer season, this variation affects the solar radiation.

The output power depends on the solar radiation falling on the PV module. The output power decreases linearly with decrease the solar radiation intensity. But the solar radiation value is not constant throughout the day i.e. varies. In the cloudless day, radiation values increase from morning to noon, then decreases till sunset. But in cloudy days, its values fluctuate from morning to night. Due to such kind of variations found in the radiation, the output power also changes throughout the day. The current which produced from the module is linearly of the radiation intensity. But the voltage drop is a logarithmic function of radiation intensity. Solar radiation effect on efficiency, when short circuit current is proportional to the radiation intensity. It also describe the open circuit voltage in a simplified manner and express the equation as shown below:

$$\mathbf{V_{oc} = \frac{kT}{q} ln\left(\frac{I_L}{I_0} + 1\right) \approx \frac{kT}{q} ln\left(\frac{I_L}{I_0}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

Using the equation 12 the cell efficiency can written as:

$$\mathbf{\eta = \frac{I_{sc}V_{oc}FF}{P_{in}} = \frac{nI_L ln\left(\frac{I_L}{I_0}\right)FF}{P_{in}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. 13$$

Where P_{in} is the solar radiation intensity, FF is fill factor, V_{oc} is open circuit voltage, I_{sc} is short circuit current and n is constant a factor used to calculate the solar radiation intensity. Generally FF is not big impact on solar efficiency but solar radiation intensity decreases with decrease the solar cell efficiency. This will happen Open circuit voltage decreases with decreases I_L as FF considered as constant.

After some calculation, the relative change of efficiency as a function of solar radiation intensity factor n can be written in the following way:

$$\mathbf{\frac{\Delta\eta}{\eta} = \frac{ln(n)}{ln\left(\frac{I_L}{I_0}\right)} \Longrightarrow \frac{\Delta\eta}{\eta} = \frac{kTln(n)}{qV_{oc}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

For Si wafer-based solar cell, the value of $\frac{kT}{qV_{oc}}$ is 0.04, putting this value in to the equation 13, we get the following relationship:

$$\mathbf{\frac{\Delta\eta}{\eta}}(\%) \approx \mathbf{4 \times ln(n)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. 15$$

Using equation 14, we conclude that at low radiation level efficiency decreases, the estimated for Si wafer-based solar cells for equation 13 used for other solar cells. As the radiation increases, voltage increases slightly while current increases hugely. Figure 9 and Figure 10 shows the I-V and P-V characteristics of PV module. We note that I_{sc} increases quasi linearly with radiation and V_{on} Increases slightly. Then the maximum power P_{map} increases faster than radiation i.e. efficiency better for high radiation. The reference radiation at STC condition is $1000W/m^2$.

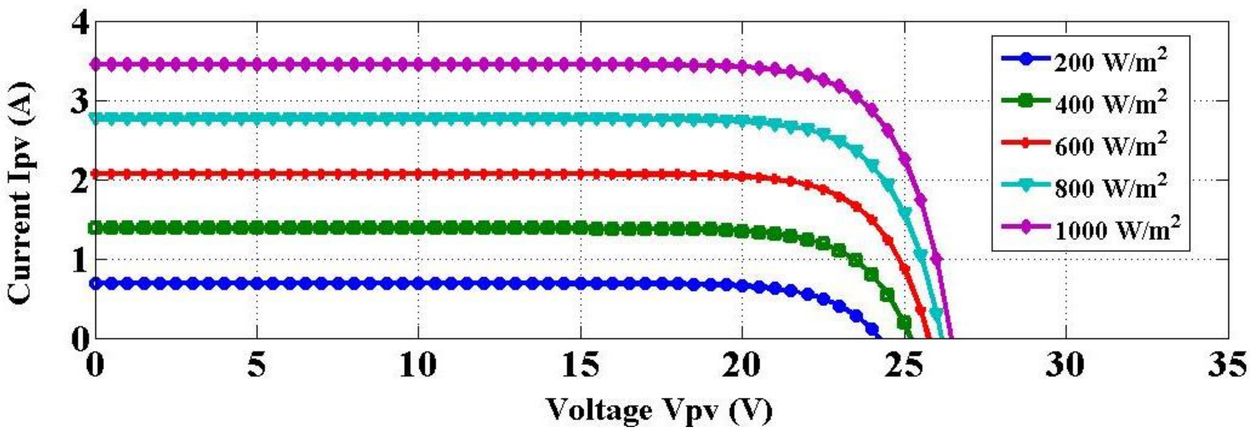


Figure 9 Effect of variation in radiation at constant temperature on I-V characteristics of solar cell

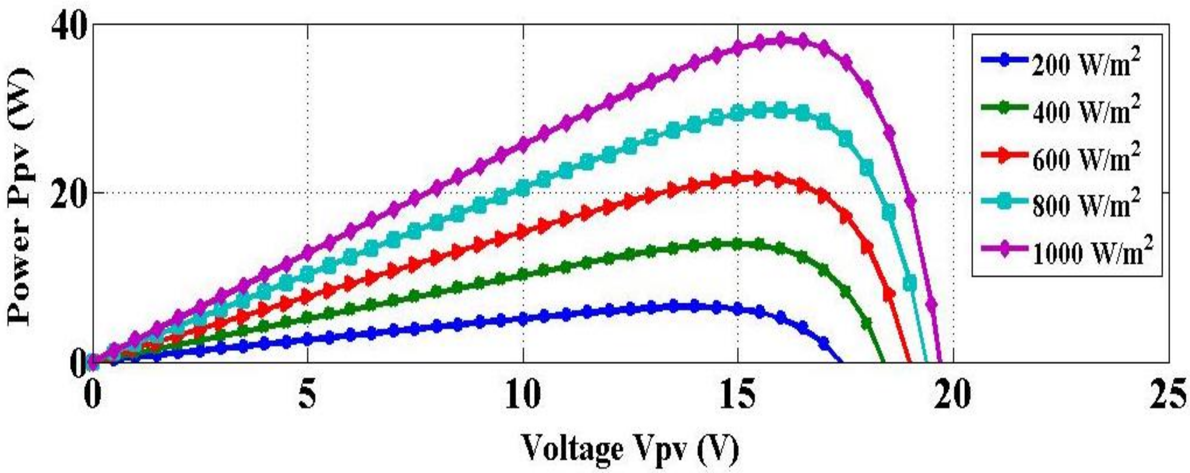


Figure 10 Effect of variation in radiation at constant temperature on P-V characteristics of solar cell

2.2.2 Temperature Effect

Solar panels produced electricity, are affected by their operating temperature, which is primarily a product of the air temperature, as well as the level of sunlight. The length and durability of sunlight received are more important factors in a solar panel's power production efficiency, temperature and other environmental factors can reduce efficiency. The production of electricity efficiency of solar panels decreases when the PV panel reaches hot temperatures. Temperature values frequently reached during summer day hours in temperate climates. Photovoltaic solar panel power production works most efficiently in cold temperatures. Cold, sunny environments provide optimal operating conditions for solar panels. Solar tracker systems that adjust the angle of the photovoltaic panel to maximize irradiance and insolation values may improve the ability to take advantage of the positive effects of cold on solar panel efficiency. Solar tracker systems that adjust the angle of the photovoltaic panel to maximize irradiance and insolation values may improve the ability to take advantage of the positive effects of cold on solar panel efficiency.

The temperature dependent solar efficiency comes from open circuit Voltage V_{oc}, which depends on the reverse saturation current I_0. It is significant with temperature. The expression for I_0 is shown below:

$$\mathbf{I_0} = \frac{\mathbf{qD_n n_i^2}}{\mathbf{L_n N_A}} + \frac{\mathbf{qD_p n_i^2}}{\mathbf{L_p N_D}} \quad \ldots\ldots\ldots\ldots \quad 16$$

Where n_i^2 is intrinsic carrier concentration, the variation in I_0 is mainly due to the intrinsic carrier concentration and other parameters are constant. n_i Is a function of temperature is expressed as equation is given below:

$$n_i^2 = k_1 e^{\frac{-E_g}{kT}} \quad \ldots\ldots\ldots\ldots \quad 17$$

Here k_1 is the constant, putting the value of n_i^2 in equation 16 we get the value of open circuit voltage:

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{K_2}\right) + \frac{E_g}{q} \quad \ldots\ldots\ldots\ldots \quad 18$$

Differentiate the above equation w.r.t. T to get the rate of change of V_{oc} as shown below:

$$\frac{d(V_{oc})}{dT} = \frac{1}{T}\left(V_{oc} - \frac{E_g}{q}\right) \quad \ldots\ldots\ldots\ldots \quad 19$$

The above equation shows the change in open circuit voltage due to increasing in temperature will always negative, open circuit voltage decreases with increase in temperature. The significant reductions in open circuit voltage as the temperature increases of the cell.

The module temperature is typically higher than the reference temperature. The module operating temperature could be up to 20 ℃ to 60 ℃ greater than the ambient temperature, depending on the conditions such as wind speed, meteorological parameters. Thus, in the general case (any condition) where module temperature goes increases. The higher temperature of the PV module is due to the glass cover present on the module, which traps the infrared radiation and module temperature increases. The following relation shows the estimation of module temperature, T_{mod}:

$$\mathbf{T_{mod}} = \mathbf{T_{amb}} + K\mathbf{P_{in}} \quad \ldots\ldots\ldots \quad 20$$

Where T_{amb} is ambient temperature, P_{in} is the radiation intensity in W/m^2 and K is the constant varies from 0.02 to 0.03 depending on the external factors. The cell temperature shows the increases short circuit current and decreases the open circuit voltage. Decreases the open circuit voltage V_{on} is more prominent than the increases in the short circuit currentI_{sc}. Then the overall efficiency and output power of solar cell and modules decreases with increases in temperature. The output current increases due to the band gap of silicon and decreases of voltage due to increases of recombination of carriers. Solar cell and module parameters varied in percentile or absolute manner with temperature, called temperature coefficients. Application of PV module in a geographical location where found significant changes in temperature. The effect of temperature on I-V and P-V characteristics as shown in Figure 11 and Figure 12. As temperature increases, the current increases slightly, while the voltage drops mostly. The current I_{sc} increase in temperature band gap energy reduces. But, open-circuit voltageV_{on} Falls rapidly with temperature rise. The maximum power P_{map}also decreases with temperature.

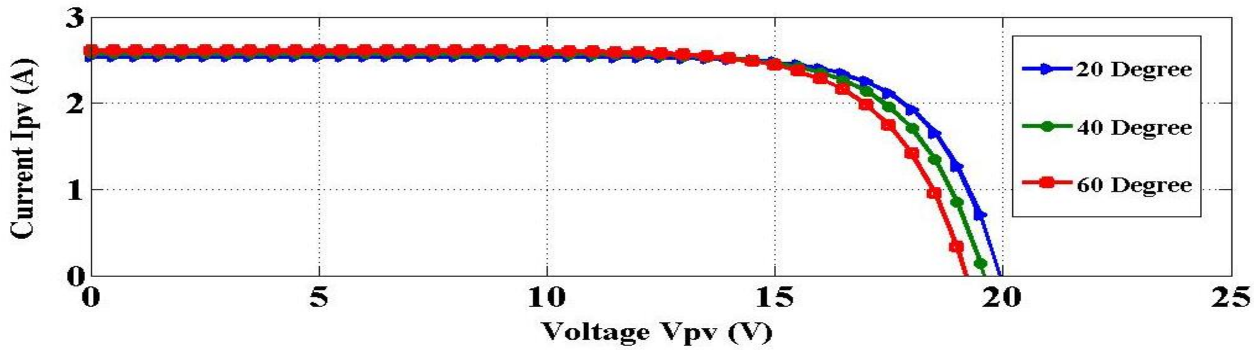


Figure 11 Effect of variation in temperature at constant radiation on I-V characteristics of solar cell

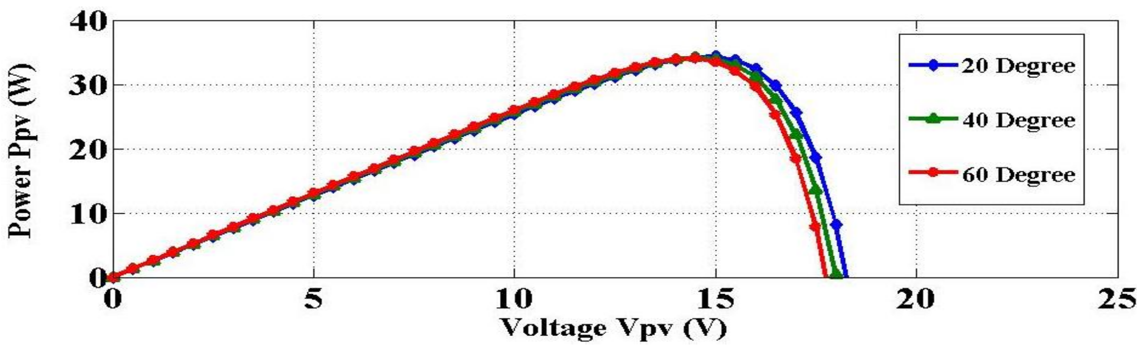


Figure 12 Effect of variation in temperature at constant radiation on P-V characteristics of solar cell

2.2.3 Effect Dust on performance of PV panels

Dust is the primary factor that significantly influences the performance of the PV installations. One of the main challenges is the energy loss due to dust collection on the optical surfaces of solar power such as PV modules. Dust collection on surface contaminated by plant products, soot, growing of organic species. Soiling is the important factor like dust gathering. Apart from that method other factors such as temperature affect, high relative humidity, and corrosion. Dust deposition on the solar surface depends on two factors: location of the power plant and local climate condition. Atmospheric dust concentration decreases exponentially w.r.t latitude. Degradation is reduced if PV panels are installed to minimize the dust deposition. Dust removal depends on Effect of the inclination angle, Attenuation of sunlight by dust layer. Gravitational settling is the primary mechanism for soil removal; the dust accumulation rate is highest under this condition. The wind causes removal of the deposited dust. The dust removal rate at a relatively high wind speed will be more efficient at a high tilt angle. Removal of the collected dust also depends on the particle diameter d and the microstructure of the soil layer. Dusty modules have significantly lower operation voltage than the less dirty or clean ones in the same string. More power output losses occur in the formation of hot spots. In long-term exposure, these hot spots cause the thermal degradation of the PV arrays. Dust particles depend on the altitude except dust storm condition, deterioration of PV installed at the high elevation for minimization of dust deposition [38].

The dust particles deposited on a PV surface at a controlled surface mass density, and the power output was measured. The effects of dust deposition on solar panels related to their use in the study of Mars and the Moon [39]. The role of wavelength in the transmittance and reflectance efficiency variations of glass samples coated with dust. The wavelength ranged from 190 to 900 nm because the majority of PV modules are not responsive outside this range. Dust accumulation on solar collectors located in deserts zones vary widely; these areas also experience dust storms that not evenly distributed over the year. Most large-scale PV modules installed at a fixed tilt angle. Photovoltaic systems equipped with solar trackers can be used to produce maximum power output and to minimize dust accumulation. Tracking also can provide panel orientation that can be used for convenient cleaning and for showing the groups facing down at night and during dust storms. High relative humidity attachment of dust on PV surface, high relative humidity also causes more absorption of solar radiation by the concentration of vapor water by the environment. Dust storms cause major loss of the performance of PV installations. These storms are mostly unpredictable, except that they occur more frequently in certain months of the year. Solar collectors equipped with tracking systems can reduce the adverse effect of such dust episodes if they are stored at peak positions to minimize the impact of dust storms. Frequency of cleaning is critical, as the adhesion of dust increases with the residence time of the dust on the collectors before each cleaning. Light rain in dusty weather leaves the collector surface spotty with a sticky soil layer that drastically degrades performance. Immediate cleaning after such events is recommended to restore systems efficiency [40].

There are various environmental factors affecting the PV panels, some of them discussed below: dust accumulation during the day is higher than at night. Accumulated dust at night is significantly coarser than that of dust deposited during the day. Given a particular time of the year and geographical location of the site, the occurrence of dust episodes was predictable based on the availability of meteorological data collected over the years? Effect of tracking photovoltaic systems settled with solar trackers used to produce maximum power output and to minimize dust accumulation. Tracking also can provide panel orientation that can used for convenient cleaning and for showing the groups facing down at night and during dust storms. Monitoring systems shows slightly lower power conversion efficiency due to the high temperature of the solar cell the performance of PV installations is affected by bird droppings. This organic material blocks incident sunlight from reaching the cell. The affected areas remain shaded until cleaned, creating potential zones of hot spots as the cells underneath act as a load to the current output from the rest of the series-connected cells. Few studies analyzed this effect and the consequent efficiency degradation.

The presence of dust on the board surface sharply reduces the energy production, which results in a significant economic loss. Nature and amount of dust getting deposited in the group depends on the temperature, type of soil, and wind speed. The problem of soiling in regions like the desert is prominent. The amount of dust varies as per season e.g. in the summer dust amount is more since it is less in a rainy season. The dust particle deposited on a PV surface at a controlled surface mass density, and the power output was measured. The light extinction coefficient due to the scattering loss is directly proportional to the area of the particles. Experimental data on soiling losses in a laboratory searched controlled environment test chamber equipped with a solar simulator to provide simulated sunlight and to measure solar radiation is pyranometer and control radiation used for simulating field conditions. The method is advantageous since dust depositions can be controlled both with respect to the particle size distributions and surface mass concentrations [41].

Figure 13 shows the study of PV modules and glass cover plates, and the effect of dust deposition on their performance such as carbon particulates. Carbon Particulate are found particularly in urban areas due to incomplete combustion of fuels in industrial plants have severe deteriorating effect on the performance of solar dust particles. The effect of dust on the maximum output power loss of a PV cell, uses different amount of ground clay, different dust deposition associated with dust density concentration, Figure 14 shows dust deposition density increases, the rate of maximum output power loss decreases.

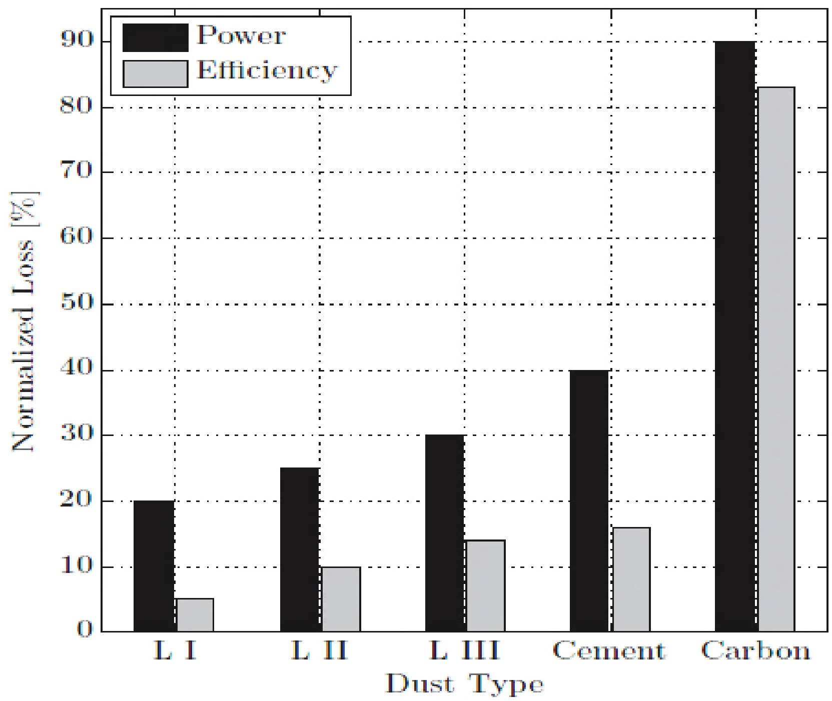


Figure 13 Normalized power and efficiency losses of PV panel caused by deposition of three different sizes of limestone particles (denoted as LI, LII, and LIII), cement, and carbon with dust concentration density of 25 g/m^2 [41]

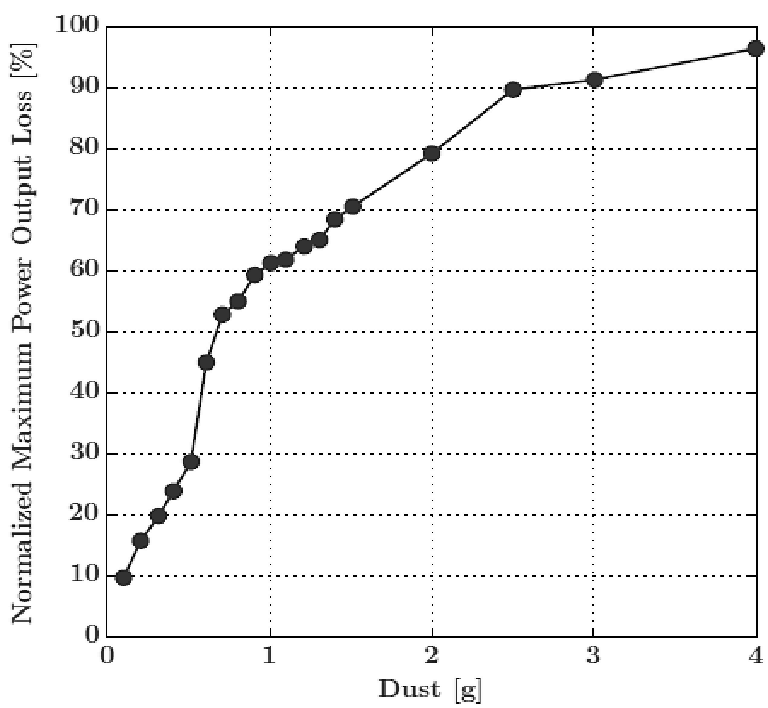


Figure 14 Losses in maximum power output of a PV cell vs. dust deposition **[41]**

2.3 Boost Converter Design and Operation

The boost converter is a DC o DC converter that gives an output voltage greater than the input voltage, which why called as a step up converter. In this case output, the current is less than input current since power must be conserved. PV modules are connected to a boost converter to enhance and regulate the output voltage. It drives the DC load by using the power tracked from the solar panel. The MPPT controller is used to track the maximum power from the solar panel. The circuit diagram of the boost converter is shown below in Figure 15.

As per the requirement of PV, a boost converter is preferable because of the increase the voltage, current, and power. A boost converter is used as the voltage increase t in the circuit technique used with low power battery applications, and the ability of a boost converter is to store the remaining energy in a battery. The energy remaining would be wasted when the small voltage at the depleted battery is unusable for a load. The remaining energy would otherwise remain untapped because many applications do not allow enough current to flow through a load when voltage degrades.

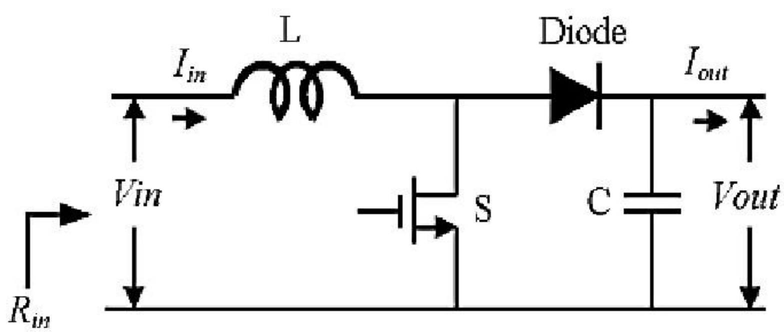


Figure 15 Circuit Diagram of Basic Boost Converter

Boost converter steps up the input voltage magnitude to get the 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 elements are coordinated to supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the direction of the duty cycle of the switch that causes the voltage change. The switch is closed, and the source charges the inductor through the switch. The load current is exponential in nature. The diode decreases the flow of current from the source to the load, and the demand of the burden is discharging of the capacitor. The diode forward biased when the switch is open. The inductor is now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is slight and in many cases is assumed constant throughout the operation [42].

There are two modes found in a boost converter. They based upon ON and OFF switching mode. The first mode of operation is charging mode when the switch is closed. The input current rises and flows through inductor and transistor. The second mode is discharging mode when the switch is open; the input current now flows through L, C, load, and diode. The inductor current falls to the next cycle. The energy stored in inductor L flows through the load. From that modest got an equation for duty cycle, and input-output voltage of boost converter is given below as follows [37]:

$$\frac{\mathbf{V_o}}{\mathbf{V_{in}}} = \frac{\mathbf{1}}{\mathbf{1-D}} \quad \ldots\ldots 21$$

The other necessary equations are related to design the boost converter:

Inductor ripple current, $\Delta \mathbf{I_L} = \frac{(\mathbf{V_g} * \mathbf{D})}{(\mathbf{f_s} * \mathbf{L})}$ …… 22

Capacitor ripples voltage, $\Delta \boldsymbol{V_c} = \frac{(\boldsymbol{I_0} * \boldsymbol{D})}{(\boldsymbol{f_s} * \boldsymbol{C})}$ …… 23

The Specifications required for the boost converter obtained from the equations associated with the implementation and design of the converter are such as$R_1 = 1\Omega$, $\mathrm{C_1} = 2mF$,$L = 0.01H$, $\mathrm{C} = 2\mathrm{mF}$,$R = 500\Omega$.

Chapter-3

Fuzzy Logic Based MPPT Controller design and Results

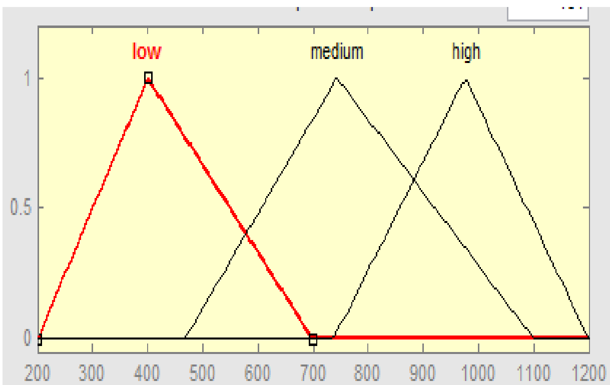
FLC is a very useful controlled process that can be assumed when the process lacks a well-posed mathematical model or provides a simple methodology for manipulating and implementing humans thinking experience-based knowledge about the control system. The fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. It has four main parts: Fuzzification, Rules, Rule Evaluation, and Defuzzification. The fuzzy models represent the nonlinear input-output relationships depends on the fuzzy partition of the input-output spaces. Thus, the membership functions tuning becomes an important issue in fuzzy modeling. The Fuzzy Membership Function Editor, where the number of membership functions and type of membership function chosen, such as trapezoidal, triangular, and Gaussian according to the process parameter. The membership function is sometimes made less symmetric to give more importance to specific fuzzy levels.

Fuzzification methods used are Mamdani and Sugeno while modern Defuzzification methods are Center of the area and Center of gravity. For the rule defining of fuzzy logic MPPT, different number of subset has been used. MPPT fuzzy logic controllers have shown to perform well under varying atmospheric conditions. Their effectiveness depends on the knowledge of the user to choosing the right error computation and coming up with the rule base table. Two different membership functions (triangular and trapezoidal) are mainly used to show that the tracking performance depends on the type membership functions considered. Fuzzy logic MPPT is based on different rules such as taking input as radiation and temperature (Case-I), taking input as radiation temperature and change in power (Case-II), and considering input from radiation, temperature, change in power and dust factor (Case-III) are considered.

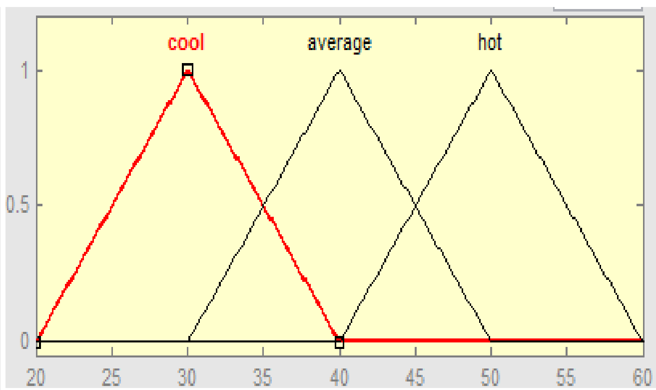
3.1 Defining Fuzzy System for MPPT Controller

In the beginning, fuzzy logic control based system consists of two inputs such as radiation and temperature measure the output voltage. It denotes the open loop system. The scale of membership functions described 200 W/m^2 to 1200 W/m^2 for radiation and 20ºC to 60ºC for temperature. Each of the inputs has three triangular membership functions that as shown Figure 16 in An FLC based MPPT model is to develop in MATLAB / Simulink environment rule base mentioned in Table 2 and Table 3 as shown below.

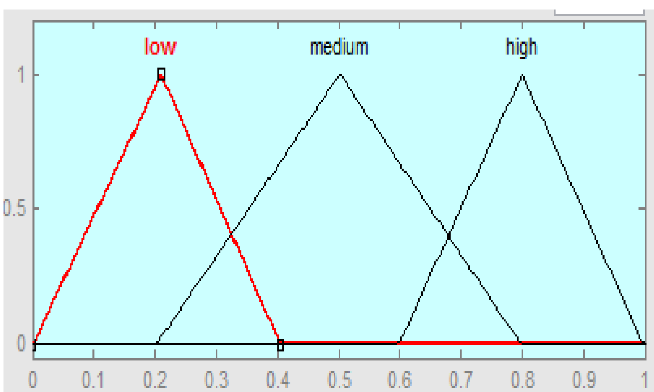
Table **2.**



a)



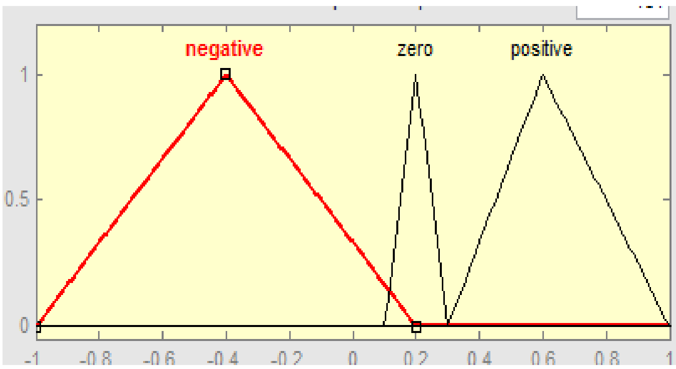
b)



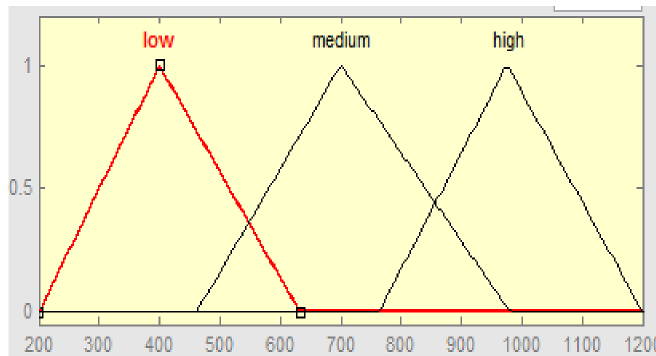
c)

Figure 16 FIS rules for Case I (Considering Radiation and Temperature) a) Radiation as Input b) Temperature as Input c) Duty Cycle as Output

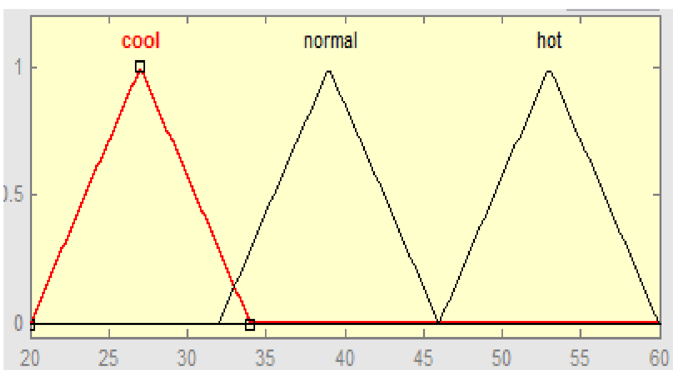
By taking different input radiation signals and rule defined in *fis* file and put that file into the fuzzy logic MPPT, get overshoot at the beginning after sometimes all signals become accurate. Again taking three inputs such as radiation, temperature and change in power, shows a closed loop system. Its output becomes more smooth and better.



a)



b)



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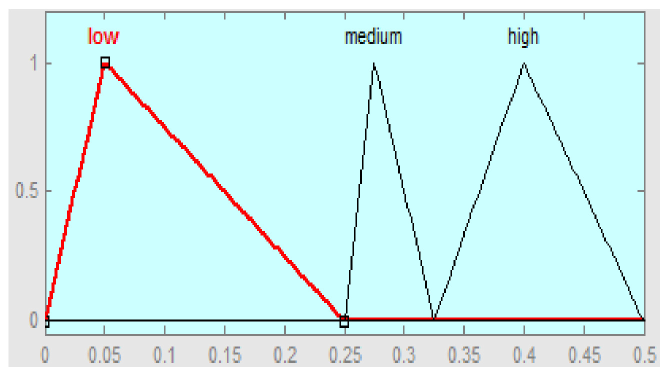

d)

Figure 17 FIS rules for Case 2 (Considering Radiation, Temperature and change in power) a) Change in power as Input b) Radiation as Input c) Temperature as input d) Duty cycle as output

Dust factor as a fuzzy system taking as inputs are wind speed, particle size, and inclination angle. That define in fis editor as shown in Figure 18.

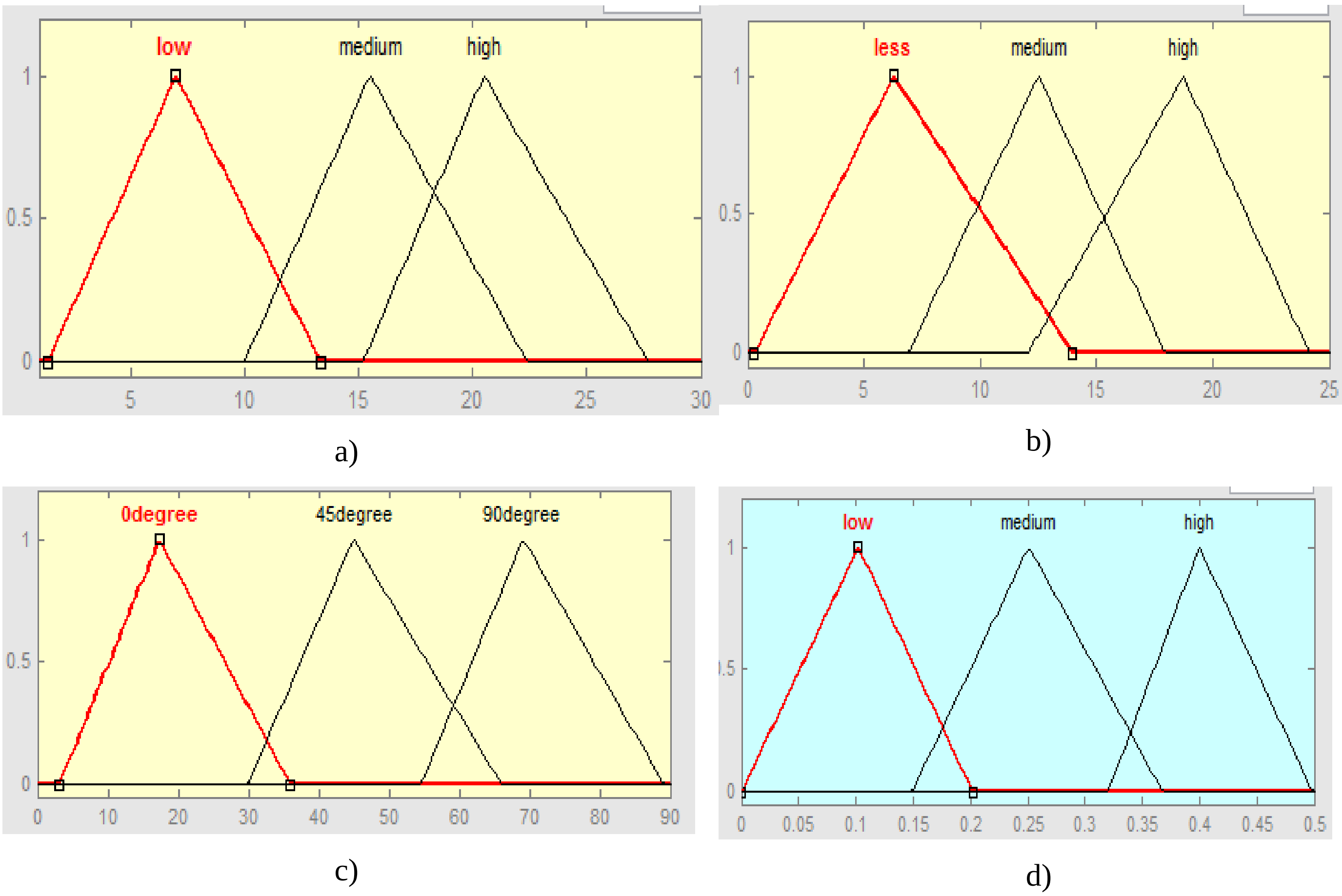

Figure 18 FIS rules for Case 3 (Considering particle size, the wind, inclination angle) a) Particle size as Input b) Wind as Input c) Inclination angle as input d) Power as output

Construct a fuzzy rules using the Graphical Rule Editor Interface, based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allows to construct the control statements automatically, by clicking on and selecting one item in each input variable box, one item in each output table, and one connection item. In Fuzzy Controller, rules are written in Table 2 and Table 3 as shown below.

Table 2 Rule defined for radiation and temperature as input and voltage as output

Radiation → **Temperature ↓**	**Low**	**Medium**	**High**
Cool	low	medium	medium
Average	medium	medium	high
Hot	medium	high	high

Table 3 Rule defined for change in power, radiation and temperature as input and voltage as output

Change in Power	**Radiation**	**Temperature**	**Voltage**
Negative	Low	Cool	Low
Negative	Low	Normal	Low
Negative	Low	Hot	Medium
Negative	Medium	Cool	Low
Negative	Medium	Normal	Medium
Negative	Medium	Hot	Medium
Negative	High	Cool	Medium
Negative	High	Normal	High
Negative	High	hot	High
Zero	Low	Cool	Low
Zero	Low	Normal	Medium
Zero	Low	Hot	Medium
Zero	Medium	Cool	Medium
Zero	Medium	Normal	Medium
Zero	Medium	Hot	High
Zero	High	Cool	Medium
Zero	High	Normal	Medium
Zero	High	Hot	High
Positive	Low	Cool	Low
Positive	Low	Normal	Low
Positive	Low	Hot	Medium
Positive	Medium	Cool	Medium
Positive	Medium	Normal	Medium
Positive	Medium	Hot	High
Positive	High	Cool	Medium
Positive	High	Normal	Medium
Positive	High	Hot	High

Table 4 Rule defined for particle size, wind and inclination angle as input and power as output

Particle Size	Wind	Inclination Angle	Power
Less	Low	0 degree	Low
Medium	Medium	45 degree	Low
Less	High	90 degree	Medium
Less	Medium	90 degree	Medium
Less	Medium	0 degree	Medium
Less	High	0 degree	Medium
Less	Low	45 degree	Medium
Less	Medium	45 degree	Medium
Less	High	45 degree	Medium
Less	Low	90 degree	High
Medium	Low	45 degree	high
Medium	Medium	0 degree	High
Medium	High	0 degree	Medium
Medium	Low	45 degree	Medium
Medium	Medium	45 degree	Medium
Medium	High	45 degree	Medium
Medium	Low	90 degree	Medium
Medium	Medium	90 degree	Medium
Medium	High	90 degree	Low
High	Low	0 degree	Low
High	Medium	0 degree	Low
High	High	0 degree	High
High	Low	45 degree	High
High	Medium	45 degree	High
High	High	45 degree	High
High	Low	90 degree	Medium
High	Medium	90 degree	medium

3.2 Simulink Models and Results

For modeling technique, six MATLAB subsystem function blocks have been used. Each block contains the mathematical equations for I_{ph}, I_d, I_{rs}, I_0. In this modeling process N_s, N_p, T, G, and V_{in} have been used as main input parameters. P_{pv}, I_{pv}, and V_{pv} taken as output parameters. These six subsystem explain the modeling technique of the PV module. Changing the parameter value from input ports as per the given specified value, I-V and P-V characteristics curves are obtained for different modules by using this model as shown in Figure 19.

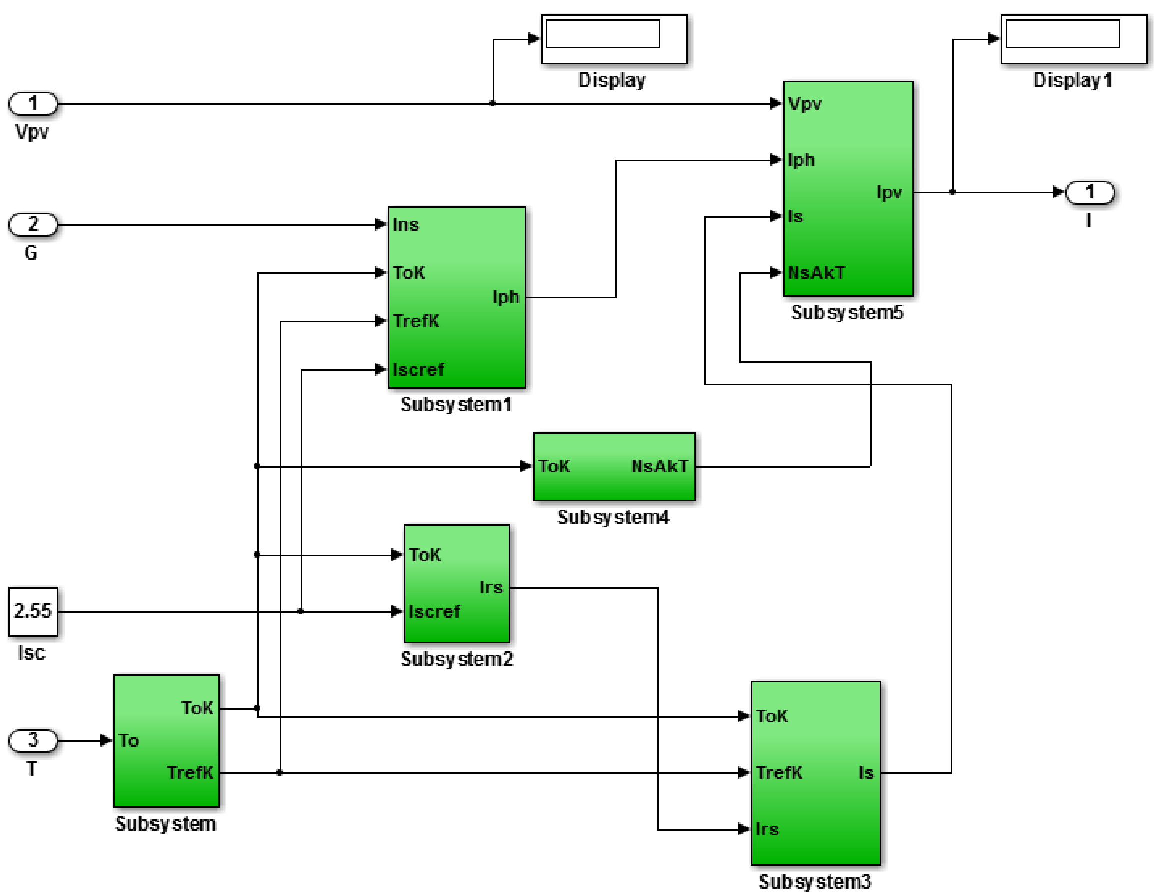

Figure 19 Simulink block diagram of a PV module

DC to DC converters used for converting the input voltage to DC output voltage. The dc-dc converter consists of an inductor, capacitors and switches are as shown in Figure 20. DC-DC Converter interface with PV system is very essential, so these converters play a role of charge controller, MPP trackers and PV interface with load. The output voltage of this converter connected across the load and whatever error voltage generated controlled by error amplifier that sensed to control the switch. The switch controlled by pulse width modulator, through which the most current generated through the load and voltage drops.

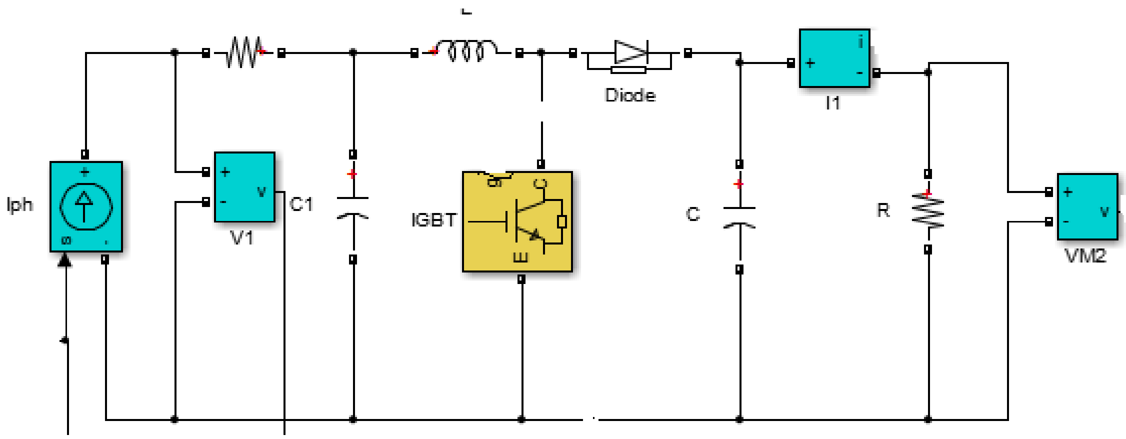

Figure 20 Simulation model of boost converter

Dust deposition of the solar surfaces causes both energy loss and permanent degradation of the surface properties, thereby affecting light transmission and reflection. These effects are functions of both the physical and chemical properties of the dust found in a given geographical location, and the climate, temperature, wind velocity, and of dust. The economical methods of dust mitigation for enhancing the surface properties of the solar collectors for maintaining high optical efficiency is needed.

Simulink block of fuzzy MPPT as shown in Figure 22, triangular or trapezoidal shaped membership function has chosen. Then defined fuzzy rules in rule editor and save fuzzy rules in fis file. Then the fis file should be put into the fuzzy MPPT Simulink model and range of the signal has been selected and tuned the signal for each case. A PV system produced maximum power is slightly depending on the radiation and temperature variations, the maximum power increases as the radiation increases and vice versa, a PV system performs better for low temperature than increasing temperature. The undesired effects on the PV power output, an electrical tracking is achieved through DC-DC converter inserted between the load and the source to make sure an impedance matching adaptation to the load impedance by varying with PV source as shown in Figure 22.

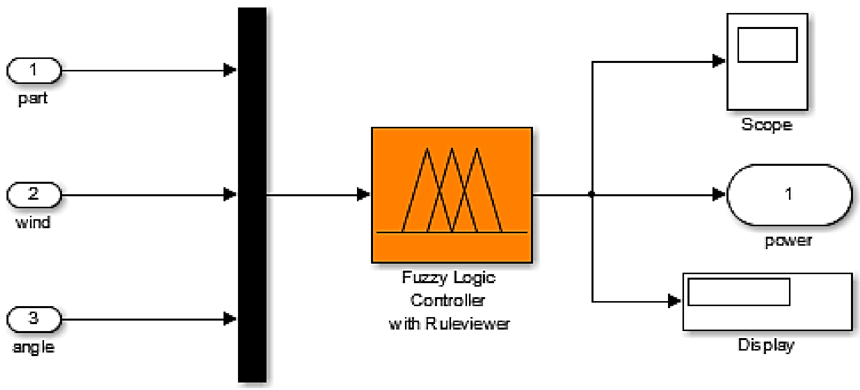

Figure 21 Dust factor fuzzy logic considering particle size, wind speed and inclination angle as input

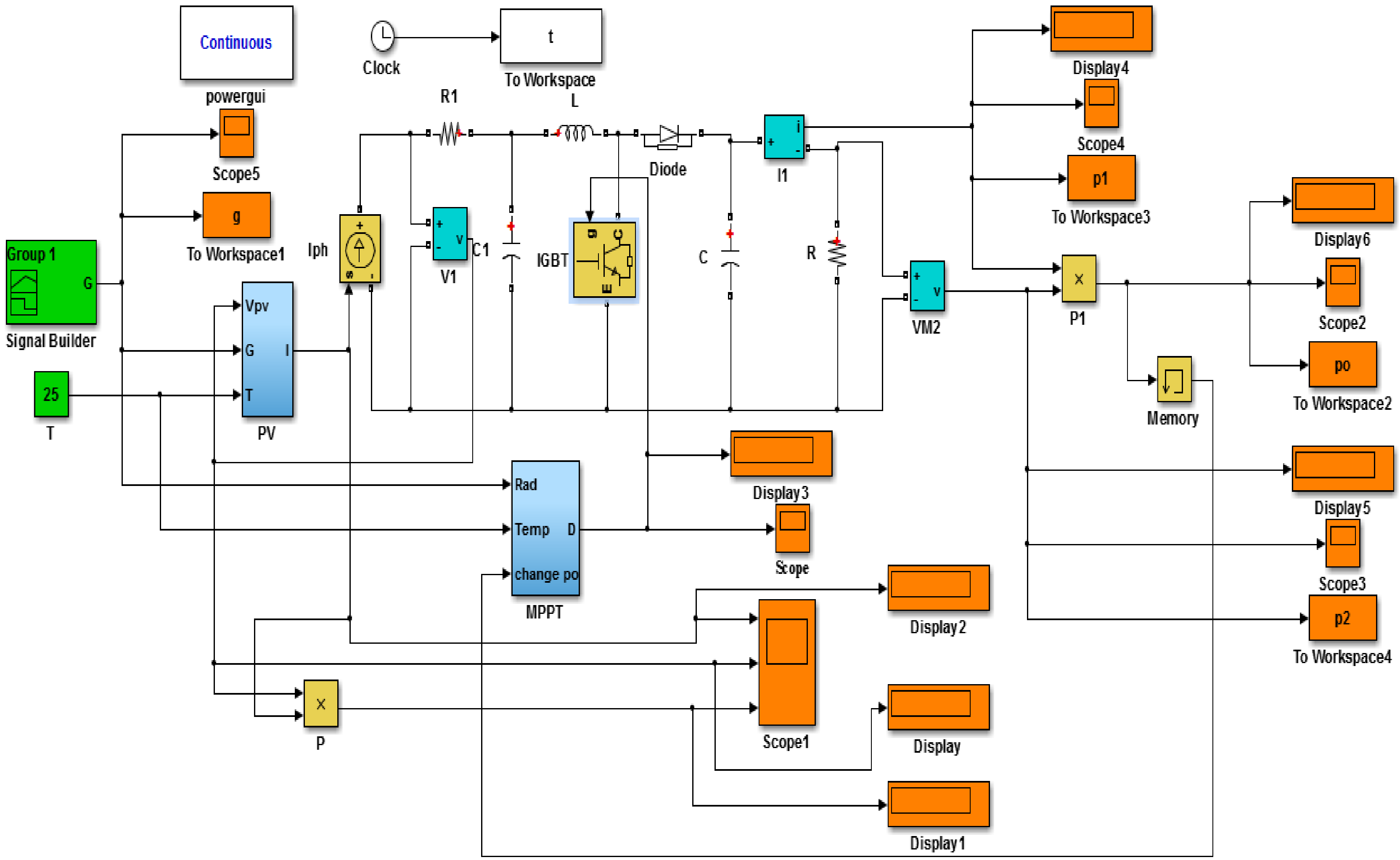

Figure 22 Complete Simulink model of PV panel with fuzzy logic MPPT

3.2.1 Simulation Result for Variable Changes of Radiation as Input

The models are shown in simulated using SIMULINK. The boost converter with fuzzy logic MPPT implemented and simulated with taking two cases, a) case-1 shows radiation and temperature as input b) case-2 shows radiation, temperature and change in power as input.

Figure 23 shows the time in X-axis, radiation and output power as double sided Y-axis. From that graph for case-1 output power sudden oscillate at 0 sec to 0.1 sec, after that curve becomes steady. For case-2, there is no fluctuation starts steadily from 0 sec to 3 sec.

Figure 24 shows the time in X-axis, radiation and output voltage as double sided Y-axis. From that graph for case-1 output voltage sudden oscillate at 0 sec to 0.1 sec, after that curve becomes steady. For case-2, there is no fluctuation starts steadily from 0 sec to 3 sec.

Figure 25 shows the time in X-axis, radiation, and output current as double sided Y-axis. From that graph for case-1 output, current sudden oscillate at 0 sec to 0.1 sec, after that curve becomes steady. For case-2, there is no fluctuation starts steadily from 0 sec to 3 sec.

From the all three comparisons of output power, output voltage, and output current are oscillated up to small value then it goes steadily for case-1. But for case-2 signal smoothly follow as per the input radiation signal.

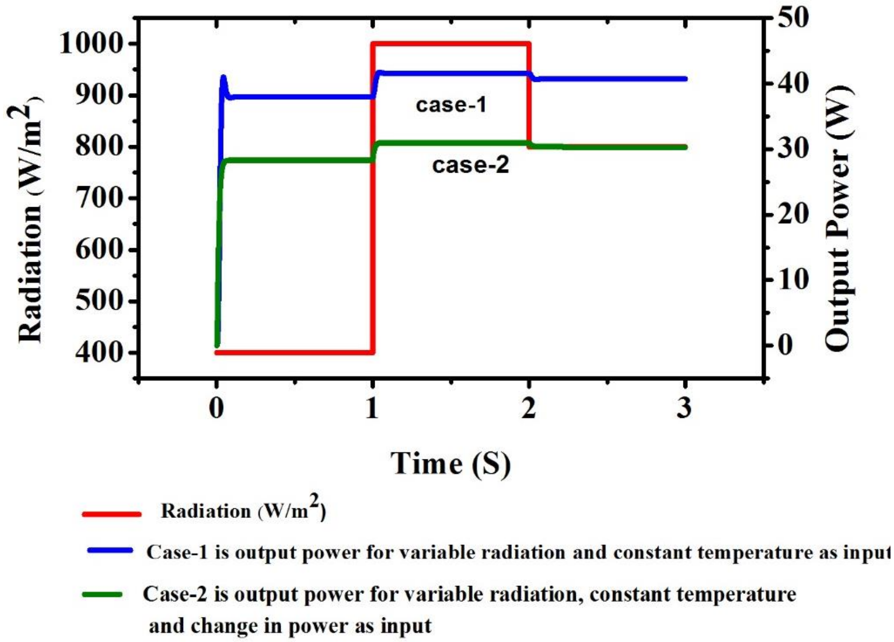

Figure 23 Output Power w.r.t time at varying radiation

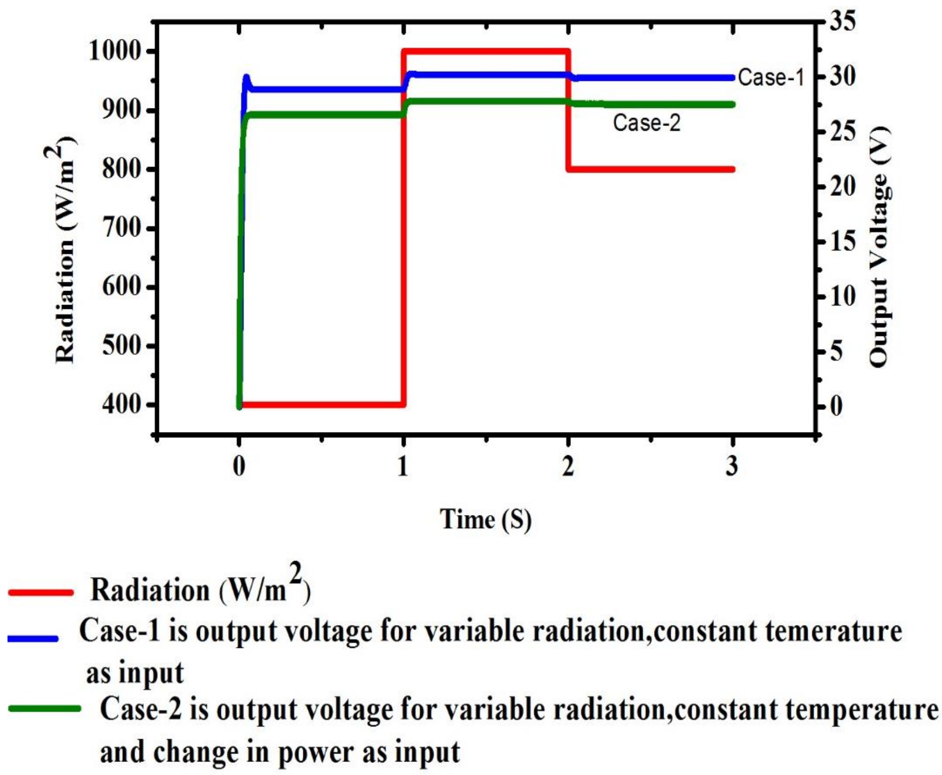

Figure 24 Output Voltage w.r.t time at varying radiation

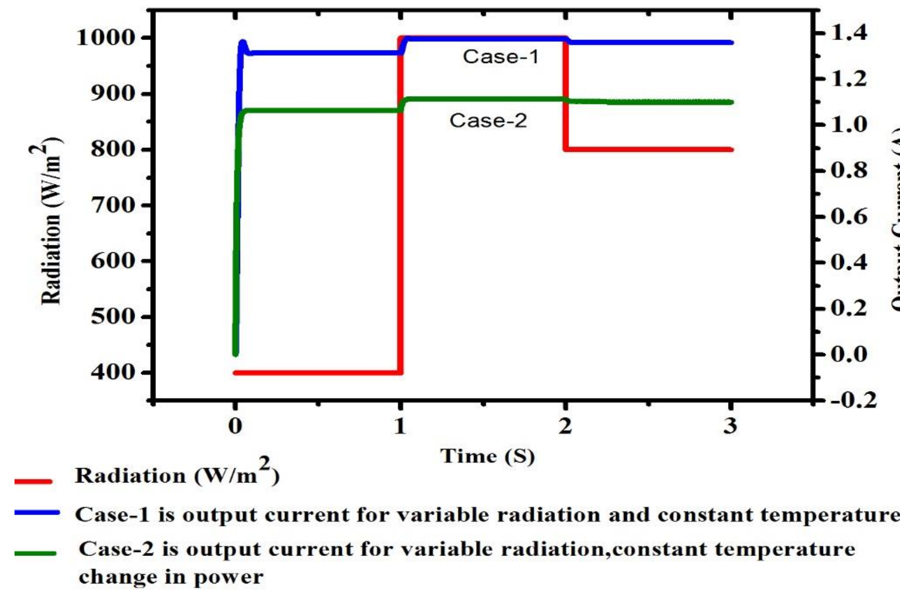

Figure 25 Output Current w.r.t time at varying radiation

3.2.3 Simulation Result for dust factor as input

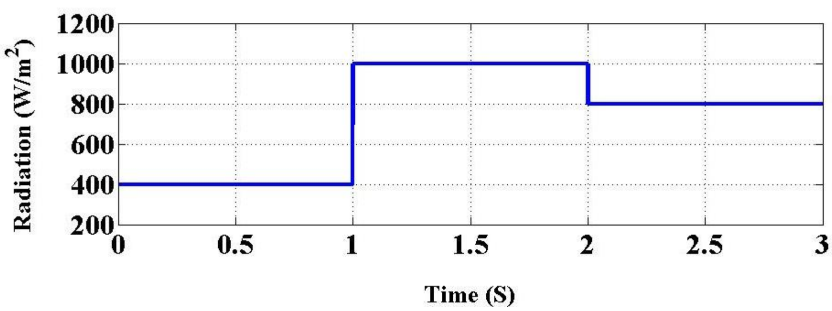

Figure 26 Variable radiation at constant temperature for dust factor

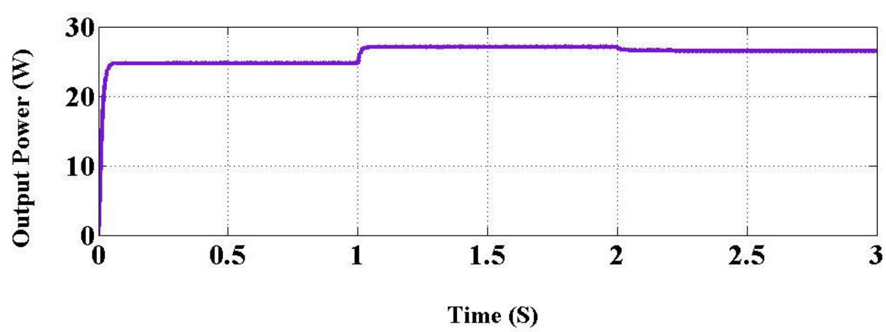

Figure 27 Output power for dust factor w.r.t time

3.3 Conclusion

This thesis presents an MATLAB/SIMULINK based model for PV panel. A geographical parameter based fuzzy logic controllers have been designed and simulated for the proposed PV system to track the MPP for various factors such as variable radiation, temperature, and dust factor. The current impact of dust deposition on the performance of solar systems, particularly PV and its response to the climatic and environmental conditions. The dust factor is one of the most important meteorological factors that mainly depends on seasons, location, dust particle size, wind speed, etc. Because of the above factors easily check the power output at MPP and causes power loss has observed and maintaining optimum efficiency is needed. Particle size as input to dust cause more energy loss.

Chapter- 4

Future Scope

Now a days the current trend across developed economic country in favor of Renewable Energy. From the last few years embraced more renewable power capacity as compared to the conventional power capacity. Photovoltaic solar energy conversion is the traditional renewable source because of its merits such as availability, low maintenance, and environment friendliness. However, current solar panels exhibit low power efficiency**.** The primary reason for the low conversion efficiency is the non-linear voltage-current (V-I) characteristics, which depends on the solar insolation and panel temperature. Functioning of the balance of system components like charge controller, converters, and maximum power point tracking (MPPT) plays a vital role in improving the overall efficiency of the solar system. MPPT technique has a quick response and can follow the peak power generated in any weather condition. As a result, MPPT strategies should be deployed to ensure the tracking of the MPP of nonlinear PV characteristics. So the photovoltaic MPPT system is developed by combining the models established of solar PV module and DC-DC boost converter. MPPT using FLC gains several advantages of faster performance, robust and simple design. This technique does not require the knowledge of the exact model of the system. Fuzzy logic is a well-known artificial intelligent tool that is used to compute output based on expert knowledge. Fuzzy Logic Controller algorithm based on three steps: expert knowledge, fuzzification and inference diagram, and defuzzification.

It is necessary to concentrate our forces to reduce the application costs and to increment their performances. The implementation topology of MPPT greatly depends on the end-users knowledge with analogical circuit, SC, OV, or CV are useful options, otherwise with digital circuit that require the use of microcontroller, P&O, IC, and temperature methods are easily to implement. Moreover, it is important to underline that analogical implementations are cheaper than digital (the microcontroller and relative program are expensive). All the cost comparable between them, the computation cost comparison is formulated taking into account the present spread of MPPT methods. The number of sensors required to implement the MPPT technique also affects the final costs. Most of the time, it is easier and more reliable to measure voltage than current, and the current sensors are usually more expensive and bulky. The irradiance or temperature sensors are very expensive and uncommon.

The major challenges of MPPT lie in its dependence on the environmental parameters; temperature, radiation, cloud factor, and the dust factor. Power output from the panel is directly proportional to the incident radiation. The decrease in temperature reduces the open circuit voltage reducing the output of the panel. With a large number of clouds and frequency of appearance of clouds passing over the panel location, there is a variation indirect and diffused sunlight throughout a day. Cloudy sky decreases the average power output of the panel because of shadowing. The presence of dust on the board surface sharply reduces the energy production, which results in a significant economic loss. Nature and amount of dust getting deposited in the group depends on the temperature, type of soil, and wind speed. The problem of soiling in regions like the desert is prominent. The amount of dust varies as per season e.g. in the summer dust amount is more since it is less in a rainy season. Due to the nature of parameters considered such as imprecision, absence of an accurate mathematical model, and nonlinear nature, FLC is used for the decision-making process.

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