MAXIMUM POWER POINT TRACKING FOR PV ARRAYS

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Acknowledgement:

The work presented in this final report is entirely from the studies of the individual student, except where otherwise stated. Where derivations are presented and the origin of the work is either wholly or in part from other sources, then full reference is given to the original author. This work has not been presented previously for any degree, nor is it at present under consideration by any other degree awarding body.

ABSTRACT:

The project composes understanding the behaviour of a PV cell/system and using an MPPT technique to get maximum power out of it. The project has certain phases like background, literature, circuit design, simulation, and report writing. Until this report, background study and literature study are being done along with a start on circuit design and simulation. The background and literature study will help in circuit design and simulation of the system. This report explains the background of the topic and gives a review of four algorithms of MPPT; *Incremental Conductance Method (**IC**)*, *Fuzzy Logic Controller method (**FLC**)*, *Artificial Bee Colony algorithm (**ABC**)*, and *ABC-Perturb and Observe method (**ABC-PO**)*. All these methods are explained with the help of flowcharts and tables. Classification of these methods is also given via tables given in the Bibliography. This report will be extended to form a dissertation, including a detailed explanation of component selection, calculations, simulations, and results.

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CHAPTER 1: INTRODUCTION TO THE PROJECT

1.1 INTRODUCTION:

The industries rapid growth and the modern lifestyle sophistications demands in increasing the energy generation. This is the point which forces stakeholder for critical scrutiny of energy consumption, complete energy audit, and environmental sustainability. Furthermore, the concerns of changing in climate and the requirement of reducing the carbon in the environment, demands the multinational and national companies to research on the alternative resources of energy, in particular the renewable energy resources. The adoption of renewable electrical energy resources helps in the reduction of oil utilization and to cut the hikes of oil prices.

The abundance of the sun light, projects the photoelectric system as first point of thinking to implement renewable energy resources. The photovoltaic power generation components are solar cells usually available in the form of array or modules and making solar panels are a great source of energy on the planet. The array of photovoltaic plays a pivotal role in providing direct energy. Many people use solar panels to power up their appliances at commercial and residential sites. Some wealthy companies have started back electricity supply to the government through pervasive networks of solar cells. Photovoltaic (PV) energy is a hot topic because of its useability and reliability. PV cells have improved since the first solar cell was demonstrated in 1954 [1]. Significant improvements include design, material, and manufacturing. In recent days, with the huge expansion in generating energy using PV cells enhances the significance of research on PV for finding the maximum power point to having maximum efficiency.

In contrast to the unrenewable and conventional power generation resources such as coal, gasoline etc., and the solar energy is free, clean and inexhaustible. The are two modes of implementation of PV panels; one is standalone systems which includes domestic, electric vehicles, water pumping, street lightning and military applications; others are application in grid connected mode such as power plant and hybrid systems [25,27].

There are two major problems are with the PV systems; one is the less amount of solar to electric conversion in case of low irradiance; second is the variation of the electricity generated by the PV panels when the weather condition is not good. The PV cell characteristics are largely affected by irradiance, temperature and weather conditions.

Now, when we have a fully upgraded and top-of-the-line PV cell, we are working on tackling the environmental effects like weather and the effects due to other obstacles like flying birds or dust accumulation on the PV cells. This project is about one of these concerns, partially shaded conditions. If there is a more prominent shade and more than one cell is not active, it can cause problems even after using such a safety [28].

A solar panel comprises PV cells connected in series. Then such panels are further connected in series and parallel combinations to achieve the required voltage, current, and power. In this case, if any cell gets damaged or shaded by some obstacle, its current approaches to zero, which affects other cells' output, badly affecting the whole system. The most straightforward technique used to resolve this issue is to bypass the PV cell when it does not provide voltage. This is a primary Maximum Power Point Tracking (MPPT) technique for partially shaded conditions and is achieved by bypassing diodes [39,40].

Despite of the benefits and advantages of solar energy in comparison with other power generating resources, the solar energy is still underlying due to the having higher capital cost. A lot of work is progress in reducing the cost of the cell of photovoltaic system and to enhance its efficiency. The efficiency of the PV system can be increase either by improving cell fabrication modes and the second is to trace the maximum power point. The most economical way to increase the solar efficiency is to work on the MPPT techniques [31].

In this case of load variation the advanced algorithms are being used to achieve the maximum power out of the system and keep the load supplied with constant voltages. The conventional techniques works by sensing the current level and voltage level of the PV cells for calculating power and adjust the duty cycle of the converter accordingly [29]. There are numerous MPPT techniques available and varies with respect to the convergence speed, cost effectiveness and oscillations at steady state. The four best MPPT techniques i.e. Incremental Conductance Method, Artificial BEE Colony Method, Fuzzy Logic Controlling Method and ABC P&O Method, are explored, simulated and concluded in this report.

1.2 AIMS AND OBJECTIVES:

The aims of this projects are as follows:

- Understanding of designed oriented Project
- Learning of research methods to rationalizing purposes
- Understanding and Power audit of Energy Generation modes
- Focusing on MPPT state of the art
- Finding research gap in the techniques of MPPT
- Evaluation of selected MPPT technique

The objectives of this project is as follows:

- Learning from the state of the art
- Drawing conclusion of conventional energy resources and listing drawbacks
- Selection of PV research on the basis of extensive research
- Understanding different MPPT techniques and its implementation is unwanted circumstances
- Defining and selecting the MPPT techniques for efficiency enhancements in shaded, cloudy and rainy conditions
- Understanding Implementation of selected MPPT techniques
- Selection of best of selected techniques
- Improving with respect to the research gap
- Implementation and best conclusion for shaded conditions

This project aims to understand the way and the thinking process of doing an outcome-based project. The project will enable us to understand the basic principles used in PV arrays and the structure of the MPPT system and gain in-depth knowledge of making an MPPT system that can tackle the partially shaded conditions. I will explain different methods and select one of them for implementation. MATLAB simulation will be used in this project to check the efficiency of the used algorithms. This project aims to improve the system design through simulations and reach a final model that is best suitable for partially shaded conditions.

1.3 METHODOLOGY:

The methodology includes all the step in methodology of research based project. Starting from selecting the research area in general, to having the basis introduction of research areas, to deducing aims, to formulating objective, to find the state of art, to the learning of state of art, to finding the research gap, implementation of technique and building the conclusion.

In my case, the same is implemented with respect to the nature and mode of my technical and research based project. The 1st step is to learn the need of utilizing the renewable resources by evaluating the energy audit. The 2nd step is to focus on the renewable energy resources for further analysis. The 3rd step is to select PV energy resources on basis of critical evaluation. Fourth step is to learn the state of art of PV implementation techniques which involves the technique to track maximum power point. The fifth step is to implement the best of the techniques of MPPT on MATLAB. The sixth is to best fit the research gap in the implement to enhance the efficiency. The next step is to make different shaded scenario and to test the model in unstable weather conditions. The last step is to build the conclusion on the basis of all the research and simulations.

1.4 REPORT ORGANIZATION:

This report consists of 3 chapters, and each has its importance in the conduct of this project. The report starts with an abstract that summarizes the whole project and tells the reader about the basic idea and the outcome. Then the first chapter introduces the reader to the basic idea and clarifies the aims and objectives along with methodology and report organization. After this, the second chapter is about literature review, which is the most critical chapter in this report. It comprises detailed answers to some basic questions about the project and then explains four algorithms that can be practised to achieve MPPT. This chapter is added with a portion for the conclusion of this chapter. The third chapter contains the Gantt chart, which presents the project's workflow in the coming time.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION OF MPPT:

Energy has been an essential requirement of men of all ages. However, its magnitude and forms did not remain constant. After the invention of electricity, we started building over it and invented many electricity-dependent things. Most of the earth's resources are being utilized to produce electricity to balance the needs. The photovoltaic cell's invention was one of the efforts to retain the earth's resources and use solar energy to produce electricity. Solar cells work under particular weather and temperature conditions, but we want to take constant energy from them. To achieve this, we use MPPT (Maximum Power Point Tracking). It is a broader term that includes traditional to modern methods. In this report, I have described the understanding of PV arrays, MPPT, its importance, and types. Furthermore, I have selected four types of MPPT based on some variables of criteria like complexity and efficiency.

Maximum power point tracking (MPPT) is a method that is mainly used in the charge controllers to extract the maximum power from the PV arrays. It uses a high-frequency DC/DC converter that takes the DC input from the PV arrays and converts it into different Voltages and currents to match the PV system with the output load (DC load, batteries). The voltage at which PV arrays produce maximum power to charge the batteries is called maximum PowerPoint. It varies with the ambient temperature, solar cell temperature, and solar radiation [32]. The optimum conditions for MPPT are given below:

- PV arrays work better at cold temperatures, and MPPT extracts maximum power from them on cold, cloudy, and hazy days [2].
- MPPT works more efficiently when batteries are drained.

2.1.1 The Inside of PV Arrays

A Photovoltaic (PV) cell converts solar energy to electrical energy. A PV module is a set of cells connected in series or parallel circuits to produce higher power. PV panels consist of one or more PV modules. PV arrays consist of one or more PV panels connected in series and parallel to complete the power generation unit [3].

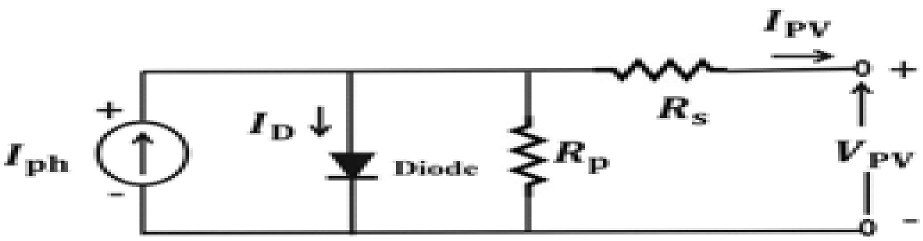

Figure 1- The equivalent circuit of PV cell

Solar cells are made up of p-n diodes in a thin layer of semiconductors. Fig. 1 shows the equivalent circuit of a perfect PV cell. This ideal structure can precisely show the PV characteristics of an ideal PV cell. I_{Ph} is the photocurrent, I_D is the diode current, R_P is the parallel resistance, R_S is the series resistance, I_{PV} is the output current, and V_{PV} is the output voltage [4].

The Fig. 2 is depicting the voltage and power characteristics of solar cell under different temperature and solar irradiation.

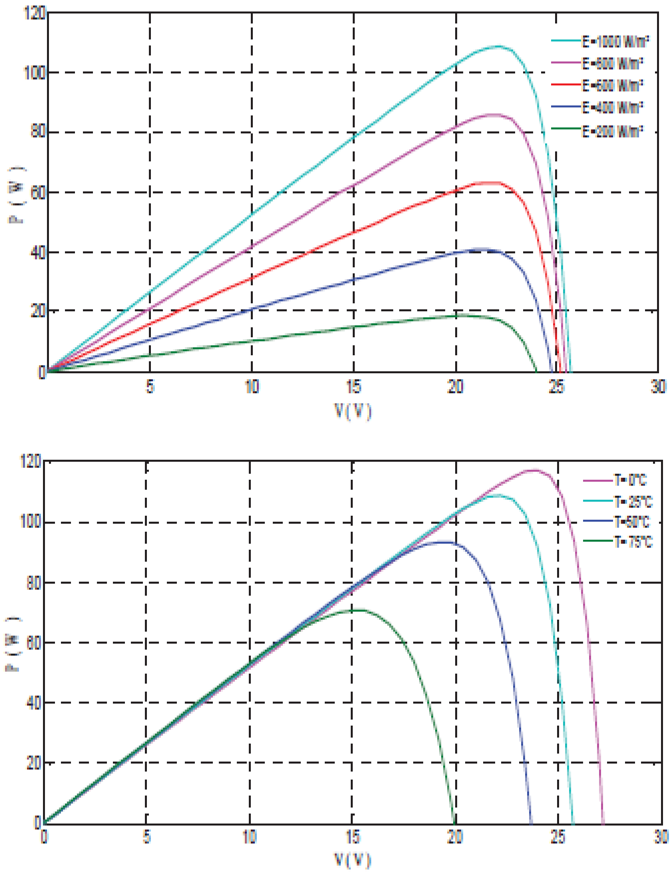

Figure 2- The Power and Voltage characteristics of PV system at different conditions

2.1.2 Necessity of MPPT for PV Arrays:

MPPT is necessary for PV arrays because it maintains the maximum power at the output. It takes the PV array output, checks the battery voltage, and converts the voltages of the PV model to get the maximum current necessary for the battery by using the concept of $P = V \times I$ equation. Also, the same for the DC loads. The PV arrays can produce a maximum voltage of 17V for maximum power at the cell temperature of 25°C. On hot days it drops to 15V, and on cold days, it rises to 18V. To maintain the voltage at 17V, MPPT is necessary for PV arrays [2].

2.1.3 The Need of MPPT in PV arrays:

The control variables approach is used in most MPPT methods that get the PV array output [5]. The controller uses current and voltage as input in this approach, and the maximum output power is captured from the PV arrays. The power converter parameter is tuned continuously to get the maximum power from the PV array. Voltage and current of MPPT converter are sensed, and the multiplying factor calculates power. After that, the maximum power sends for the iterative process [6].

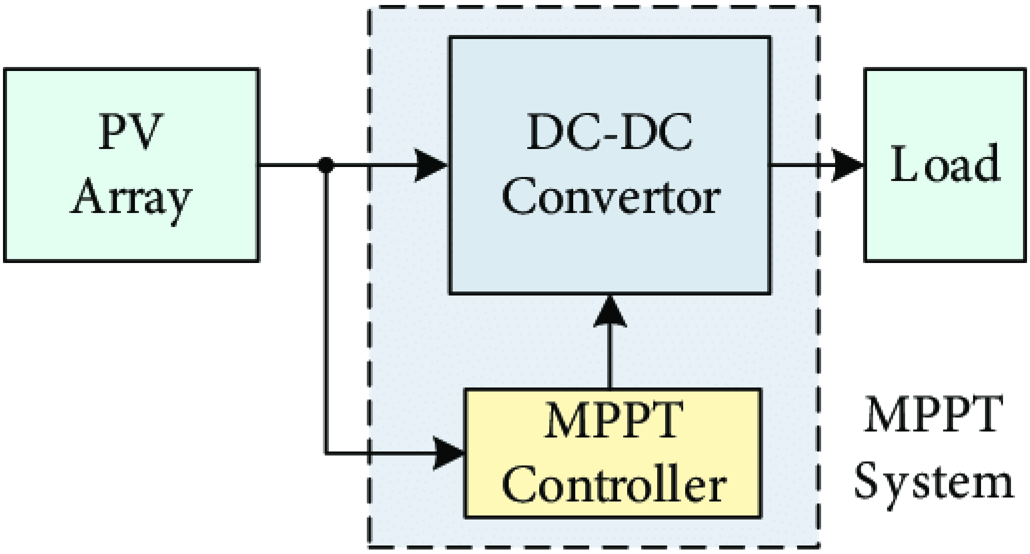

Figure 3- The PV System with MPPT Technique

2.2 Classification of MPPT for PV Arrays

The output of the PV arrays gives the P-V curve that shows the single peak under normal irradiation conditions and temperature but shows multiple nonlinear peaks for the partial shading conditions (PSCs). Therefore, the MPPT controllers pay much attention to optimizing the output of PV arrays. Traditional MPPT methods are simple and reliable for normal conditions, but they fail to find PSCs' local and global peaks. The advanced MPPT methods are more efficient than traditional methods, but they also have limitations that can be resolved using hybrid methods. The main MPPT techniques for PV systems are divided into three groups according to their optimized principles, control theory, and implementation [7].

- **Traditional MPPT methods**
- **Intelligent control based MPPT methods**
- **MPPT methods for PSCs**

I have found some characteristics tables for the above methods, which compare different methods based on their efficiency, usability for PSCs, hardware implementation, and tracking time. Considering the tables (table. 2 & table. 3), I have chosen the Incremental conductance (IC) method from the traditional methods and the Fuzzy logic controller (FLC) method from the intelligent control-based methods. I have selected two methods, the *Artificial-Bee-Colony* algorithm (ABC) and ABC-P&O, from the MPPT methods for PSCs.

2.2.1 INCREMENTAL CONDUCTANCE METHOD (IC):

This method is based on the fact that the maximum point is achieved when the power versus voltage curve is zero. The value will be positive on the left of the maximum output power point and will be negative right side of maximum output power point. This system also oscillates when the MPP is achieved due to the noise and measuring faults and to overcome this, the certain value ϵ is being assigned other than zero at the time of maximum power output. The value of the oscillation's amplitude is also dependent on the ϵ and it decreases by increasing the value of ϵ.

At the same time, the ϵ is introduced to overcome the errors and noises, and if the value of the ϵ is increasing constantly just to handle the amplitude of the oscillations, it will keep on deviating the operating point away from maximum power output power point.

The incremental conductance method was developed to overcome the limitations of the perturb and observe (P&O) method. It uses the incremental conductance property of photovoltaic cells and corrects the oscillations caused by different techniques even when the P & O method is optimized. This method is based on the comparison of the PV conductance $\frac{\text{Ipv}}{\text{Vpv}}$ with the derivative conductance $\frac{\Delta\text{Ipv}}{\Delta\text{Vpv}}$ instantly [8].

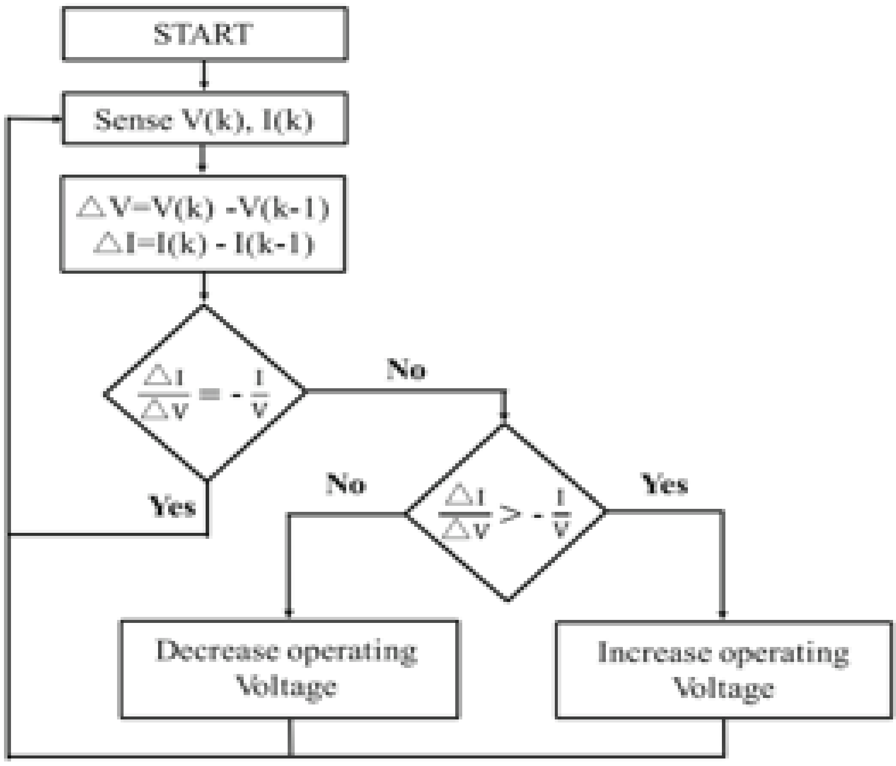

Figure 4- The flowchart of IC Method

The IC method works by checking the voltage operating point again and again, at which the conductance is equal to the incremental conductance. The main advantage of this system is that it can detect the relative power to the maximum power point (MPP). Therefore, it can check when the MMP will reach. It can precisely track the MPP in variable weather conditions [9]. It has some disadvantages, too; under the low level of insulation, the differentiation process becomes complex, and noise is measured with unsatisfactory results.

The operating zones of IC are given as follows [10]:

If $\frac{\Delta Ipv}{\Delta Vpv} > -\frac{Ipv}{Vpv}$ then OP is on the left of the MPP.

If $\frac{\Delta Ipv}{\Delta Vpv} < -\frac{Ipv}{Vpv}$ then OP is on the right of the MPP.

If $\frac{\Delta Ipv}{\Delta Vpv} = -\frac{Ipv}{Vpv}$ then OP is at the MPP.

The graph shown in fig. 4 clearly explains the operating zones of this method. The goal of mppt is to define the voltage at which the solar panel delivers the most power. It compares the instantaneous conductance with the incremental conductance and increases or decreases the voltage according to the above conditions. It is based on the derivative of PV panel power concerning the voltage and try to balance the power curve slope at zero [12, 33]. The MPPT achieves when instantaneous conductance becomes equal to the incremental conductance. The IC MPPT technique was developed by I Muta, T Hoshino, K.H Hussain, and M Oskada [13].

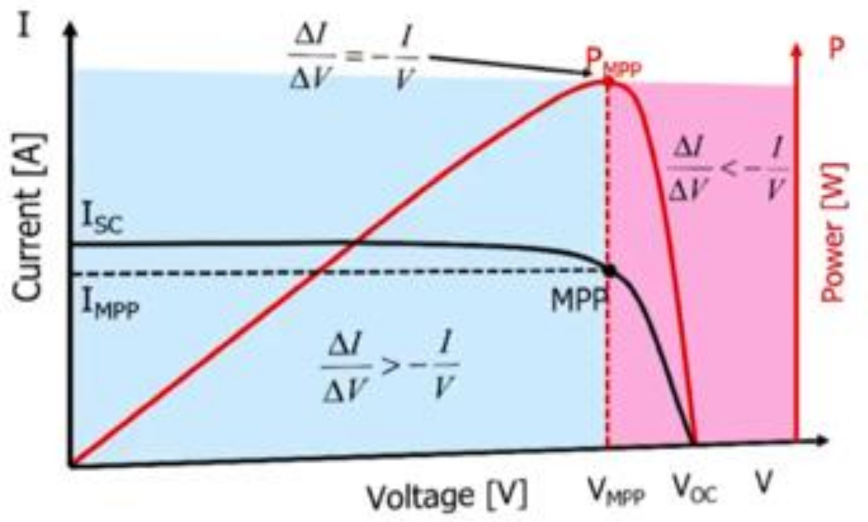

Figure 5- P,V and I curves

2.2.2 FUZZY LOGIC CONTROLLER METHOD (FLC):

With the increase in the computing power of microcontrollers and cost reduction, the FLP in MPPT has become popular. Its primary advantage is that the system model is not required, but the designer must know some information about the system's reaction to the inputs qualitatively. We do not need to think about the operating point, non-linearity, and uncertainties like the previous method. FLC is composed of three parts (fig. 6) [13]:

- Fuzzification
- Rules inferences
- Defuzzification

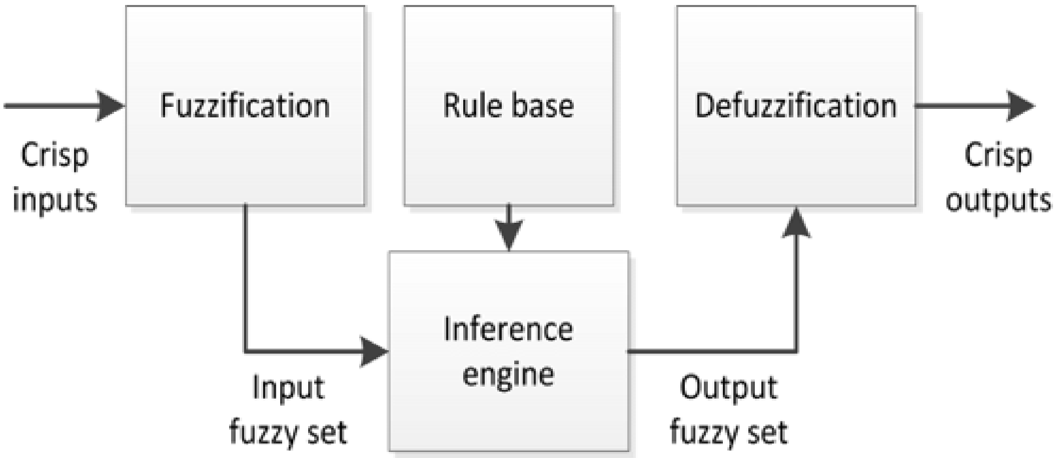

Figure 6- The Block Diagram of Fuzzy Logic Controller

Fuzzification takes the numerical input variables and transfers them into linguistic variables using the membership function. The accuracy of the FLC depends on the number of memberships functions, the more significant the function greater the accuracy. Five memberships are mostly depicted (fig. 7): negative large, negative small, zero, positive large, and positive small [14].

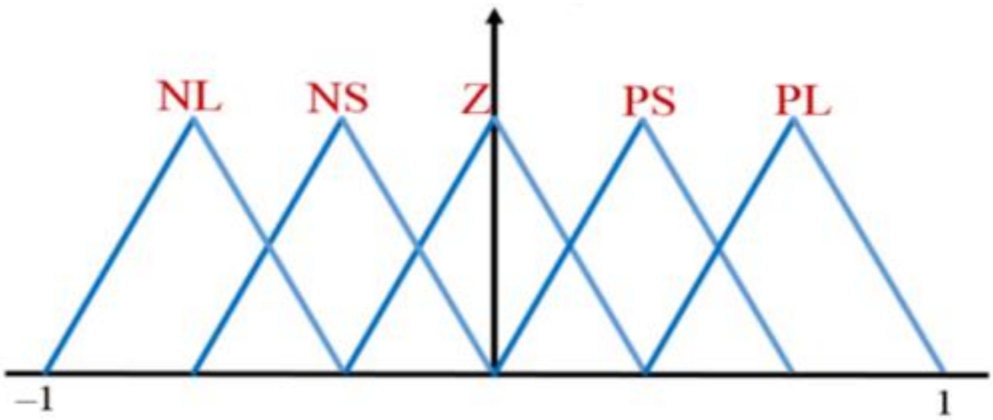

Figure 7-Fuzzy Membership Function

The **rules inferences** are the workstation in the FLC structure. It is the part where the controller decisions are taken. It is analogue to control the gain. The main challenge for the FLC is to write the rules to relate the input to the output. There is no defined method to design the FLC rules. By using equation 1, we can construct the fuzzy rule table. Table 1 shows the five linguistics variables rule table [15]. The rule structure of FLC can be expressed as follows:

$$\text{Rk: If } x = \text{Ai} \quad \& \quad dx = \text{Bi Then Output is Ci} \qquad (1)$$

Where, R_k is the kth rule. ***x*** and ***dx*** are the input variables for FLC. $\boldsymbol{A_i}$, $\boldsymbol{B_i}$ and Ci are the linguistic labels for the inputs and output. At the **Defuzzification,** the linguistic data is converted back to crisp data. The main defuzzification methods are Bisector of Area, Mean of Maxima, Centre of Gravity, and Centre of Gravity for Singleton. The most commonly used method is the Centre of Gravity [16].

Table 1-Fuzzy Rules Table

e|ê	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

In fuzzification process demands each variable being used is to be written in terms of the rules guided by fuzzy set notations. The kernel portion of fuzzy logic controller is the interference system of the fuzzy logic. The fuzzy interference is a system to formulate and map a given input by the defined logic into an output [34]. This mapping is very important and further being used for the decision purposes. In Defuzzification, the system calculates the output of the fuzzy logic controller. It actually maps the statement of the fuzzy logic which correspond to the certain output and turns into a non-fuzzy control statement [37].

2.2.3 ARTIFICIAL BEE COLONY ALGORITHM (ABC):

ABC is based on stochastic algorithms, which have solved many optimization problems. Its algorithm convergence norms are not dependent on initial conditions, and it utilizes very few controlled variables. This algorithm is classified into three groups [17,35]:

- The employed bees
- The onlooker bees
- The last scouts' bees.

This algorithm can be understood by comparing to the example: We consider the employed bees exploit the food production sources or search for the food. The onlooker bees decide to select the food source. The last scout's bees randomly search for the new food. Same as these groups work together with coordination to get the optimal solution in lesser time.

In the first step, the ABC generates the arbitrarily distributed population of SN solutions by setting the control parameters. After initializing parameters, the population repeats the cycles of the search process of the employed bees, onlooker bees, and scout bees. After each cycle, the employed bees produce a new solution and evaluate its fitness. After the shared information, the onlooker bees find a new solution within the neighbourhood and calculate the probabilities. It was employed to track the MPP, and the duty cycle presents the maximum power as the food source of the ABC algorithm. The fitness of duty cycles is chosen as the generated power of the PGS. For the evaluation of the duty cycle, the controller successively outputs the PWM signal according to the value of the current duty cycle, and the PV voltage and current can be measured. The measured values can calculate the corresponding power of every duty cycle. The overall illustration of this algorithm is shown in fig. 8.

ABC was mainly designed to track the MPP under different irradiance. It is better than other methods like P&O because it gives similar results at low irradiance. It has fast MPPT accuracy and gives 99% efficiency for partial shading PV systems. It can solve multimodal and multidimensional optimization problems efficiently [18].

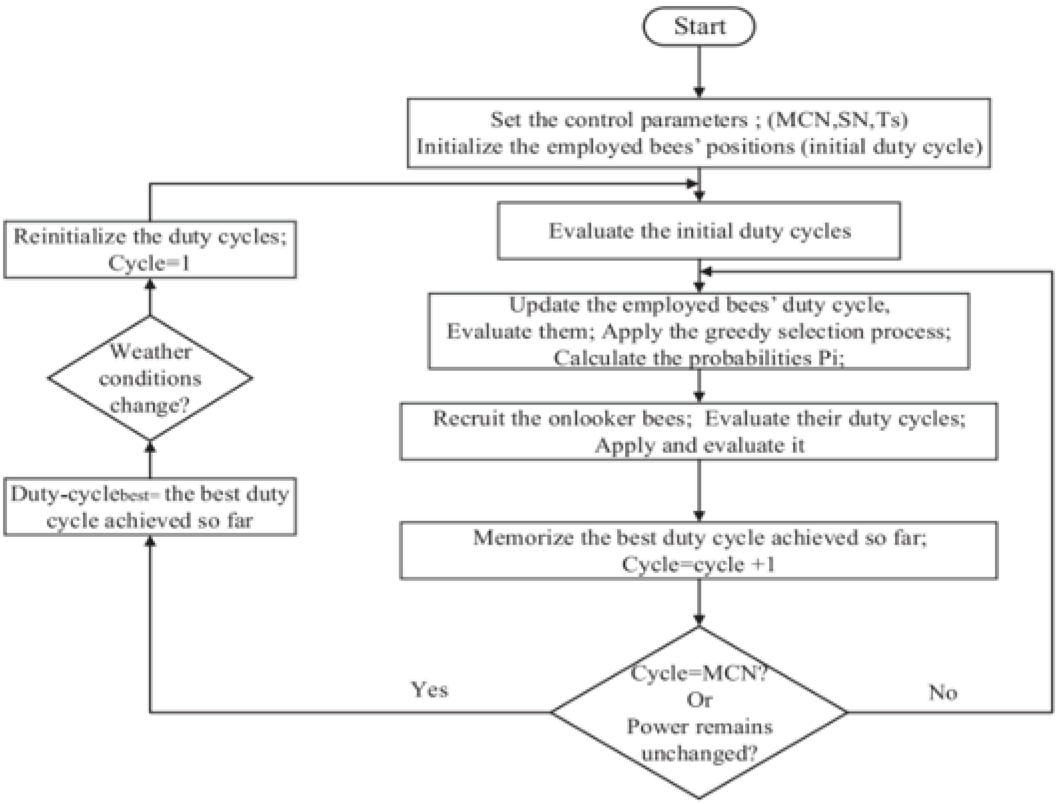

Figure 8- The flow chart of ABC based MPPT technique

2.2.4 ABC-PERTURB AND OBSERVE (P&O) METHOD:

The flowchart of the ABC-PO algorithm is shown in fig. 8. The first part is the general GMPP tracking section of the ABC algorithm. The following are the five steps engaged in the ABC-PO algorithm.

- Initialization phase
- Evaluation phase
- Employed bee phase
- Onlooker bee phase
- Finishing phase

In the **initialization phase**, consider that the colony's size is N; half is the employed bee colony (N_E), and the other half is the onlooker bee colony. The employed bees select the different food sources positions by using the below formula:

$$\mathrm{Di} = \mathrm{Dmin} + \mathrm{rand}[0, 1] * (\mathrm{Dmax} - \mathrm{Dmin}) \quad (2)$$

D_{min} = 0.1 and D_{max} = 0.9 represents the value of duty ratio for minimum and maximum conditions and i = 1, 2. . . N_E.

The maximum cycle number (MCN) is selected in the evaluation phase, and the quantity of nectar is evaluated for every cycle. In the **employed phase**, each employee bee updates the new position by using the given equation:

$$Di - new = xi + \emptyset\mathrm{i}[\mathrm{Di} - \mathrm{Dk}] \qquad (3)$$

k = 1, 2. . . NE & $\emptyset_i$ = [−1, 1].

- If P_{out} exceeds the last location, the bees working at the new place will stay there.
- Else it shifts back to the previous location.

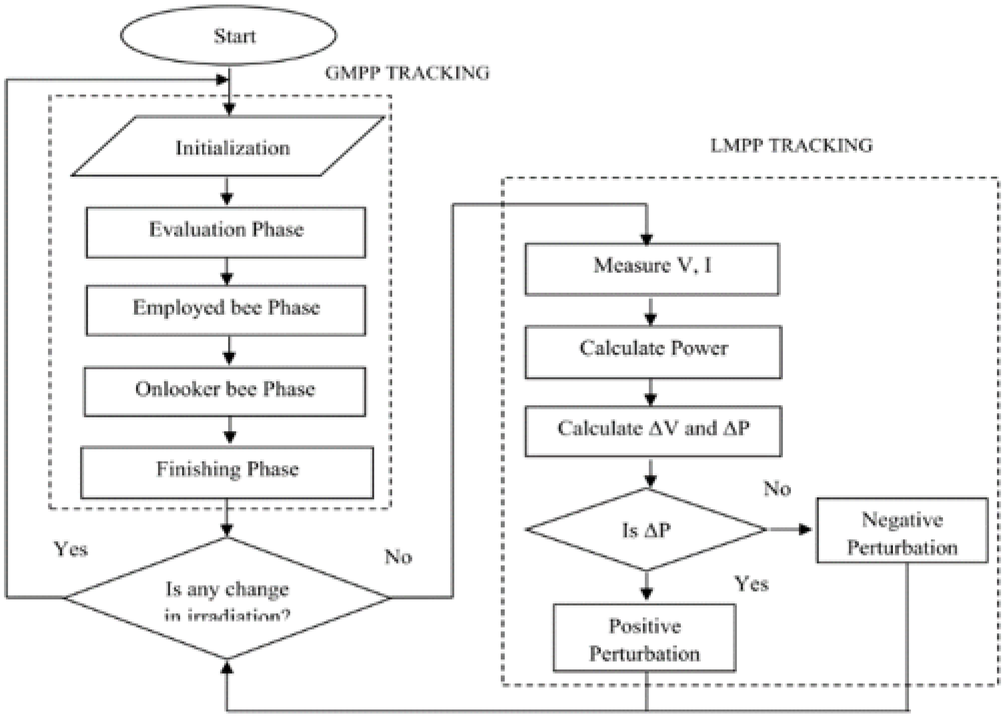

Figure 9- The flowchart of ABC Perturb & Observe Technique

In the **onlooker phase**, the employed bees communicated the output power generated at different events to onlooker bees. By using the probability factor, a peak value is detected. The entire procedure ends if the PV system output is not improved further or the MCN number is reached. It is the **finishing phase**. After these steps, the algorithm settled at GMPP. Then, it checks the change in irradiance by calculating the output power. If the output changes, the algorithm starts to locate the present GMPP again. If there is no change in output, the ABC algorithm finds the LMPP. Then the GT of ABC and LT of P&O are combined to provide the GMPP with fast and well-organized tracking under changing irradiance conditions [19, 36]. It has fast MPPT accuracy and gives 99% efficiency for partial shading PV systems.

2.3 PV CELL EQUIVALENT CIRCUIT AND SIMULATION:

To better understand the electronic behaviour of a solar cell, it is necessary to construct an electrically equivalent model based on discrete electrical components with well-known behaviour. A current source in parallel with a diode can represent an ideal solar cell; in actuality, no solar cell is perfect; thus, shunt resistance and a series resistance component are added to the circuit as shown in fig. 10 with some additional components.

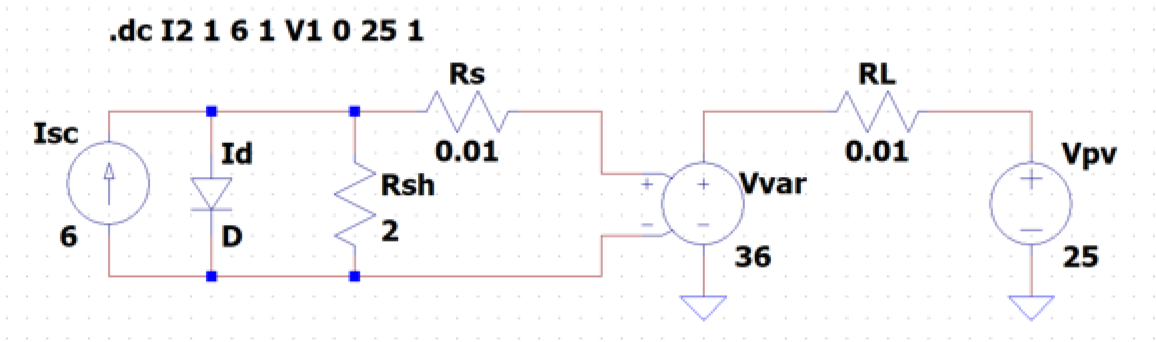

Figure 10-PSpice Equivalent Circuit of a Solar Cell

The series resistor (R_S) shows the resistance due to semiconductors, metal electrodes, and the contact resistance between the semiconductor plates and electrodes. The series resistance is minimal for good solar cells because it drops the output voltage and decreases the maximum output power. The shunt resistor (R_{sh}) is due to the leakage current through the P-N junction. It is as large as possible for good solar cells because it acts as a sink for current and decreases the maximum output power [20].

From the simulation point of view, I have made the equivalent circuit of a solar cell in PSpice and added some extra components to show the results of an equivalent model of a solar panel. The V_{VAR} is the variable voltage source, and it shows the 36 PV cells in series with R_L load resistance. V_{PV} is the PV voltage, and a constant voltage source shows it.

The characteristics equation is given below using Kirchhoff's current law (KCL).

$$IL = Isc - Id - Ish \qquad (4)$$

By the Shockley diode equation, the current through the diode is:

$$Id = Io\ (\exp\left(\frac{qVpv + ILRs}{nkT}\right) - 1)$$

By Ohm's law, the current through the shunt resistor is:

$$Ish = \frac{Vpv + ILRs}{Rsh}$$

By substituting **Id** and **Ish** in equation 4, the characteristic equation, which relates solar cell parameters to the output current and voltage, is given below:

$$IL = Isc - Io\ (exp\left(\frac{qVpv + ILRs}{nkT}\right) - 1) - \frac{Vpv + ILRs}{Rsh}$$

- $I_L[A]$: output current

- *I_{SC}[A]:* photogenerated current
- *I_d [A]:* diode current
- *I_{sh}[A]:* shunt current
- *I_L[A]:* output current
- *I_0[A]:* reverse saturation current
- *V_{PV}[V]:* voltage across the output terminals
- *n =* diode ideality factor
- *q[C]:* elementary charge
- *k =* Boltzmann's constant
- *T[°C]:* absolute temperature
- *R_{sh}[Ω]:* shunt resistance
- *R_S[Ω]:* series resistance

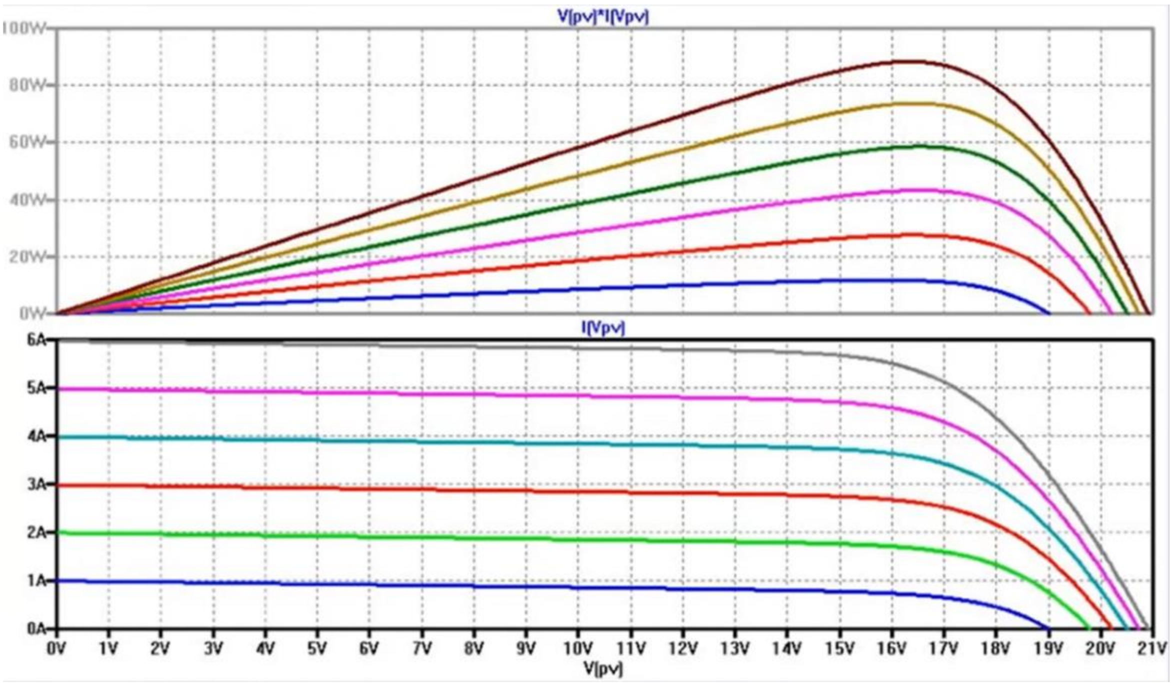

Figure 11- P-V and I-V characteristics of a cell

I get the I-V and P-V characteristics curves for different irradiation by simulating the circuit by changing the current source value from 1 to 6 Amp. By seeing these curves, one can analyse how output power increases with the irradiation increase. The resulting curves are shown in fig. 11.

2.4 Conclusions:

This chapter has successfully explained the fundamental concerns about the topic in the introduction section. We learned what PV arrays are, what is MPPT, why it is necessary for it, and how MPPT is used in PV arrays. Afterwards, we have explained four algorithms for MPPT that can be used for partially shaded conditions. Each algorithm is explained through flowcharts and tables. Then there is a portion for simulation in which we have successfully designed the circuit for a PV cell in PSpice. Simulation results are shown in graphs showing how changes in PV current and voltage affect the system's output power. Power is maximum where both current and voltage are at their max value simultaneously. Our MPPT system will track this point and try to maintain the power around this value.

CHAPTER 3: PROJECT PLAN

The planning of the entire project is presented in this part of the report. The project has been separated into two significant milestones: an interim report and a dissertation. Until now, I have been working on the Interim report, which focuses mainly on the project's goals, objectives, literature review, and a discussion of the project's simulation. I will begin working on circuit design, simulations, and the dissertation. A timetable and Gantt chart are presented in Table 3 and Table 4.

Table 2. Gantt Chart

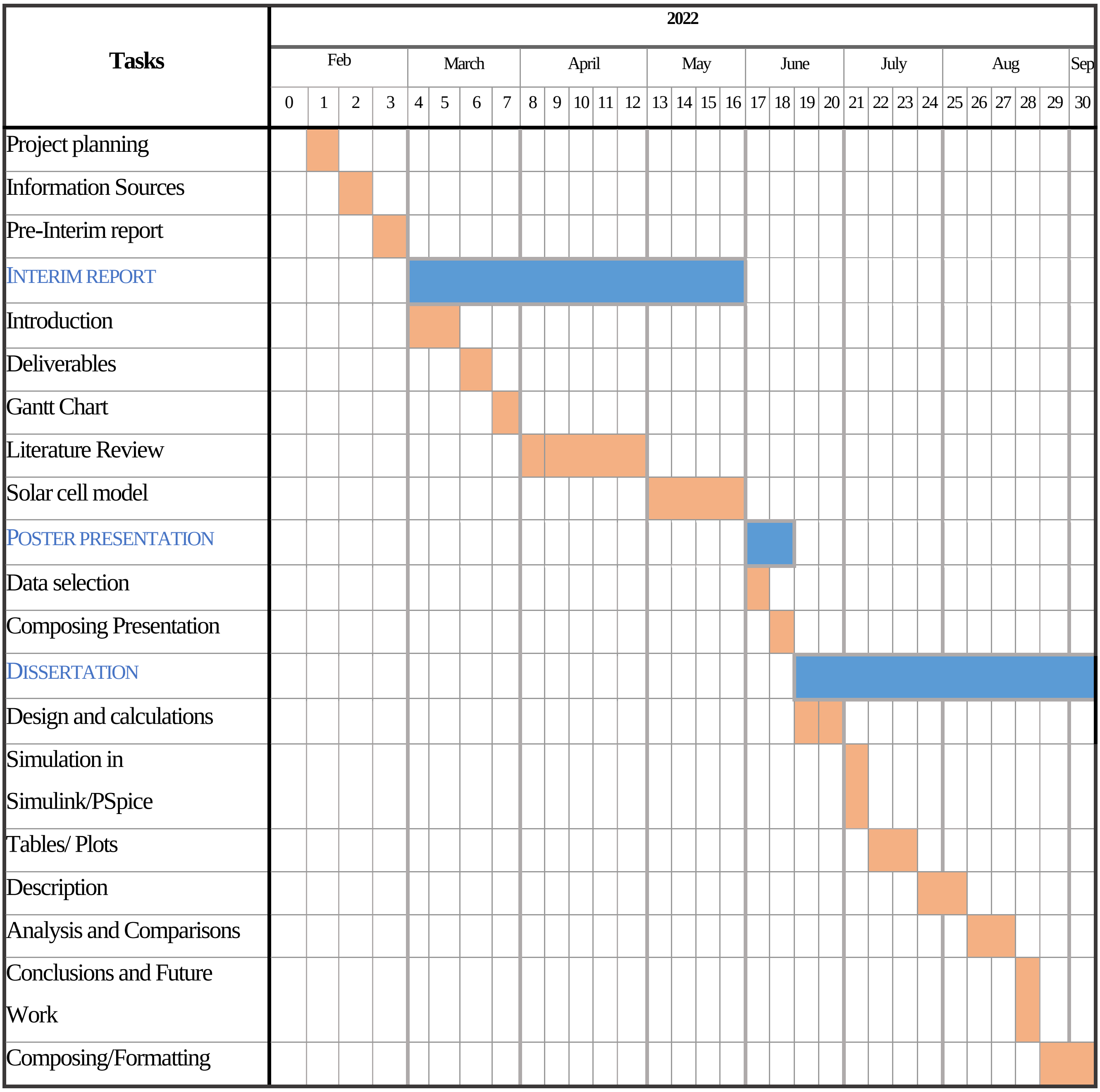

Table 3. Time allocation table for tasks.

Task No.	Task Name	(Week)
1	Project planning and conducting a survey	1
2	Using Information Sources	2
3	Pre-Interim report	3
	Interim report	04 – 18
4	Introduction, Aims and Objectives	04 – 05
5	Deliverables or specific outcomes	06
6	Gantt Chart	07
7	Literature Review	08 – 12
8	Solar cell model	12 – 16
	Poster presentation	17 – 18
9	Data selection	17
10	Composing the presentation	18
	Dissertation	19 – 30
11	Design and calculations	19 –20
12	Simulation in Simulink/PSpice	21
13	Tables and Plots	22 – 23
14	Description of information	24 – 25
15	Analysis and Comparisons	26 – 27
16	Conclusions and Future Work	28
17	Composing/Formatting's	29 – 30

CHAPTER 4: SIMULATIONS AND RESULTS

4.1 INTRODUCTION:

In this chapter, the IC technique is used as the MPPT controller to extract the maximum power from the PV panel. The discussion will be on the characteristics of PV panel, circuit design in the Simulink and the power efficiency of the PV panel with and without MPPT across the load of 50ohms in partial shaded conditions.

4.2 CIRCUIT CHARACTERISTICS AND ASSUMPTIONS:

Table. 5 shows the characteristics of the PV panel that we have used in our circuit for simulation. The circuit is being designed to meet the closest power rating of the panel.

Table 4. Electrical characteristics of PV panel

Parameters (1000M/m^2, 25^{O}C)	**Values**
Module Type	250M-60
Maximum Power (Pmax)	250W
Maximum power voltage (Vmp)	30.7 V
Maximum Power current (Imp)	8.15 A
Open Circuit Voltage (VoC)	37.3 V
Short Circuit Current (Isc)	8.66 A

The simulation time of all the graphs is 1 second except the general simulations like shown in Figure 11**.** We have simulated our PV panel before final simulation for P-V and I-V curves.

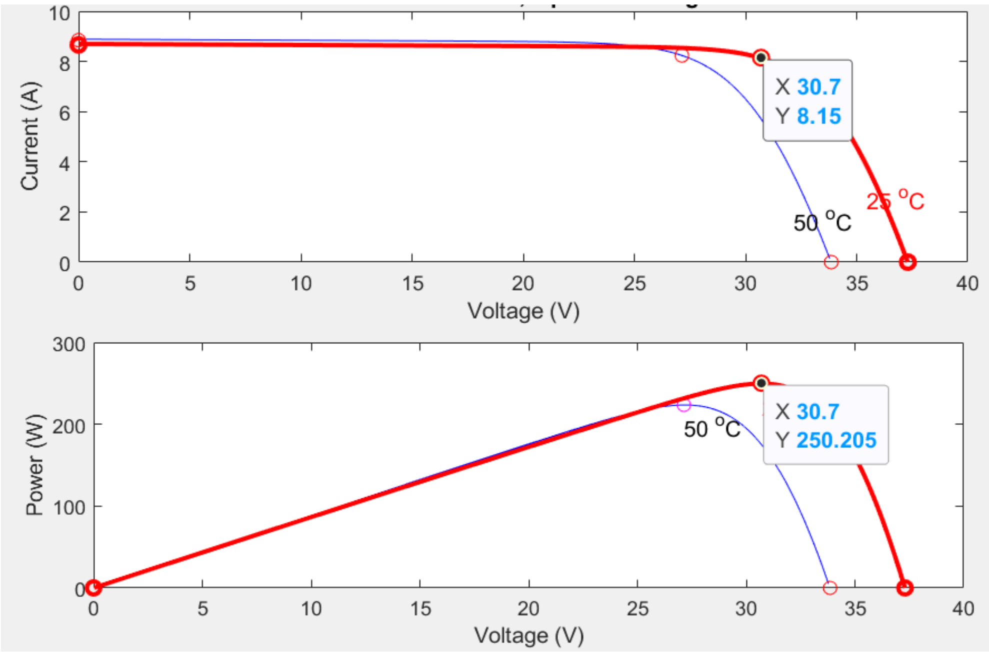

Figure 11. PV and IV curves of PV panel.

These curves are important towards showing and depicting the results that are discussed in the coming part of this report. These curves are also important in giving idea about the behaviour of panel under different values of temperature.

4.3 CIRCUIT AND SIMULATIONS:

Figure. 2 shows the circuit for IC MPPT technique with boost converter in MATLAB. The technique is implemented in the MATLAB block and independently connected with the converter. The solar irradiation and temperature are the inputs of the PV panel and voltage, and current are taken as output from it. The MATLAB block gets the voltage and current as input from the PV panel and uses them to returns the duty cycle (in terms of a PWM waveform) by applying the incremental conductance technique. This PWM is applied to control the switching of boost converter. The PWM generator provides a

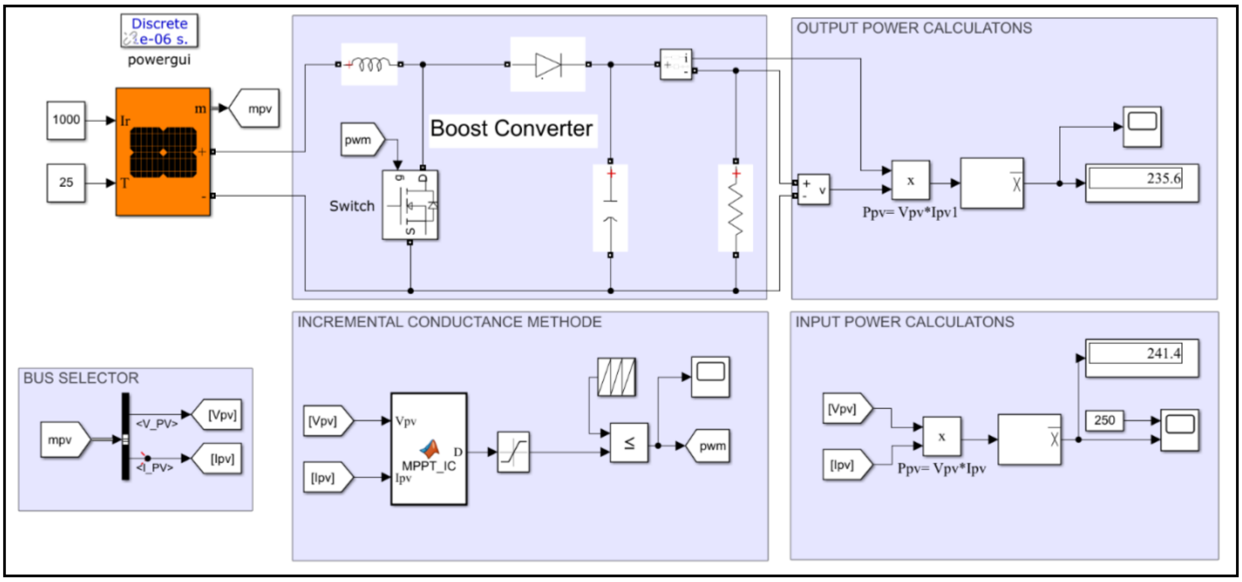

Figure 12. Circuit in MATLAB.

triangular waveform for the pulse width modulation [23]. The boost converter uses the duty cycle and delivers the power to the load, accordingly.

The converter is used to match the source and load impedance. When we decrease the duty cycle of PWM waveform below 50 percent, the converter shows a high resistance to source and decreases the current and does the opposite when duty cycle is increased above 50 percent. The average input and output voltages can be determined by the given equation.

$$\frac{V_{out}}{V_{in}} = \frac{1}{(1-D)}$$

Vin and Vout are the respective input and output voltages of the boost converter and D is the duty cycle of PWM signal. The value of capacitor and inductor can be calculated by the given equations [24].

$$C = \frac{D}{Rf\left(\frac{\Delta V_o}{V_o}\right)}$$

$$L = \frac{DR(1-D)^2}{2f}$$

4.3.1 WITHOUT MPPT:

- **AT NORMAL CONDITIONS**

  At normal conditions, the performance of PV panel is not good. It is not much efficient with respect to power and stability. Below is the figure showing power curve of PV panel without MPPT. The output power of the PV panel is 27.35W without MPPT across the

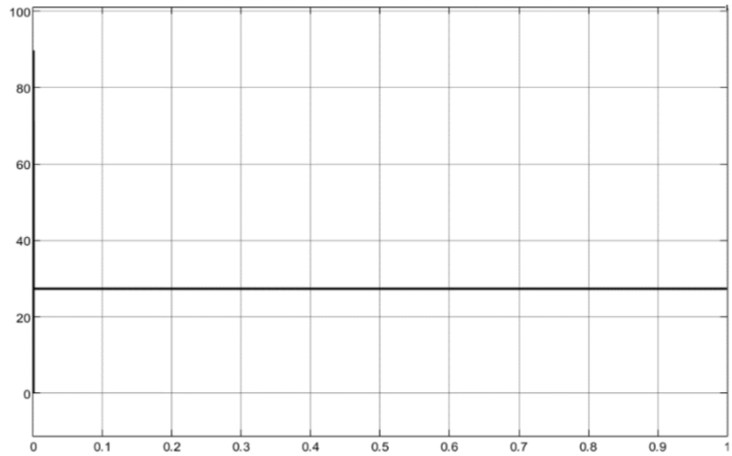

Figure 13. PV output power without MPPT at normal conditions.

  load of 50 Ohms.

- **AT PARTIALLY SHADED CONDITIONS**

The performance is little worse at partially shaded conditions. It provides even less power than in normal conditions at the output because of less irradiance falling on the panel. The output power of the PV panel is 25.57W without MPPT across the load of 50 Ohms.

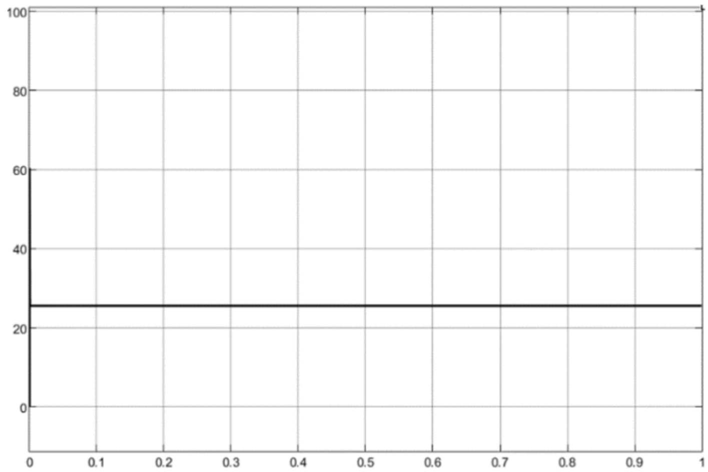

Figure 14. PV output power without MPPT in Partially shaded conditions.

4.3.2 WITH MPPT:

- **AT NORMAL CONDITIONS**

  The output power of the PV panel is 241W with MPPT across the load of 50ohms with a settling time of 0.17s. Figure. 15 showes the PV output power with MPPT at Normal conditions:

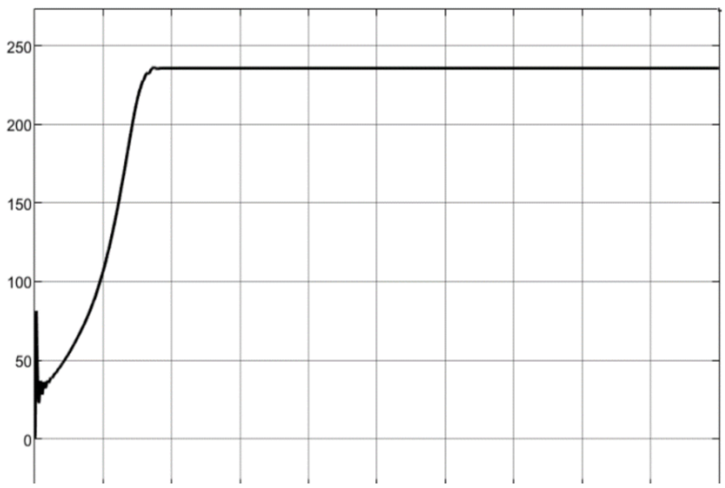

Figure 15. PV output power with MPPT at Normal conditions.

- **AT PARTIALLY SHADED CONDITIONS**

The output power of the PV panel is 119.3W with MPPT across the load of 50ohms with a settling time of 0.165s. Figure. 16 showes the PV output power with MPPT under shaded conditions.:

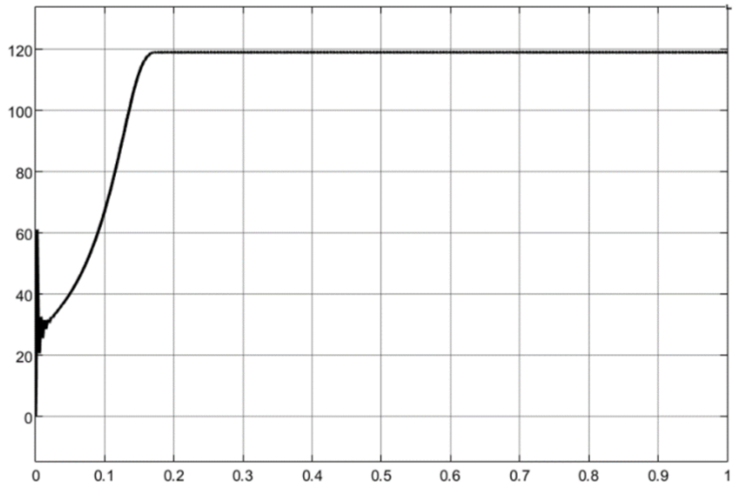

Figure 16. PV output power with MPPT under shaded conditions.

4.4 Results and Discussion:

In the table below, it is clearly mentioned that the circuit is 97% efficient with MPPT.

Table 5. Results of PV panel at 1000 & 500 W/m^2.

Weather Conditions	Measurements	Without MPPT	With MPPT
Fixed irradiance	Power (W)	27.35	241.4
	Maximum power voltage (Vmp) (V)	36.98	32.21
1000W/m^2, 25^{O}C	Maximum Power current (Imp) (A)	0.740	7.495
	Power Efficiency	11%	97%
Partial shading	Power (W)	25.57	119.3
	Maximum power voltage (Vmp) (V)	35.75	32.02
500W/m^2, 25^{O}C	Maximum Power current (Imp) (A)	0.715	3.728
	Power Efficiency	21%	95%

4.5 CONCLUSION:

According to the simulation, it is clear that MPPT technique can extract maximum power under shaded conditions. The oscillations increase with the decrease in irradiance but settling time decreases. Under normal circumstances, it can give more than 97% efficiency with settling time of 0.17 seconds.

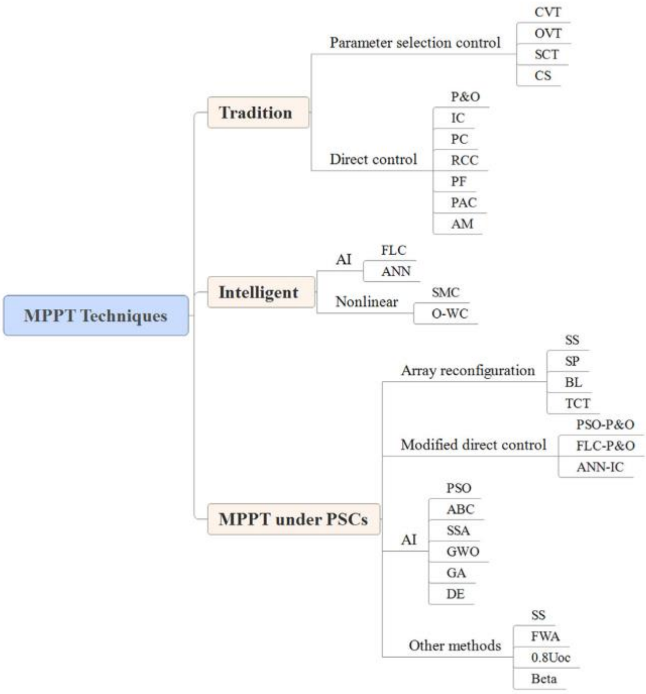

Figure 12. Simplified classification of some standard MPPT control methods [6]

Table 7. Performance comparison of some MPPT methods for PV system [6]

Category		MPPT	MPPT performance indicator					
			Complexity	Tracking speed	Cost	Efficiency	Accuracy	Hardware implementation
MPPT methods under PSCs	Array reconfiguration methods	SS, SP, BL, TCT, etc.	High	Slow	High	<90%	Medium-low	Difficult
	Improve direct control methods	ABC-P&O, ACO-P&O, PSO-CI, etc.	High	Fast	High	>99%	High	Difficult
	Artificial intelligence methods	PSO	Medium-high	Fast	High	>98%	High	Medium
		ACO	Medium-high	Fast	High	>98.5%	High	Medium
		ABC	Medium-high	Fast	High	>99%	High	Medium
		FA	Medium-high	Fast	High	>98.5%	High	Medium
		SSA	Medium	Fast	High	>99%	High	Medium
		GA	Medium-high	Fast	High	>98%	Medium-high	Easy
		DE	Medium	Fast	High	>98%	Medium-high	Easy
	Other methods	SS, RS, FLS, FWA, etc.	Medium-high	Fast	High	>98%	Medium-high	Medium
		Bate method	Medium	Fast	High	>98%	High	Easy
		0.8Uoc	Medium-low	Medium	Medium	<90%	Medium-low	Easy

CODE:

Table 6. Performance comparison of some MPPT methods under PSCs [6].

Category		MPPT	MPPT performance indicators						
			Complexity	Tracking speed	Cost	Efficiency	Accuracy	Preference with PSC	Hardware implementation
Traditional MPPT technology	Control methods based on parameter selection	CVT	Low	Medium	Low	<90%	Low	Unable	Easy
		OVT	Low	Medium	Low	<90%	Low	Unable	Easy
		SCT	Low	Medium	Low	<90%	Low	Unable	Easy
		CS	Low	Slow	Medium	<90%	Low	Unable	Easy
	Direct control methods based on sampled data	P&O	Medium-low	Medium	Medium	>95%	Medium	Unable	Easy
		IC	Medium	Medium	Medium	>97%	Medium-high	Unable	Easy
		PC	Medium-high	Medium	High	>97%	Medium-high	Unable	Difficult
		RCC	Medium	Medium	Medium	>97%	Medium	Unable	Easy
		PAC	High	Slow	High	<90%	Medium-low	Unable	Difficult
		AM	Medium	Slow	High	<90%	Medium	Unable	Difficult
		PF	Medium-low	Slow	Medium	>90%	Medium-low	Unable	Easy
The MPPT method based on intelligent control	AI control methods	FLC	Medium-high	Fast	High	>98%	Medium-high	Able	Medium
		NN	High	Fast	High	>98%	Medium-high	Able	Difficult
	Nonlinear control methods	SMC	Medium	Fast	High	>98%	Medium-high	Able	Medium

```
function D = MPPT_IC(Vpv,Ipv)

del=0.00001;
do=0;
dmin=0;
dmax=1;

persistent Vold Dold Iold;

if isempty(Vold)
    Vold=0;
    Iold=0;
    Dold=do;
end
dv=Vpv- Vold;
di=Ipv- Iold;

if dv == 0
    if di== 0
        D= Dold;
    else
        if di > 0
            D = Dold - del;
        else
            D = Dold+del;
        end
    end
else
    if di/dv == -(Ipv/Vpv)
        D=Dold;

    else
        if di/dv > -(Ipv/Vpv)
            D=Dold-del;
        else
            D=Dold+del;
        end
```

```
    end
end

% if D >dmax || D <= dmin
%     D=Dold;
% end

% data store
Dold=D;
Vold=Vpv;
Iold=Ipv;

end
```

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