STUDY OF ADVANCED MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUES FOR PHOTOVOLTAIC SYSTEMS

Thesis submitted to Jadavpur University, Kolkata

towards the fulfilment of the requirements for the

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IN

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Thesis submitted
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Dedicated to

To my Parents and The Department of Electrical Engineering and Faculty council of Engineering & Technology, Jadavpur University, for all the knowledge and wisdom imparted to me in this period and for preparing me for my life ahead.

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Certificate of Approval

The forgoing thesis, entitled as **"Study of Advanced Maximum Power Point Tracking(MPPT) Techniques For Photovoltaic Systems"** is hereby approved by the committee of final examination for evaluation of thesis as a creditable study of an engineering subject carried out and presented by **Mr. Pranab Sur** (Examination Roll No.: M4ELE19003) , Registration No 140657 of 2017-18) in a manner satisfactory to warrant it's acceptance as a perquisite to the degree of **Master of Electrical Engineering.** It is understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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Certificate of Recommendation

This is to certify that Mr. Pranab Sur (Examination Roll No. M4ELE19003) has completed his dissertation entitled, **"Study of Advanced Maximum Power Point (MPPT) Techniques For Photovoltaic System"**, under the direct supervision and guidance of Dr**. Suparna Kar Chowdhury,** Professor, Electrical Engineering Department, Jadavpur University and **Prof. Dipten Maiti,** Assistant Professor, Electrical Engineering Department, Jadavpur University and Dr**. Arindam Kumar Sil**, Assistant Professor, Electrical Engineering Department, Jadavpur University. We are satisfied with his work, which is being presented for the partial fulfilment of the degree of Master of Electrical Engineering (Machine) of Jadavpur University, Kolkata-700032.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

It is hereby declared that the thesis entitled **"STUDY OF ADVANCED MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUES IN PHOTOVOLTAIC SYSTEMS"** contains literature survey and original research work by the undersigned candidate, as part of his degree in Master of Electrical Engineering.

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It is also declared that all the materials and results, not original to this work have been fully cited and referred throughout this thesis, according to rules of ethical conduct.

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ABSTRACT

The conventional MPPT methods like Perturbation & Observation, Incremental Conductance, Hill Climbing can track the maximum power point (MPP) in photovoltaic systems in stable environmental conditions only. The performances of these methods are not satisfactory when temperature and insolation varies rapidly.

Modified Adaptive Hill Climbing Method (MAHC)and β method can track the MPP under varying atmospheric conditions also.

Simulations of the techniques were done in the MATLAB environment. The performances of the said techniques under variable environmental conditions are studied in the thesis.

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CHAPTER-3: DIFFERENT TYPES OF SOLAR CELLS:

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CHAPTER-1: INTRODUCTION

1.1 Objective:

Conventional energy sources (coal, oil, gas) are shrinking day by day. Moreover, pollution produced from the uses of these types of sources is higher. So, the whole world is trying to shift towards various kind of non-conventional energy sources like solar, wind etc. Solar energy is one of the major renewable energy sources with the potential to meet many of the challenges faced by the world.

The **International Solar Alliance (ISA)** is an alliance of more than 122 countries is initiated by India. The headquarter is situated in Gwal Pahari, Gurugram, India. The primary objective of the alliance is to work for efficient exploitation of solar energy to reduce dependence on fossil fuels.

Photovoltaic (PV) power generation has a crucial role to play due to the fact that it is a green source and can be installed anywhere.

The efficiency of a PV generation system depends mainly on three factors:

i) The efficiency of the PV panel (in commercial PV panels it is between 9-15%),

ii) the efficiency of the converter (96-97%) and

iii) the efficiency of the maximum power point tracking (MPPT)algorithm (which is above 98%).

Improvement of the efficiency of the PV panel and the inverter is not easy. It depends on the electronic components used and technology available. Instead, improving the efficiency of MPPT with new control algorithms are easier, it is not expensive and can be employed even in installed plants which are already being used. This would lead to an immediate improvement in PV power generation.

The algorithms are necessary because PV arrays have a nonlinear I-V characteristic with a certain point where the power produced is maximum. This point depends on the ambient temperature and on the irradiance. Both temperature and irradiance change during the day time and also change depending on the season of the year. Besides, irradiation may change rapidly due to changing atmospheric conditions such as clouds.

It is important to track the maximum power point accurately under all possible conditions so that the maximum power is always obtained. In the recent years a number of MPPT algorithms have been reported. European Standard EN 50530 published in May, 2010, specifies the methods for testing the efficiency of MPPT both statically and dynamically.

The objective of this thesis is primarily to review different MPPT algorithms. According to the standard mentioned, the popular and simple method, *perturb and observe* (P&O), *incremental conductance* (InCond) are studied. After that two advanced method namely, β method and Modified adaptive hill climbing method are analysed and simulated in MATLAB.

1.2 THESIS STRUCTURE:

- **ANALYSIS OF I-V & P-V CHARACTERISTICS OF SOLAR PANEL:**

Before the discussion on any kind of MPPT algorithm the P-V characteristics of solar panel must be analysed in details. Because most of the MPPT algorithms proposed so far are based on the nature of solar P-V characteristic. The P-V curve can be divided in two portions i.e. two sides of MPPT point. One side has positive slope and other has negative slope.

- **ANALYSIS OF ADVANCED MPPT ALGORITHMS:**

Research interest in MPPT algorithms for PV panels has grown significantly over the past few years across the world. As awareness of solar power uses is increasing in various section of our life, it is desirable to extract maximum amount of power from PV panel. Although the efficiency of solar panel is not very high, research is going on this section too. In this thesis the main objective will be discussion, analysis and simulation of some MPPT algorithms. A good MPPT algorithm is that which responds on rapidly varying atmospheric condition and track the MPP as fast as possible. In this thesis the response of the **β method** and **MAHC method** with the steady and dynamic conditions are described.

1.3 LITERATURE SURVEY:

In the rapid changing environmental condition, the conventional methods like perturbation & observation [1],[2] and Incremental conductance [2]do not work satisfactorily.

Considering this drawback two fast and robust methods named **β method** proposed by S. Jain & V. Agarwal [12] **and MAHC method** proposed by W. Xiao & W.G. Dunford [14] are discussed. First method is **β method** in which an intermediate variable β is considered. β is taken as a variable which depends on temperature but independent of radiation.

β = ln(I(k)/V(k)- C*V(k)

Another method named **Modified Adaptive Hill climbing method** can be considered as an extension of hill climbing method. It works well in steady as well as dynamic condition. Automatic parameter tuning i.e. a tuning parameter 'a' is considered to make a difference between dynamic response and steady state response.

$$a(k) = M\frac{|\Delta P|}{a(k-1)}$$

Where $\Delta P = P(k) - P(k-1)$ it is entitled as the change of power

And a(k-1) is the previous value of a(k)

And M is a constant parameter

CHAPTER-2: THEORY OF SOLAR CELL:

2.1 PRINCIPLE OF OPERATION:

Solar cells are the basic units of photovoltaic panels. Usually Silicon is used to make solar cell. There exist other materials but they are costly, and therefore economically not so viable. Solar cells work on photoelectric effect. Extrinsic semiconductors are capable of transforming electromagnetic radiation directly into electrical energy. A solar cell is a p-n junction which is constructed by two separate layers of silicon doped with required quantity of impurity atoms: n layer is constructed usually with atoms of valency 5 called donor atoms and p layer is usually constructed with atoms of valency 3 called acceptor atoms.

Finally, it can be concluded that solar cell or photovoltaic cell convert the energy of electromagnetic domain to electrical domain.

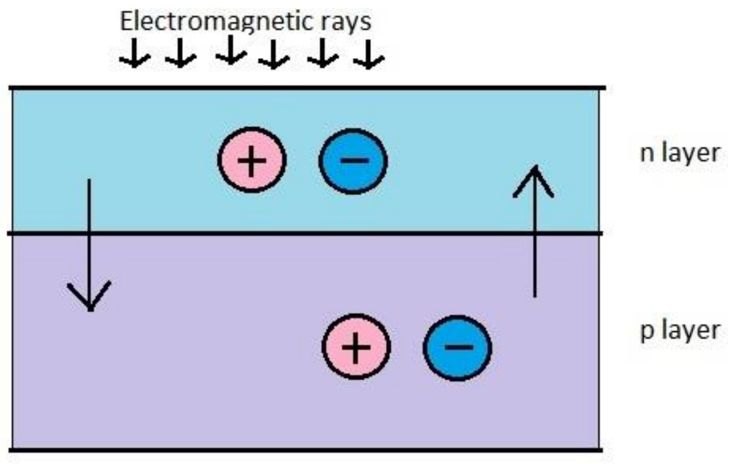

Fig 2.1: Solar Cell

2.2 EQUIVALENT CIRCUIT OF SOLAR CELL:

The equivalent circuit as shown in Fig 2.2 consists of a current source I_{ph}, Diode current I_D, Shunt resistance R_{sh}, series resistance R_s. The magnitudes of the parameters like I_L, I_0, R_S, and R_{SH} are dependent upon the physical size of the solar cell.

By comparison of identical cells, a cell with the junction area of double size of another will have twice the I_L and I_0 because it is of twice the area where photocurrent is generated and across which diode current can flow.

An ideal solar cell can be shown merely by a current source parallel with a diode. But practically there are some non-idealities. So, a high value shunt resistance and a low value series resistance are added with the ideal one.

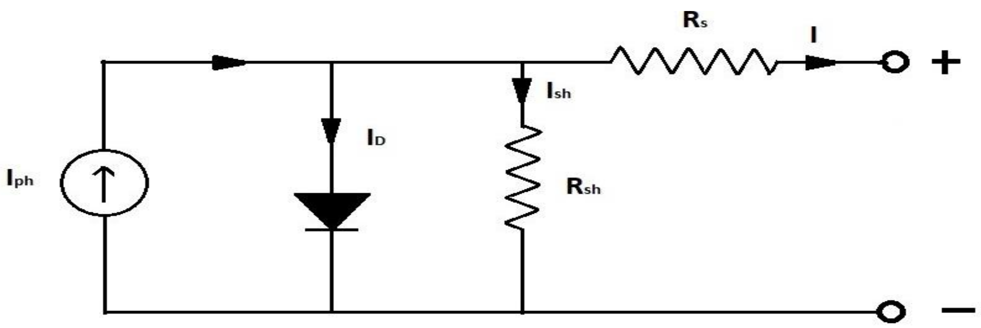

Fig-2.2: Equivalent circuit of solar cell

2.3 CHARACTERISTIC EQUATIONS OF SOLAR CELL:

The equivalent circuit shown in Fig 2.2 is characterised by equations given below:

Reverse saturation current, $I_{rs} = \frac{I_{sc}}{e^{\left(\frac{q \times V_{OC}}{n \times N_S \times K \times T}\right)} - 1}$ 2.1

Photo current, $I_{ph} = [I_{sc} + k_i.(T - 298)].\frac{G}{1000}$ 2.2

Saturation current, $I_o = I_{rs} * \left(\frac{T}{T_n}\right)^3 \times e^{\left[\frac{q.E_{go}.\left(\frac{1}{T_n} - \frac{1}{T}\right)}{n * k}\right]}$ ...2.3

Current through shunt resistor, $I_{sh} = \frac{(V + I.R_S)}{R_{sh}}$ 2.4

Output Current, $I = I_{Ph} - I_D = I_{Ph} - I_0\left[e^{\left(\frac{q(v + IR_S)}{mkT_C}\right)} - 1\right] - I_{sh}$ 2.5

Symbols	Description	Value
I_{ph}	Photo Current(A)	I_{ph}
I_{sc}	Short circuit current(A)	I_{sc}
k_i	Short circuit of cell at 25^0c and 1000 W/m^2	0.0032
T	Absolute temperature	T
T_n	Nominal temperature	T_n
G	Solar Irradiation (W/m^2)	G
q	Electronic charge	1.6×10^{-19}
V_{oc}	Open circuit voltage (V)	V_{oc}
n	The ideality factor of diode	1.3
K	Boltzmann's constant (J/K)	1.38×10^{-23}
E_{go}	Forbidden Band gap energy	1.1
N_s	Number of cells connected in series	N_s
N_p	Number of PV module connected in parallel	N_p
R_s	Series resistance	0.221
R_{sh}	Shunt resistance	415.405
V_t	Diode Thermal Voltage	V_t

2.4 I-V & P-V CHARACTERISTICS OF PV CELL:

From the above equations (2.1 to 2.5), the non-linear characteristics of PV cells can be plotted. The I-V characteristic is given in Fig 2.3 and P-V characteristic is given in Fig 2.4.

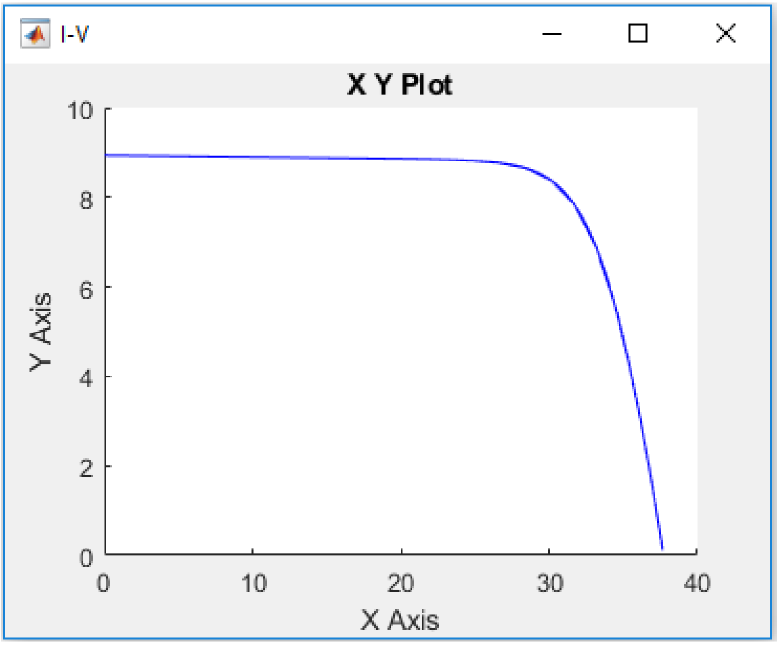

Fig-2.3 I-V characteristics of solar cell.

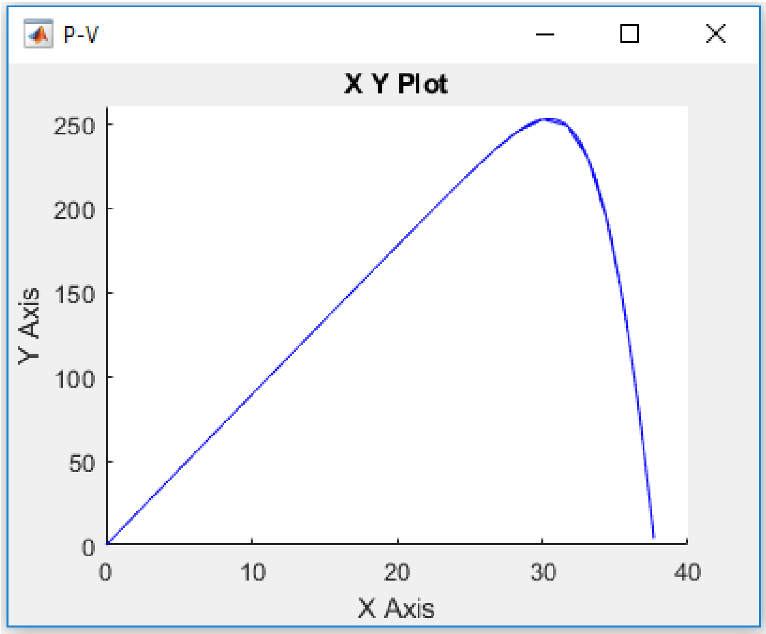

Fig-2.4 P-V characteristics of solar cell

2.5 OPEN CIRCUIT VOLTAGE (V_{OC}):

The terminal voltage of the cell when no current passing is called the open circuit voltage.

V (at I=0) = V_{oc}……………………….………………..…..2.6

V_{OC} is also the maximum voltage across the cell. Assuming the shunt resistance is large enough the open circuit voltage equation can be written as follows

$V_{OC} \approx nV_T \ln(\frac{Ip+Io}{Io})$ where V_T=KT/q…………………………2.7

2.6 SHORT CIRCUIT CURRENT (I_{SC}):

The current flowing through the terminal when cell is short circuited is called short circuit current I_{SC}, at this condition the impedance is low.

I (at V=0) = I_{SC}……………………………..………………2.8

I_{SC} is the maximum current that can be supplied by the cell. For an ideal cell, this maximum current is the total current produced in the solar cell by photon excitation.

2.7 MAXIMUM POWER POINT:

The volt-ampere characteristics of a solar cell is non-linear. The point at which the product of VI is maximum is called the maximum power point. The power produced by the cell in Watts can be calculated by the equation P=VI along the V-I curve. At the extreme points i.e. at I_{SC} and V_{OC} points, the power will be zero and the power will be maximum in-between. The voltage and current at this maximum power point are denoted as V_{MP} and I_{MP} respectively.

2.8 FILL FACTOR:

The Fill Factor (FF) is essentially a measure of quality of the solar cell. The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell.

The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}. Graphically, the FF is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the IV curve. The typical fill factor for commercial cells 0.6 to 0.8. The FF is illustrated below.

$$FF = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{mp}} \qquad \text{……………………………………………………..2.9}$$

2.9 EFFECTS OF TEMPERATURE AND IRRADIANCE ON SOLAR PANEL:

The overall performance of solar cell varies as the Irradiance and Temperature varies. So, the two major factors that have to be taken into consideration are the irradiation and the temperature.

Irradiance is defined as the measure of the density of power of sunlight received at certain location on the earth and is measured in watt per metre square. For these reasons, the MPP is different at the different time of a day and different seasons also. So, the MPP must constantly be tracked and make ensure that the maximum available power is obtained from the solar panel.

The effect of the irradiance on the voltage-current (V-I) and voltage-power (V-P) characteristics is shown in Figure 2.6, where the characteristics curves are shown in per unit, i.e. the voltage and current are normalized using the V_{OC} and the I_{SC} respectively.

The photo-generated current is directly proportional to the irradiance level, so any change in the irradiation level leads to a change photocurrent.

$I_{sc} \approx I_p \propto$ Insolation……………………………………….….2.10

So, the short circuit current is directly proportional to the photocurrent; therefore, it is directly proportional to the irradiance. As a result, when the irradiance level changes, the voltage-current characteristic varies.

The variation of current with solar irradiance is logarithmic. So, the effect on the open circuit voltage is relatively small. The Fig 2.5 and 2.6 represents I-V and P-V curves at constant temperature (25°C) for three different insolation values. Curve shows that the change in the current is greater than in the voltage for all practical purpose the variation of voltage on the irradiation is often neglected. As the irradiance effect on both the current and voltage is positive, when irradiance increases, the effect on the power is also positive. So, the more irradiation, the more power is generated.

It is known that the short circuit current is nearly proportional to photo-current and photo-current is also proportional to insolation level i.e. irradiance level. When temperature increases then the short circuit current (I_{SC})increases because at higher temperature the band gap energy is reduced so more free electrons jump to the conduction band.

This increment value is nearly 0.1%/K for silicon. Open circuit voltage Voc will decrease with the increase in temperature. This decrement is nearly -2.12mV/K. So, it can be concluded that Voc has negative temperature co-efficient. As, the current co-efficient is positive and voltage has negative temperature co-efficient, the temperature effect on power will be negative i.e. as the power increases power decreases.

The temperature and the irradiation depend on the atmospheric conditions, which are variable during the year and even during a single day; they can vary rapidly due to fast changing conditions such as clouds. This causes the MPP to shift constantly, depending on the irradiation and temperature conditions. If the operating point is not close to the MPP, huge power losses happen.

So, it is essential to track the MPP in such variable conditions to ensure that the maximum power can be obtained from the installed PV panel. Now -a-days in a solar power converter, this maximum power point tracking is entrusted to the MPPT algorithms.

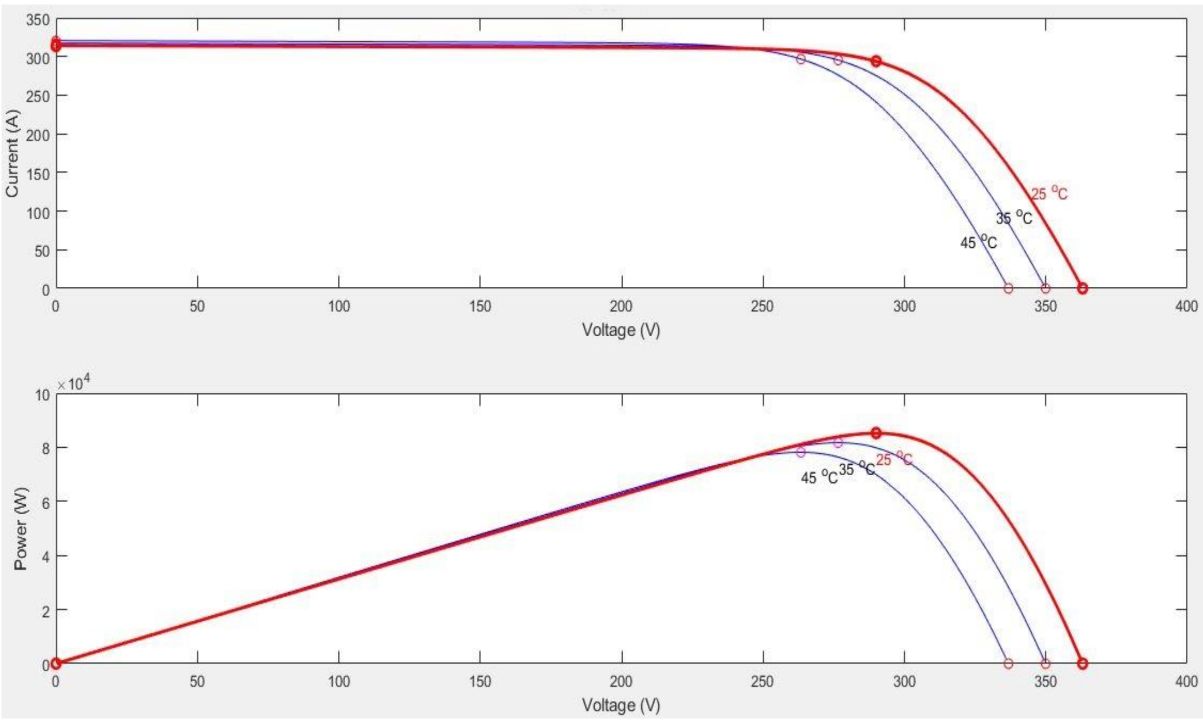

Fig-2.5: Effect on maximum voltage and current by Temperature increment.

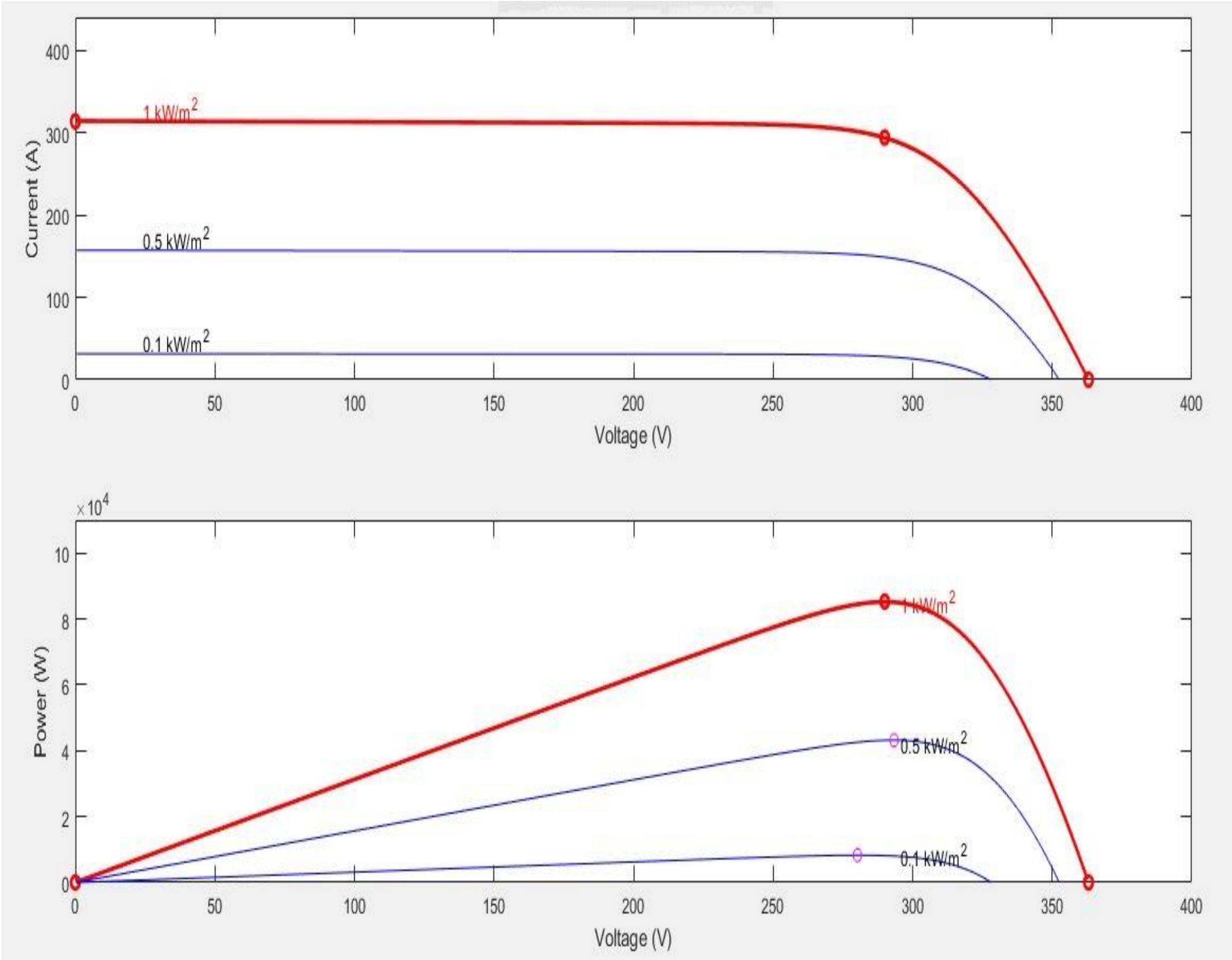

Fig-2.6: Effect on voltage and current by varying irradiance

2.10 CELL CONNECTIONS:

In solar panel solar cells are connected in series -parallel combination. In the following figure two identical cell characteristics are shown when they are connected in series and when they are connected in parallel.

It is seen that if two identical cells are connected in parallel, current will be added but voltage remains same value. On the other hand, if two cells are connected in series, voltage will be added but current will be same valued.

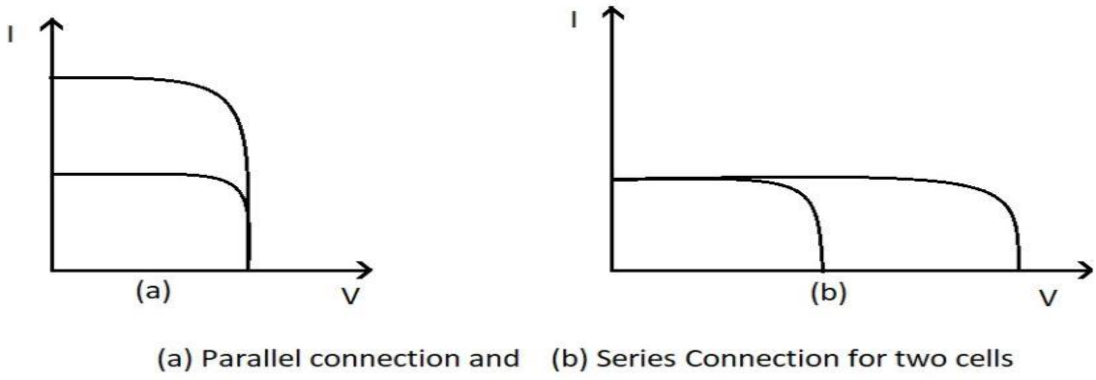

Fig-2.7: Parallel and Series connection of two cells.

2.11 PHOTOVOLTAIC MODULES:

A single solar cell is not able to provide the required useable output. To develop a useful output power level of a PV system, number of such PV solar cells should be connected. Actually a solar module is connected with Npm nos. of solar cells in parallel branches each consist of Nsm nos. of solar cells in series to provide required standard output voltage and power. Range of one PV module can be rated up to 350 watts approx. Practically a single solar cell generates a little amount of power ranges from 0.1 watt to 2 watts.

So, for power system consideration it is not practical to use. Sufficient number of such cells are connected in series-parallel combination to form a commercially available solar unit which is named as solar module or PV module. Like in a battery bank the battery cells are connected, the solar cells are connected in same manner in PV module.

To get desired levels of current and voltage PV modules are made from solar cells connected in various series and parallel combinations. Solar cells should be encapsulated as they have to be weatherproofed and electrical connections also must be robust and corrosion free. The typical construction diagram of a PV module is given in Figure-2.8.

The cells are brittle so, they are generally encapsulated in an airtight layer of polymer like ethylene vinyl acetate (EVA). So, during transport and handling the PV cells are cushioned and in that way are protected. The top cover should be tempered glass treated with an antireflection coating so that the maximum amount of light is transmitted to the cell and minimum reflection is occurred. To protect from moister and prevents them from environmental chemical attack the underneath is a barrier sheet of polyvinyl fluoride (PVF) (it is also known as Tedlar), a synthetic polymer (CH2CHF)n. To mount PV panels and for proper handling, aluminium frame is used. It also gives extra protection for panel. Sometimes, frameless modules are used in facades for aesthetic reasons. At outdoors, to survive the PV modules at least 20 to 25 years under different environmental conditions.

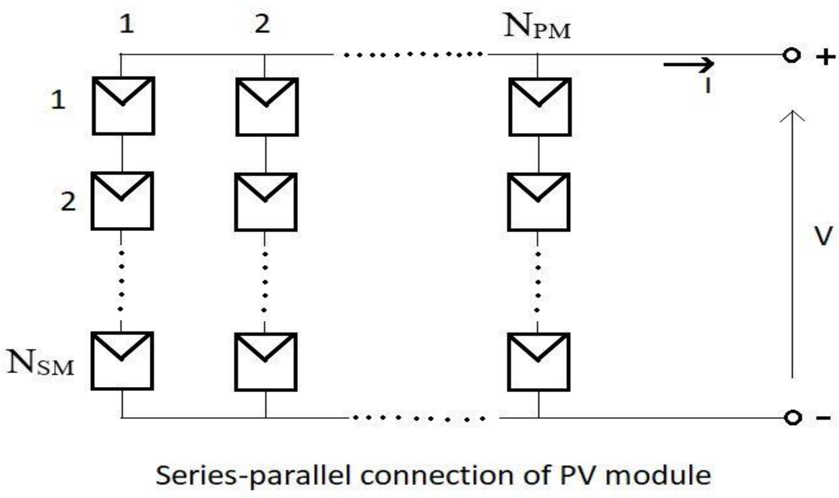

Fig-2.8: series-parallel connection of a PV module

CHAPTER-3: DIFFERENT TYPES OF SOLAR CELLS:

There are various materials available for manufacturing solar cell. But Silicon has been almost the only material used for manufacturing solar cells over the past few decades. Silicon is used in more than the 80% of the production. Silicon is so much popular because it is one of the most abundant materials in the Earth's crust, in the form of silicon dioxide, and itis not toxic.

Two major types of silicon solar cells are Monocrystalline and polycrystalline silicon solar cells. There is another type, amorphous silicon, but the efficiency is worse than with the previous two types so it is comparatively less used. Other new solar cells are made of copper indium gallium (di)selenide solar cell (CIGS), cadmium telluride solar cell (CdTe), amorphous silicon solar cell(a-Si), Dye sensitized solar cell (DSSC), Organic solar cell (OPV). Much research and development (R&D) effort is being done to develop new materials, but now a days there are no commercial substitutes to the above types of solar cells.

Efficiency is an important characteristic of solar cells, which is the percentage of solar radiation transformed into electricity. It is measured under Standard Test Conditions (STC), irradiance of 1000 W/m^2, air mass coefficient (it characterizes the solar spectrum after the solar radiation has travelled through the atmosphere) A.M 1.5, and a cell junction temperature of 25°C. The higher efficiency, the smaller surface is needed for a given power. This is important because in some applications the space is limited and other costs and parameters of the installation depend on the installed PV surface.

3.1 MONOCRYSTALLINE SILICON TYPE:

The one of most efficient type solar cell is Monocrystalline silicon solar cell. These are made from wafers (very thin slices) of single crystals obtained from pure molten silicon. As the structure of the crystal is highly ordered, these single crystal wafers have predictable and uniform properties. However, the manufacturing process occurs at high temperatures, which is expensive. The efficiency of these cells is around 18-20% and the surface needed to get 1 kW in STC is about 7 m2.

3.2 POLYCRYSTALLINE SILICON TYPE:

This type of cells is also made from wafers of pure molten silicon. However, the crystal structure of these type is randomly arranged, as the silicon cools, it crystallizes simultaneously in many different points producing an irregular structure: crystals of random sizes, shapes and orientation.

Efficiency of this panel is lower than the previous type as these structures are not as ideal as in the monocrystalline cells. The efficiency of polycrystalline silicon is lower, around 11-15%. However, the process of manufacturing is less expensive, so the lower efficiency is compensated in some way. The surface needed to obtain 1 kW in STC is about 8m2.

3.3 AMORPHOUS AND THIN-FILM SILICON TYPE:

Amorphous silicon means the non-crystalline form of the silicon and it can be deposited as thin-films onto different substrates. This deposition is generally made at low temperatures.

The manufacturing process is comparatively simple, easy and cheap than in the crystalline cells. But the drawback of these cells is their lower efficiency, around 6-8%. This efficiency can be measured under STC. However, under weaker or diffuse irradiation, such as that in cloudy days, the performance can be higher than in crystalline cells and their temperature co-efficient is smaller.

Despite having low efficiency, the thin film is a competitive and promising technology, because of amorphous silicon is a better light absorber than crystalline. At early days solar cells were of thin-film technology. Since the 1980s they have been used in consumer electronics applications, such as calculators.

Thin film technologies are advantageous because it is easy to manufacture at low temperatures using inexpensive substrates and continuous production methods, avoiding the need for mounting individual wafers and the potential for lightweight and flexible solar cells. However, these advantages are seen to be common to most of the thin-film solar cells, not only that cells made from amorphous silicon.

Now-a-days, one more type of silicon named microcrystalline silicon has been developed. Also, it can be made as thin-films onto different substrates, minimizing the quantities of crystalline silicon needed and improving the efficiency of amorphous silicon. But, the light absorption capacity of microcrystalline silicon compared to amorphous silicon is not so more. By trapping the incident light within the film, a better solution can be obtained. More R&D is required because this type of silicon is not a commercial technology yet.

3.4 OTHER CELLS AND MATERIALS OF SOLAR MODULE:

In case of solar cell, major challenge is to increase the overall efficiency. As was mentioned in the beginning of this chapter, there are other materials apart from silicon that can be utilised for manufacturing solar cells. These compounds are also made of thin film deposited, so the advantages they have same as the silicon thin film solar cells but with a better efficiency.

Among these compounds, CIGS and CdTe already used in commercial solar cells. The efficiency is around 11-14% and it will rise in the coming years as the technologies are improved. It is generally said that thin film technology is one way to achieve the grid parity, i.e. the point at which the comparable cost of generating electricity is equal, or cheaper than grid power. The toxicity of some of the compounds and the shortage of some of the required elements that used in PV panel are main disadvantages of these technologies.

The other compound used in commercial thin film solar cells, in case of CdTe. Though it is not as toxic as its individual components, but in manufacturing process some precautions must be taken.

For space applications Gallium Arsenide (GaAs) has been used mainly for two reasons: One of them, it is comparatively less susceptible to suffer damage from the space radiation than silicon, and another, it has direct bandgap of 1.42 eV, so advantage of a greater part of the solar spectrum can be taken by it. Though it is a more expensive material, space projects can afford it, because for space programme cost is not the most important factor to decide the components. Recently, investigation is going on it to be used in terrestrial PV applications using mirror or lenses (light concentrators) to focus the light upon small cells.

Using flexible substrate flexible modules can easily be made using flexible substrates and they can be used to build integrated PV: roofs, windows, because they can be manufactured in many shapes, sizes. The above-mentioned technologies are non-commercial yet, but it can be expected that in the coming years they will become competitive, low cost and will increase the possibilities of PV power generation. Commercially, the silicon and thin film solar cells described before are the current technologies.

However, the significant matter for this work is that all the different solar cells hinted briefly above have similar non-linear voltage-current and voltage-power characteristics and in similar way they are affected by irradiation and temperature. Only contrasts between them are different levels of sensitivity and efficiencies, so the same algorithms can be utilized to track the MPP for all type of solar cells.

CHAPTER-4: CONVENTIONAL MAXIMUM POWER POINT TRACKING ALGORITHMS

4.1 Maximum Power Point Tracking: As discussed earlier, the maximum power point of any PV panel varies with the variation of the atmospheric conditions (solar irradiance and temperature). There will be one optimum terminal voltage for the PV array to obtain the maximum power out of it.

Use of MPPT algorithms is important because with change in irradiation and temperature MPP of solar panel changes. To maximize the output power from PV panel MPPT algorithm is required. MPPT ensures that maximum power is obtained from the solar panel despite change in operating conditions.

Over the last few decades various methods to find the MPP have been reported. The methods are different in various aspects like sensors, complexity, cost, range of usefulness, speed of convergence, faithful tracking when irradiation and/or temperature change, hardware needed for the implementation, popularity etc. P&O and Incremental conductance method are very popular and easy to use among these algorithms.

But these methods have disadvantages. Most of these algorithms result a local maximum and some provide an approximated MPP like the fractional open circuit voltage or short circuit current. But in general conditions only one maximum exists in the V-P curve However, if irradiation changes rapidly, maximum point is not fixed. if the PV array is partially shaded, there are multiple maxima in these curves. In order to overcome this problem, some fast-tracking algorithms have been implemented in this paper.

4.2 HILL-CLIMBING TECHNIQUES:

Hill climbing principle is the basis of both P&O and InCond algorithms, which consists of moving the operation point of the PV array by a fixed small step in the direction in which power increases. In case of constant irradiation, Hill-climbing methods are one of the simpler and popular MPPT methods due to their good performance and ease of implementation.

The both methods require low computational power and their simple algorithm is well known. The drawbacks are: oscillations around the MPP and during fast changing atmospheric conditions they can track the MPP in the wrong direction.

4.3 PERTURBATION AND OBSERVATION:

"Hill-climbing" method also includes the P&O algorithm, but the uses of both the names depend upon how it is executed. In Hill-climbing method the duty cycle of the power converter is being perturbed. On the other hand, in P&O algorithm the operating voltage of PV panel is used for perturbation. Modifying the voltage between the PV panels and the power converter involves perturbing the duty cycle of power converter.

So, both the hill-climbing and P&O refers to the same approach. In P&O technique, what will be the next step for perturbation depends on the last perturbation and the last increment of the Power and what were their sign.

If the difference between previous power and last power is measured as positive then perturbation should be continued in same direction, on the other hand the difference between previous power and last power measured is measured as negative then the perturbation should be opposite direction.

It is followed from following figure that when perturb point on the left side of MPP, increment of voltage results power increment and when perturb point on the right side of MPP increment of voltage results power decrement.

The algorithm is executed depending on these facts. This perturbation process is continued till the MPP is achieved. It is clear that the operating point swings around the MPP resulting power oscillation also.

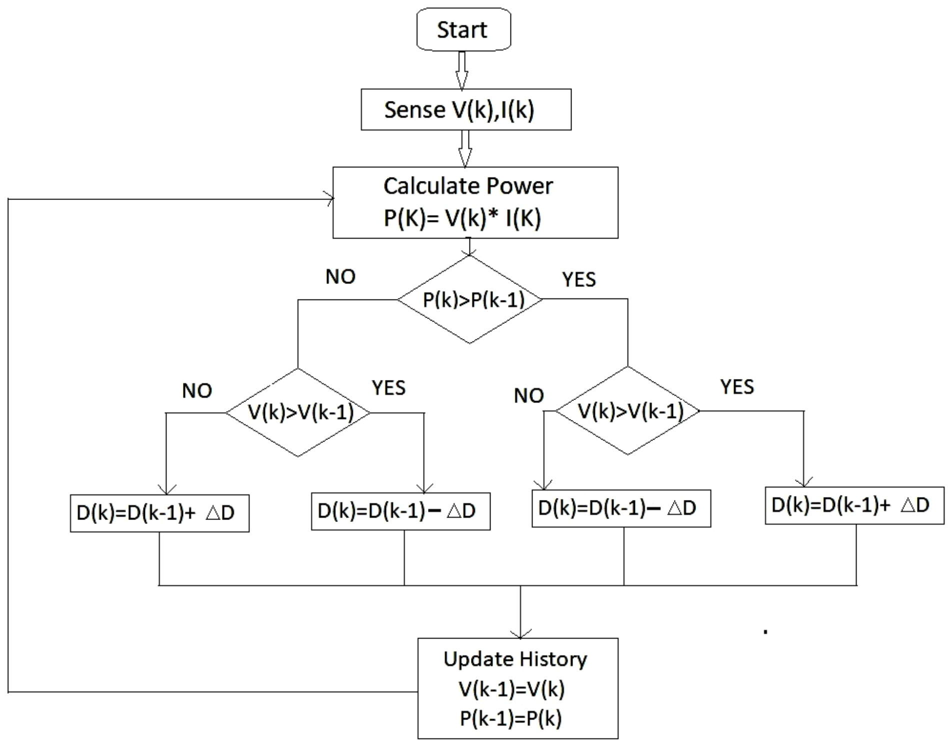

Fig-4.1: Algorithm of P&O method.

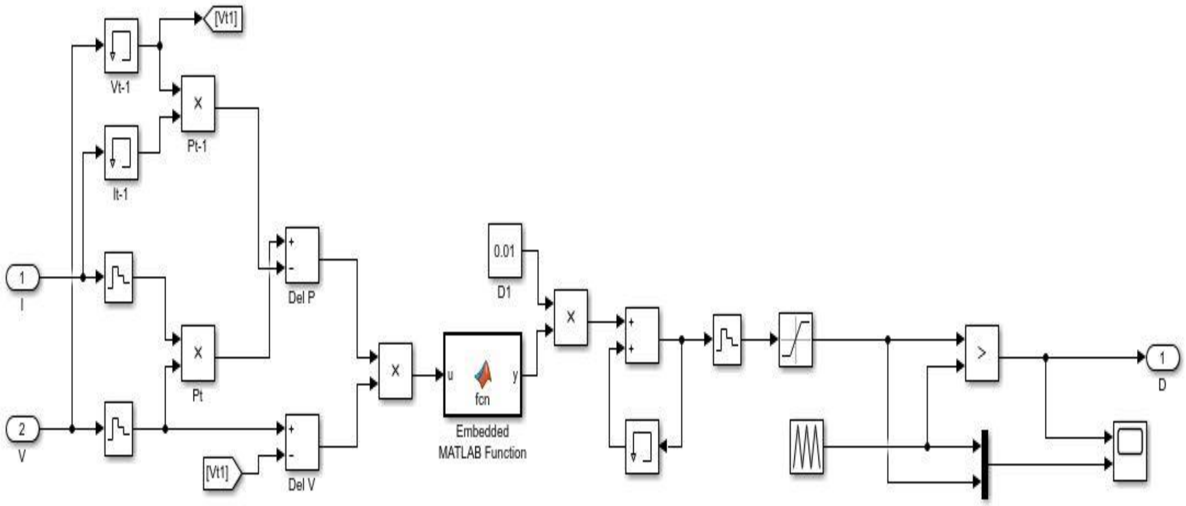

Fig-4.2: Block Diagram of P&O algorithm in Simulink

4.4 Incremental Conductance:

The slope of P-V curve is such that at MPP the slope is zero. Based on this theory the incremental conductance algorithm is framed. As shown in Fig2.4 at left of the MPP slope of the curve is positive and negative on the right side.

$\frac{dv}{dp} = 0$on the MPP

$\frac{dv}{dp} > 0$at the left

$\frac{dv}{dp} < 0$at the right

The change in the MPP can be detected by comparing the change in the voltage vs. the change of the power between two consecutives readings.

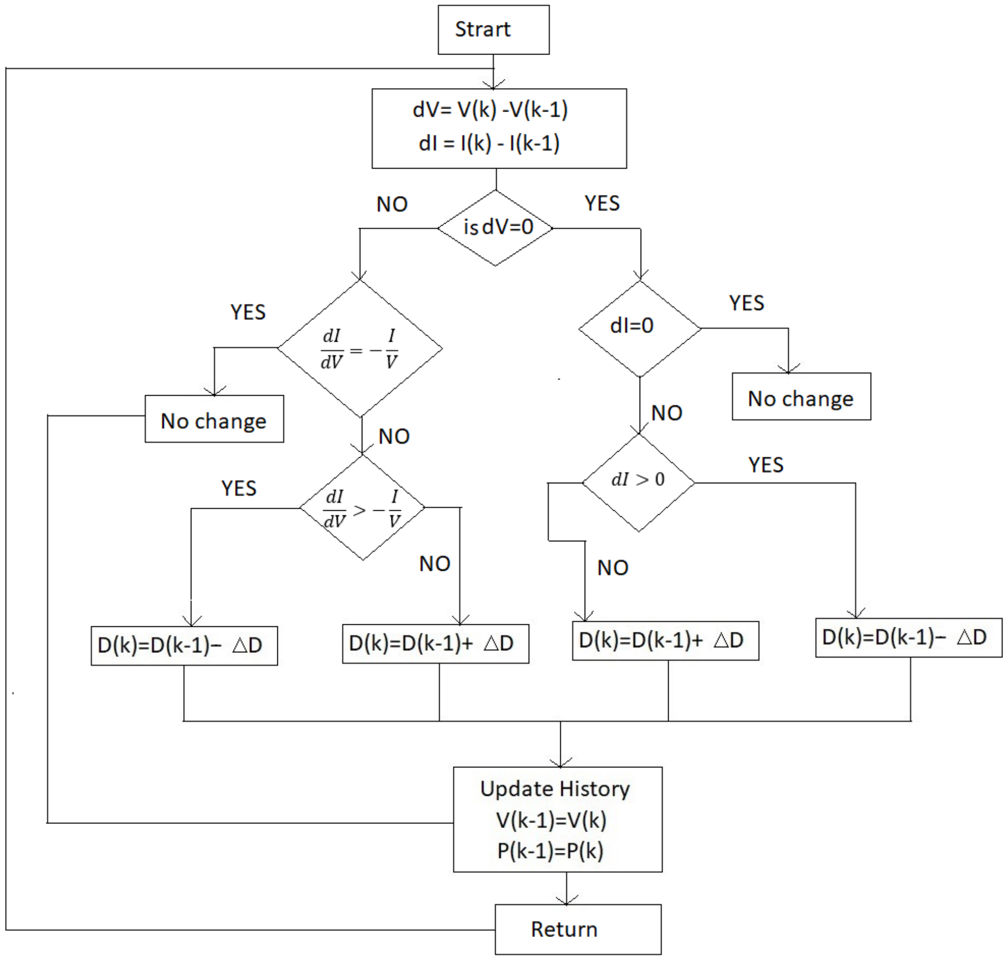

Fig-4.3: Algorithm of Incremental Conductance technique.

The speed of attaining MPP relies on the step size of the perturbation of the reference voltage.

Mainly two disadvantages are found in these conventional techniques. The first is that in case of rapidly changing irradiation tracking of MPP can be lost easily. However, the curve upon which the algorithm is framed changes not only change with the perturbation of voltage or duty cycle, but changes with the solar insolation also.So, it is not feasible for these algorithms to decide whether the change of power is owing to the change in insolation or the change in voltage or duty cycle steps.

The other disadvantage is the oscillation in the steady state around the MPP. This happens because of the fact the control is discrete and the step of discretization has a certain size. If this step size is very small then reaching time of MPP will be very large.

If the step size of voltage or duty cycle changes, the size of oscillation also changes. The amplitude of oscillation is higher if step of perturbation is higher. If the step size is so small the oscillation decreases, so a suitable solution should be accommodated.

At variable atmospheric situation to obtain the maximum power output from the solar module, the MPP should be tracked efficiently. In the next chapter it will be shown some modification to both P&O and InCond techniques so that under rapidly changing irradiation the tracking can be done a satisfactorily.

4.5 COMPARISON BETWEEN CONVENTINAL METHOD AND ADVANCED METHOD:

[1] Conventional method works with fixed iteration step size. Whereas in advanced method use variable step size. These methods are adaptive. In steady state step size is small but in transient state step size is large.

[2] Conventional method works with one step algorithm. Other side advanced methods work with two step algorithms. It uses conventional methods in steady state and uses adaptive method in transient state.

[3] As the conventional methods uses fixed step size it takes long time to reach the MPP. Whereas the advanced methods combine adaptive variable step size and the fixed step size.

CHAPTER-5: ANALYSIS OF ADVANCED MAXIMUM POWERPOINT TRACKING ALGORITHMS

5.1 Modified Adaptive Hill Climbing Method:

To design a well-performed MAHC algorithm these following requirements are important:

Stability: For a dynamic control system, stability is a fundamental design consideration. In solar power system both the switch mode power converter and output characteristics of PV module have non-linear characteristics. So, to deal with the MPPT algorithm with the PV array stability is critical factor.

In MPP tracking, large value of step size of control is expected but a certain limitation is there. Whether Perturbation step will be small or large is required to be decided by parameter calculation.

Dynamic response: A faithful MPPT control technique should respond quickly with the fast-changing environmental conditions i.e. temperature & irradiance.

Steady state error: After achieving the appropriate operating point, it is ideal for the system to stay operating at the optimal point. But in changing atmospheric conditions MPP will not remain same. So, during the steady-state a little fluctuation of output power is preferable.

Robustness to disturbances: The disturbance is not only by temperature and irradiance, but PV modules made of different technologies reacts differently to the atmospheric change. Even two modules of same make are not identical. So, it is desirable to frame a MPPT control system robust to all type of disturbances.

The plain HC method has a disadvantage, that it is not good in both steady-state and transient state. How the modified Adaptive Hill climbing method can remove this disadvantage is described below.

Automatic tuning Parameter:

As discussed in the Hill Climbing Method, the MPP can be tracked by slope of duty cycle curve. The peak point of the curve (Fig-5.1) is considered as MPP, left side of this $\frac{dP}{dD} > 0$, at the right of this curve $\frac{dP}{dD} < 0$, and at peak $\frac{dP}{dD} = 0$. Slope is considered as program variable whose value will be either 1 or -1, i.e. slope either remains same or changes its sign. It indicates the direction that must follow on the hill-shaped P-D curve (in Fig-5.1) in order to increase the output power. "a(k)" represents the incremental step of duty cycle, which is a constant number between 0 and 1. Here, a(k) is defined here as automatic tuning parameter.

"a" is taken large during transient stage and "a" is small in steady state. In this method this problem is solved by the automatic tuning parameter "a".

Here the automatic tuning parameter is defined by

$a(k) = M \frac{|\Delta P|}{a(k-1)}$……………………………………….2.12

Where $\Delta P = P(k) - P(k-1)$ is the change of power due to change in duty ratio.

And a(k-1) is the previous value of a(k), a(k)>0

And M is a constant parameter

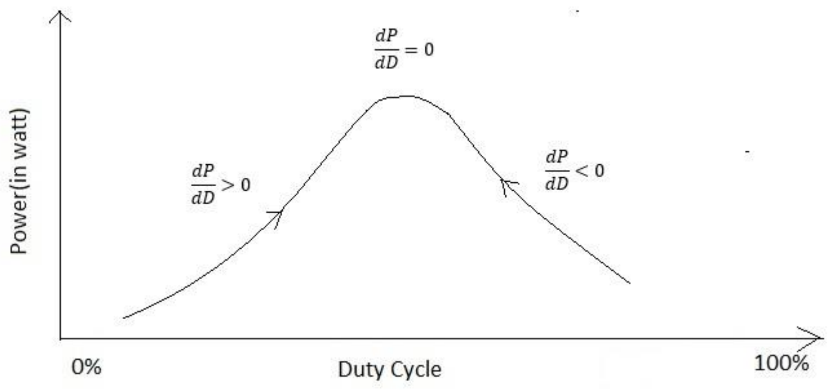

Fig-5.1: Change of output power with respect to Duty cycle.

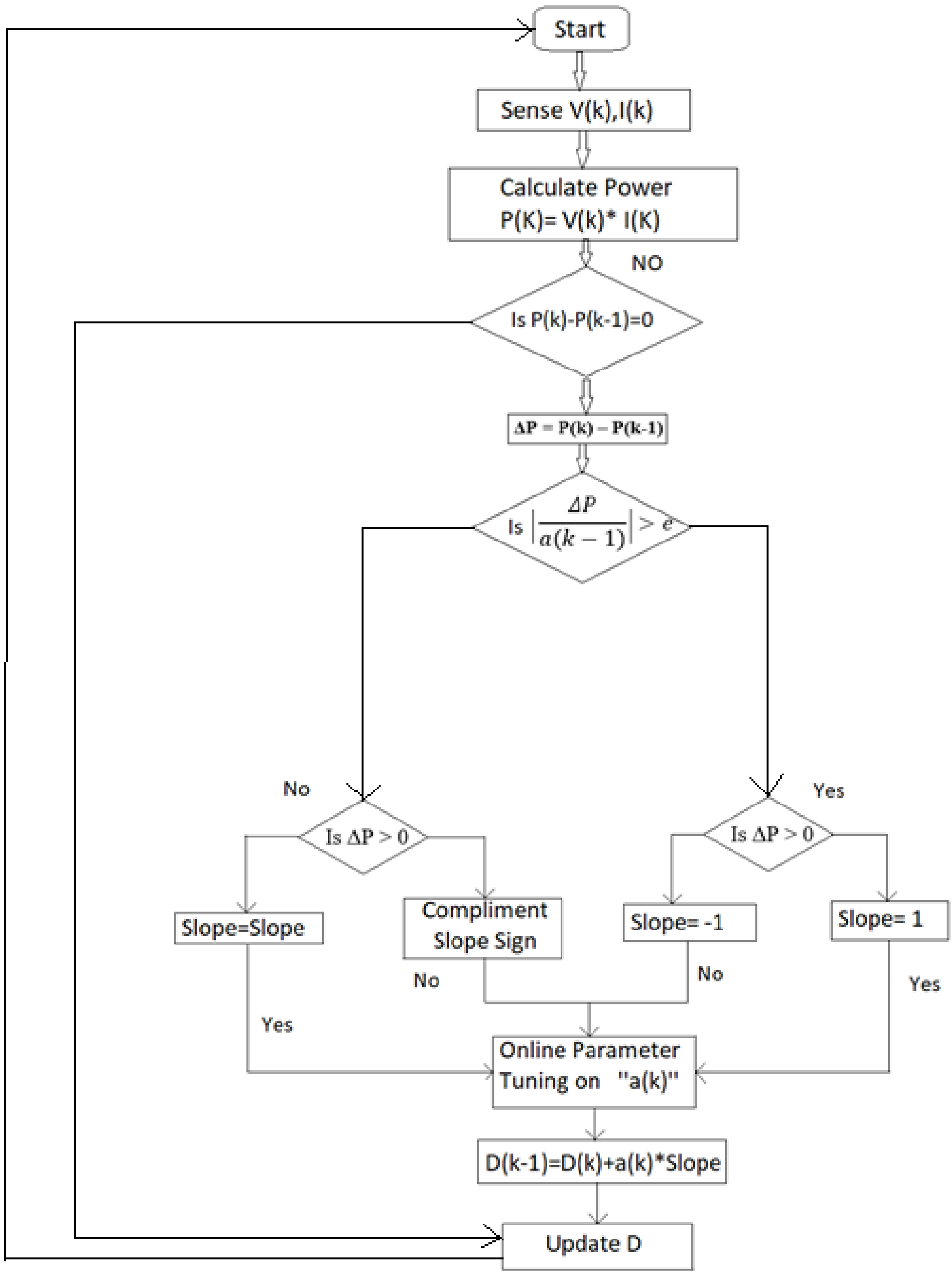

Fig-5.2: Algorithm of Modified Adaptive Hill Climbing Method

Control mode switching:

As discussed earlier that in conventional Hill climbing method at rapidly changing environmental conditions the operating point drifted from the MPP. This problem is avoided by switching the control mode. Switching indicator is stated as $\left|\frac{\Delta P}{a(k-1)}\right|$. A threshold value 'e' is considered for switching condition. If $\left|\frac{\Delta P}{a(k-1)}\right|$ is greater than the value 'e' the controller assumes the change of power is occurred by change of irradiance. If $\left|\frac{\Delta P}{a(k-1)}\right|$ is smaller than the value of 'e' (Fig-5.9) the controller understands that the system is in steady state or there occurred a large variation in power due to large step of 'a' only. And in steady state the algorithm follows the conventional HC method. The parameters 'a' and M make the controller adaptable to varying situation.

In the Fig-5.3 MPPT of MAHC method is implicated with a photovoltaic module. In the Fig-5.4 the algorithm of MAHC method is represented by Block diagram in MATLAB Simulink. In Fig-5.15, it can be seen that output voltage is oscillating because duty ratio is perturbed and always trying to get the MPP point. As the voltage is oscillating, the power will be oscillating also (Fig-5.6)

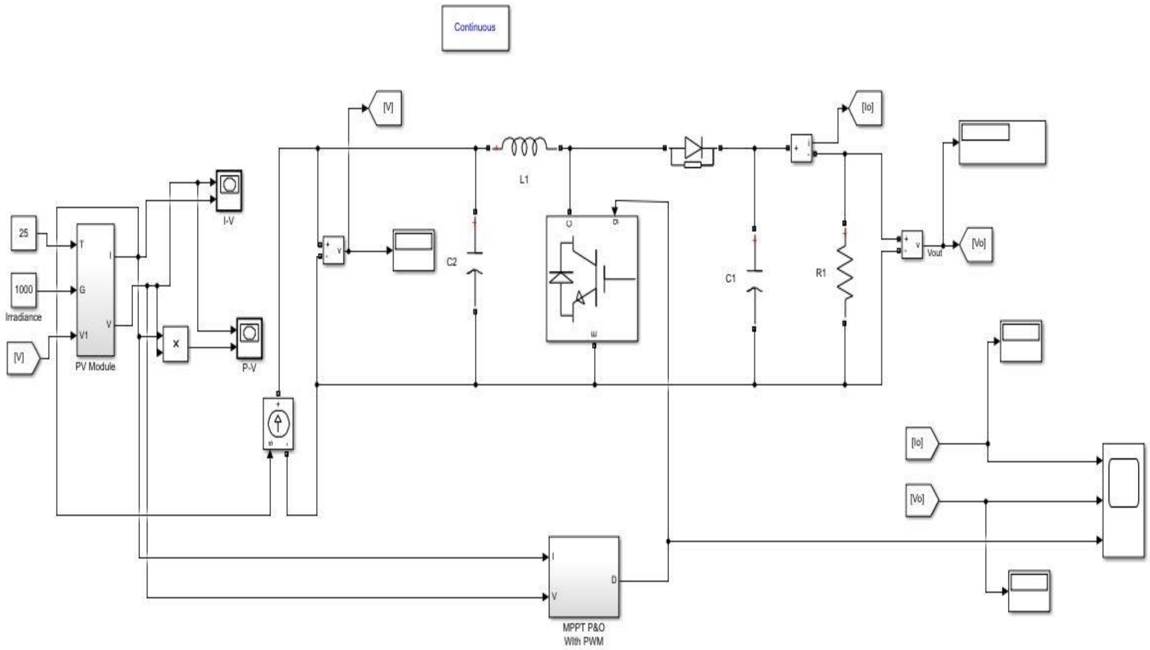

Fig-5.3: Circuit implementation of solar module with MAHC MPPT

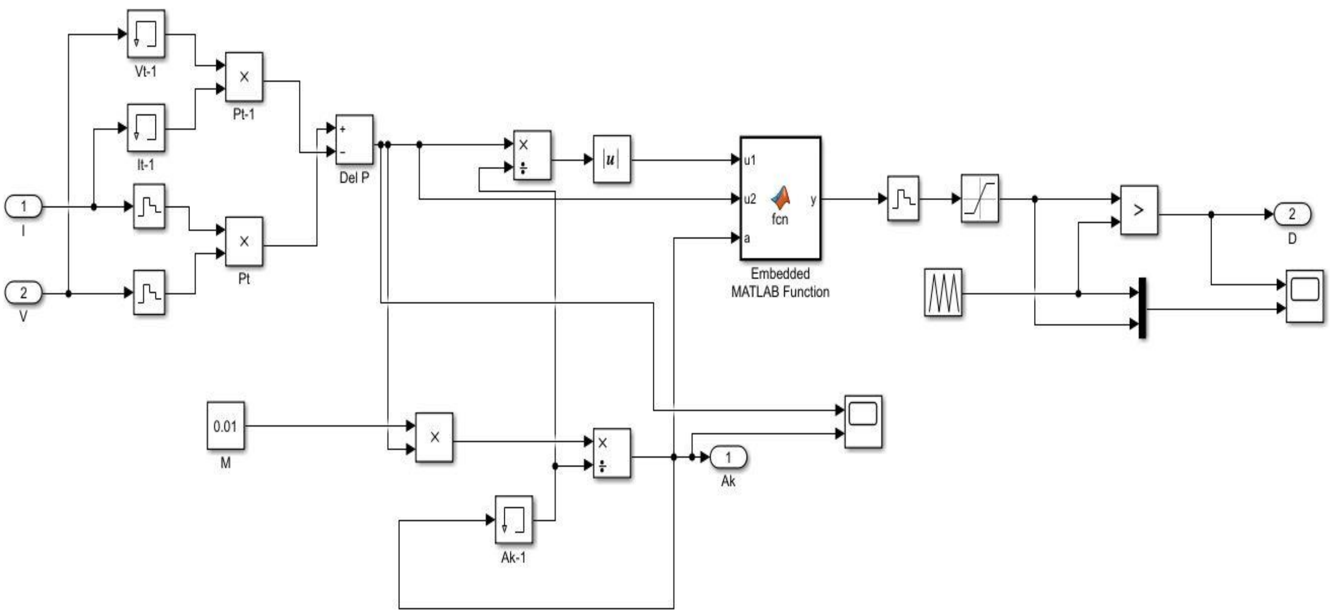

Fig-5.4: Block diagram of MAHC MPPT in Simulink.

5.2 Beta(β) method:

It should be pointed out that all the conventional tracking methods use fixed, small iteration steps, determined by the accuracy and tracking speed requirements. If the step-size is increased to speed up the tracking, the accuracy of tracking suffers and vice versa.

β method works in two stages. At the first stage the operating point reaches quickly within a close range of actual MPP. Then the second stage which employs a conventional method is used to reach the operating point to the exact MPP. The β method has some advantages over conventional method as given following:

1)The method tracks an intermediate variable β instead of tracking power. The limitation of conventional methods can be overcome where it is necessary to define a small iteration step of voltage or duty cycle to track the MPP.β can be denoted by a formula

$\beta = \ln(I(k)/V(k) - C*V(k)$

With relatively larger and variable iteration step size this β parameter facilitates fast tracking. So, this scheme is comparatively efficient than the conventional ones. In conventional scheme due to small step size it requires large iteration steps to reach MPP.

2)The accuracy of the tracking is not compromised because this is taken care of by the second stage which tacks power in smaller step. But the second stage does not require a long duration because the first stage brings the operating point at the nearer zone of MPP quickly.

3)By analysing 1 & 2 it is seen that for fast changing environment this scheme is suitable.

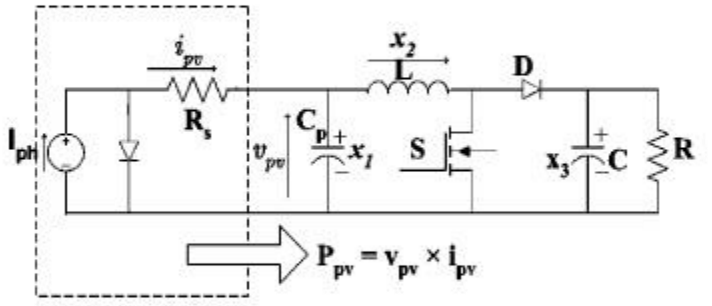

Fig.5.5 PV converter system

Considering the dotted portion of Fig.5.7, and taking the derivative of P_{pv} with respect to V_{pv},we get

$$\frac{dp_{pv}}{dv_{pv}} = i_{pv} + v_{pv} \times \frac{\partial i_{pv}}{\partial v_{pv}}$$

It is known that, $i_{pv} = I_{ph} - I_0 \times (e^{c\times(i_{pv}\times R_s + v_{pv})} - 1)$

Applying the MPP condition yields, $\frac{dp_{pv}}{dv_{pv}} = 0$

$$= i_{pv} + v_{pv} \times \frac{-I_0 \times (e^{c\times(i_{pv}\times R_s + v_{pv})}) \times c}{1 + I_0 \times (e^{c\times(i_{pv}\times R_s + v_{pv})}) \times R_s \times c} \ldots\ldots 2.12$$

Solving 2.12 for i_{pv}/v_{pv} and taking natural log on both sides of it

$$\ln\left(\frac{i_{pv}}{v_{pv}}\right) - c \times v_{pv} = \ln(I_0 \times c) + R_s \times c \times i_{pv}$$

$$-\ln(1 + I_0 \times (e^{c\times(i_{pv}\times R_s + v_{pv})}) \times R_s \times c)$$

The left side quantity is called β.

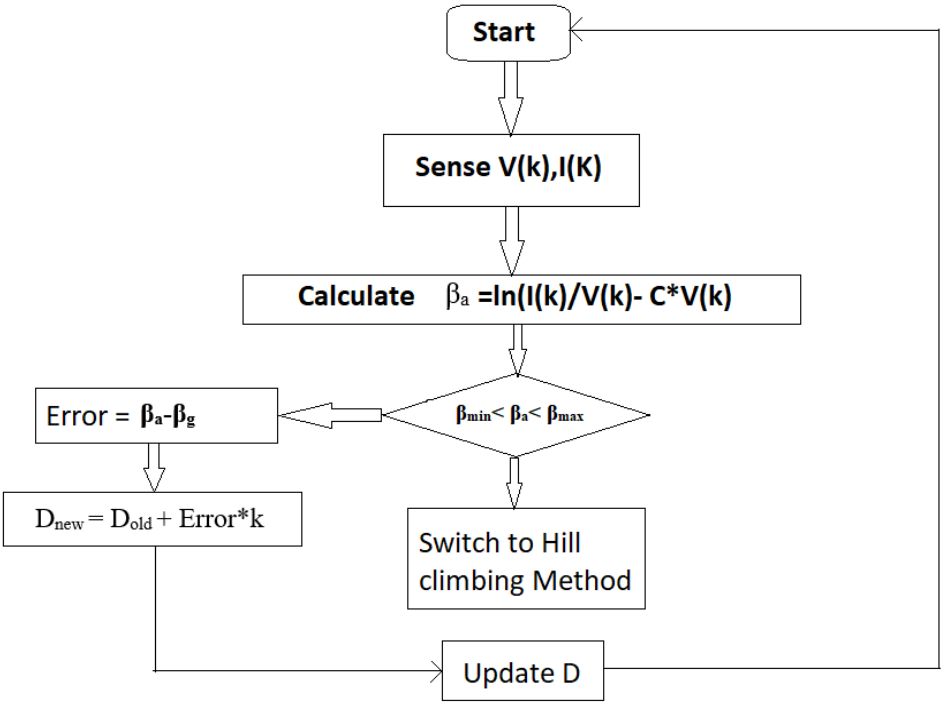

Fig-5.6: Algorithm of Beta method.

The theory of β method is described by Jain and Agarwal [12],[13] and there β is defined by

$$\beta = ln\left(\frac{i_{pv}}{V_{pv}}\right) - c \times V_{pv}$$

Here V_{pv}=Output voltage of PV module.

i_{pv}= Output current of PV module.

$c = \frac{q}{N_s AKT}$, is diode constant.

$D_{new} = D_{old} + (\beta_a - \beta_g) \times k$..........................2.13

D_{new} and D_{old} means the step size of new and old.

$(\beta_a - \beta_g)$ is variable step size

$\beta_g$is value between $\beta_{min} and\ \beta_{max}$.

k is defined as regulator of variable step size.

In this algorithm,β_{min} and β_{max} are the range of the parameter β,β_a is a real valued parameter i.e. its value changes depends on the voltage and current measured. When the value ofβ_g lies in between $\beta_{min}and$ β_{max},it is to be noted that the operating point reaches near MPP, then it switches to conventional method which increases precision and reduces the complication of the algorithm.If the β_a is not seen in between the range ,it means MPP point not near to the operating point and then β method turns into the first stage. In Fig-5.9 MPPT of β Method is implicated with photovoltaic module.The circuit contains PV moduleswith boost converter.The duty cycle of boost converter is control by MPPT. In Fig-5.10 MPPT of β method is block diagram in MATLAB Simulink.

In Fig-5.11, it can be seen that output voltage is oscillating because β_g is guiding value for calculating the variable step size as Eq..2.13 so duty ratio is updated by the new value and always trying to get the MPP point. As the voltage is oscillating, the power will be oscillating also (Fig-5.12).

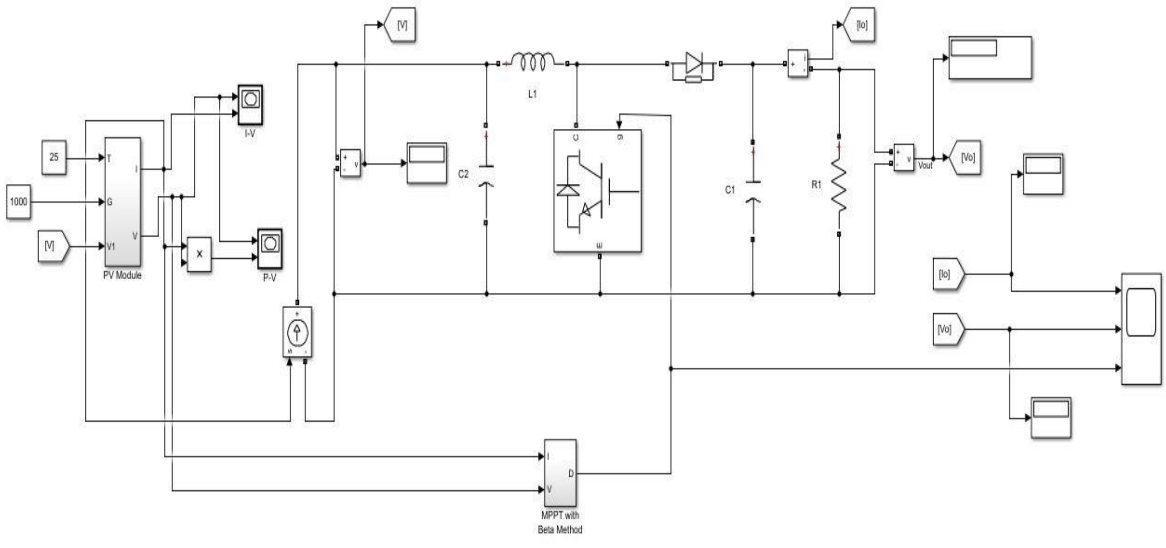

Fig-5.7: Circuit implementation of solar module with β-Method MPPT

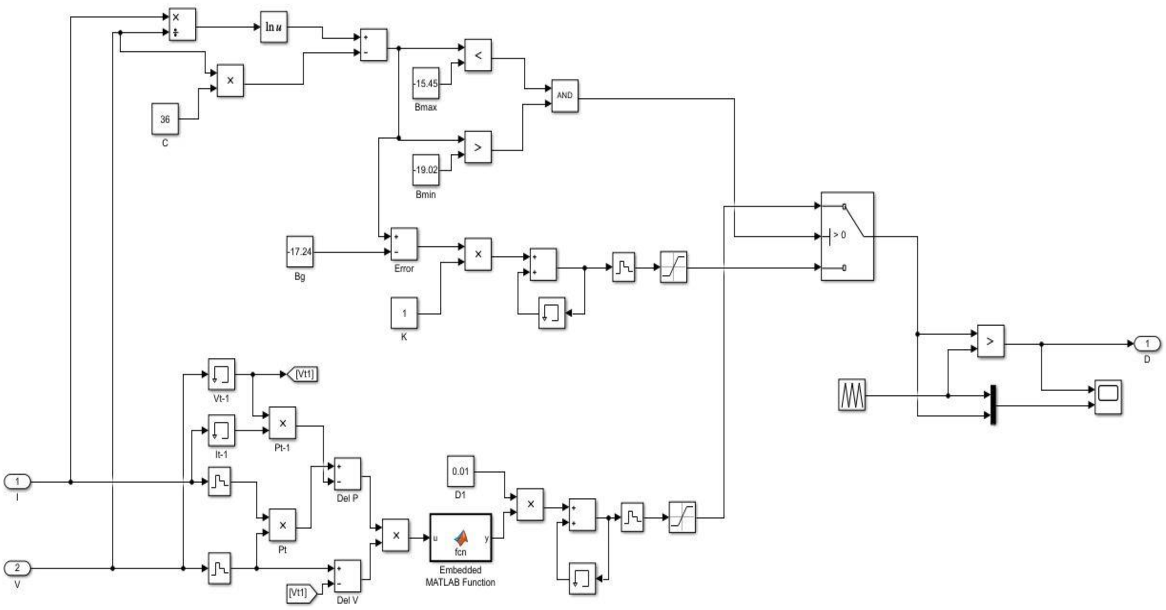

Fig-5.8: Block diagram of β-Method MPPT in Simulink

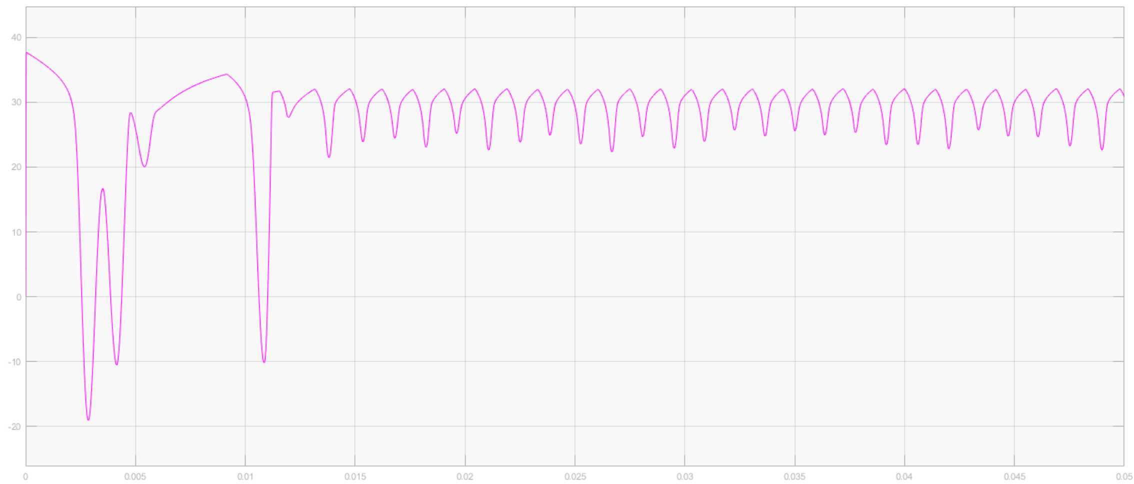

Fig-5.9: Waveform of PV voltage using β-Method MPPT

X axis - Time(second)

Y-axis - PV voltage

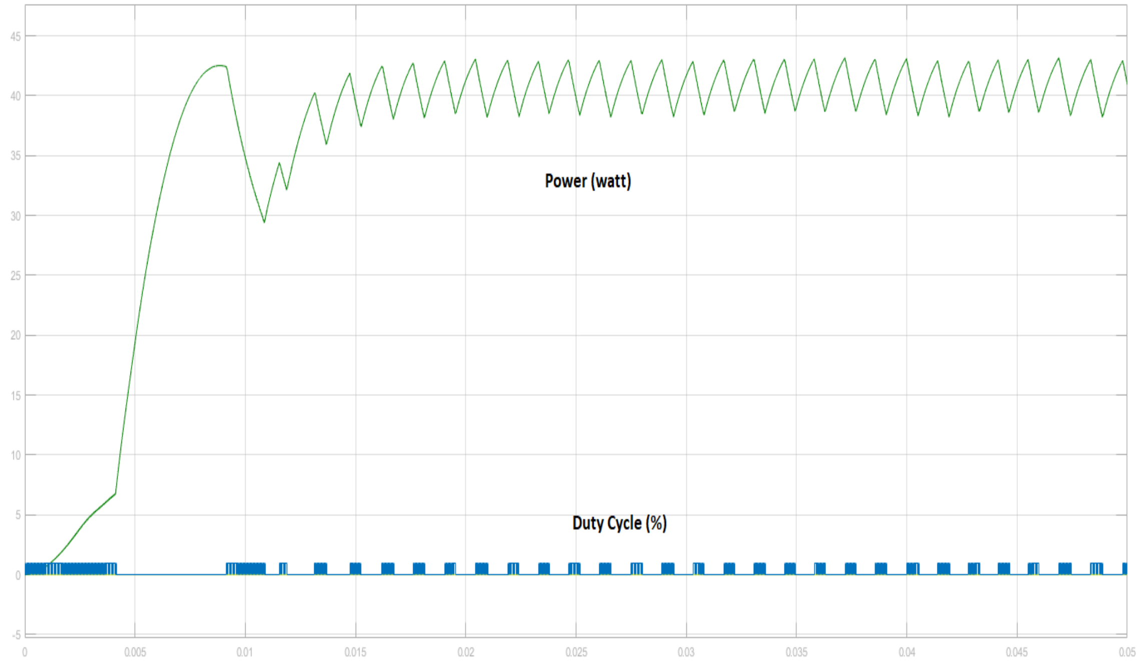

Fig-5.11 Waveform of Output power using β-METHOD MPPT

X-axis- Time (Second)

Y-axis- Output power(watt) and Duty Cycle (%)

5.3: CONCLUSION:

In this thesis a two advanced method have been analyzed and simulated in MATLAB-Simulink. The simulation results show that in variable environmental conditions and in parametric differences these two methods work better than the conventional method.

In Modified adaptive hill climbing method a control switching parameter ‘a(k)’ is adopted for transient condition.

In β method an intermediate variable parameter β is considered for dynamic response. The method will adopt variable step size and fixed step size for the transient stage and the steady state respectively. In the transient stage an adaptive variable iteration step size is used, while in steady state the method switches into a conventional method like HC, P&O and INC method with a fixed iteration size. On the other hand,

5.4 Abbreviations

AC …………………..Alternate Current
A.M………………….Air Mass coefficient
CdS………………….Cadmium Sulphide
CIGS………………...Copper Indium Gallium (di)selenide
DC…………………...Direct Current
ESR………………….Equivalent Series Resistance
GaAs………………...Gallium Arsenide
HC…………………..Hill Climbing
InCond………………Incremental Conductance
LCD…………………Liquid Crystal Display
MPP…………………Maximum Power Point
MPPT………………. Maximum Power Point Tracking
MAHC………………Modified Adaptive Hill Climbing Method
P&O…………………Perturb and Observe
PV…………………...Photovoltaic
R&D…………………Research and Development
STC………………….Standard Test Conditions

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