FUZZY PERTURB AND OBSERVE BASED MPPT OF PV ARRAYS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ELECTRONICS & COMPUTER ENGINEERING
(With Specialization in System Modeling and Control)

By

ANKUR SINHA

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)
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CANDIDATE'S DECLARATION

I hereby declare that the work, which is being reported in this dissertation report, entitled **"Fuzzy Perturb and Observe based MPPT of PV arrays",** is being submitted in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **System Modeling and Control,** in the Department of Electronics and Computer Engineering, Indian Institute of Technology, Roorkee is an authentic record of my own work, carried out from June 2012 to June 2013, under guidance and supervision of **Dr. Ranajit Mitra**, Professor Emeritus, Department of Electronics and Computer Engineering, Indian Institute of Technology, Roorkee.

The results embodied in this dissertation have not submitted for the award of any other Degree or Diploma.

Date:

Place: Roorkee

Ankur sinha

CERTIFICATE

This is to certify that the statement made by the candidate is correct to best of my knowledge and belief.

Date:

Place:

Dr. Ranajit Mitra

Professor Emeritus

Department of E & CE

Indian Institute of Technology, Roorkee

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Ankur sinha
M.Tech (SMC)

Dedicated to my loving parents and friends

ABSTRACT

In this dissertation we have proposed very simple but efficient technique to track maximum power from photovoltaic module for a step change in temperature and radiation. Temperature is changed from 320.18 K to 600 K at 0.15 s and radiation is changed from 100 W/m^2 to 1000 W/m^2 at 0.05 s. We have compared the results for MPPT control using perturb and observe with fuzzy MPPT control and perturb and observe technique. In fuzzy MPPT techniques output from perturb and observe block is compared with PV module output voltage to get an error signal. This error signal is then feed to fuzzy controller. Fuzzy controller processes this error signal and generates a control signal which passes through PWM generator and produces pulse signal. The duty cycle of the pulse varies with control signal and is used to switch ON or OFF DC to DC converter. By using P & O based controller maximum power is obtained but significantly large oscillation is observed. The fuzzy MPPT controller achieves maximum power with less oscillation. In this case, the oscillation causes significantly lesser loss of energy at the load end. So we achieve efficient performance of PV arrays while using fuzzy P & O MPPT controller.

CONTENTS

LIST OF FIGURES

1. Introduction

Renewable energy source is the best energy source in today's time. As we know energy crisis is the main problem in today's environment and to cope up with this problem an alternate energy source is needed. Another main advantage of using renewable energy is that, it is harmless source of energy to the environment unlike conventional sources. Among all renewable source of energy one of the best sources available is sun [2]. Energy coming from sun can be use to generate electricity. Now a day's energy generation via renewable source worldwide is typically less than 10%. Renewable energy is using in place of conventional fuels in many areas such as automobiles, electricity generation, and rural energy services. In our ancient time these energy was the main source of energy. But at that time only a few percentage of total available energy was used. Solar energy can be produced from sun by the help of solar radiation, and this work is consummate with the help of photovoltaic cells. Photovoltaic cell converts solar energy into electrical energy. Although efficiency of solar cells is not so much but after applying some technologies that are emerging now days, we can improve its efficiency significantly. Our main objective is to draw maximum amount of power from solar panels and this can be done with the help of some control strategy. Renewable energy cannot be used throughout; due to continuous change in environmental condition and the effect over it. Suppose we have installed a PV panel, it will work well in summer days but in cloudy days it won't work because radiation coming from sun is varying very rapidly in these days. So, it is very necessary to store the energy therefore solar charger is also needed. For maximizing the power from PV panel extra electronics circuit is required. Some of the techniques for maximum power tracking are perturb and observe, incremental conductance and by fuzzy controller we can maximize the power. But whatever be the method the only objective is to maximize the output power. Now a day's some new techniques are also being introduce and some are under process. They differ only in circuit complexity but logic is same.

1.1 Distribution of solar Radiation

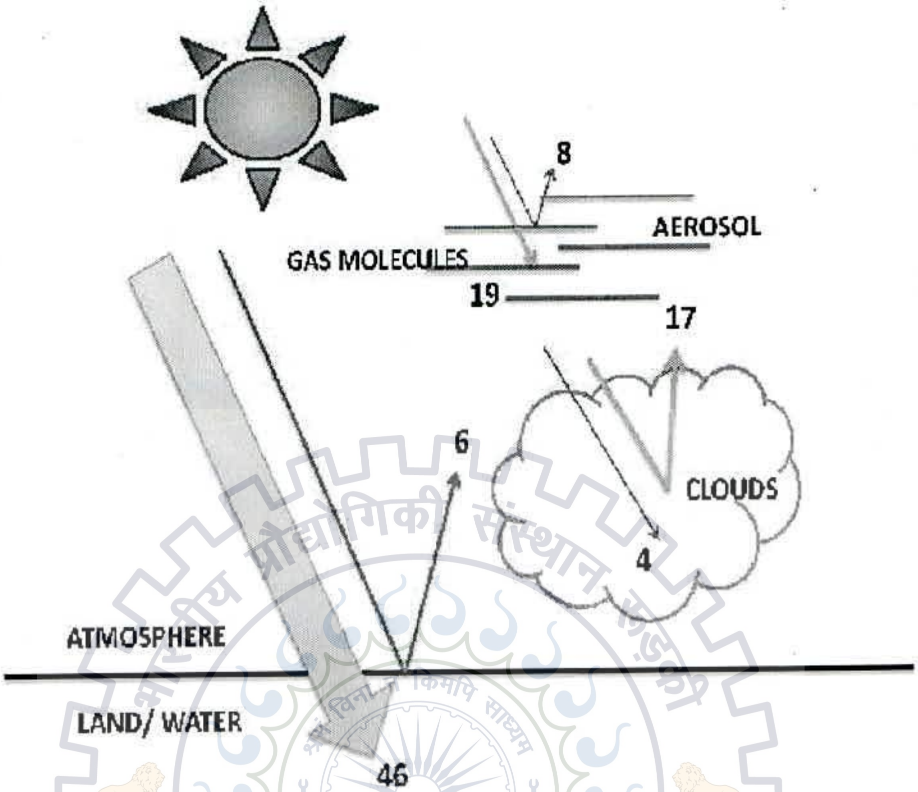


Fig.1.1 solar radiation distribution

From above figure it is clear that from total amount of energy from sun a small portion of energy is available that can be used. 8% percentage of solar radiation is reflected back due to upper layer and 17% is reflected from the clouds [3-5]. And from remaining 75 % some radiation are absorbed (19%) and scattered due to scattering effect (17%).And we know that three portion of earth surface is full of water and only one part is land available. So theoretically a very small amount of solar energy is available.

1.2 Spectrum of sun

Photovoltaic device is the function of solar irradiation level. So, it is important for us to know about the spectral analysis of sun radiation.

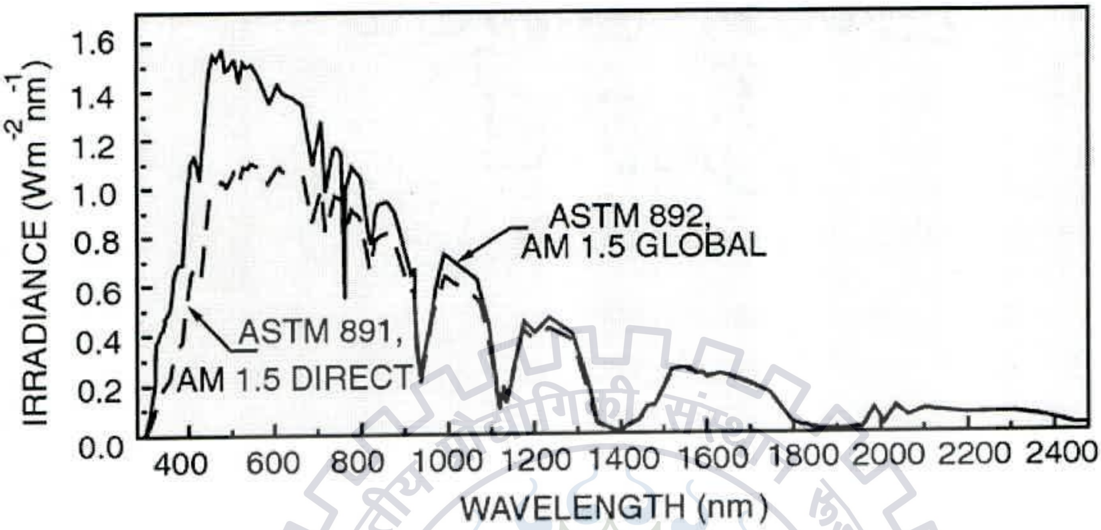


Fig. 1.2 Spectrum distribution of sun

The total power in earth atmosphere is about 1366 w/m^2 .this amount of power is too much for utilization on earth, but due to various losses occur as mentioned above cause about 33% to spread on earth. In this 1366 w/m^2 almost 50 % is infrared light and 40 % is visible light and 10% ultraviolet light.

2. Literature Review

In this thesis we are trying to maximize the output power by maximum power point tracking method of photovoltaic array. Actually this is based on impedance matching of output of PV arrays with the load. For tracking maximum power some methods are proposed, but among all the method available perturb and observe method is one of the best methods to track maximum power point. This method is based on variation of sample of output voltage and current for every cycle of algorithm. In initial step power is measured by taking the sample of voltage and current. In the next step, value of the power obtained is compare with the previous value and according to sign of change in power; a decision is taken by controller to increase or decrease the value of voltage. This process is done for each cycle of algorithm until power reaches its maximum value.

Basic problem involved with PV module is that independently it cannot deliver the maximum amount of power to the load because the photovoltaic cell output current and output voltage is totally dependent on the atmospheric temperature and solar radiation that falls on it. Secondly the amount of power generated is also the function of cell temperature itself. So to increase the efficiency of PV arrays perturb and observe algorithm must be applied [6]. This algorithm just checks whether the obtained sample value of voltage and current and hence power is at maximum value or not for given value of temperature and irradiation. And if maximum value is not achieved then it just adds some value to the voltage to the previous value and same cycle runs until maximum power point is achieved. When maximum power point is achieved then small perturbation in the value of voltage give rise to oscillation around maximum value. This leads to loss in the output power. This is the main disadvantage of perturb and observe approach. Another disadvantage of perturb and observe approach is that it cannot recognize the sudden change in radiation level. So to remove this problem another approach such as incremental conductance is used.

Actually in this PV system a DC to DC boost converter is introduced. This is the main block that is used as an interface between source (PV array) and the load. It simply works as impedance matching device. It basically receives pulse signal from perturb and observe block with some duty cycle and is used as switching signal for DC to DC converter.

3. Different characteristics of solar arrays

Photovoltaic arrays basically consist of several cells connected in parallel and series to form a module and combination of this module form arrays. Series combination of cells increases the total amount of voltage developed across the terminal of modules and hence that of array and parallel combination of these series cells enhances the total amount of current generated from the cell in the module resulting in increased value of current in array.

These photovoltaic cells are nothing but simply a p-n junction diode made of silicon material. Basic phenomenon by which voltage and currents are generated is photoelectric effect. Photo means light when incident on the p-n junction that is depletion reason energy transference takes place between the photon and electron. Electron gets enough energy from photon and get excited from its ground level to the excitation level. Due to generation of electrons, holes are also generated which forms electric field near the junction and photo current is developed which is further used as output current of array.

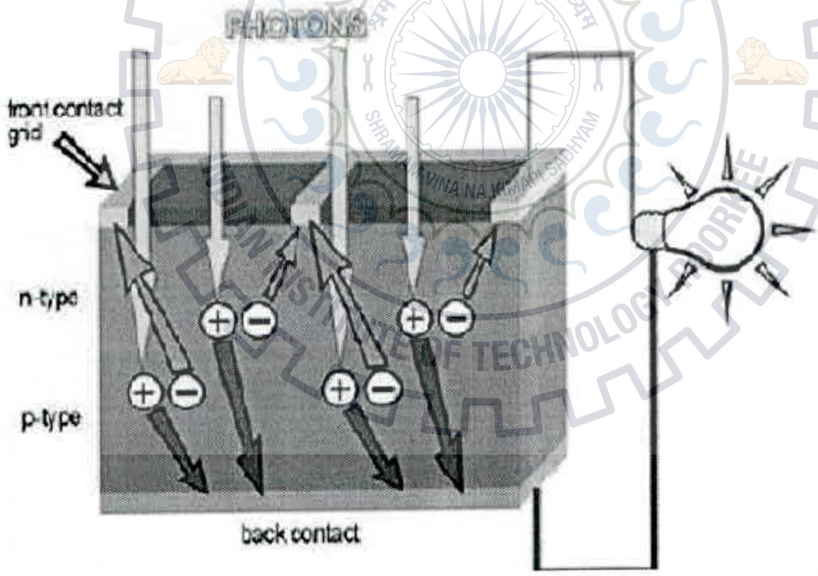


Fig.3.1 energy transference between electron and photon

3.1. Electrical Equivalent Circuit of PV Solar Cell

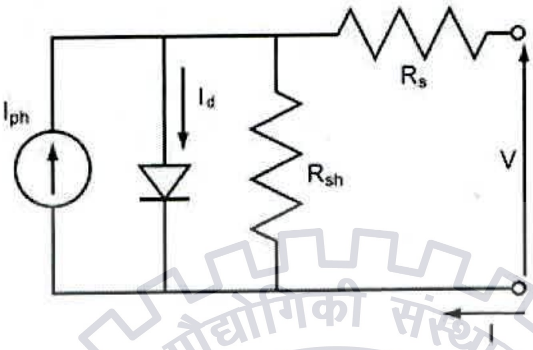


Fig. 3.1.1 equivalent circuit of PV cell

In the above figure 3.1.1, I_{ph} is the current produced from solar cell and I_d is the current absorbed by diode and I is the load current and V is the load voltage. R_{sh} is the shunt resistance of the diode and R_s is the series resistance provided by cell. I_d is the leakage current and T is operating temperature of cell. The load current I is computed as:

$$I = I_{ph} - I_d\{\exp[\frac{q(V + IR_s)}{nKT}] - 1\} - \frac{V + IR_s}{R_{sh}}$$

Correspondingly, we can compute the load voltage V from the above load current value I as:

$$V = \frac{AKT_c}{e}\ln(\frac{I_{ph} + I_d - I}{I_d})$$

Where,

A: constant adjustable parameter

V: PV cell output voltage

T_c: operating temperature of the cell (300 K).

R_s: series resistance (0.001 Ω).

I_{ph}: photocurrent, (5 A).

I_o: reverse saturation current of the diode (2*10^-4 A).

I_c: PV cell output current that is I

k: Boltzmann constant (1.38 × 10^-23 J/K).

e: electron charge (1.602 × 10^-19 C).

R_{sh}: shunt resistance of solar cell (6.5 kΩ)

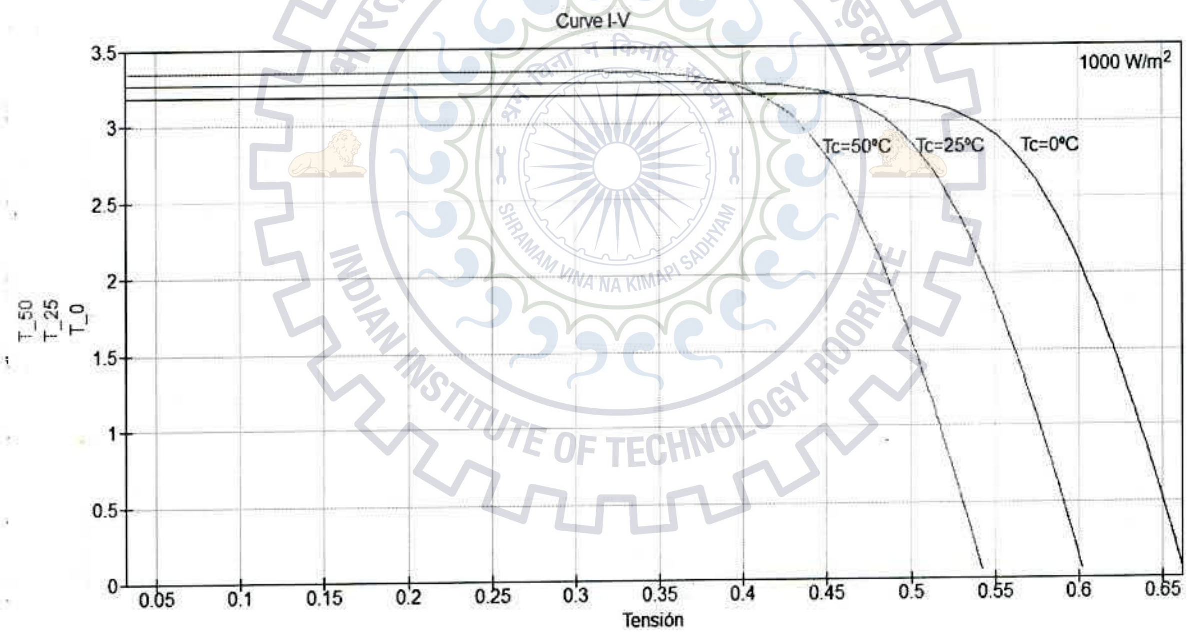


Fig.3.1.2 plot of output current versus voltage at different temperature for fixed radiation of $1000 w/m^2$

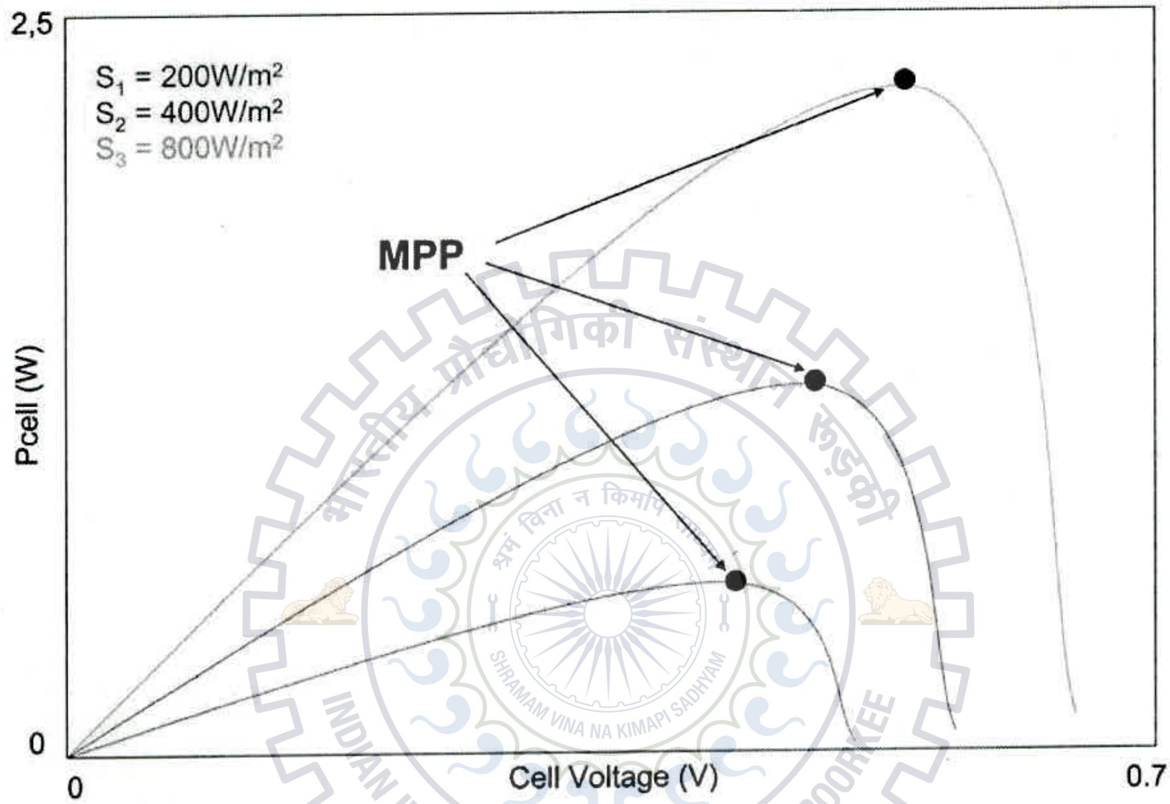


Fig. 3.1.3.output power versus voltage characteristics for different radiation level for fixed temperature of 27 K

In above plot it is clear that the power and voltage characteristics (p-v) are non linear in nature. Therefore, it is hard to find out the point at which value of power will be maximized. And it is also clear that by increasing temperature maximum power point shift to a lower value than previous value and similarly by increasing irradiation maximum power point shift to its higher value [5, 10].

4. Need for Maximum Power Point Tracking

Energy coming from sun is incident on PV module and it generates power which is used for application purpose in household or some other place where alternative source of energy is required other than conventional source of energy. Only few percentage of incident power is converted from PV array. So the efficiency that is defined as incident power to PV array to output power of PV array at a given environmental condition, is very low almost 30% to 35% [10]. Therefore it is not much profitable. To draw maximum amount of power and to increase efficiency of system it is required to track that value of voltage and current at the output of PV array at which point power would be maximum. And for this reason, tracking of maximum power is required. Maximum power point tracking uses different type of control algorithms to find out that maximum power point. Some of them use perturb and observe algorithm, incremental conductance algorithm, curve sweep method, constant voltage etc. All these methods differ only in the stability of maximum power point. Since installation of PV array is costly and the cost of electricity generated from PV array is more costly than the cost of conventional electricity. So, whenever any user makes use of this system then they want to use all of the power generated from it that is why it should operate on its maximum power. Also the PV array system performance depends not only on the operating point of system but also on the quality of system design [8]. As discussed previously, there are many different algorithms are used to track the maximum point and they vary not only on the stability of operating point but also on simplicity and on the hardware use. Again they have different speed of convergence, cost and sensor used. Initially the cost of solar cell was too high but with the evolution in technology and manufacturing process become easy and simple, the cost of solar cell reduced to a large extent. This energy source is one of the best solution for upcoming days because availability of fuels are decreasing day by day and power requirement is increasing, and also generation of energy is pollution free and it required little maintenance. But here we are applying perturb and observe algorithm to maximize the power.

In all algorithm used to track maximum power only one logic is involve that is derivative of output power with respect to output voltage must be equal to zero.

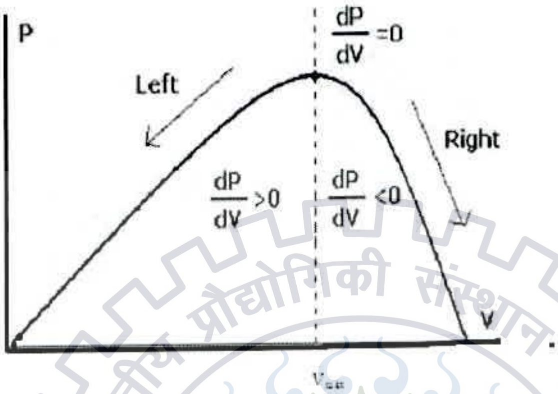


Fig. 4.1 P- V characteristics .

$\frac{dp}{dv} = o$ For $V = V_{max}$.

$\frac{dp}{dv} > o$ For $V < V_{max}$

$\frac{dp}{dv} < o$ For $V > V_{max}$

As shown in the figure derivative of power with respect to voltage is less than zero is left side of V_{max} and if derivative of power with respect to voltage is less than zero, it indicate left side of Vmax and if derivative of power with respect to voltage is equals to zero then it will be the point of our requirement.

5. Controlling by perturb and observe Technology

Here observation means to observe the output power and perturbation means perturbation of output power generated from array. Controller may increase or decrease the power according to the condition. And this in turn is done by perturbing the voltage or current. This algorithm first samples the value of voltage and the current then it calculates the value of the power [11, 12]. In next step it checks the value of previous power with new power calculated and then finds out the difference of the power between them if it is positive then operating point moves toward right side till it reaches MPPT. If difference in power comes out negative, it means new power is less than current one, in this case operating point will shift in left side till MPPT is not reached.

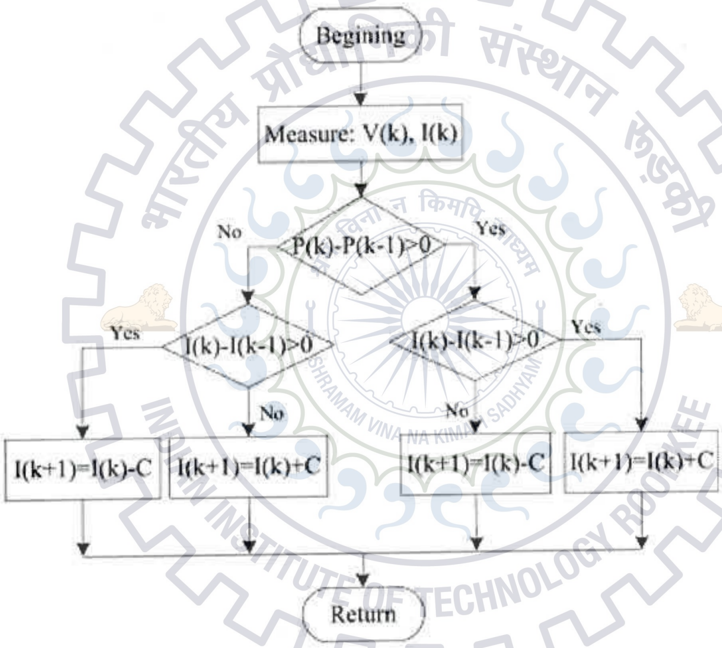


Fig. 5.1 flowchart of perturb and observe

Logic behind Perturb and observe algorithm is perturbing the operating point. When operating voltage of output of the PV array is perturb slightly and due to this small increment in voltage if change in power is positive then it means that maximum power is not attend yet. So further increment of voltage is required and we will do the same thing until MPPT is achieved. And if change in power is negative after increment of voltage then it means MPPT is reached and we will have to decrease the voltage level. But, one disadvantage of perturb and observe is that when operating point is already at MPPT then further increment or decrement creates oscillation at output of system and due to this fluctuation some energy is lost. In P & O algorithm, increment in the voltage causes low speed of response. Same problem is created when sampling rate is low. To reduce oscillation about MPPT it is necessary to make increment low, if increment is high then steady state error will be high. Higher value of increment ensures the fastness of working of algorithm but at the same time it will generate more and more steady state error. Low increment is very necessary for tracking maximum power point. Speed is not so important here but major point is to get maximum power for given environmental condition. Actually speed of algorithm can be increased by different ways without disturbing increment in any parameters. It can be increased with the increase in sampling rate. So, we have to take care of these two values simultaneously. For this purpose, we have to make compromise between speed of algorithm and steady state error. And we all know that this is the fundamental problem of all control systems. We have to compromise between error and speed always and another problem with perturb and observe method is that it cannot respond for fast varying atmospheric condition. Because when temperature and radiation vary very fast then MPPT controller recognizes that MPPT has been reached and it starts decreasing the resulting power. Actually this algorithm is not very satisfactory for fast varying condition [13]. If difference in power and voltage both are negative then this algorithm will decrease the value of voltage. If power difference and voltage difference is both positive then in that case this algorithm will increase the power.

6. Block diagram of overall system

Block diagram of the overall control system consist of obviously a PV array that is system from which we are getting power. And this power is going in two circuit one in maximum power point tracker and another in DC to DC boost converter. Actually this system plays an important role because it is the circuit which varies the parameter of PV array that is power, voltage and current. Actually in short we can say that this dc-dc converter is an impedance matching device or we can say that it is working like step up transformer [14]. Transformer either increases or decreases ac input signal. DC to DC converter is not exactly transformer because input to it is almost dc signal and transformer doesn't work on dc. So we can say that it is dc equivalent of transformer. So, finally we conclude that it is working as an interface between source and load for matching of impedance.

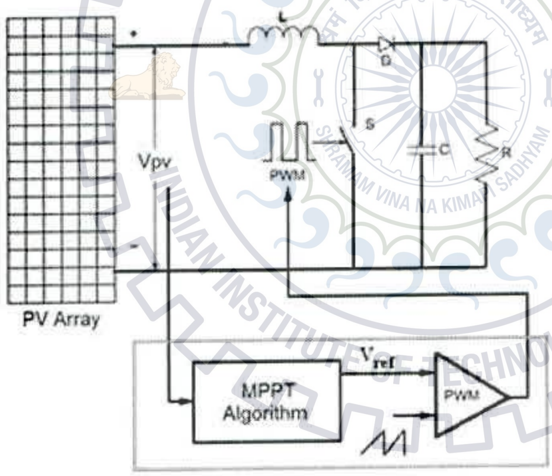


Fig. 6.1 basic block diagram of control system

Here in the above block diagram it is clear that output of PV array is going in both DC to DC converter as well as MPPT controller block. And the output of MPPT controller is going to pulse width modulation circuit which is used actually to convert irregular control signal into pulse signal with variable duty cycle depending upon the control signal given by MPPT system. Each time when MPPT algorithm runs it gives some control signal to PWM generator and according to this control signal it generates a pulse signal of some duty cycle. Here in PWM circuit a triangular wave of some fixed frequency and some fixed maximum amplitude is introduce to compare with incoming control signal. Now the signal generated from PWM generator is then fed to the gate of MOSFET in DC to DC converter .here MOSFET is working as switch and also we have assumed that this switch is in complete conduction mode and also circuit is in steady state that is DC to DC converter. This converter circuit actually multiplies the input voltage by some factor that is depending on duty cycle. By the help of this duty cycle continuous on and off of switch takes place and in this manner controlling is done by DC to DC converter. DC to DC converter is directly connected to load; this load may be resistance or some battery charger to charge the battery. Charger is required because at night hours sun lights is not present and to maintain continuous power from solar array some storage of power is required. So there is an arrangement of storing power to use at night or some other days whenever there is no sunlight like cloudy days. Due to this reason sometimes PV system is fail during this system but due to lack of power this days optional form of power is required and this can be done with the help of renewable source of energy and this is done by sun which is heavy form of energy available free of cost. Secondly this arrangement as shown in block diagram is less expensive arrangement and also there is no maintenance problem. It can be easily handled. But basic reason is that initial installation charge is high but after the discovery of different type of manufacturing process of photovoltaic cell it becomes less expensive as compare to conventional source of energy. The main working of DC to DC converter is to change the input resistance of PV array by varying the input parameter such as voltage and power. And by varying these parameters it tries to match the impedance by looking up the load.

7. DC to DC converter

DC to DC converter is a switching circuit, which consist of some passive elements such as capacitor and inductor and active elements like, diode, and MOSFET. It regulates the fluctuating DC to somewhat less fluctuating. Signal coming to gate controls the switching action of MOSFET. Here MOSFET is working as a switch and is in complete conduction mode. Besides MOSFET we can use other switches as well but other switches have problem of higher delay time and more loss. Secondly when MOSFET is in ON state, it provides less resistance, so i^2Rt loss is less. To analyze this circuit we have certain assumptions. We have assumed initial current through inductor to be zero and initial voltage across capacitor as zero [4, 15]. With these assumptions and analysis, we can generalize the performance of the circuit for any valued initial conditions.

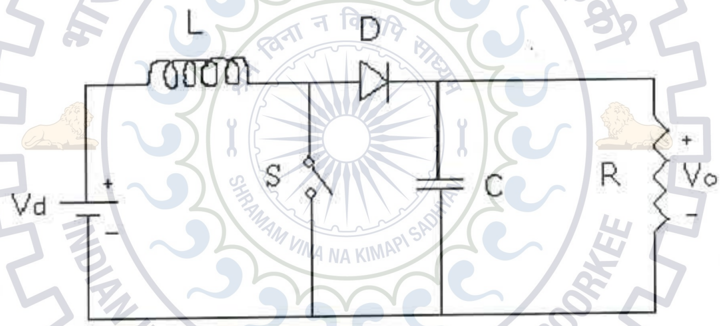


Fig 7.1 DC to DC converter

This DC to DC converter is initially in steady state. So it implies that initial value of voltages and currents is zero. We have considered high value of capacitance to prevent instant change in voltage. The circuit behavior observed with initial conditions helps to determine its behavior for other general values of initial conditions.

Further, we have assumed that diode used for analysis is an ideal diode that is in forward biased the forward resistance is zero and when it is reversed biased the reversed resistance is infinity. So, for forward bias it is like straight wire with no resistance and like open circuit when reverse biased. As previously said that controlled signal received from PWM generator controls MOSFET which in turns takes a control signals from MPPT controller. Now keeping these assumptions, we are going to analyze this circuit.

7.1 When MOSFET (switch) is closed.

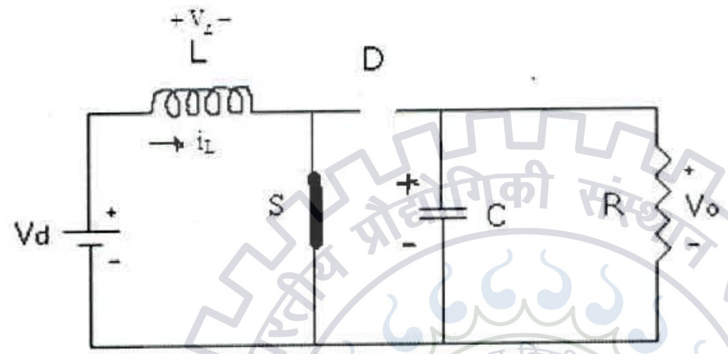


Fig. 7.1.1 when switch is closed

$$V_L = v_d = L\frac{di_L}{dt}$$

$$\frac{V_d}{L} = \frac{di_L}{dt} \qquad (1)$$

From equation 1, it is clear that the rate of change of inductor current is constant. Because voltage coming from PV array V_d is almost constant.

7.2 When MOSFET (switch) is open.

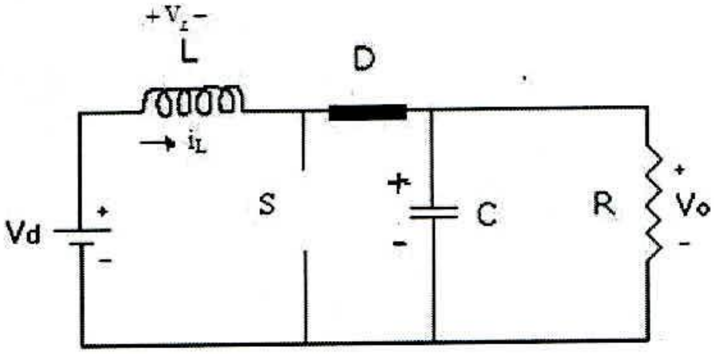
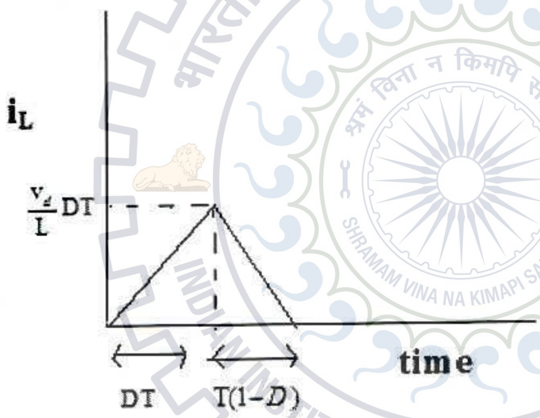


Fig.7.2.1 when switch is open



i_L= inductor current

7.2.2 This plot is between inductor current versus time.

Now,

$V_d = V_L + V_{out}$

$V_L = V_d - V_{out}$

$$\frac{V_L}{L} = \frac{V_d - V_{out}}{L} = \frac{di_L}{dt} \qquad (2)$$

$$di_L = \frac{V_d - V_{out}}{L} dt$$

So, from t =DT to t = T(1-D) current must go from whatever be value be to zero. Therefore

$$i_f - i_i = \frac{V_d - V_{out}}{L} dt$$

$$0 - i_i = \frac{V_d - V_{out}}{L} dt$$

$$\text{Or, } \frac{V_d - V_{out}}{L} dt + i_i = 0$$

$$\frac{V_d - V_{out}}{L} T(1-D) + \frac{V_d}{L} DT = 0$$

$$V_{out} = \frac{V_d}{1-D} \qquad (3)$$

According to above equation (1) it is clear that during ON time of switch i.e., in time interval 0 to DT, the rate of change of current was constant. Current through inductor increases linearly. At time t=DT inductor has maximum current. After that time instant switch suddenly opens and inductor start releasing its energy which was earlier stored in form of magnetic field. This energy is stored in the capacitor in form of electric field. so during time interval t=DT to t=T(1-D), the rate of change of current must be same in order to make the assumption true, that was steady state. so final current must go to zero. It implies that rate of change of current must be negative. According to equation (2), output voltage must be higher than the input voltage. In the same way if there is some initial condition available in the circuit then the inductor final current must go to initial current during the time when switch is open. So from this point we observe that it is the DC to DC converter which plays a very important role to track maximum power. Therefore DC to DC converter takes the same value of voltage and current as MPPT block. And according to the value of power it generate a signal which is used as control signal for DC to DC converter circuit and it increases the output voltage and hence the output power. So, basically DC to DC converter varies the input resistance of PV panel and work as impedance matching device.

Here, we have connected battery as a load for simulation purpose. If we connect PV arrays directly to the load (bulb) then illumination of the bulb is dimmed and fluctuates. But if we connect DC to DC converter and controller in between load and PV arrays then we observe that illumination of bulb is very high but still fluctuates. This fluctuation is due to oscillation of power around MPPT as already mentioned and it can be shown via simulation results. But .if apart from the algorithm we have used so far, if we use incremental conductance method, then our fluctuation would be lesser as compared to perturb and observe technology [3-7]. Due to this fluctuation about MPPT some amount of energy is lost. So several advance technological work is on progress to ensure maximum power with almost low loss as well as efficient power tracking [11, 15].

We have set higher sampling rate to avoid fluctuation in the output of the system. Main demerit of perturb and observe method is that it cannot recognize sudden change in the environmental condition. It treats the sudden change in environmental condition similar to perturbation. And sudden change in temperature is directly proportional to radiation of sun. So in such case, the algorithm considers that change is due to larger step size taken rather than environmental condition.

So to increase the performance of this system we have to make slightly different approach by introducing some intelligence type of controller. Now a day's fuzzy type of controller is very efficient and demanding controller because it is based on perspective of human beings. It is based on totally different approach than others conventional controllers. In simple P & O technique we have observed that oscillation is significantly high at maximum power point. We are trying to reduce the oscillation by introducing fuzzy controller. We have combined the fuzzy concept of controller along with P & O technique. In this case, perturbation causes slight increase in the value of voltage which again lies in the same membership function of voltage. Thus the oscillation to achieve maximum power is low. We have compared the output of MPPT controller in case of simple P & O technique with that in fuzzy P & O technique. This fuzzy PI controller generates a control signal which is passed to PWM generator and it generates pulse signal with variable duty cycle which is used as control signal to the switch of the DC to DC converter. As we have discussed that for sudden change in atmospheric condition P & O approach does not perform well. The introduced fuzzy PI controller reduces the oscillations. Here same process is repeated periodically until MPPT is reached under different condition of temperature and radiation. Duty cycle is generated by our fuzzy controller which actually controls the switching frequency of switch used in DC to DC converter. Hence, the performance of the system improves while using MPPT controller in fuzzy P & O method.

8. Fuzzy Controller Used To Track MPPT

Fuzzy logic control is one of the best control strategy used in controlling the system, as it eliminates the need of system mathematical model. It consists of three blocks- first fuzzification block, second rule base block and third defuzzification block. Fuzzy system receives error or/and derivative of error process it and generates control signal that is crisp value, which is used to control the system [12].

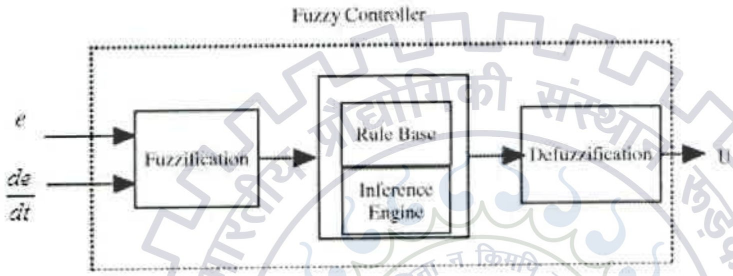


Fig.8.1 basic block diagram of fuzzy controller

In above figure it is clear that there are three part of fuzzy control system which is used to control the system in efficient manner. Rule base block is basically collection of some rules that depend upon the number of inputs and outputs. And during defuzzification some inference engine is used which is use to calculate the crisp value of output control signal. Some of the inference engines are Mamdani inference engine, Takagi- sugeno inference engine and so on. But these two inference engines are most popular and commonly used in designing controller in matlab [9]. Actually in mamdani implication [2] we don't bother about the system because it is adaptive system. But in takagi sugeno implication [3] system should be known to us. Takagi sugeno is actually indirect adaptive.

(a) Fuzzification

Since rule base block is made of certain number of membership function, so when a crisp value of input variable comes into the controller then it is mapped by these membership functions and this process is called fuzzification. These variables are called fuzzy variables. for each variable there is certain number of membership function in the given universe of discourse. So here in our block diagram there are two fuzzy variables are present one is error and other one is derivative of error. On introducing MPPT fuzzy

PI control we have also two fuzzy variables available. One is the output coming from difference between the MPPT controllers which is based on perturb and observe algorithm and the output voltage of PV panel and second fuzzy variable is derivative of the above difference signal.

(b) Rule base

In the processing part of fuzzy control, some set of rules are introduced. For each input variable there is a rule and also result of each rule is generated. By combining these result to get a crisp value of the output control value, which is used as control signal for the system. Fuzzy rules are basically based on approximate reasoning. Rules are like IF-THEN type. Suppose if error has some value then it will generate some value of output like that. It consists of antecedent and consequent part. If we have two inputs variable as fuzzy sets and each has three membership functions and output variable has also three membership function. Then there are total nine rules will form. All possible combinations are formed as rules [10]. Membership function can have different shape such as triangular, trapezoidal, it can be bell shaped, or it can be like Gaussian type of curve, it may be exponential type of curve also possible. Universe of discourse is adjusted according to the range of input variables that is coming into the controller. There are different types of interpretation of fuzzy rules such as modus poneus, hypothetical syllogism etc.

(c) Defuzzification

Defuzzification process is the last processing done in fuzzy controller. Actually in defuzzification there is an averaging of the entire fired rule at a time for a given value of error. After averaging we will get a crisp value of control signal for that error signal. It implies that for a particular value of error produce some value of control signal which force the system to work as per expectation with less error. Actually this averaging is aggregation that is recommendation of all the rules.

For a good defuzzification several things are required such as continuity, unambiguity, plausibility, and computational complexity. There are different defuzzifications rules are there (Mamdani inference) such as centre of area or centre of gravity defuzzification but this process of defuzzification is slow. Second method is centre of sum defuzzification, next centre of largest area, height defuzzification (takagi sugeno), bisector method of defuzzification, largest of maxima, middle of maxima, smallest of maxima.

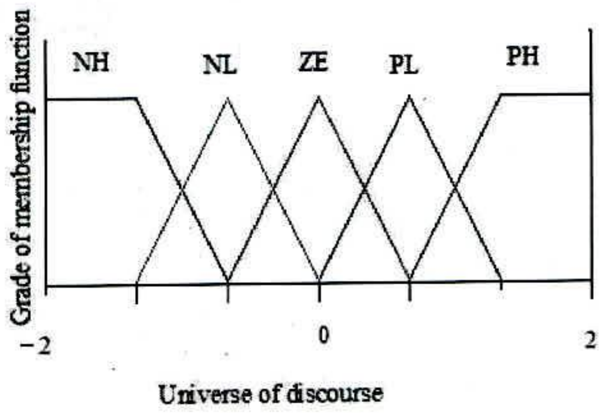


Fig. 8.2 membership function for input (e) of fuzzy control in MPPT

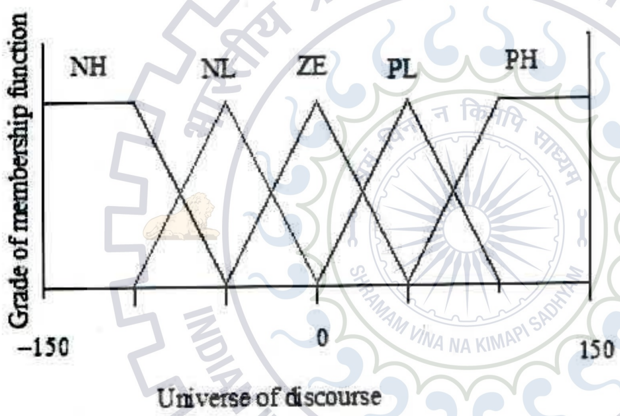


Fig.8.3 member function for input (CE) of fuzzy controller

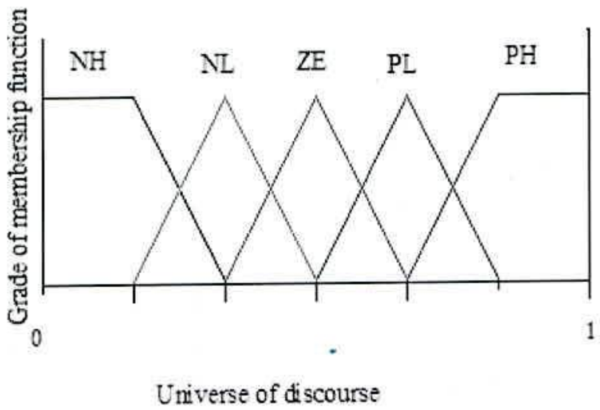


Fig.8.4 membership function of output variable of fuzzy controller

E \ CE	NH	NL	ZE	PL	PH
NH	PS	PB	PB	PS	M
NL	S	PS	PB	PB	PB
ZE	PB	M	M	M	S
PL	VS	S	S	PB	PB
PH	VS	VS	PB	PB	PB

This is the rule base for fuzzy controller based MPPT with perturb and observe technique actually by introducing fuzzy controller along with the perturb and observe block then oscillation at the maximum power point reduced by some amount and this lead to reduction in loss at the load end.

9. Simulink model

9.1 Simulink Model of PV Module

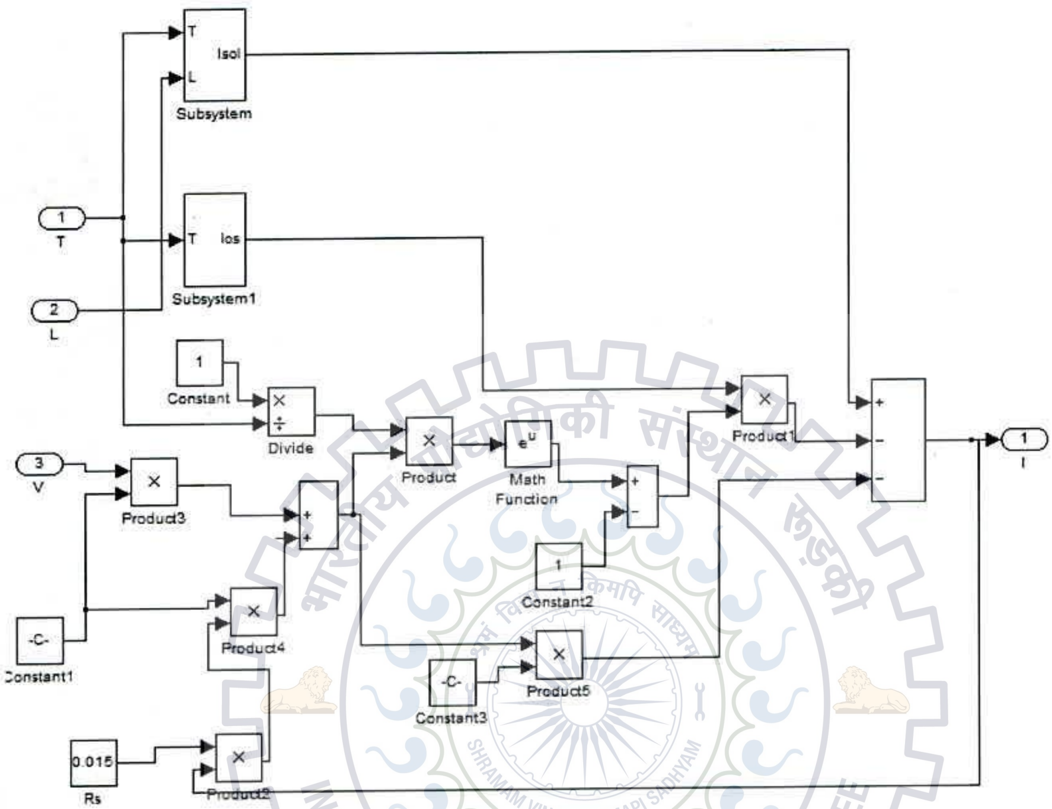


Fig 9.1 Simulink model of PV cell

In fig 9.1 Simulink model of PV array is shown. Here L represents the radiation level. This model is based on the mathematical relation between output voltage V and current I as discussed in chapter 3. Series resistance of cell is taken as 0.0015 Ω. Ambient temperature is 300 K and value of shunt resistance is 6.5 kΩ.

9.2 Simulink model of P & O algorithm

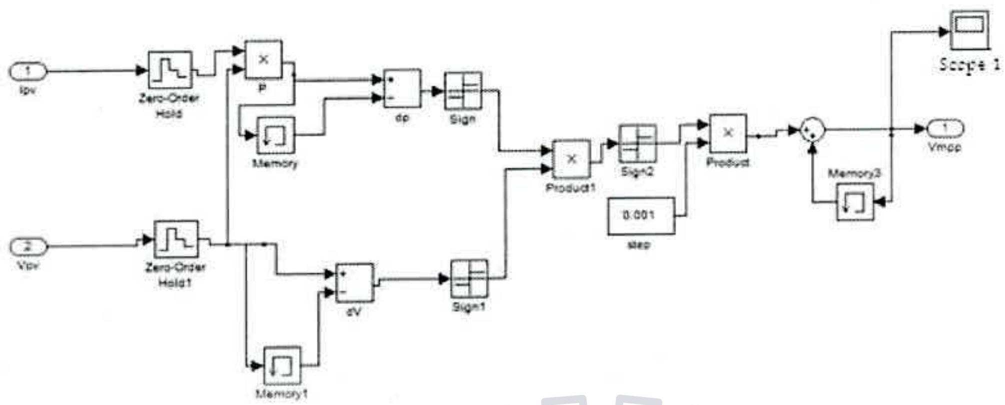


Fig 9.2 Simulink model of perturbs and observe

In the above figure, I_{pv} and V_{pv} are the solar cell's output voltage and current respectively. Sample of current and voltage is taken and it is hold by zero order hold circuit. Holding of sample values are required to compare with new sample value. Power is also calculated in above figure 9.2 by multiplying the sample value of current and voltage. Change in power and voltage both are checked during each cycle. And according to sign some constant step size is added. In our model step size is fixed to 0.001. After simulation control signal can be view from scope 1.

9.3 Simulink model of MPPT of PV array using P&O

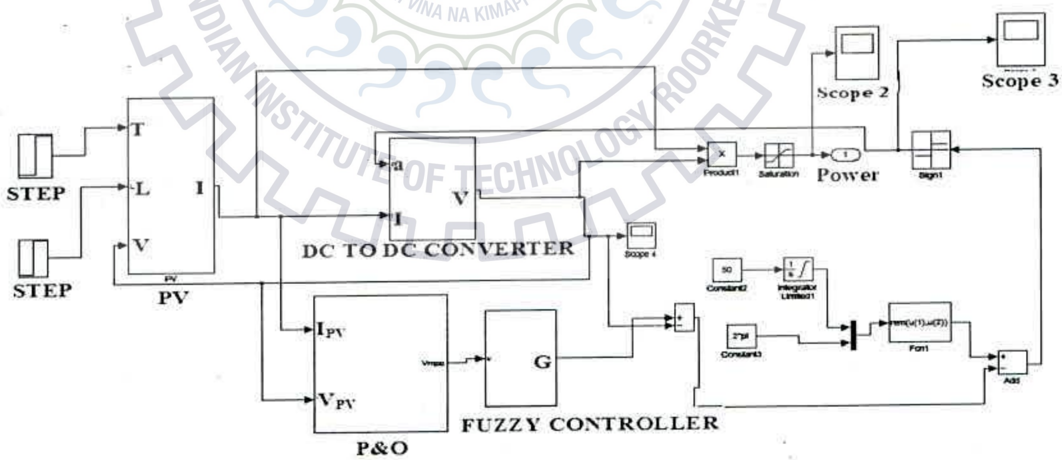


Fig .9.3 Simulink model of MPPT of PV array using P & O algorithm

Above figure is the Simulink model of MPPT of PV array using P&O algorithm for step change in both temperature (T) and radiation (L). Here an extra block of fuzzy controller is added after P&O block. Control signal generated from controller is used to ON or OFF the switch in DC to DC converter. Temperature is changed from 320.18 K to 600 K at t=0.15 s and radiation is changed from100 w/m^2 to 1000 w/m^2 at t=0.05 s. A pulse signal is observed in scope 3 with varying duty cycle. Maximum power is obtained in scope 2 with some oscillation.

9.4 Simulink model of MPPT of PV array using P&O

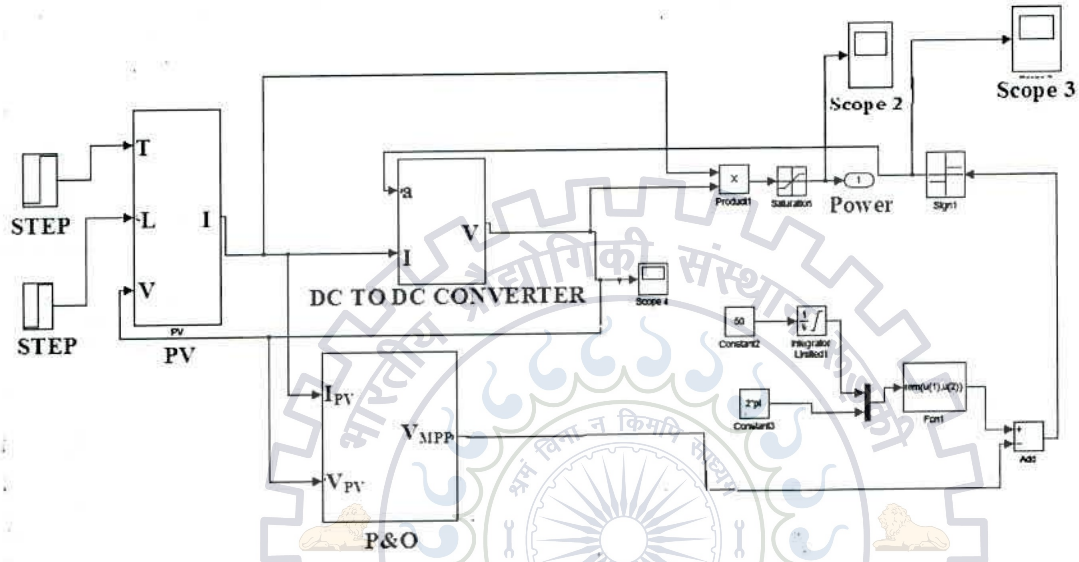


Fig. 9.4 MPPT of PV array using P&O

Above figure is the Simulink model of MPPT of PV array using P&O algorithm for step change in temperature as well as radiation. Here control signal is generated by P&O block. This control signal is directly feed to PWM generator which generate pulse signal. Maximum power is obtained on scope 2. And duty cycle is observed in scope 3.

10. Results:

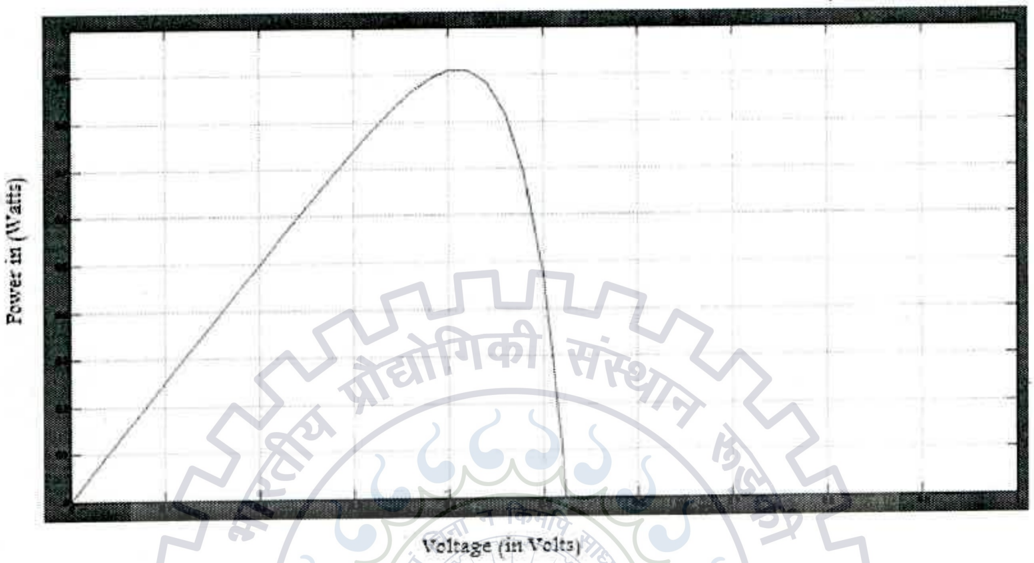


Fig.10.1 PV output power versus voltage plot

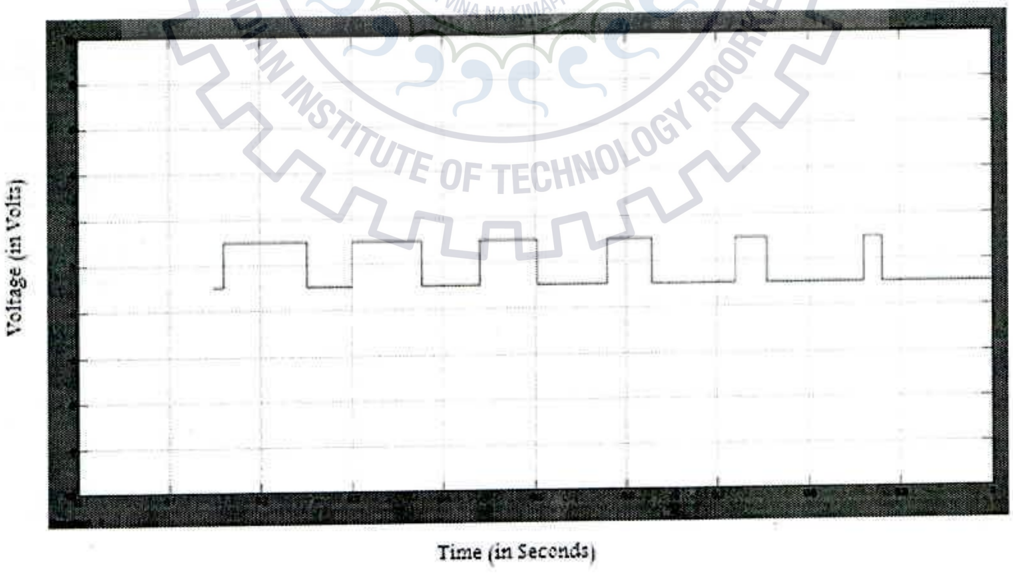


Fig.10.2 duty cycle output of PWM generator

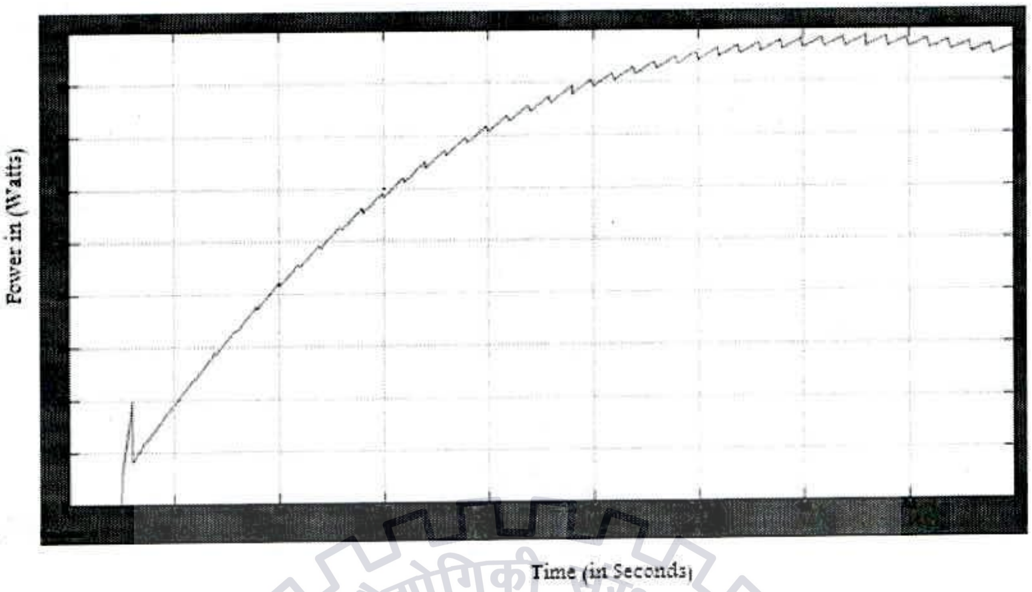


Fig.10.3 output power of control system when perturb and observe algorithm is used

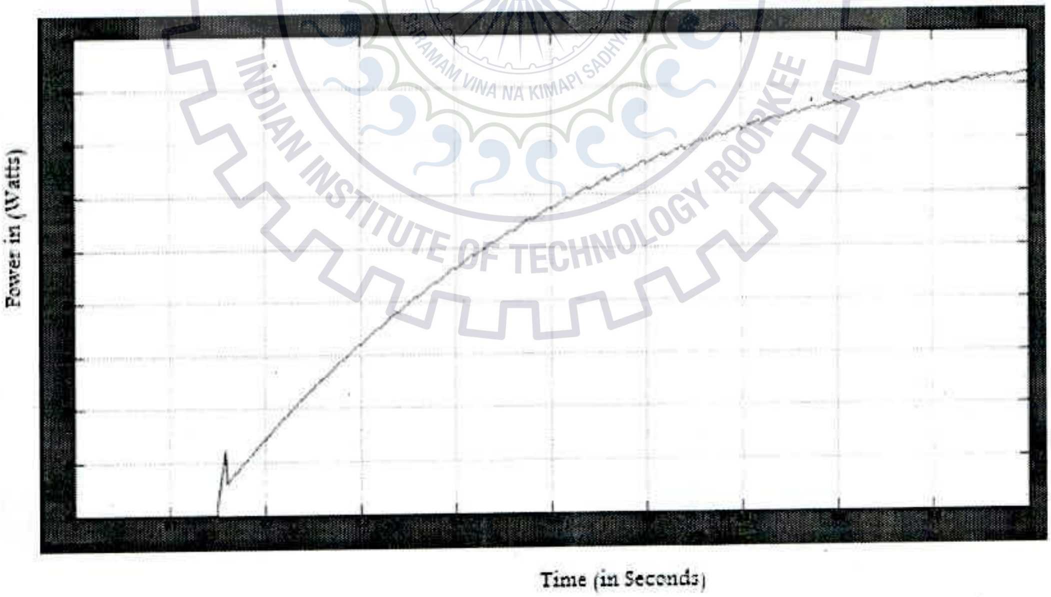


Fig.10.4 output power of control system when fuzzy controller is used MPPT with perturb and observe.

From figure 10.3 and 10.4 it is clear that in both cases maximum power is reached successfully but in first case oscillation of power is more than comparison with second one where oscillation is there but smaller than previous

11. Conclusion

We have simulated the PV module in matlab and showed the P-V characteristics in fig 10.1 for fixed value of temperature is 300 K and radiation is 1000 w/m^2. As shown from the P-V curve there is a unique point at which maximum power exists for particular value of voltage. So in this dissertation we are trying to track maximum power point efficiently by fuzzy P & O MPPT controller for step change in the input temperature from 320.18 K to 600 K and input irradiation from $100 w/m^2$ to 1000 w/m^2 (figure 10.4).

We have compared the result from simple P & O technique with that of fuzzy P & O MPPT controller (See Figure 10.3-4). And we conclude that both track the maximum power but fuzzy based perturb and observe MPPT controller tracks maximum power more efficiently than simple perturb and observe based MPPT controller and the output power fluctuation of fuzzy based controller is lesser as compared to simple perturb and observe controller.

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