

Maximum Power Point Tracking of PV Arrays using Different Techniques

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ABSTRACT

The increasing demand for electricity and depleting fossil fuels made the solar Photovoltaic (PV) systems to be a better alternative for the future power requirements. The fact that the output of the PV system is dependent upon the solar irradiance and temperature demands a means to maximize the output of the PV system by continuously tracking the maximum power point(MPP) under changing atmospheric conditions. This paper presents the design and implementation of various techniques like perturb and observe (P&O) method, incremental conductance method, constant current method and constant voltage method. The performance of the techniques have been analyzed through simulation

Keywords –Solar Photovoltaic (PV) system, Maximum Power Point(MPP),Maximum Power Point Tracking(MPPT), perturb and observe(P&O) method, incremental conductance method, constant current method, constant voltage method

I. INTRODUCTION

The use of efficient photovoltaic solar cells has emerged as an important solution in energy conservation and demand side management. Owing to their initial high costs, they were not an attractive alternative for users who are able to buy cheaper electrical energy from the utility grid. However, they have been extensively used in pumping and air conditioning in remote and isolated areas where utility power is not available or too expensive to transport. Although solar cell prices have decreased considerably during the last years due to new developments in the film technology and the manufacturing process [1], PV arrays are still considered rather expensive compared with the utility fossil fuel generated electricity prices.

Photovoltaic system as a number of applications such as water pumping, domestic and street lighting, electric vehicles, hybrid systems, military and space applications, refrigeration and vaccine storage, power plants, etc., all in either stand-alone or grid-connected configurations. A PV array is by nature a nonlinear power source, which under constant uniform irradiance has a current–voltage (I–V) characteristic like that shown in Fig.1. There is a unique point on the curve, called the maximum power point (MPP), at which the array operates with maximum efficiency and produces maximum output power. As it is well known, the MPP of a PV power generation system

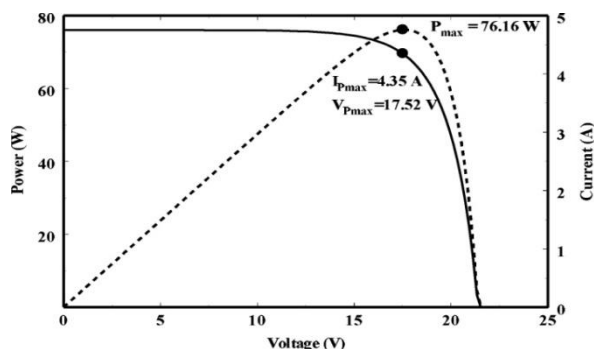


Fig. 1. PV array I–V and P–V characteristics.

depends on array temperature, solar insolation, shading conditions, and PV cells aging, So it is necessary to constantly track the MPP of the solar array. A switch-mode power converter, called a maximum power point tracker (MPPT), can be used to maintain the PV array's operating point at the MPP. The MPPT does this by controlling the PV array's voltage or current independently of those of the load. If properly controlled by an MPPT algorithm, the MPPT can locate and track the MPP of the PV array. However, the location of the MPP in the I–V plane is not known a priori. It must be located, either through model calculations or by a search algorithm. Fig. 2 shows a family of PV I–V curves under increasing irradiance, but at constant temperature. Needless to say there is a change in the array voltage at which the MPP occurs. For years, research has focused on various MPP control algorithms to draw the maximum power of the solar array. These techniques include look-up table

methods, perturbation and observation (P&O) methods [3]–[6], and computational methods [7].

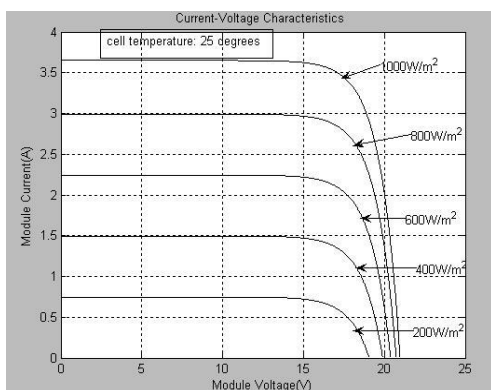


Fig.2. PV array (I –V) characteristics at various insolation levels.

This paper presents the design and implementation of various techniques like perturb and observe (P&O) method, incremental conductance method, constant current method and constant voltage method. The performance of the techniques has been analyzed through simulation.

II. SIMULATION OF THE PV SYSTEM

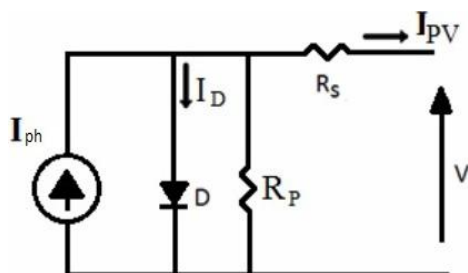


Fig 3:Equivalent circuit of the solar cell
 An equation that represents I-V characteristics of a solar array is given by the following mathematical equation as:

$$I = I_{ph} - I_s \left[\exp\left(\frac{q(V + IR_s)}{mkT}\right) - 1 \right] - \frac{V + IR_s}{R_p} \quad \dots(2.1)$$

Equation (2.1) is used in computer simulations to obtain the output characteristics of a solar cell. To simulate the selected PV array, a PV mathematical model having N_p cells in parallel and N_s cells in series is used according to the following equation (neglecting shunt resistance):

$$I = N_p I_{ph} - N_p I_s \left[\exp\left(\frac{q(V + IR_s)}{mkTN_s}\right) - 1 \right] \quad \dots(2.2)$$

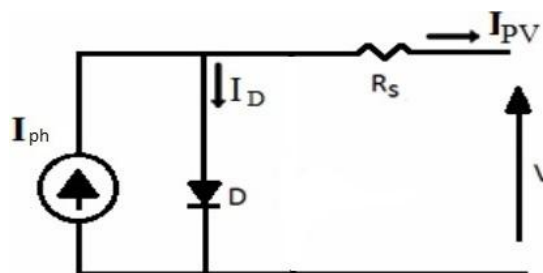


Fig 4:Model neglecting shunt resistance

Assuming that the selected solar module has N_p equal to 1, the above equation can be rewritten as:

$$I = I_{ph} - I_s \left[\exp\left(\frac{q(V + IR_s)}{mkTN_s}\right) - 1 \right] \quad \dots(2.3)$$

In particular, the cell reverse saturation current, I_s , varies with temperature according to the following equation as:

$$I_s = I_{s(T_1)} \left(\frac{T}{T_1}\right)^{3/m} \exp\left(\frac{qV}{mk} \left(\frac{1}{T} - \frac{1}{T_1}\right)\right) \quad \dots(2.4)$$

$$I_{s(T_1)} = I_{sc(T_1)} / \left(\exp\left(\frac{qV_{oc(T_1)}}{mkT_1}\right) - 1\right) \quad \dots(2.5)$$

The photo current, I_{ph} , depends on the solar radiation (S) and the temperature (T) according to the following equation as:

$$I_{ph} = I_{ph(T_1)} (1 + K_0(T - T_1)) \quad \dots(2.6)$$

$$I_{ph(T_1)} = S * I_{sc(T_1, norm)} / S_{norm} \quad \dots(2.7)$$

Where

$$K_0 = (I_{sc(T_2)} - I_{sc(T_1)}) / (T_2 - T_1) \quad \dots(2.8)$$

The series resistance of the cell is given as:

$$R_s = (dV/dI_{V_{oc}}) - (1/X_V) \quad \dots(2.9)$$

Where

$$X_V = I_{0(T_1)} * (q/mkT_1) \exp\left(\frac{qV_{oc(T_1)}}{mkT_1}\right) \quad \dots(2.10)$$

The PV power, P , is then calculated as follows:

$$P = N_p I_{ph} V - N_p I_s \left[\exp\left(\frac{q(V + IR_s)}{mkTN_s}\right) - 1 \right] = I \times V \quad \dots(2.10)$$

The specifications of the selected PV array shown in Table 1

At temperature=25°C		
Open Circuit Voltage	V_{oc}	21.0 V
Short circuit current	I_{sc}	3.74 A
Voltage at max power	V_m	17.1 V
Current at max power	I_m	3.5 A
Maximum power	P_m	60.0W

Table 1: Specifications of the PV panel

the quantity in a given direction and the power drawn from the PV array is probed. If it increases, then the operating voltage is further perturbed in the same direction whereas, if it decreases, then the direction of operating voltage perturbation is reversed. The drawbacks of this method are that the operating point oscillates around the MPP, even during sunny days when the irradiance is slowly varying, giving rise to the waste of some amount of available energy, slow response speed, and even tracking in wrong way under rapidly changing atmospheric conditions.

III. MPPT BY P&O METHOD

In a typical P&O MPPT method, the operating voltage of the PV array is perturbed by changing

In this method, first the values of voltage and current are initialized and the array power for these values is found. Next the power corresponding to the perturbed voltage is found and compared with the previous power. If it results in increase of the power, then the perturbation is continued in the same direction by moderating the voltage.

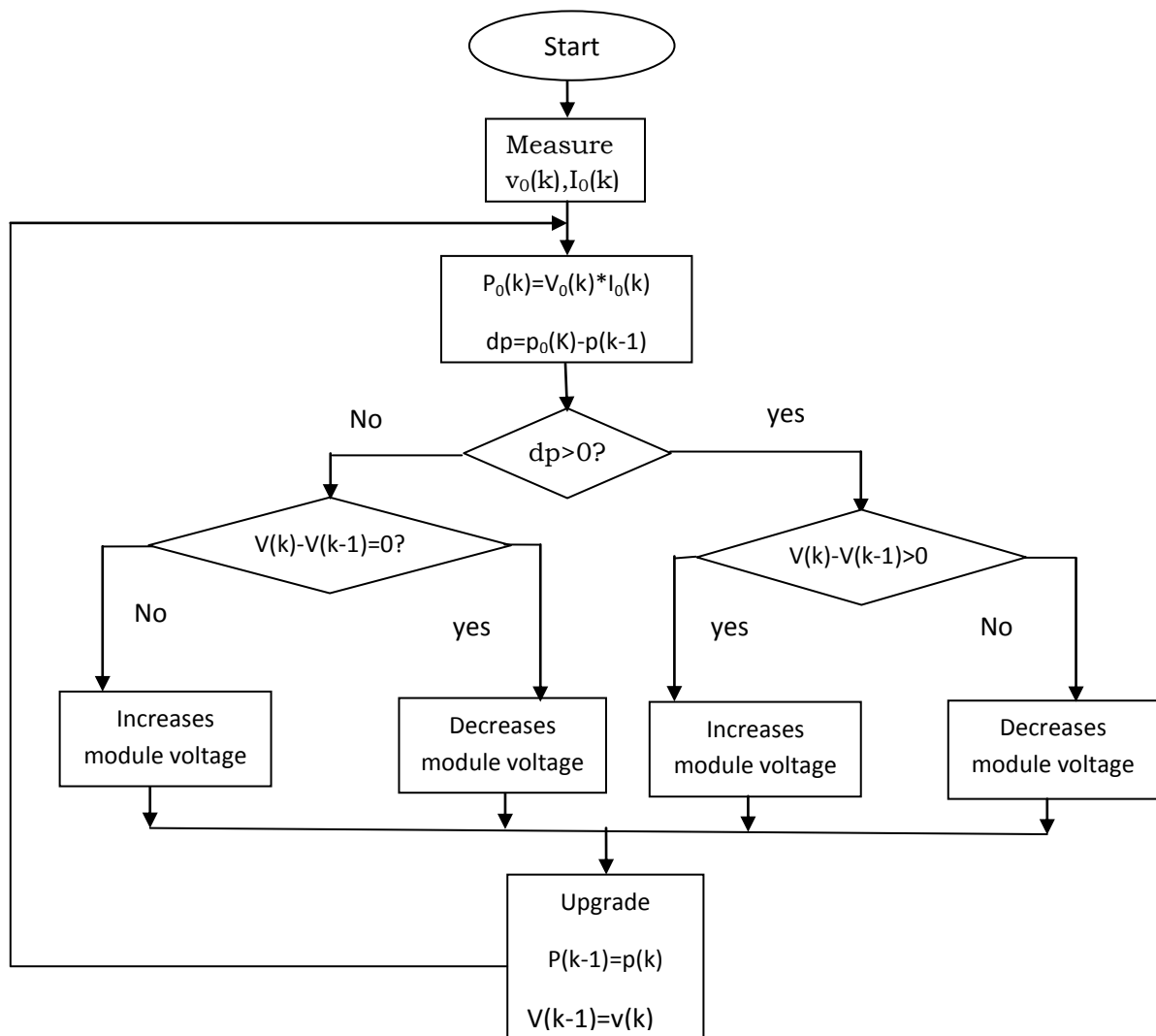


Fig.5: Flowchart for implementing P&O method

Otherwise, it is perturbed in the reverse direction. The sequence of operations performed is shown in the flowchart given in Fig 5. A Mat lab program is written for the implementation of the method on 60W solar panel and the result is presented.

In the implementation if this method, the change be considered either as the perturbation in the voltage or the perturbation in the current. In this work, a perturbation in the voltage is considered for the implementation of P&O method, and then the power changes are sensed are accordingly the voltage modifications are implemented.

The P&O method of tracking maximum power point is implemented in Mat lab environment. Maximum power obtained is found as 59.7637 W.

IV. MPPT BY INCREMENTAL CONDUCTANCE METHOD

The incremental conductance method is used an MPPT method. The advantage of using this method to track MPP is that it is more efficient than the P&O method in a way that it is able to correctly locate the operating point of the PV array. There is a tradeoff between the power efficiency and reliability of tracking MPP. Since the P&O method will move away from the power operating point under rapidly changing light condition and not be able to go back the maximum operating point quickly, this will lead to the inefficient use of the PV array and hence this affects the whole system

performance of tracking MPP. Other advantage of using this method is it does not depends on the device physics.

This method uses the source incremental conductance for its MPP search method. It is more efficient than Perturb and Observe method and independent of device physics. The output voltage and current from the source are monitored upon which the MPPT controller relies to calculate the conductance and incremental conductance, and to make its decision to increase or decrease duty ratio output.

Mathematics of the Incremental Conductance method is discussed below.

The output power from the source can be expressed as

$$P=V*I \quad \dots(5.1)$$

The fact that $P=V*I$ and the chain rule for the derivative of product yields

$$(1/V)dP/dV = (I/V) + dI/dV \quad \dots(5.2)$$

Let us define the source conductance G as

$$G=I/V \quad \dots(4.1)$$

And the source incremental conductance as

$$\Delta G=dI/dV \quad \dots(4.2)$$

It is learnt that the operating voltage below at the maximum power point if the conductance is larger than the incremental conductance and vice versa. The job of this method is therefore to search the voltage operating point at which the conductance is equal to the incremental conductance. These ideas are expressed by equations 4.3, 4.4, 4.5 and are graphically shown in Fig 6.

$$dP/dV < 0, \quad \text{if } G < \Delta G \text{ ----(4.3)}$$

$$dP/dV = 0, \quad \text{if } G = \Delta G \text{ ----(4.4)}$$

$$dP/dV > 0, \quad \text{if } G > \Delta G \text{ ----(4.5)}$$

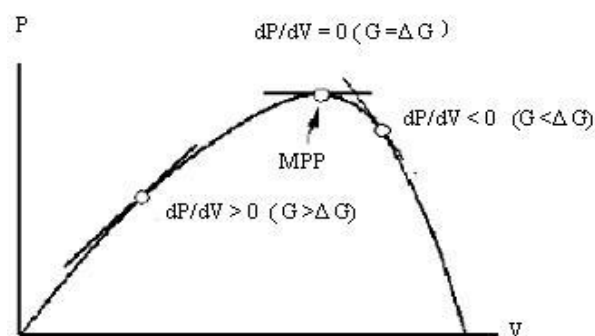


Fig.6: The P-V curve

The program flow chart for this algorithm is shown in Fig 7. the operating output current ($I_{in}(k)$) and voltage ($V_{in}(k)$) are measured from the solar panel. The incremental changes dV and dI are approximated by comparing the most recent measure values for ($I_{in}(k)$) and ($V_{in}(k)$) with those measured in the previous cycle ($I_{in}(k-1)$) and ($V_{in}(k-1)$). Then G and ΔG are computed as per the equations 4.1 and 4.2. From equation 4.4, if $dP/dV=0$ (i.e. $G = \Delta G$) is true, then the system operates at the MPP and no change in operating voltage is necessary, thus the adjustment step is

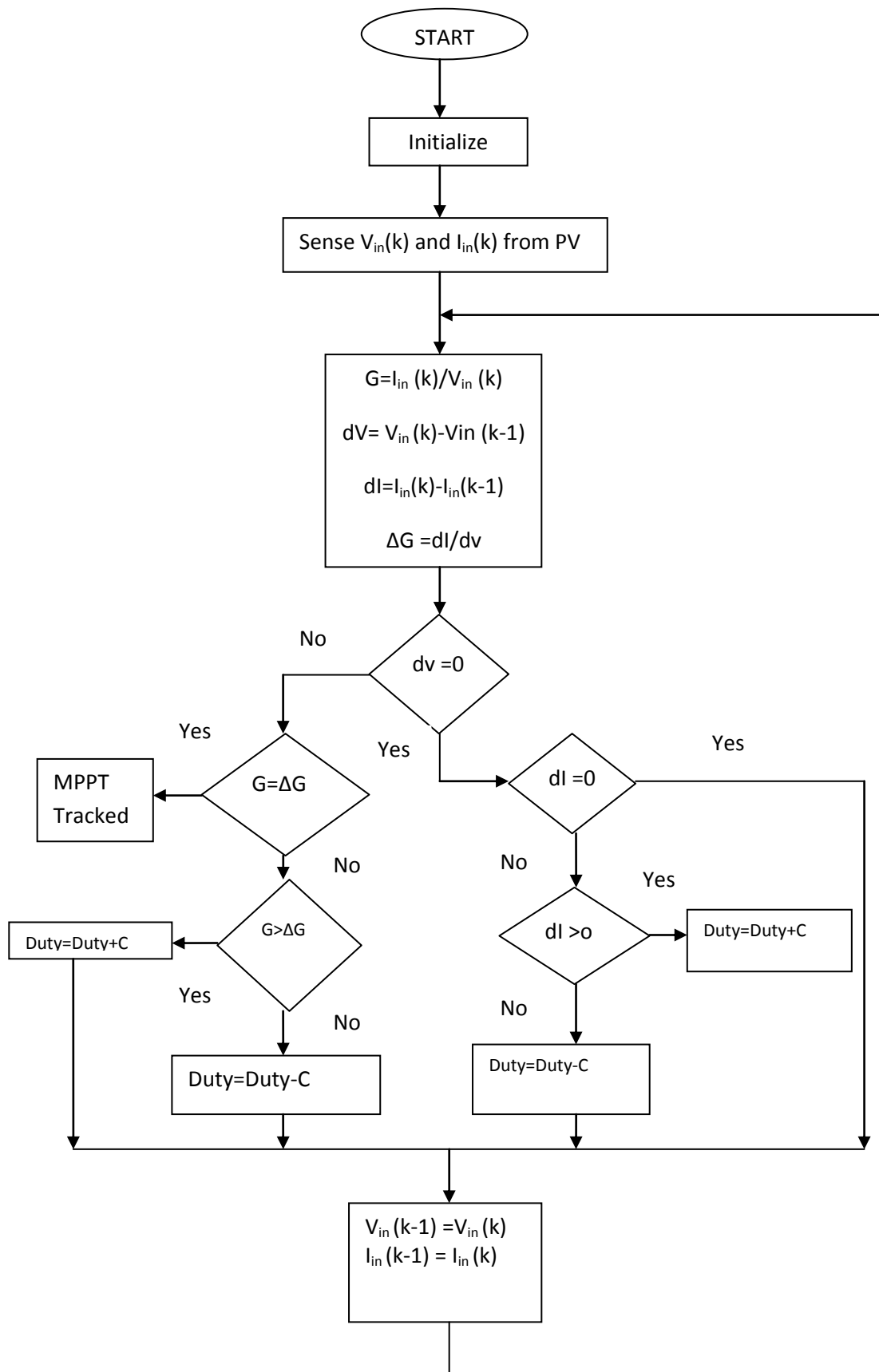


Fig.7: flow chart of Incremental conductance method

bypassed i.e. no adjustment for the duty ratio and the current cycle ends. If equation 4.4 is false, equation 4.3 and 4.5 are used to determine whether the system is operating at a voltage greater or less than the MPP voltage and hence to increase or decrease the duty ratio by a step-size of some value accordingly.

If the system is operating at the MPP during the previous cycle, the incremental change of the operating voltage is zero ($dV=0$). This would lead a division by zero i.e. $\Delta G = dI \div dV = dI=0$, which is impossible for calculation. To avoid this, the condition ($dV = 0$) is checked first and if true leads to another branch in the algorithm with further tests on possible changes of the panel's operating conditions. Since the voltage $dV = 0$, that means the voltage has not changed; now the only useful information about possible changes are found from the current measurement. If dI is equal to zero, the operating conditions have not changed and therefore the adjustment of the system voltage is bypassed. If $dI > 0$, the duty ratio is increased by step size and if $dI < 0$, the duty ratio is decreased by step size. The program then returns and starts tracking again until the MPP is reached. The maximum duty cycle ratio is set at 90% and the minimum is at 10% and hence contributes to the efficient power transfer of the converter. The programming results are also presented.

The incremental conductance method is implemented using Mat lab programming. The maximum power tracked using Incremental Conductance method is 59.9902 W. The oscillations around operating point in P&O method are eliminated in this method.

V. MPPT BY CONSTANT CURRENT METHOD

This method is based on the observation that MPP current (I_{mp}) has almost a linear relation with short-circuit current (I_{sc}) of the PV panel.

$$I_{mp} = M_c * I_{sc} \quad \dots (5.1)$$

Where M_c is called the current factor and is equal to 0.86 for the silicon panel has different values for different solar panels ranging from 71% to 86%.

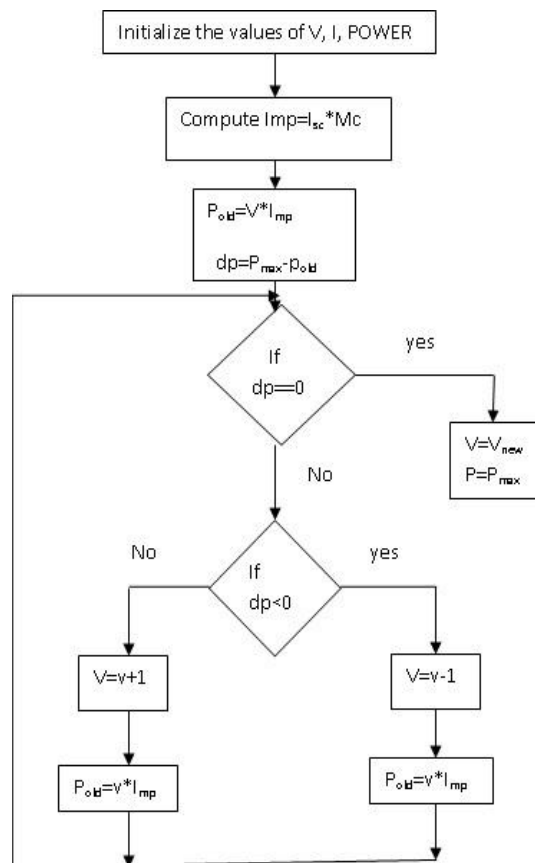


Fig.8: Flow chart for constant current MPPT method

In this method, the short circuit current, I_{sc} is computed for the considered 60 watt solar module. Then, it is multiplied by a factor, M_c of suitable value (0.86 in this case) to obtain the current (I_{mp}) corresponding to the maximum power. For this fixed value of current, the power is computed for different voltages. If the difference between the power computed and the peak power is larger than the tolerance value, then value of voltage is either incremented or decremented depending on the power obtained. For that corresponding voltage and MPP current (I_{mp}), this process is repeated till the difference is in the tolerance range. The program flow chart for constant current algorithm is shown in Fig. 8.

The constant current method is implemented in Matlab environment. Maximum power obtained is found as 59.641 W.

VI. MPPT BY CONSTANT VOLTAGE METHOD

This method is based on the observation that MPP voltage (V_{mp}) has almost a linear relation with open circuit voltage (V_{oc}) of the PV panel

$$V_{mp} = K * V_{oc} \quad \dots(6.1)$$

Where, K called the voltage factor is equal to 0.71 for silicon panel and has different values for different solar panels ranging from 71% to 86%.

The PV panel is locked at the reference voltage given by equation 6.1. The open-circuit voltage required to determine the MPP voltage is measured by disconnecting load from the PV panel after regular intervals. The measured value of V_{oc} and K are stored and used for determination of the PV panel voltage V . To operate the panel at MPP, the actual PV panel voltage V is compared with the reference voltage V_{ref} , which corresponds to the MPP voltage V_{mp} . The error signal is processed to make $V = V_{ref}$. The error signal is used to change the duty cycle of a dc-dc converter, interfaced between the PV panel and the load, so as to make the PV panel voltage equal to the MPP voltage as shown in fig 9.

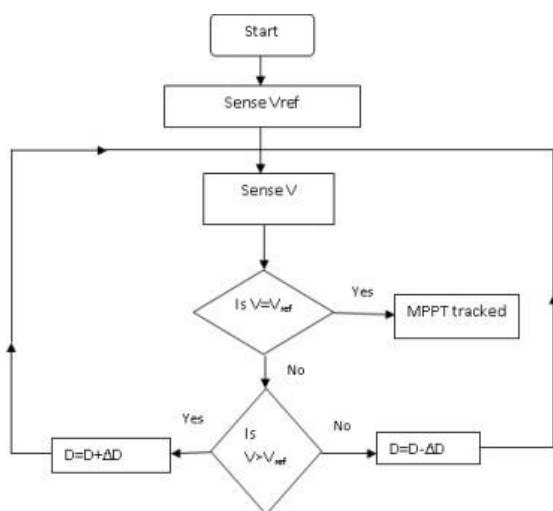


Fig.9: Flow chart of constant voltage method

This method is very simple to implement, but it is not accurate. A problem with this method is that the available energy is wasted when the load is disconnected from the PV array; and also the MPP is not always located at 71% of the array's open circuit voltage. There is substantial power wastage, as it does not take in to account the effects of changes in solar insolation and temperature.

Simulation and results

The PV panel is formed by the combination of many PV cells connected in series and parallel to provide the desired output voltage and current. The PV panel exhibits a non linear insolation dependent V-I characteristic, mathematically expressed for the solar cell array consisting of N_s

cells in series and N_p cells in parallel as shown in equation 5.12.

$$I = N_{ph} I_{ph} - N_p I_s \left[\exp \left(\frac{q(V + I R_s)}{m k T N_s} \right) - 1 \right] \quad \dots(6.2)$$

Equation 5.12 can be rewritten in terms of array voltage as:

$$V = (N_s m k T / q) \log \left((N_{ph} I_{ph} - I + N_p I_s) / N_p I_s \right) - (I R_s N_s / N_p) \quad \dots(6.3)$$

Where

- q- Electric charge
 - m- Diode ideality factor
 - K- Boltzmann's constant
 - T- Absolute temperature
 - R_s - cell series resistance
 - I_{ph} - photo current
 - I_s - cell reverse saturation current
 - N_p - number of parallel strings
- I and V are the panel current and voltage respectively.

To determine the operating point corresponding to maximum power, equation 6.3 is used in simulation.

The simulation results are shown in below fig 10, Fig 11 and Fig 12.

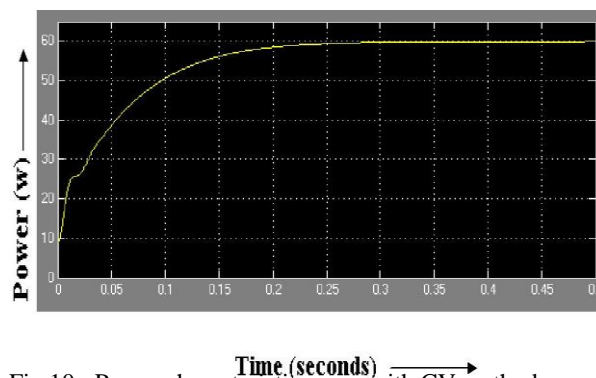


Fig.10: Power characteristic curve with CV method

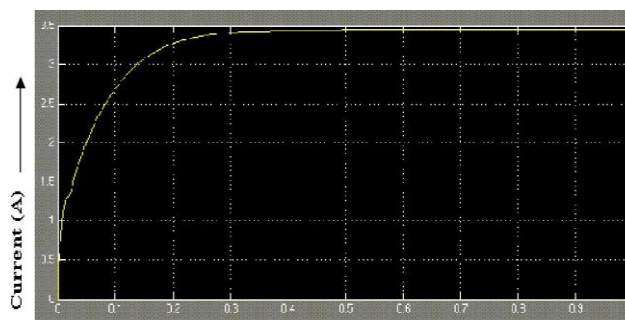


Fig.11: Current characteristic curve with CV method

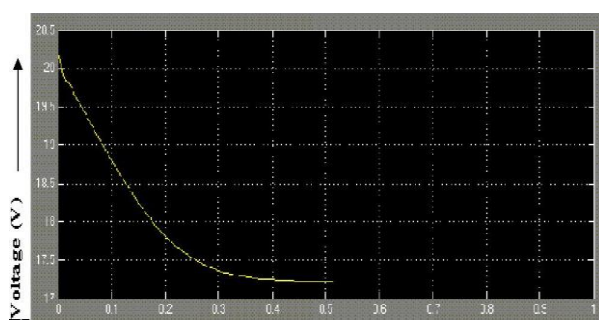


Fig.12:Voltage characteristic curve with CV method

Constant voltage maximum power point tracking is implemented on a 60 W panel using Matlab Simulink and the graphical results are presented. It is assumed that the voltage at minimum power point is 0.71 times that of the open circuit voltage of the panel.

VII. CONCLUSIONS

In Perturbation and Observation method, a small perturbation is given to the module voltage and the peak power is tracked using the method. The maximum power point tracking of the module for the Perturbation and Observation method is carried out using Matlab program and the maximum power tracked for the considered 60W module is 59.7637W. The method is simple to implement. But it was observed that the maximum power oscillates around the actual peak power obtained from modeling. This method is suitable for the large variations in temperature conditions.

P&O method will move away from the power operating point under rapidly changing light condition and will not go back to the maximum operating point quickly. This is overcome in Incremental Conductance method. In Incremental Conductance Method, the maximum power point tracking of PV module is carried out using Matlab program. It is found that a maximum power of 59.99W is achieved.

In Incremental Conductance method, the calculation of conductance and incremental conductance from output voltage and current are involved in the evaluation of MPP. The Constant Current method approximates the MPP current as a constant percentage of the short-circuit current. The maximum power point tracking of solar cells with the Constant Current method is carried out using Matlab program. The maximum achievable power obtained by this method is 59.641W, assuming the current multiplication factor as 86% which varies from panel to panel.

Although, Constant Current method is one of the simplest methods to implement the maximum power point tracking of solar cells, its practical

implementation finds difficulty in finding out the short circuit current of the PV array. Constant Voltage method is based on the observation that MPP voltage has almost a linear relation with open-circuit voltage of the PV panel. In Constant Voltage MPPT method, the maximum power point tracking of solar panel is carried out by running Simulink model in Matlab/Simulink environment. A maximum power of 59.96W is achieved for rated ambient conditions. The tracking time taken to achieve this power is 0.49 seconds. This method suffers from the disadvantage that measuring the open-circuit voltage requires a momentary interruption of PV power.

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