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Performance Analysis of Perturb & Observe and Open Circuit Voltage Algorithms for MPPT Tracking at Different Environmental Conditions

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Abstract— Photovoltaic PV is eco-friendly source of energy. Due to increase in ecological pollution and decrease in usual means of power, the importance of non-conventional energy sources has grown up rapidly. The output of PV systems depend on atmospheric conditions like temperature and irradiance. Also efficiency of PV system is very much less which needs to be increased. Installation cost is another problem existed with photovoltaic modules. Different techniques are used to get high power. MPPT of PV system at any condition is necessary to transfer maximum available power. Therefore, to generate maximum power at output of PV, installation of MPPT is necessary. Using MPPT, high efficiency of PV is also ensured. Different algorithms are utilized to track down MPP of PV. Out of all algorithms used, two algorithms are discussed briefly over here i.e. Perturb & Observe (P&O) and Open Circuit Voltage algorithms for MPPT at different environmental conditions by changing irradiance and temperature. Variation in temperature and irradiance level results in different output of PV cell. By changing slight temperature and irradiance, voltage and current at the MPP changes. Results which are obtained as a result of changing external conditions are simulated in PSIM and LTSpice and are then compared with each other. Effect on MPP, maximum voltage and maximum current at MPP are observed by changing environmental and atmospheric conditions like irradiance level and temperature. After comparing both these algorithms. Two different software named PSIM and LTSpice IV are being used for implementation and modelling of PV cell and both algorithms.

Keywords— MPPT, Maximum Power Point Voltage, Maximum Power Point Current, Perturb and Observe and Incremental Conductance.

I. INTRODUCTION

Photovoltaic (PV) provides green sustainable mean electric power, of which sun is the fuel, a renewable energy. Due to increase in ecological pollution and decrease in usual means of power, the importance of non-conventional energy sources has grown up rapidly. The main sources of pollution free power includes solar, wind turbine, geothermal, biomass and hydro. However, there are some drawbacks of renewable energy systems which have large cost of installation and small transformation efficiency of photovoltaic arrays. Photovoltaic also has nonlinear IV and PV characteristics curves and is greatly varied with change in irradiance and temperature.

Undeterred all the favorable factors put forwarded by photovoltaic cell energy generation, initial implementation cost is very large and efficiency of transformation of energy is very small. To achieve high efficiency in operation, some techniques are necessary to use for extracting maximum power available at PV panels output. It has been noticed that temperature greatly govern PV output voltage, and output PV voltage and irradiance has both a linear relation.

Normally, there is always a distinctive point on IV and PV curves and that point is known is Maximum power point (MPP) and efficiency of whole photovoltaic system (converters, PV cell, array, etc.) at MPP is maximum and generates its maximum power which is available at the output depending on environmental conditions. As MPP changes with seasons and insolation, it is very impossible to constantly keep track of MPP and get highest power at the output of PV system.

MPPT play vital role in a PV generation system. It has important role due to current and voltage characteristic which is nonlinear in nature of photovoltaic array or module. At changing temperature and solar irradiance, the nonlinear relation between power and voltage that PV becomes more complicated so the solving the problem of MPP analytically gets very difficult and as a result different algorithms have been proposed to track down MPP. All different MPPT are different from each other on the basis on different requirements like the number of required sensors, popularity, implementation hardware, complexity, cost, speed of convergence, efficiency range etc. Many algorithms are put forward to track the MPP that is MPPT of PV array. Those algorithms are Perturb & Observe, Incremental Conductance, short circuit, open circuit algorithm, fuzzy logic controller method etc.

The algorithm which sampled the operating voltage in the required direction to get maximum power, is called P&O algorithm. This iteration will continue unless it finally reaches the MPP.

II. PHOTOVOLTAIC CELL

For understanding the electronic behavior, it is necessary to design an electrical equivalent model of it. This model is based on well define behavior of discrete ideal components of electrical. Ideal PV cell might be electrically designed by current source connected in parallel with the diode. Practically, no ideal PV cell exist, due to which series and shunt resistances are connected.

Figure 1 shows that the total current generated by PV cell is equal to difference of current source and the current that flows through diode, minus the current which flows through shunt resistance
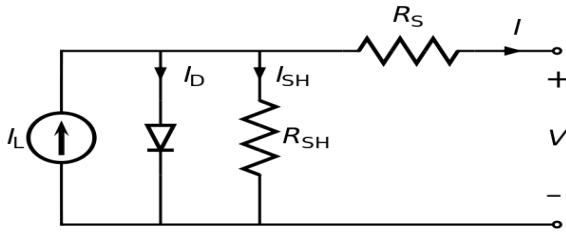

Figure 1. Single Diode PV Cell

Characteristic equation of PV cell is given in equation 1

$$I = I_L - I_0 \left(e^{\frac{V+IR_S}{nV_T}} - 1 \right) - \frac{V+IR_S}{R_S} \tag{1}$$

A. Modelling of PV cell in LTSpice IV

F Solar cell or Photovoltaic cell is modeled in LTspice and curves between V and I, and V, P are observed at different Irradiance level, parallel and series resistances given in figure 2.
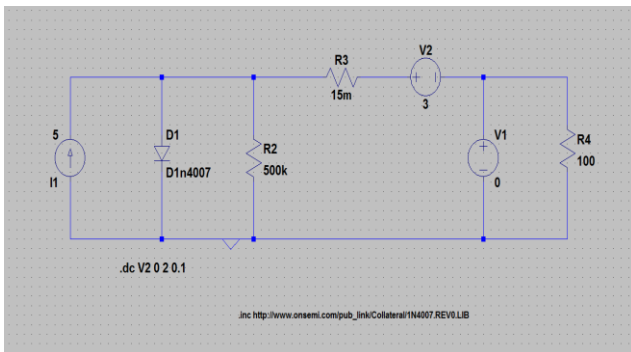

Figure 2. Basic Model of PV Cell

After simulating circuitry of PV cell in LTspice, the curve between I and V that is IV Curve is obtained at different irradiance level as shown in figure 3
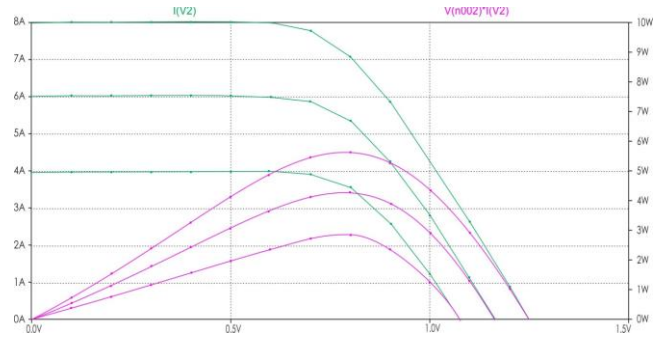

Figure 3. I-V at different Irradiance

B. Power Loss

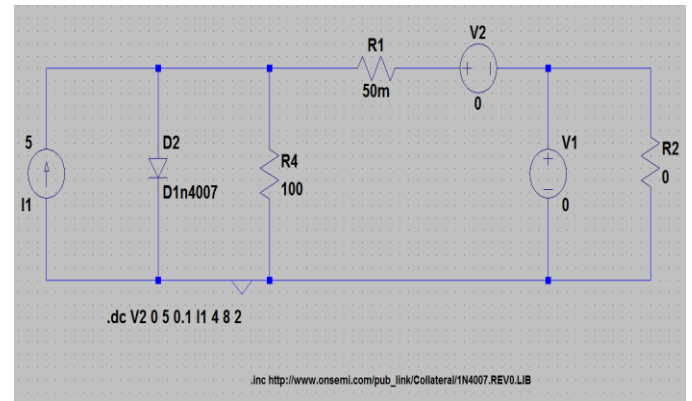The circuit diagram for calculating power losses in PV cell is given figure 4.

Figure 4. PV cell for Power loss

It has been observed that the current loss due to recombination is more than any other loss in photovoltaic cell. Graph of the power losses in PV cell is shown in figure 5.
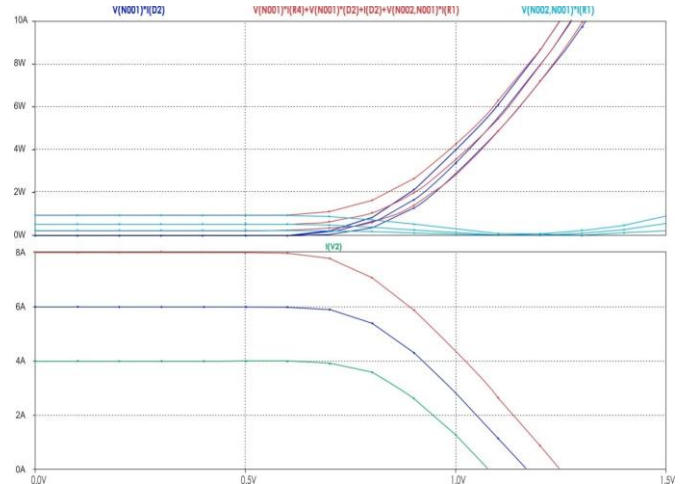

Figure 5. Power loss due to recombination

III. MPPT Algorithms in Photovoltaic Cell

MPPT is the process in which higher and greater is extracted out of photovoltaic module and is done with MPPT controller. By using MPPT, solar system efficiency can be increased gradually. The solar photovoltaic source has been acknowledged the most important resource of energy with the advancements in Power electronic technology. It is environmental friendly energy and is present in a very huge amount which is free. The use of MPPT can enhance PV efficiency. For tracking MPP efficiently, many MPPT methods have been developed. Among all the mostly used algorithms are P&O and Incremental Conductance algorithms. All other algorithms have a lot of drawbacks of either being slow or wrong tracking.

Power versus voltage curve has just on maximum point in normal conditions which isn't problem. But when the array is shaded partially, the number of maximum points increased from one to multiple. So some algorithms are implemented in order to relieve this problem. These techniques differed from each other in many aspects like cost, complexity, sensors required etc. Depending on the objective of the circuit algorithms are suggested that which one should be used.

A. Perturb and Observe (P&O)

This is mostly used method on commercial level. In most of the practical PV systems P&O is used dominantly due to its high reliability, simple implementation and high efficiency.

This is actually a trial and error method. In this method, MPPT is usually based on calculating power of PV system and power change by sampling the PV array current and voltage. It is operating by incrementing or decrementing the PV array voltage after fixed time interval.

Suppose a certain perturbation resulting in an increment or decrement in the PV power, following perturbation should be produce in similar or reverse way. Unless the MPP has been reached, chopper duty cycle constantly changed and repeated. It tells that system is oscillating around the MPP. Reducing step size of perturbation can reduce oscillations. But much smaller step reduces speed of MPPT which is its main drawback. For varying values of temperature and irradiance levels, PV system will give different curves and each curve will have highest power. At that stage maximum voltage is being deliver to the converter.

The P&O can easily be implemented but has many disadvantages which include

i) The energy from PV system can't be utilized fully because PV array isn't operated often at MPP due to slow error process and trial.

ii) The PV array operates in the mode of oscillation even if the sunshine is at steady-state which results in inverter output fluctuation.

iii) Because of sudden changes in sunshine the PV system might be failed to track thee MPP in correct direction.

B. Incremental Conductance

It is the process in which incremental changes in PV module's current and voltage are measured by controller to forecast impact of voltage change. This algorithm is complex than P&O but track the varying conditions quickly than P&O. It also produces oscillations in power. Under rapidly varying irradiation conditions it track more quickly and accurately than P&O but is costlier circuit.

In this, incremental conductance, dI/dV, of PV array is used to calculate the sign of power changing with respect to voltage, dP/dV. It calculate MPP by comparing incremental conductance (I_Δ/V_Δ) to array conductance (I/V). The output voltage is the voltage at MPP when both of above conductance becomes equal. Controller will maintain this voltage unless and until a change in irradiance or temperature occurs.

This algorithm works on principal of calculating slope of curves between power and voltage or power and current. If slope is zero of PV array it means that this system in at the MPP, positive slope means left of MPP and negative means right of MPP. Also Inc-Cond is based on the observation that $dP/dV = 0$, and that $P = IV$ at MPP. Current taken from PV is shown as function of voltage: $P = I(V)V$. Hence, $dP/dV = VdI/dV + I(V)$. Taking this to zero gives: $dI/dV = -I(V)/V$. So MPP is achieved if incremental conductance and negative of instantaneous conductance becomes equal.

Two main disadvantages of these techniques are in. Main drawback is that it easily loss track of MPP if irradiance changes quickly. It tracks the MPP very well in case of step change because curve doesn't keep on changing and the change is instantaneous. However, when change in irradiation follows a slope, the curve in which this method is based varies with irradiance, hence change in current and voltage is not just because of voltage perturbation. Hence, it is not possible to find whether power change is because of its own increase in voltage or change in irradiance.

C. Open Circuit Current

This uses the rough linear relation between V_{MPP} and V_{OC}, which continuously changes with change in temperature and irradiance level

$$V_{MPP} = K_1 V_{OC}$$

K_1 is constant number which is dependent on PV module properties and it should be calculated in advance by measuring V_{MPP} and V_{OC} for different temperatures and irradiation levels. The value of K_1 is being reported among 0.70 ad 0.77.

As K_1 is known, value of V_{MPP} is measured periodically by calculating the open circuit voltage V_{OC}. The converter needs to shut down momentarily for the measurement of V_{OC} so in every measurement power loss occurs. Other problems in this technique are that this technique is not capable of tracking MPP under irradiance slopes, because the determination of V_{MPP} is discontinuous and also because the relation is just supposition so the MPP reached is not the actual one.

Some techniques have been proposed for overcoming these problems. Like the use of pilot cell for obtaining open circuit

voltage V_{OC}. Pilot cells are like PV cells but not used to generate current and are only used to get characteristics parameters like open circuit voltage V_{OC} without disturbing or interfering with converters. The pilot cells are carefully selected and placed so that it represents the characteristic of PV module and the conditions of irradiation. Using pilot cell has also a drawback which is that the system cost is increased. This technique is used in the systems where cost is not an issue as these are very precise and can be implemented easily. It is also cheap in a sense that it doesn't need any DSP and just a single voltage sensor is used. But as in under partial shading this method is not valid and accurate because the value of K1 changes. Instead of this, voltage sweep is proposed but this increases the complexity and cost of system. Power losses also increase during sweep.

IV. MPPT ALGORITHMS SIMULATION IN PSIM

A. Modelling of Perturb & Observe (P&O) Algorithm

To simulate Perturb and Observe algorithm in PSIM we can divide the whole circuitry in three parts

- Sensing part is to sense current and voltage of PV module
- Buck converter to track the V_{MPP}.
- Control unit to generate the required PWM after processing the P&O algorithm.

Simulation results are given below which are simulated at different environmental condition

✓ Temperature = 25°C, Radiation= 1000$W/m2$

At standard condition the MPP of the panel is 60W and when the algorithm is run on PSIM it tracks the MPP in 2ms which is in figure 6.4. In figure red line shows MPP of PV array at standard condition whereas blue line is the operating power of PV array which shows that the algorithm tracks the MPP as shown in figure 6
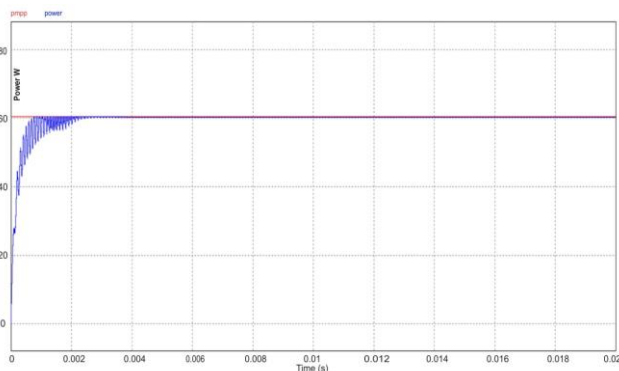

Figure 6.   At Standard Condition

✓ *Temperature = 25°C, Radiation = 1200W/m2*

At this environmental condition the P_{MPP} is 77W as in figure 7. When P&O algorithm is simulated at this specific condition the P_{MPP} is tracked in 3ms.
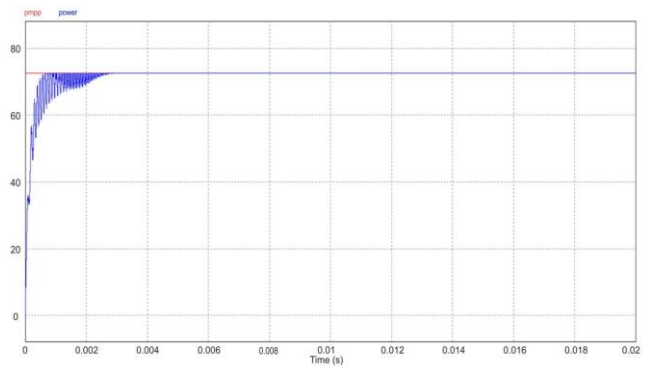

Figure 7.   At Temperature= 25°C and Radiation = 1200W/m2

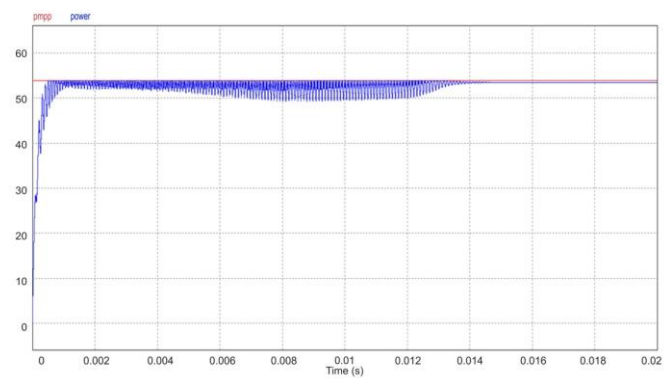✓ *Temperature = 50°C, Radiation = 1000$W/m2$*

Figure 8.   At temperature= 50°C, Radiation = 1000$W/m2$

The P&O algorithm is simulated with different environmental condition and it tracks the MPP very fast as compared to other algorithms. At low radiation level and low temperature, the exact MPP is not able to track using this algorithm whereas the Temperature and Radiation level close to standard value are tracked accurately and in less time. This algorithm is more suitable to places where environmental conditions do not vary much.

B. Modelling of Open Circuit Voltage Algorithm

The method which gives linear relation between V_{MPP} and V_{OC} of the photovoltaic module, during changing environmental conditions like change in irradiance and temperature levels and is known as Open circuit Voltage algorithm.

$$V_{MPP} = K_1 V_{OC} \qquad (2)$$

K_1 is a constant number which depends on PV array characteristics which should be calculated in advance by measuring V_{MPP} and V_{OC} for wide range of temperatures and irradiation levels. The value of K_1 is among 0.70 ad 0.77.

Simulation results are given below which are simulated at different environmental condition

✓ IV and PV Curve at standard condition

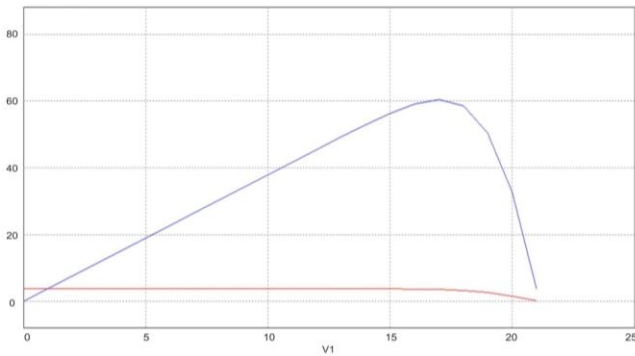The curves between voltage and current, and Voltage and Power simulate in PSIM are given in Figure 9

Figure 9. IV & PV

$V_{MPP}= 17.1V$
$I_{MPP}= 3.5A$
$P_{MPP}= 60.4W$

✓ Tracking of MPP voltage at standard condition

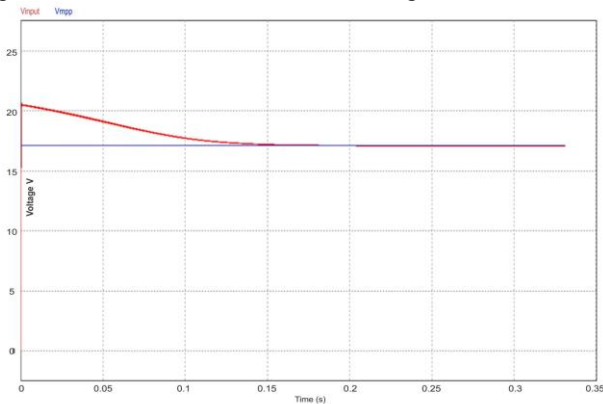The voltage at MPP is being tracked using this algorithm in PSIM which is shown in Figure 10

Figure 10. MPP tracking at standard condition

$V_{Panel} = 17.09 \ V$
$P_{Panel} = 60.5 \ W$

✓ *Tracking of MPP current at standard condition*

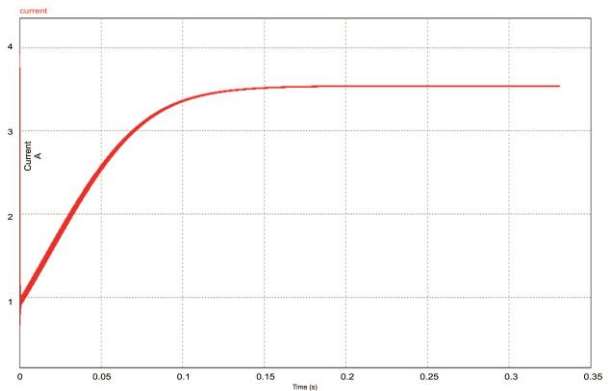PV panel current is being tracked using open circuit voltage algorithm in PSIM which is shown in figure 11

Figure 11 MPP Current Tracking

$I_{Panel} = 3.54A$
$P_{Panel} = 60.5W$

CONCUSLION

MPPT maximizes power extraction out of PV arrays which results in increasing the overall efficiency of PV system. Different MPPT algorithms can be used depends on environmental conditions and applications. Constant voltage algorithms suits when the solar irradiance is less while P&O method and Inc Conductance methods suit high solar irradiance level. If the environmental conditions are varying quickly the P&O method efficiency decreases due to which the amount of power to be extracted from PV system decreases. P&O method tracks true MPPT while Open Circuit Voltage does not track true MPPT. Both of the algorithms can be made digital as well as analog. Periodic tuning is very effective in case of Open circuit voltage algorithm. For Pakistan environmental conditions which on average are not varying quickly so P&O algorithm and Inc Conductance algorithms are suggested.

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