A DISCUSSION ON MPPT TECHNIQUES FOR OPTIMAL ELECTRICITY GENERATION FROM SOLAR ENERGY

[1]Sonam, [2]Vijay Garg
[1]PG Student, [2]Asst. Prof
[1]Name of Department of 1st Author,
[1,2,3]Electrical Engineering,
[1]UIET, Kurukshetra University, Kurukshetra, Haryana

Abstract: - The solar energy is one of the most abundant renewable energy source available on the earth and it can be used to generate clean and cheap electricity using photovoltaic phenomenon. This phenomenon is used to converter sunlight into electric energy using PV cell or array. PV array's output power depends on the climate conditions like irradiance and temperature. To get the maximum output from the PV panel, the idea of Maximum Power Point Tracking (MPPT) is introduced. By using its algorithm, it tracks the point where power produced by the system is maximum by analyzing its voltage and current. Overall efficiency of the PV system can be enhanced with the help of MPPT. This paper discuss about the various MPPT techniques like perturb and observe, incremental conductance, fractional open circuit voltage, fractional short circuit current, fuzzy logic control, artificial neural network etc., that are being used nowadays.

Keywords: - MPPT, Solar Energy, Perturb & Observe, Incremental Conductance, PV Array, Solar Cell, MPP

1. INTRODUCTION

The electricity demand is increasing and conventional resources cannot fulfilled it, create pollution. Renewable resources create no pollution hence are growing at a fast rate as a source of electricity generation. Renewable resources like sunlight, wind, rain, tides and geothermal energy that can be naturally replenished. Solar energy is one of the most significant renewable energy resources and it is clean, pollution free and available in abundance. Harvesting solar energy is quite easy and it follows the principle of photovoltaic effect to generate electric energy. PV cell is a semiconductor p-n junction diode, formed by sandwiching the n-type and p-type regions. As sunlight strikes junction of PV cell, the transmitted light is absorbed by semiconductor device which causes flow of free electron from low energy level to high energy level this creates the electron and hole pairs all over the Junction, which causes the flow of current. Semiconductor absorbs light energy and this energy excites free electrons from a low energy level to higher energy level.

Diode Current of PV array is:-

$$I_d = I_o\left\{\exp\left(\frac{qV_d}{nKT}\right) - 1\right\} \quad (1)$$

Thermal voltage of diode is:-

$$V_t = \frac{n\,KT_{cell}}{q} \quad (2)$$

Using eq_n 2 in eq_n (1), it is further modified to become as:

$$I_d = I_o\,\{\exp\left(\frac{V_d}{V_t}\right) - 1 \quad (3)$$

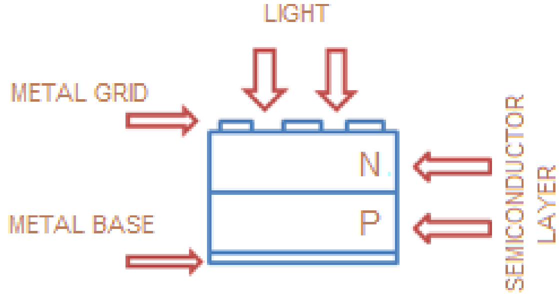

Fig 1 P-N Junction Diode

2. AN OVERVIEW OF MPPT TECHNIQUES

Only 30 to 40 percent of the solar radiations are converted into electrical energy through a solar panel. Maximum power point tracking techniques are used to enhance the performance of the solar panel. MPPT block is connected to the DC-DC converter of the system, this converter is used as the interface between the solar panel and load. MPPT is used to match the load impedance to the optimal impedance of the PV module. This also helps to reduce losses of the PV system. Fluctuating climatic conditions causes oscillation around maximum power point of PV array which affects the performance characteristics (P-V, I-V curves) of PV array causing the reduction in the overall efficiency. MPPT detects the PV array voltage and current, it tracks the maximum power point by adjusting its voltage under varying irradiance. Triggering of DC-DC converter is controlled by the MPPT through switching devices. To match the MPP of PV array under different atmospheric conditions a suitable converter must be chosen. MPPT is used to haul out the maximum power of the PV cell and transfer this power to the load.

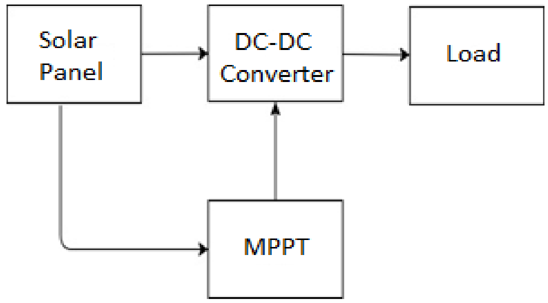

Fig 2. Block Diagram of MPPT

3. DIFFERENT MPPT TECHNIQUES

There are various MPPT techniques used for the optimization of electric energy produced by solar panel. These techniques are discussed below.

3.1 PERTURB AND OBSERVE METHOD

The P&O method compares the past and present value of power to determine the change in PV module's voltage and current. If the PV array's operating voltage changes (increment or decrement) and power increases $(dP/dV > 0)$, then control system will make the PV array operating point to move in the same direction, otherwise the operating point will move to the opposite direction. In next perturbation cycle the algorithm continues in the same fashion until the MPP is obtained. When the MPP is reached, the output power oscillates around its maximum power point under fast changing atmospheric conditions, resulting in power loss in the PV system.

If ratio of power and voltage is $(\frac{dP}{dV} < 0)$, then the operating point will be at the right side of MPP, but if this ratio is $(\frac{dP}{dV} > 0)$, then the operating point will be at the left side of MPP and if ratio is $\left(\frac{dP}{dV} = 0\right)$, then operating point will lie at MPP. Fig 3 depict I-V curve of P&O technique.

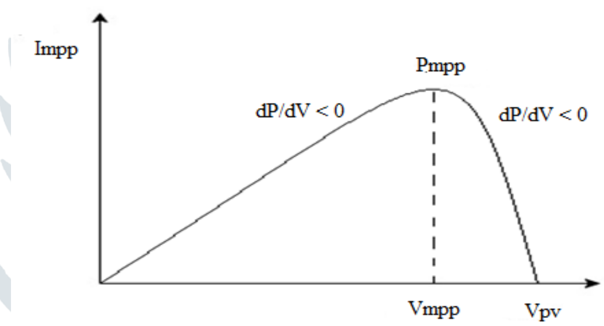

Fig 3 P-V curve of P & O

3.2 INCREMENTAL CONDUCTANCE METHOD

Incremental Conductance (IC) method overcomes the disadvantage of the perturb and observe method in achieving the MPP during changing atmospheric conditions. In IC method, the controller measures the small changes in the PV array current and voltage to estimate the change in power. The following equation describes the algorithm of Incremental Conductance (IC):-

$$\frac{dIpv}{dVpv} + \frac{Ipv}{Vpv} = 0 \qquad (4)$$

Vpv PV array voltage
Ipv PV array current

When condition $\frac{dIpv}{dVpv} + \frac{Ipv}{Vpv} < 0$ is satisfied, then the operating point will lie at the right side of the MPP, when condition $\frac{dIpv}{dVpv} + \frac{Ipv}{Vpv} > 0$ is fulfilled then the operating point will lie at the left side of the MPP, but if condition is $\frac{dIpv}{dVpv} + \frac{Ipv}{Vpv} = 0$, then the operating point will lie at the MPP.

The IC method is used to obtain the maximum power point by comparing the incremental conductance and the array conductance of the system. The point at which these conductances are same, is maximum power point of the PV system.

3.3 FRACTIONAL OPEN CIRCUIT VOLTAGE

In fractional open circuit voltage technique maximum power point voltage V_{mpp} varies linearly with the open-circuit voltage V_{oc} and V_{mpp} changes with varying irradiance and temperature.

$$V_{mpp} = k_{oc} * V_{oc} \qquad (5)$$

V_{mpp} Maximum Power Point Voltage
V_{oc} Open circuit voltage

k_{oc} Open Circuit Constant

The value of k_{oc} varies from 0.75 to 0.9 and which depends on the performance characteristic of PV system. Once the constant k_{oc} is known, the MPP voltage V_{mpp} can be obtained by measuring V_{oc}. The above mentioned relationship between V_{oc} and V_{mpp} is only an approximation, so we can't say that the MPP reached is not real.

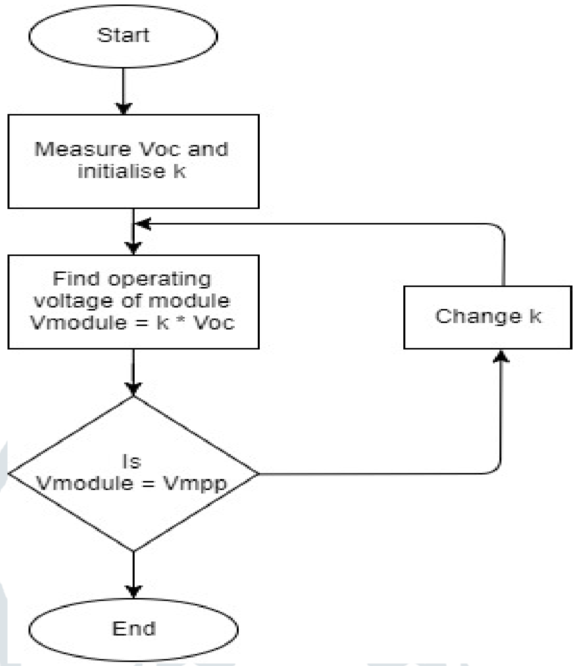

Fig 4 Flowchart of FOCC method

3.4 FRACTIONAL SHORT CIRCUIT CURRENT METHOD

In fractional short circuit current method there is linear relationship between I_{scc} and I_{mpp} of the PV system which changes with varying irradiance and temperature.

$$I_{mpp} = k_{sc} * I_{scc} \qquad (6)$$

I_{mpp} Maximum Power Point Current

I_{scc} Short Circuit Current

k_{sc} Short Circuit Constant

Constant current factor (k_{sc}) varies from 0.7 to 0.8. This technique requires the measurement of current I_{scc}, for this purpose static switch is added in parallel with the boost converter to short the PV array.

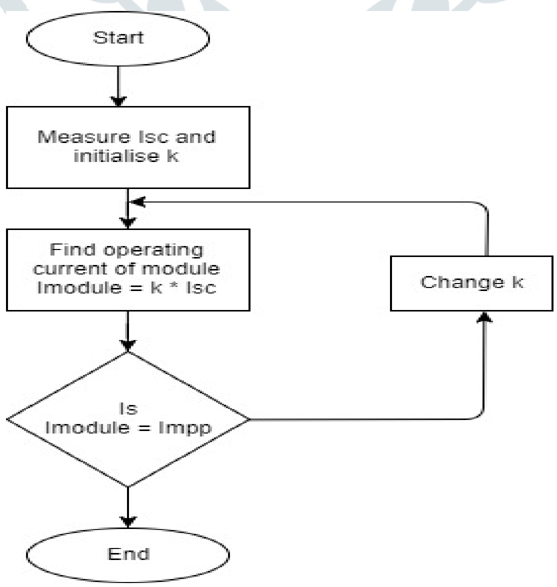

Fig 5 Flowchart of FSCC method

3.5 TEMPERATURE METHOD

In temperature method the short-circuit current (I_{sc}) of the solar array varies linearly with the irradiance (G) and remain constant in case of changing cell temperature, while the open circuit voltage (V_{oc}) of solar panel is in linear relationship with the PV array temperature. In this algorithm, on the back surface of the PV array and voltage sensors a temperature sensor is connected to measure the temperature T and the photovoltaic output voltage.

$$V_{mpp}(T) = V_{mpp}(Tref) + u_{vmpp}(T - Tref) \qquad (7)$$

$V_{mpp}(T)$ Maximum power point voltage
$V_{mpp}(Tref)$ Maximum power point voltage at reference temperature
u_{vmpp} Temperature coefficient of Vmpp
T Measured temperature
$Tref$ Reference temperature

Above equation clearly represents that the maximum power point voltage V_{mpp} is dependent on temperature T only. By assessing the photovoltaic temperature, maximum power point can be estimated.

3.6 FUZZY LOGIC CONTROLLER

In recent time the fuzzy Logic controller for MPPT became popular as it uses microcontroller for its processing which improves the power of the system and reduces the cost. This technique can be used for the complex as well as non-linear systems also. For the functioning of fuzzy logic controller no any accurate mathematical model is required, it works with estimated inputs.

The inputs to the fuzzy controller are the error and change in error as specified below and its output controls the duty cycle of the pulse width modulation block. The user is free to compute E and CE as per their choice. The error is given by the following equation.

$$E(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \qquad (8)$$

Change in error is denoted by

$$CE(k) = E(k) - E(k-1) \qquad (9)$$

FLC has three stages:-
Fuzzification
Decision-making
Defuzzification

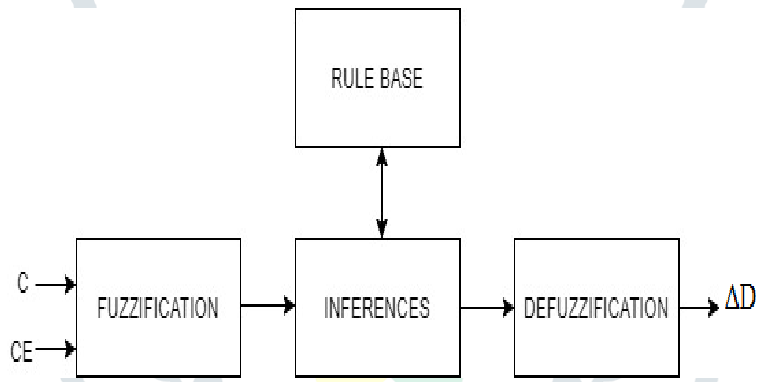

Fig 6 Block Diagram of FLC

Fuzzification is the process that is used to convert the crisp inputs into linguistic variables based on the degree of membership. Accuracy of the controller depends on the number of membership function, for accurate operation of controller. Membership function should be larger. Error and change in error signal i.e E, CE are the FLC input. For the processing of the system, these signals are converted into linguistic variables.

Decision making base rule: - The process of mapping the output from a given input using fuzzy logic is called fuzzy inference. Two cases are considered for this.

First case: If *E* is positive, the operating point will lie at the left of the MPP and if change of error *CE* is positive, then the operating point approaches toward the MPP and vice-versa.

Second case: If *E* is negative, the operating point will be at the right of the MPP, if *CE* is positive, operating point moves away from the MPP and vice versa if *CE* is negative.

Defuzzification:- Defuzzification is inverse process of fuzzification as it converts the fuzzy output into crisp values. There are various types of defuzzification like center of gravity method, center of area, middle of maxima, mean of maxima etc, used to convert linguistic variables into crisp value.

3.7 ARTIFICIAL NEURAL NETWORK

Artificial neural network is a powerful machine learning technique to derive non-linear models, which is complementary to the conventional techniques. This technique is developed by generalizing the mathematical models of biological nervous systems. Learning of neural networks are classified as supervised learning, unsupervised learning and reinforcement learning. The neural network consists three layers: input layer, hidden layer and output layer. PV array parameters such as $V_{oc,}I_{sc}$, Irradiance and temperature change can be used as input variable. The output signal is duty cycle, which is used for switching of the converter to operate it at the MPP. The hidden layer helps to achieve the MPP; the performance of system depends on the training of the neural network and once the neural network gets trained, it does not require detailed or accurate information about the PV system.

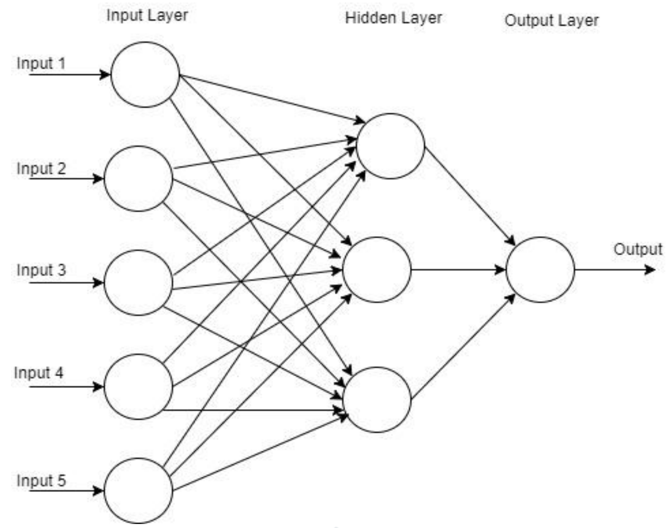

Fig 7 Artificial Neural Network

3.8 PARASITIC CAPACITANCE

The parasitic capacitance method is advance form of the IC method that considers the parasitic capacitances (PC) of the solar cells in the system**.** This method uses the switching ripple of the MPPT for the perturbation. In this technique a series of filters and multiplier are used to measure array power and voltage's average ripple and it also detects array conductance**.** The IC algorithm defines the path of the operating point to the maximum power point. The main disadvantage of this method is that the parasitic capacitance of a single module is very low, and it is considerable only when several modules are connected in parallel.

3.9 VARAIBLE STEP SIZE

For the fixed step size of PV array power drawn contributes in faster dynamics, but it also causes large steady state oscillation which results in the lower efficiency. To overcome this variable step size IC is introduced. Following question shows the duty cycle for the determination of variable step size:-

$$D(k) = D(k-1) + N * [\Delta P/\Delta D] \quad (10)$$

The scaling factor 'N' can be obtained as:-

$$N < \Delta Dmax\,[dP/dV] \quad (11)$$

If above mentioned equation fails, inspite of working on inconsistent step size IC, MPPT will work with a consistant step size. If the operating point is extreme to the MPP, step size deviation is large but when the operating point is close to the MPP, the step size reduces until it reaches the MPP. Good transient and steady state response is ensured by the vibrant performance of variable step size MPPT.

3.10 LOAD MATCHING METHOD

The maximum operating point for variable irradiance level are obtained and based on their results, a matching load is determined. For the tracking of maximum power point, this method does not require any circuit or algorithm. The value of load is so chosen, that average load voltage obtained is close to the maximum power point voltage. For varying load conditions this method does not work properly.

3.11 RIPPLE CORRELATION CONTROL METHOD

In PV system, PV array is connected to the converter, which is a switching device and the switching action of the converter produces voltage and current ripples to the PV array. So the power generated from PV array is related to the ripples produced. The Ripple correlation control utilizes ripples to track MPP and it does not require artificial perturbation. RCC correlates time derivative of power dp/dt either with time derivative of PV current di/dtor voltage dv/dt to drive the power gradient to zero to get MPP.

$dv/dt > 0$, $di/dt > 0$ and $dp/dt > 0$ then the operating point is below MPP ($V < Vmpp, I < Impp$)

$dv/dt > 0$, $di/dt > 0$ and $dp/dt < 0$ then the operating point is above MPP ($V > Vmpp,\ I > Impp$)

We observe that on the left of MPP, product of $\frac{dp}{dt}, \frac{di}{dt}$ or $\frac{dp}{dt}, \frac{dv}{dt}$ is positive, on the right this product is negative and at the MPP product is equal to zero.

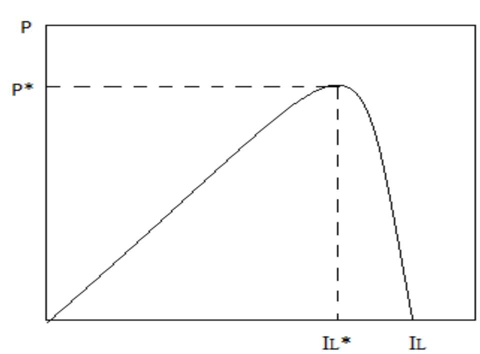

Fig 8 P-V curve of RCC

By combining the dc component I_L and ripple component I_r input current i_L of the converter formed. With the variation in irradiation and temperature input current i_L varies and power obtained is the combination of ripple and average component. As shown in the Fig. 4 there is nonlinear relation between dc component of inductor current and the average component P. Shifting of $I_L{}^*$ is determined by inductor current and array power. When I_L is left of I_L^*current ripple and power ripple in phase and the product of $\frac{dp}{dt} * \frac{diL}{dt}$ is positive, when I_L is right of $I_L *$, the product of $\frac{dp}{dt}$ and $\frac{diL}{dt}$ is negative.

$$\frac{dI_L}{dt} * \frac{dp}{dt} > 0 \quad I_L < I_L^* \qquad (12)$$

$$\frac{dI_L}{dt} * \frac{dp}{dt} < 0 \quad I_L > I_L^* \qquad (13)$$

REFRENCES

[1] Jacob James Nedumgatt, Jayakrishnan K. B., Umashankar S., Vijayakumar D., and Kothari D P, "Perturb and Observe MPPT Algorithm for Solar PV Systems-Modeling and Simulation", India Conference (INDICON).

[2] Mohamed E. El Telbany, Ayman Youssef, and Abdelhalim Abdelnaby Zekry, "Intelligent Techniques for MPPT Control in Photovoltaic Systems: A Comprehensive Review" 4th International Conference on Artificial Intelligence with Applications in Engineering and Technology 978-1-4799-7910-3/14/2014.

[3] Akankshi Trivedi, Ankit Gupta, Rupendra Kumar Pachauri and Yogesh K. Chauhan4, 2016 "Comparison of Perturb & Observe and Ripple Correlation Control MPPT Algorithms for PV Array" 1st IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems 978-1-4673-8587-9/16/2016.

[4] Saleh Elkelani Babaa, Matthew Armstrong and Volker Pickert, "Overview of Maximum Power Point Tracking Control Methods for PV Systems" Journal of Power and Energy Engineering, 2014, 2, 59-72.

[5] S. Malathy and A, R. Ramaprabha, "Maximum Power Point Tracking Based on Look up Table Approach", Advanced Materials Research Vol 768 (2013) pp 124-130.

[6] Ahmed Ali, Ali N Hasan and Tshilidzi Marwala, "Perturb and Observe Based on Fuzzy Logic Controller Maximum Power Point Tracking (MPPT)", 3rd International Conference on Renewable Energy Research and Applications, 978-1-4799-3795-0/14/2014.

[7] Dr. L.V. Narasimha Rao and Ramesh. Vaddi, "Simulation of Cuk Converter Using Incremental Conductance MPPT with Direct Control Method", International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 4, April 2014.

[8] Vinay P and Manju Ann Mathews,2014 " Modelling and Analysis of Artificial Intelligence Based MPPT Techniques for PV Applications" International Conference on Advances in Green Energy (ICAGE), 978-1-4799-8050-5/14/2014.

[9] Abdelhalim Sandali, Oukhoya Tarik and Ahmed Cheriti, "Simple and Fast Maximum Power Point Tracking for Grid Connected Photovoltaic Systems" IEEE Workshop on Control and Modelling for power Electronic, 978-1-4673-4916-1/13/2013.

[10] S.Gomathy, S.Saravanan and Dr. S. Thangavel, " Design and Implementation of Maximum Power Point Tracking (MPPT) Algorithm for a Standalone PV System" International Journal of Scientific & Engineering Research Volume 3, Issue 3, March -2012.

[11] Hadeed Ahmed Sher, Ali F Murtaza, Khaled E Addoweesh and Marcello Chiaberge, "An Intelligent Off-line MPPT Technique for PV Applications" IEEE Conference on Systems, Process & Control (ICSPC), 978-1-4799-2209-3/13/2013.

[12] Mohammed abdul khader aziz biabaniand Fazeel Ahmed, "Maximum power point tracking of photovoltaic panels using perturbation and observation method and fuzzy logic control based method" International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT),978-1-4673-9939-5/16/2016.

[13] Liu Yang, Zhang Yunbo, Li Shengzhu and Zhang Hong, "Photovoltaic Array MPPT Based on Improved Variable Step Size Incremental Conductance Algorithm", Control And Decision Conference (CCDC), 2017 29th Chinese 978-1-5090-4657-7/17/2017.