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Review on Computational Analysis of different MPPT Based Grid Interactive System using PV Array for Active & Reactive Power Control

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Abstract: **In this Paper we a grid interactive solar photovoltaic system is developed. The proposed system takes DC power input from solar photovoltaic module using a MPPT controller. MPPT (maximum power point tracking) is a mechanism used for obtaining optimum power from PV cell in varying intensity of sunlight. The Power obtained from the MPPT is then fed to the Inverter Circuit and then interfaced with the grid. The various techniques used for developing the MPPT logic are compared in this paper. Vector control method is also used for controlling active & reactive output to the grid. The proposed model will be developed using MATLAB/Simulink**.

Key words:Photovoltaic System, Maximum Power Point Tracking (MPPT), Fuzzy Logic Controller, Hysteresis Current Control.

List of Nomenclature

I & V : *Cell output current and voltage;*
I_S : *Cell reverse saturation current;*
I_{PH} : *Light generated current;*
T_C : *Cell temperature in Celsius;*
k : *Boltzmann's Constant;*

q: Electron charge, $1.6*10^{-23}C$;

k_1: *Short circuit temperature coefficient at Isc*
λ: *Solar irradiation in* W/M^2;
Iscr: Short circuit current at 25 degree Celsius;
E_G: *Band gap energy for silicon;*
A: Ideality Factor;
I_{RS}: *Cell saturation current at* T_{ref};
R_{SH}: *Shunt Resistance;*
R_S: *Series Resistance;*

I. INTRODUCTION

In finding solutions to overcome a global energy crisis, the photovoltaic (PV) system has attracted significant attention in recent years. There are many motives for increasing the use of grid-connected PV systems, which has led to expectations of high installation rates of these systems around the globe. With the worldwide increase in energy demand, rising rate of consumption of nuclear and fossil fuels, increasing awareness about global warming and environmental pollution etc. has drawn attention towards the renewable energy source like Photovoltaic (PV). The grid interactive photovoltaic system becomes a promising renewable energy system as it is clean and safe, zero fuel cost, negligible maintenance and running cost, zero noise and air pollution.

Due to high cost of PV panels, the effective utilization of PV system is crucial. The grid connected PV system eliminates the need for battery. During day time, the PV system supplies active power to the load and at night or low insolation it can be utilized to supply the reactive power requirement of the load relieving the grid burden. Hence, the utilization factor of the PV system increases. Most of the grid connected PV system has two stages: one is DC-DC boost converter with maximum power point tracking (MPPT) and the other is DC-AC inverter. But two stages increase power loss and hence reduce efficiency. Fuzzy logic is becoming popular for MPP tracking which overcomes the disadvantages of conventional methods. Fuzzy logic MPPT control is simple to implement, gives better convergence speed, and improves the tracking performance with minimum oscillation. Many standalone PV system and two-stage grid connected PV system uses fuzzy logic controller for MPP that takes at least two inputs and generates the control output. In fuzzy logic based MPPT is used for single-stage grid connected PV system that takes PV actual power and reference power as inputs and generates the firing pulses for the inverter. The reference power is determined from open circuit voltage (Voc) and short circuit current (Isc) of PV array under varying insolation condition that imposes practical difficulties. The input to the novel fuzzy logic controller is the slope of the P-V curve and the output is the change in power. The fuzzy logic controller generates incremental power Pref to be added with the reference power Pref, which is further used to generate reference current for the hysteresis current controller.

II. DESCRIBTION AND BLOCK DIAGRAM OF THE SYSTEM

The topology used for simulation study of the PV system using the proposed algorithm is shown in fig. 1. It consists of five major components namely, Fuzzy logic based MPPT that generates the incremental power Pref to be added with reference power (Pref), the reference current generator that generates the reference current to be injected into the grid using instantaneous power (*p*-*q*) theory, the hysteresis current controller that provides gating signals to the power converter, and the power converter that injects the required current in a controlled manner so as to meet the active and reactive power requirement of the load either partially or completely.

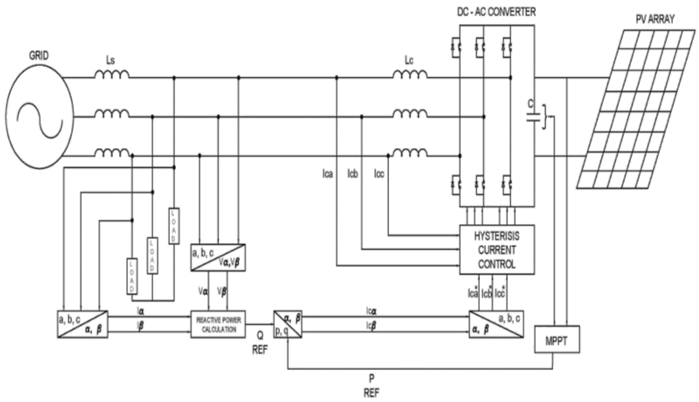


Fig. 1 Block diagram of the proposed system.

III. DESIGN OF PHOTOVOLTAIC SYSTEM.

PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of PV module depends on the solar insolation, the cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature. The equivalent circuit for the solar module arranged in NP parallel and NS series is shown in Fig. 2.

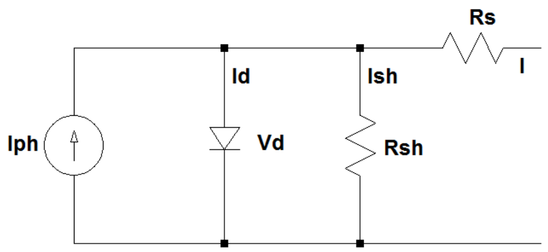


Fig. 2 Equivalent circuit diagram of PV Module.

The Characteristic equation for a photovoltaic cell is given by,

$$I = N_P I_{PH} - N_P I_S \left[exp\left(\frac{q(V/N_S + IR_S)/N_P}{kT_C A}\right) - 1\right] - (N_P V/N_S + IR_S)/R_{SH} \qquad (1)$$

Where,

$$I_S = I_{RS}(T_C/T_{ref})^3 exp\left[\frac{qE_G\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)}{kA}\right] \qquad (2)$$

$$I_{PH} = [I_{SC} + K_1(T_C - T_{ref})]\lambda \qquad (3)$$

The I-V and P-V curves for a solar cell are given in the following figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current. I-V & P-V curves for different solar irradiation can be observed in the fig. 3 & fig. 4 respectively.

IV. DESIGN OF INCREMENTAL CONDUCTANCE BASED MPPT.

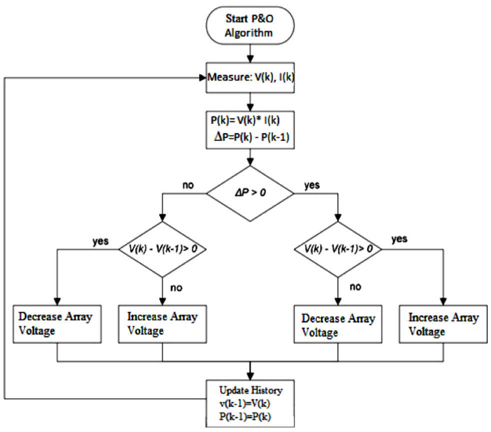
Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array. At MPP the slope of the PV curve is 0.

$$dI/dV_{MPP} = - I/V \qquad (4)$$

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then MPP is reached. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. However the complexity and the cost of implementation increase. As we go down the list of algorithms the complexity and the cost of implementation goes on increasing which may be suitable for a highly complicated system. This is the reason that Perturb and Observe and Incremental Conductance method are the most widely used algorithms.

V. DESIGN PERTURB AND OBSERVE BASED MPPT.

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power ΔP is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If ΔP is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed.



1. FLOWCHART OF PERTURB AND OBSERVE ALGORITHM.

VI. DESIGN OF FUZZY LOGIC BASED MPPT.

From the simulated I-V and P-V characteristics of the PV module, it can be seen that the characteristics are highly nonlinear. Also, there is single point on P-V curve corresponding to MPP. The MPP changes with change in insolation and temperature. Therefore, an MPPT controller is required to extract maximum available power from the PV array under varying load and changing environmental conditions.

Fuzzy logic can model or control non-linear systems that can be difficult to model mathematically. A fuzzy control system is designed based on the experience and knowledge of a human plant operator. Fuzzy logic controller generates precise solutions from ambiguous, imprecise, noisy, or missing input information. It gives appropriate performance for varying dynamics. The fuzzy logic is chosen for tracking MPP as it gives better performance, higher convergence speed, robust and simple to design compared to conventional methods. The major objective of the proposed controller is to track and extract maximum power from the PV arrays for a varying solar insolation and cell temperature.

The fuzzy rule base should be precisely defined based on the knowledge in order to generate an output change in power Pref as per the magnitude of the input, to operate the PV array at MPP. When the slope of P-V curve is positive then to reach towards MPP, the change in reference power is negative. Similarly, if the slope of P-V curve is negative then to move the operating point at MPP, the change in reference power is positive. Depending upon the magnitude of the slope, the step change in reference power is zero, small, medium or large. Thus, fuzzy based controller applies variable steps as per the current operating position and hence, gives higher convergence speed. The seven rules used for tracking the MPP in the proposed technique are listed in Table I

Table I. FUZZY RULE BASE.

$\Delta P/\Delta V$	NB	NM	NS	ZO	PS	PM	PB
ΔP_{ref}	PB	PM	PS	ZO	NS	NM	NB

The input to fuzzy logic controller is P(k)/V(k) and output is the incremental change in power that is to be extracted from the PV array. From the prior knowledge of input and output range, the fuzzification process divides the input and output into seven linguistic fuzzy sets: negative big (NB), negative medium (NM), negative small (NS), zero (ZO), positive big (PB), positive medium (PM) and positive small (PS).

VII. ACTIVE & REACTIVE POWER EQUATIONS.

The p-q theory based on instantaneous active and reactive power is used to generate the reference currents. According to the p-q theory, load currents and voltages of point of common coupling (PCC) are transformed from a-b-c coordinate's reference frame to α-β coordinate's reference system. The mathematical relations of the load current and voltage of the PCC in the two different coordinate systems are given by,

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} V_{S\alpha} \\ V_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \quad (6)$$

As per p-q theory, the instantaneous active and reactive load powers are given by,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_{S\alpha} & V_{S\beta} \\ -V_{S\beta} & V_{S\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (7)$$

The instantaneous reactive power with which the inverter feeds the load is given by,

$$q = V_{S\alpha} i_{L\beta} - V_{S\beta} i_{L\alpha} = \begin{bmatrix} -V_{S\beta} & V_{S\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (8)$$

The load reactive power calculated in the above equation is used as reference reactive power (q* =q).

The reference for active power is generated as per the amount of power that can be supplied by PV array under varying insolation and temperature. The proposed fuzzy logic based MPPT algorithm after sensing Vpv and IPV gives the maximum power Ppv of PV array which is used as the reference active power (p*= Ppv at MPP).

The reference currents in α & β system are obtained using,

$$\begin{bmatrix} i_{L\alpha}\ * \\ i_{L\beta}\ * \end{bmatrix} = \frac{1}{{V_{S\alpha}}^2 + {V_{S\beta}}^2} \begin{bmatrix} V_{S\alpha} & V_{S\beta} \\ -V_{S\beta} & V_{S\alpha} \end{bmatrix} \begin{bmatrix} p\ * \\ q\ * \end{bmatrix} \quad (9)$$

The three phase reference currents (*ica**, *icb**, *icc**) in a-b-c system are calculated using inverse α-β to a-b-c transformation given by,

$$\begin{bmatrix} i_{ca*} \\ i_{cb*} \\ i_{cc*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{L\alpha}\ * \\ i_{L\beta}\ * \end{bmatrix} \quad (10)$$

VIII. DESIGN OF HYSTERESIS CURRENT CONTROLLER.

The hysteresis current controller compares the three phase reference currents (*ica**, *icb**, *icc**) generated using with the actual inverter currents (*ica*, *icb*, *icc*) and the hysteresis band current control determine the timing and duration of each switching pulse. This can be implemented using simple logic as given below:

If *ica* > *ica** + *hb* then S1 is OFF and S4 is ON

If *ica* < *ica** - *hb* then S1 is ON and S4 is OFF

Where, *hb* is the hysteresis band (shown in Fig. 5) around the reference current which is usually 5 % of the maximum current to be injected by the inverter.

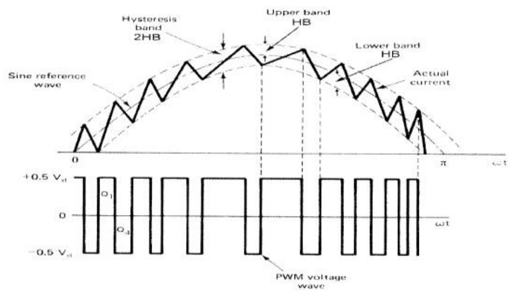
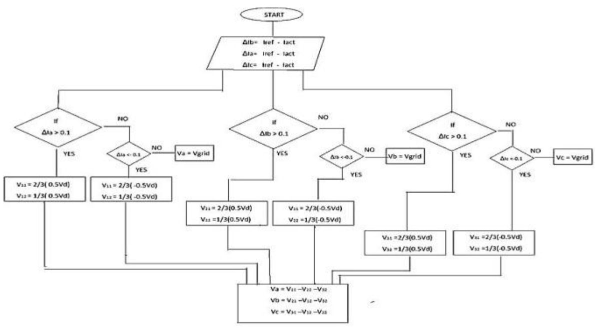


Fig. 5 Hysteresis Current Control band showing upper and lower hysteresis band.

A. FLOW CHART OF HYSTERESIS CURRENT CONTROL.



B. INVERTER.

The three-leg, six switch voltage source inverter is used in this system (shown in fig.1) to integrate PV array with the grid. The inverter not only integrates PV system with grid, but also injects the active and reactive power in a controlled manner. The switching pulses for the inverter are generated using hysteresis current controller after calculating reference currents using p-q theory.

The switching losses of the inverter are supplied by the PV system during day time and at night it is supplied by the grid. In the proposed system, the inverter is utilized effectively as it is not disconnected from the grid at night but still compensating the reactive power demand of the load.

IX. SIMULATION RESULTS

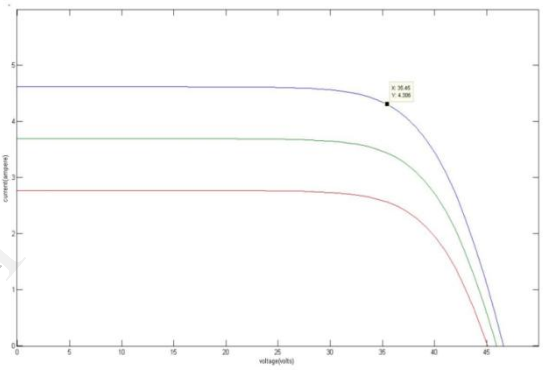


Fig. 3 I-V curve of Solar cell at different solar irradiation.

The figure 3 shows characteristics curve of current versus voltage for PV Array. Here we can observe that the curve changes as the insolation value changes.

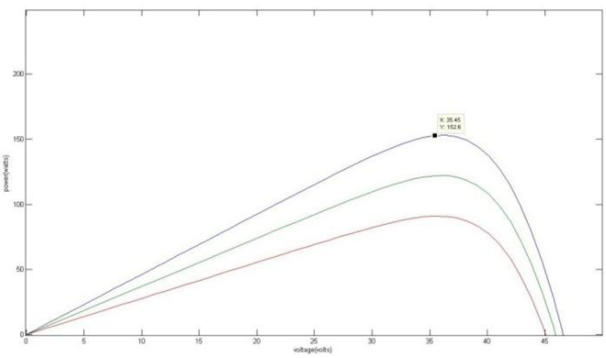


Fig. 4 P-V curve of Solar cell at different solar irradiation.

The figure 3 shows characteristics curve of power versus voltage for PV Array. Here we can observe that the curve changes as the insolation value changes. The peak power obtained is tagged in the figure for a particular voltage level.

X. CONCLUSION

Comparison of several MPPT techniques, applicable to grid-connected inverter configurations has been presented. The choice of an MPPT scheme is application specific. Overall, the Fuzzy Logic method is the fastest method and will particularly be suitable for fast changing environmental conditions. Further, its application is independent of the array configuration. Perturb & observe and incremental conductance methods can track the MPP accurately for all environmental conditions, as small steps are used for tracking.

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