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Design and Analysis of Perturb and Observe MPPT Techniques for Inverter in Photovoltaic System

Shruthi K J *, Giridhar Kini P **, Viswanatha C*** and Rajashekar P Mandi ****

Renewable energies are the most sought after alternatives for electric energy generation. The improvement in semiconductor and power electronics technology has led to precise operation of system at maximum power point, thus increasing the efficiency of the PV system. Many maximum power point tracking (MPPT) algorithms have been developed in recent times which provide maximum power tracking under varying conditions. Among the existing algorithms, perturb and observe (P & O) is the most explored technique. In this paper a comparison between the conventional P & O and improved P & O method is brought about. A MATLAB simulink based simulation study of PV module/ array is carried out and both the MPPT algorithms are explored for z-source inverter in photovoltaic system.

Keywords: *Solar Photovoltaic (SPV) system, Modeling of PV arrays, Z-source inverter (ZSI), Perturb and Observe (P & O), Improved perturb and observe (IP & O), Maximum power point tracking (MPPT)*

1.0 INTRODUCTION

The output functions of Solar photovoltaic (SPV) such as output voltage, current and power of the PV array are never constant. The output from the PV array is governed by several factors; such as solar radiation level, temperature and the load demand current. Thus to ensure maximum power tracking of a SPV system, a suitable method for operating the system at maximum power extraction point is very essential. Perturb and observe (P & O) is a popular maximum power point tracking (MPPT) algorithm, widely used in PV systems mainly for its simplicity and ease of implementation. This algorithm can be used to track MPP under all conditions (irrespective of PV panel type or atmospheric conditions). However there are some drawbacks of this method such as oscillations around MPP, slow system response under rapidly changing atmospheric conditions. P & O method is basically based upon sensing of average PV panel voltage (V_{pv}) and current (I_{pv}) [1-3].

A new improved P & O method (IP & O), is used to overcome the drawbacks of P & O method and to improve the system response time. In IP & O method, the reference step size and hysteresis bandwidth for power comparison is automatically adjusted. This improves the total PV output power by 0.5% in comparison with traditional P & O method. IP & O method provides higher reliability but at the cost of increased complexity.

In this paper the detailed explanation of PV cell modeling, traditional P & O method and IP & O method and the comparison between both the MPPT algorithms is presented. Both the MPPT

* *Energy Efficiency and Renewable Energy Division, Central Power Research Institute, Bangalore- 560080. E-mail : shruthi.cpri@gmail.com*;
** *E&E department, Manipal Institute of Technology, Manipal 576104. E-mail : giridhar.kini@manipal.edu*
*** *Diagnostics Cables and capacitors Division, Central Power Research Institute, Bangalore 560080. E-mail : viswa@cpri.in*
**** *Energy Efficiency and Renewable Energy Division, Central Power Research Institute, Bangalore -560080. E-mail : mandi@cpri.in*

techniques are used to generate gate signals for z-source inverter.

2.0 PHOTOVOLTIC CELL MODELLING

A solar cell model comprises of light- generating current source, diode, series resistance R_s (indicating internal power loss due to current flow) and parallel resistance R_{sh} (corresponds to leakage current flow to ground) as shown in Figure 1 [4-5].

Double exponential equation for of the solar PV cell is given by equation 1.

$$I = I_{ph} - I_{sat}\left\{\exp\left(\frac{V + IR_s}{k_o}\right) - 1\right\} - \frac{V + IR_s}{R_{sh}} \quad ....(1)$$

where

k_o ≡ AKT/q

I,V - cell output current and voltage (V)

I_{ph} - light generated current (A)

I_{sat} - cell reverse saturation current (A)

A - ideality factor (=1);

k - Boltzmann's constant (=1.3805 x 10^{-23} N.m / K)

T - cell temperature (°C)

q - electronic charge (=1.6 x 10^{-19} C)

R_s - series resistance (Ω)

R_{sh} - shunt resistance (Ω).

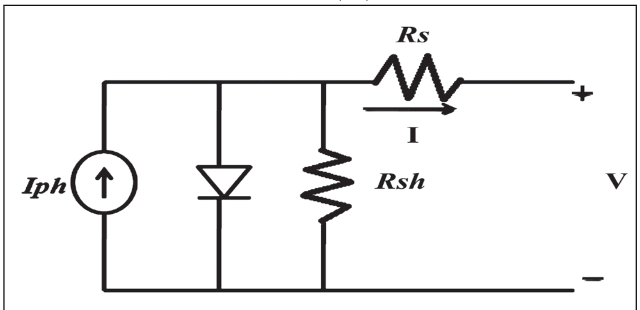

FIG. 1 SOLAR CELL CIRCUIT

The net total current is obtained from the light generated current I_{ph} and the diode current I_d as shown in Figure 2. The general characteristic curve of SPV module is as shown in the Figure 3.

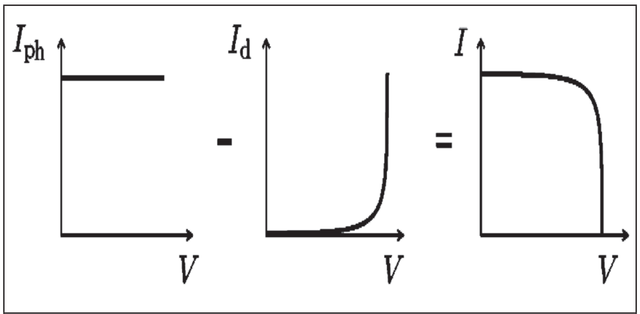

FIG. 2 I-V CHARACTERISTICS OF CELL CURRENT (I)

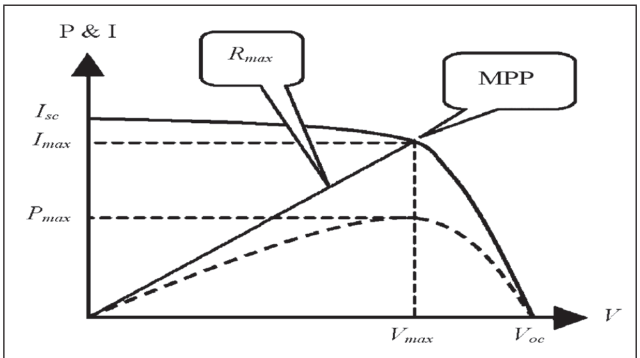

FIG. 3 GENERAL CHARACTERISTIC CURVES OF SOLAR ARRAY

3.0 INVERTER TOPOLOGY

Inverter is power electronic converter topology to convert dc energy to ac energy. The output from the PV array is of dc form and the grid energy is in ac form [6-10]. Thus inverter is required for this energy conversion. Usually the dc voltage from the PV panel will not be of grid nominal value. The inverter takes care of generating the output voltage and frequency to match with that of the grid requirement.

Figure 4 shows a grid connected inverter in SPV system. Inverter action is controlled by switching of solid state switches [7], [9]. The switching action of the switches is controlled by MPPT technique.

Inverter used is Z-source inverter (ZSI). This inverter topology has many advantages in comparison with the traditional voltage source and current source inverters. ZSI has impedance network on its dc side. Impedance network consists of 2 inductors and 2 capacitors connected as shown in Figure 5. In Figure 5 impedance network is followed by a full bridge inverter topology. The important advantage of using ZSI is that it can buck or boost the output voltage irrespective of the input dc voltage level [11-15].

ZSI has shoot through period in which the switches in the same arm are on at the same time. This provides the boosting in the impedance network which will appear at the inverter output. The output voltage of ZSI is controlled by boost factor B given by equation 2.

$$B = \frac{1}{1-\frac{2T_o}{T_s}} \qquad ....(2)$$

T_o- shoot through period

T_s- Total switching period

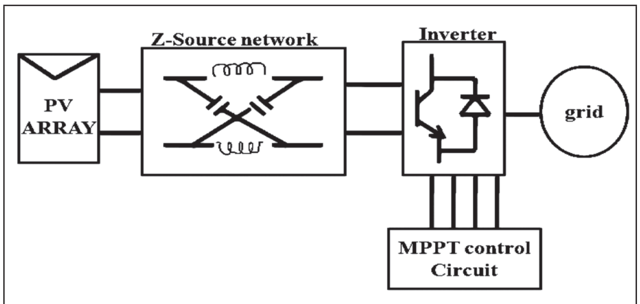

FIG. 4 GRID CONNECTED INVERTER WITH MPPT CONTROL

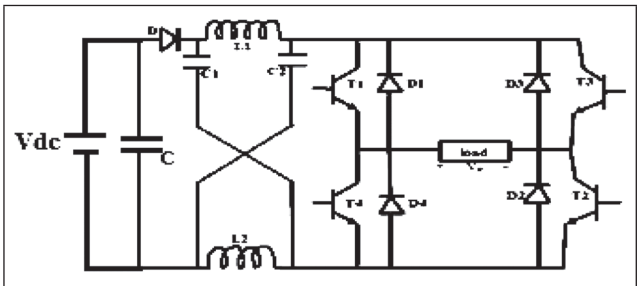

FIG. 5 Z-SOURCE IMPEDANCE NETWORK WITH FULL BRIDGE INVERTER

3.0 PERTURB & OBSERVE MPPT

In P & O MPPT algorithm very few parameters are to be measured and thus are one of the most preferred MPPT algorithms. They operate by periodically perturbing (i.e. incrementing or decrementing) the array termed voltage and comparing the PV output power with that of the previous perturbation cycle. In case of increasing power, the perturbation value is increased in same direction in next cycle, else it should be decreased. That is the PV array voltage will be perturbed in every cycle. This results in oscillations causing power loss especially in case constant or slowly varying atmospheric conditions. One of the method to reduce power loss in such atmospheric condition is by reducing the perturb step. However the same perturb step cannot be used varying atmospheric conditions since it results in power loss. The block diagram of P & O is as shown in Figure 6.

To develop a minimum power loss MPPT algorithm is to operate the MPPT at very high sampling rate. Also instead of comparing the average values, the instantaneous values of voltage and peak current control (for one cycle speed response) will reduce power loss significantly and improve system performance.

The proposed MPPT system employs peak current control. The switch is turned on by a clock signal and turned off when the actual current reaches the reference current. Therefore, the reference current can be perturbed (increased or decreased) in every switching cycle, meaning that the perturbation cycle or refresh rate is equal to the switching cycle.

In this algorithm, a reference signal for the outer control loop, a fixed perturb value is used. Perturb control signal can be either PV reference voltage or current. The fixed perturb step is determined by the system designer from previous experience. Though the tracking is slow in case of small variation, power oscillations are minimum. In the case of large perturb step, faster tracking is achieved with increased oscillations. A PI/hysteresis Controller is used for generating control signals for inverter. The size of the perturbation is selected based upon the inductor size and clock frequency.

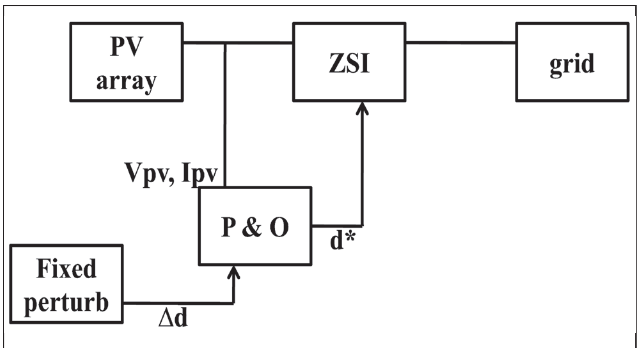

FIG. 6 FIXED PERTURB WITH P & O

4.0 IMPROVED PERTURB & OBSERVE MPPT

In improved perturb and observe (IP & O) algorithm, the duty cycle of the converter is used as perturb signal unlike voltage and current in the previous algorithm. This results in simpler control and thus enabling direct control of the converter's duty cycle. The perturb step is fixed and designer dependent. In order to improve the performance of P&O techniques, the modified calculation of the perturb value is utilized instead of the fixed values. In Figure 7, block diagram of IP & O is as shown.

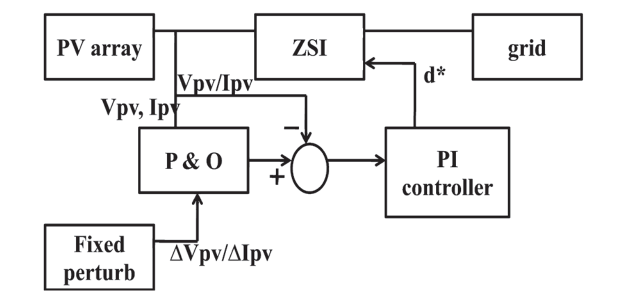

FIG. 7 IMPROVED FIXED P & O

5.0 SIMULATION RESULTS

ZSI model for both P & O and IP & O method is designed and simulated in MATLAB simulink. The impedance network value is inductor, L1 = L2 = L = 0.6 μH and capacitor C1 = C2 = C = 1200 μF. The inverter is designed for 220 V grid voltages, 50 Hz frequency.

The simulation waveform of ZSI using the above values is as shown in Figure 8.

The PV output voltage and current using P & O is shown in Figure 9 & 10 respectively. The PV output voltage and current waveforms using IP & O is shown in Figures 11 & 12. Power comparison curve for both P & O and IP & O is as shown in Figure 13.

Table 1 list out the efficiency comparison for both MPPT techniques while Table 2 illustrates the overall comparison of both MPPT techniques.

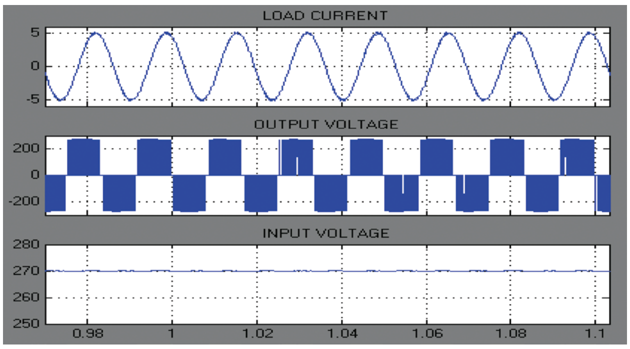

FIG. 8 OUTPUT LOAD CURRENT, OUTPUT VOLTAGE AND INPUT VOLTAGE OF ZSI

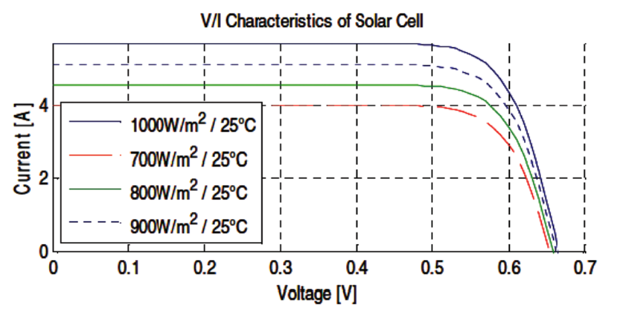

FIG. 9 V/I CURVES OF SOLAR CELL AT DIFFERENT IRRADIATION LEVELS

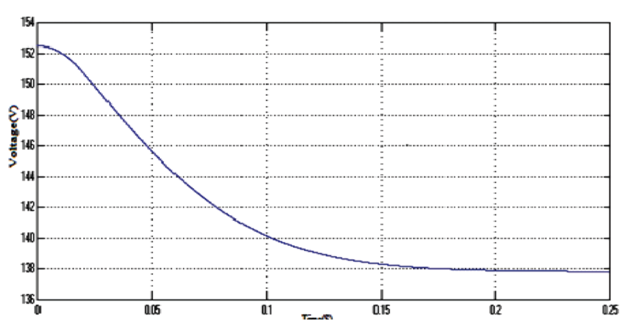

FIG. 9 PV ARRAY OUTPUT VOLTAGE FOR P & O

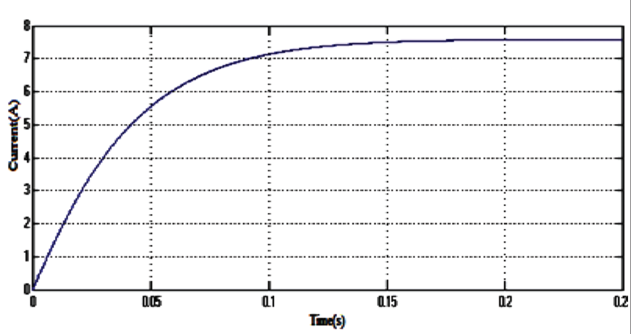

FIG. 10 PV ARRAY OUTPUT CURRENT FOR P & O

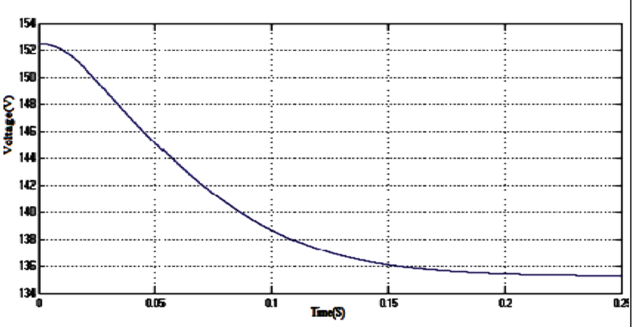

FIG. 11 PV ARRAY OUTPUT VOLTAGE FOR IP & O

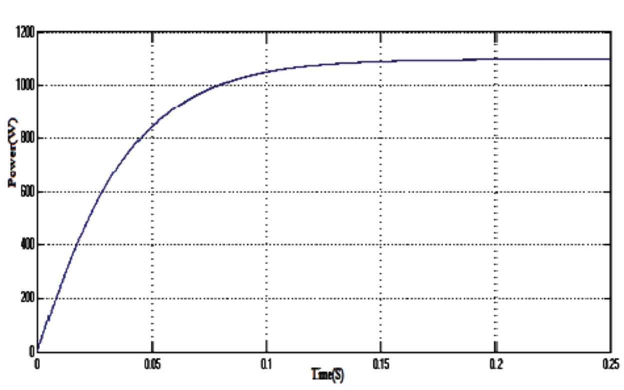

FIG. 12 PV ARRAY OUTPUT CURRENT FOR IP & O

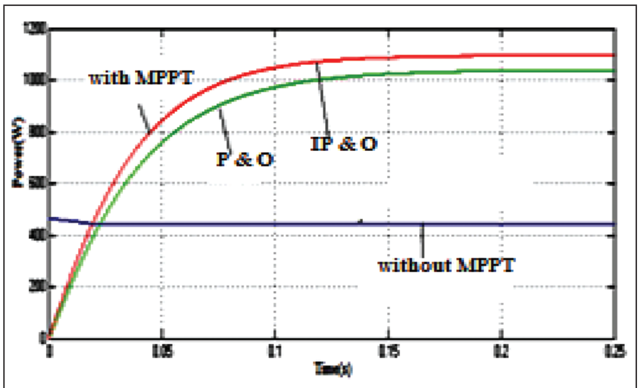

FIG. 13 POWER COMPARISON OF P & O AND IP & O

TABLE 1

EFFICIENCY COMPARISON FOR BOTH MPPT TECHNIQUES

MPPT	V	I	P	η
P & O	138.7	7.456	1048	90%
IP & O	136.1	9.201	1097	94.4%

TABLE 2

COMPARISON BETWEEN P & O AND IP & O

Specifications	P & O	IP & O
Cost	Relatively low	Moderately low
Reliability	Accurate with oscillations around MPP	Precise with oscillations around MPP
Complexity	less	More
Efficiency	90%	>90%
Performance under rapidly varying conditions	Slow response & unpredictable performance	Higher response & efficient performance

6.0 CONCLUSION

This paper proposes design of photo voltaic system, simple Z source inverter with perturb and observe (P&O), improved perturb and observe (IP&O) for MPPT control. The ZSI using both MPPT techniques are designed and their performance is evaluated in MATLAB simulink.

- The PV cell output voltage varies with atmospheric parameters such as temperature and irradiation. The proposed IP & O for ZSI, is based on modified P & O, which automatically adjusts the reference step size and hysteresis bandwidth for power conversion.
- The improved P&O method is based on auto-tuning perturbation. The Improved perturbation and observation (IP&O) has higher tracking response in comparison with traditional P & O algorithm.
- IP & O shows efficient performance under rapidly changing atmospheric conditions thus better reliability.
- A drawback is oscillation around MPPT which is inherent in P & O based MPPT. Also the complexity level is higher than traditional P & O method.
- Applications of Improved perturbation and observation (IP&O) are impedance matching and Micro grid technology.
- In future, Advanced MPPT techniques like adaptive perturbation (AP&O), fuzzy

logic controller and neural networks can be developed.

- This paper presents use of P & O and IP & O for single phase ZSI and it can be further extended to three phase ZSI.

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