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# Performance Enhancement Strategies for Grid Connected Photovoltaic Energy Systems

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**Abstract:** The irregular nature of renewable energy resources presents the significant challenges like voltage variations, harmonic distortions during the integration of their generation to the grid. In this paper a mathematical analysis of PV array with different MPPT topologies in a grid connected mode is formalized. Due to non-uniform irradiation and temperature the characteristics of PV array are highly non-linear. Along with PV array, converter and grid interfacing scheme are simulated in MATLAB/SIMULINK environment. The primary objective of the project is to utilize the deficient power required for PV energy through grid system and to feed excess power of the energy to the utility grid.

**Keywords:** Maximum Power Point Tracking (MPPT), Incremental Conductance (INC), Artificial Neural Networks (ANN), Grid Interfacing Systems, Photovoltaic (PV).

## I. INTRODUCTION

The grid connected photovoltaic power generation is one of the rapid growing energy resources techniques. The renewable energy resources like solar generation is integrated to utility grid carrying significant challenge both for utilities and system operator. As solar generation is very uncertain in nature and drastically affects the performance of connected systems.[1]. In such scenario requires fast and dynamic responding compensation devices which can assist to provide least undesirable effect to mitigate this high solar PV generation penetration. In spite of advantages, the energy conversion efficiency of PV generation is currently low, and the initial cost for its execution is still considered as high. Hence the use of MPPT approaches is necessary to extract the optimal power from PV panels, in order to achieve extreme efficiency in operation.[2]

## II. SIMULATION OF THE PV SYSTEM

The operation of solar panel or solar cell is explained by the process of photovoltaic effect [3]. The below figure shows the corresponding circuit of PV cell and specifications are also tabulated.

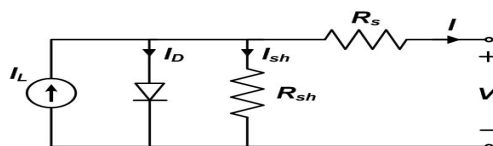


Fig 1: Equivalent Circuit of PV Cell

From the Equivalent circuit, the Characteristic equation of PV cell is

$$I = I_{ph} - I_D - I_{sh} \rightarrow (2.1)$$

By placing all the values of currents, we calculate the current obtained from a PV cell. Diode current

$$I_D = I_0 * \left( \exp \left( \frac{q(V_{PV} + I_{PV} R_s)}{aKT} \right) - 1 \right) \rightarrow (2.2)$$

$I_0$  is the reverse saturation current which is varied with temperature, and it is given by the following equation

$$I_0 = I_{0ref} \left( \frac{T}{T_{ref}} \right)^3 * \left( \exp \left( \frac{qE_g}{K_T} \left( \frac{1}{T_{ref}} - \frac{1}{T} \right) \right) \right) \rightarrow (2.3)$$

$$I_{0ref} = \frac{I_{sc}}{\exp \left( \frac{V_{oc}}{a} - 1 \right)} \rightarrow (2.4)$$

The current  $I_{ph}$  depends on temperature (T) and the solar irradiation (G). The equation can be expressed as

$$I_{ph} = \frac{G}{G_{ref}} (I_{ref} + \mu(T - T_{ref})) \rightarrow (2.5)$$

The current flowing in the shunt resistance is given by

$$I_{sh} = \frac{V + I \cdot R_s}{R_{sh}} \rightarrow (2.6)$$

By placing the equations 2.2, 2.5 and 2.6 in equation 2.1 we get

$$I = I_{ph} - I_0 * \left( \exp \left( \frac{q * (V_{pv} + I_{pv} * R_s)}{aKT} - 1 \right) - \left( \frac{V + I \cdot R_s}{R_{sh}} \right) \right) \rightarrow (2.7)$$

To simulate the PV array from the above equation, the mathematical model contains  $N_p$  cells in parallel and  $N_s$  cells in series.

Assuming that the solar array has cells in parallel,  $N_p$  equal to 1 and then the equation is

$$I = I_{ph} - I_0 * \left( \exp \left( \frac{q * (V_{pv} + I_{pv} * R_s)}{aKT N_s} - 1 \right) - \left( \frac{V + I \cdot R_s}{R_{sh}} \right) \right) \rightarrow (2.8)$$

Table 1: Description of the PV array

At Temperature=25°C		
Open circuit voltage	Voc	32.9V
Short circuit current	Isc	8.21A
Voltage at max power	Vm	26.3V
Current at max power	Im	7.61A
Maximum power	Pm	200Wp
Temp coefficient of Isc	$\alpha$	$3.18 * 10^{-3} A/^{\circ}C$

In Figs.2a and 2b, the power characteristics of the analyzed PV cell, considering solar irradiation and temperature changes, are shown.

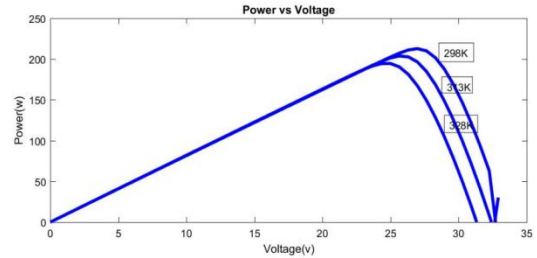
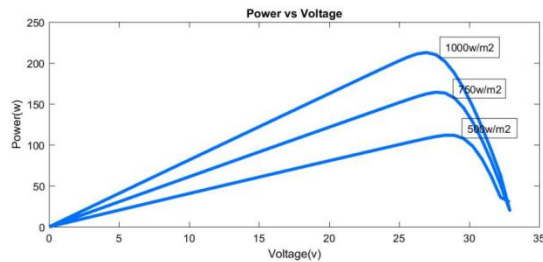


Fig 2a: PV power characteristic for different irradiation levels. Fig 2b: PV power characteristic for different temperature levels.

The above curves represent non-linear characteristics, and they are strongly influenced by climatic changes.

### III.MPPT TECHNIQUES

#### A. MPPT by P & O method

Perturb and observe method is one of the hill climbing technique based on the voltage -power characteristics of PV array. This algorithm is mostly used for PV systems because of its low complicatedness and easy to implement.[5]

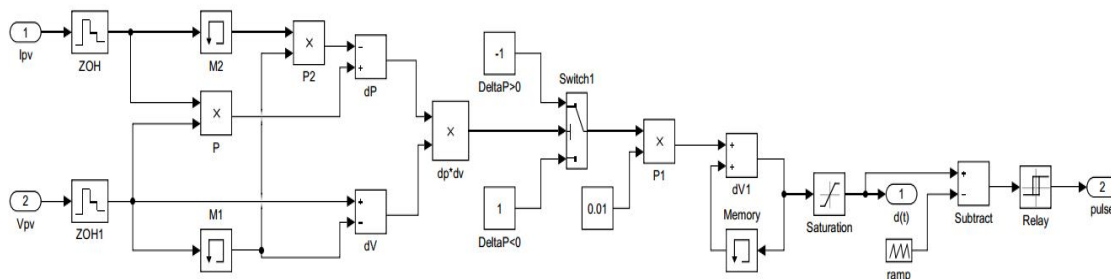


Fig 3a: Implementation of P&O method using MATLAB/Simulink.

The P&O method operates by periodically incrementing or decrementing the output terminal voltage of the PV panel and comparing the power obtained in the current cycle with the previous cycle power (performs  $dP/dV$ ). [4]

$$\text{Signal} \left( \frac{dP}{dV} \right) * (-K_r) = d \rightarrow (3.1)$$

### B. MPPT by Incremental Conductance method

This method is more efficient than the P&O algorithm in terms of tracking the maximum power point of PV array correctly.

The oscillations around the MPP are eliminated by this method. Due to this state, the MPP can be develop in terms of increase in the array conductance.[6]

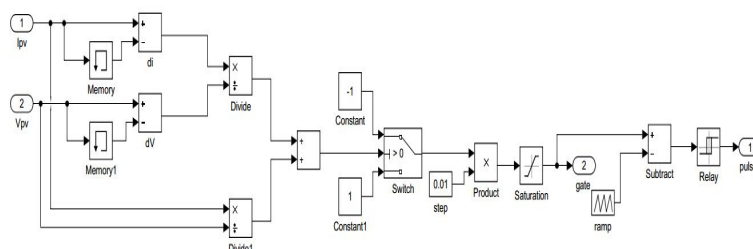


Fig 3b: Implementation of INC method through MATLAB/Simulink.

By using the equation (3.2), it is possible to find the IC conditions presented by (3.3)

$$\left(\frac{di}{dv}\right) = \frac{d(v \cdot i)}{dv} = i + v \frac{di}{dv} = 0 \rightarrow (3.2)$$

$$\frac{di}{dv} = -\frac{i}{v} \rightarrow (a) ; \frac{di}{dv} > -\frac{i}{v} \rightarrow (b) ; \frac{di}{dv} < -\frac{i}{v} \rightarrow (c) \rightarrow (3.3)$$

The equation (a) represents condition at the MPP, (b) represents the condition at the left side of MPP and the equation (c) represents the condition at the right side of MPP.

### C. MPPT by Constant Voltage method

This algorithm is based on the fact that the voltage of PV array at MP is linearly proportional to its open circuit voltage at maximum power point.

$$K = \frac{V_{mp}}{V_{oc}}$$

Where 'k' is a proportional constant and its value depends on technology of the material used, fill factor and climatic conditions. The value of 'k' is ranging from 0.71 to 0.86 [7],[8].

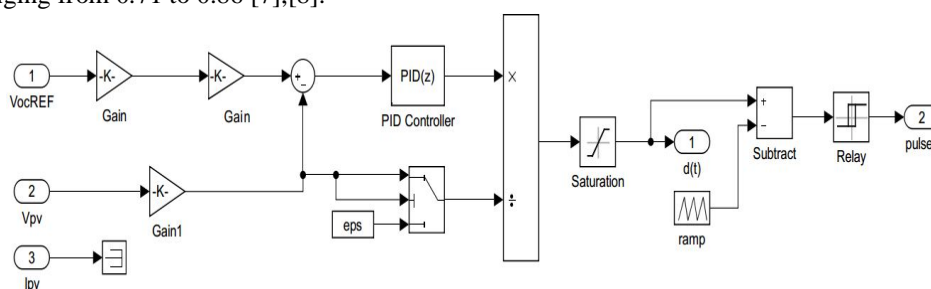


Fig 3c: Implementation of CV method through MATLAB/Simulink

The CV technique uses empirical results, representing that voltage at MPP ( $V_{MPP}$ ) is around 70% to 80% of the  $V_{OC}$ , during the standard climatic conditions. This is favourable method because only the PV module voltage is sufficient to measure and a simple control loop can reach the MPP.

### D. INC method using ANN controller

Along with fuzzy logic controllers another technique of implementing MPPT are the artificial neural networks. Neural networks generally have three layers. They are input layer, hidden, and output layers. The input parameters of neural network can be PV array variables like  $V_{oc}$ ,  $I_{sc}$ , and climatic data like temperature (T) and irradiance (G) or any combination of these[9]. The output is generally one or more reference signals like a duty cycle ratio, used to drive the power converter to operate at or near to the MPP. How nearer the operating point gets to the MPP depends on the algorithms used by the hidden layer and how good the neural network has been trained [11],[12].

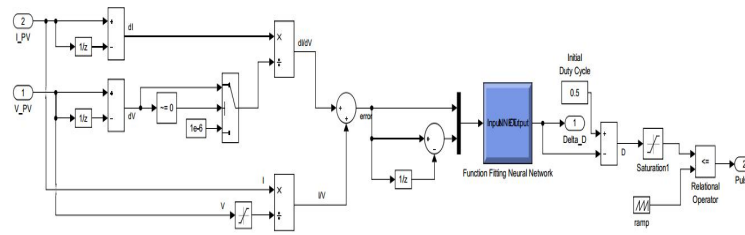


Fig 3d: Implementation of INC method using ANN controller MATLAB/Simulink

#### IV. CONVERTER

Fig4a. Shows the system configuration of the proposed converter, which has a capacitor, two inductors and four switch-diodes. Two of the switches work as power switches and the remainders are applied for the synchronous rectifiers. MPPT has basically a load matching problem. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required [10]. The steady-state analysis of the proposed converter in step-up mode is discussed as follows.

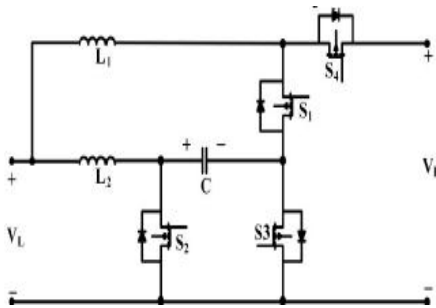


Fig 4a: proposed converter circuit

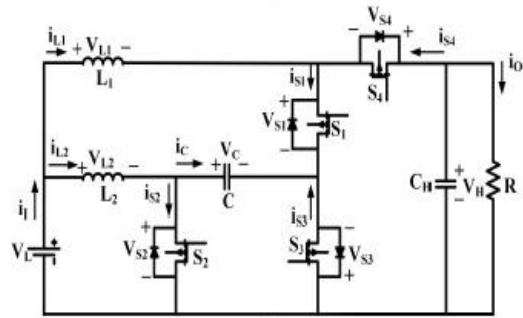


Fig 4b: Proposed Converter in step up mode

##### A. Operating Principle of proposed converter in Step Up Mode

In this operation mode, S1 and S2 work as power switches and S3 and S4 are the synchronous rectifiers. The steady-state analyses are described as follows. The operating principle of Converter can be explained in two modes.

Mode1 switches S1 and S2 are turned on

Mode2 when switches S3 and S4 are turned on

During the interval S1 and S2 are turned on and S3 and S4 are turned off.

- 1) *Mode 1:* During the interval S1 and S2 are turned on and S3 and S4 are turned off. In this interval the energy of the DC source  $V_L$  is transferred to inductor  $L_2$ . Inductor  $L_1$  is magnetized by the DC source  $V_L$  and the energy stored in capacitor  $C$ . Capacitor  $C_H$  is also discharged to the load. The following equations can be obtained in this mode.[13].

$$V_{L1} = V_L + V_C \rightarrow (4.1) : V_{L2} = V_L \rightarrow (4.2)$$

- 2) *Mode 2:* During this interval S1 and S2 are turned off and S3 and S4 are turned on. Here capacitor  $C$  is charged by the input source  $V_L$  and the energy stored in inductor  $L_2$ . Capacitor  $C_H$  is also charged by the input source  $V_L$  and the energy stored in inductor  $L_1$ . Therefore the voltages across the inductors can be written as

$$V_{L1} = V_L - V_H \rightarrow (4.3) : V_{L2} = V_L - V_C \rightarrow (4.4)$$

Applying volt second balance at inductors  $L_1$  &  $L_2$  results in

$$V_L = D(V_L + V_C) + (1 - D)(V_L - V_H) = 0 ; V_{L2} = DV_L + (1 - D)(V_L - V_C) = 0$$

On simplifying above equations we get

$$(V_C/V_L) = 1/(1 - D) : (V_H/V_C) = 1/(1 - D)$$

$$(V_H/V_L) = 1/(1 - D)^2$$

Hence voltage gain of the proposed converter is higher than conventional buck/boost converter in step up mode.



Figure7 shows the comparison of converter output power with various MPPT techniques at various irradiances.

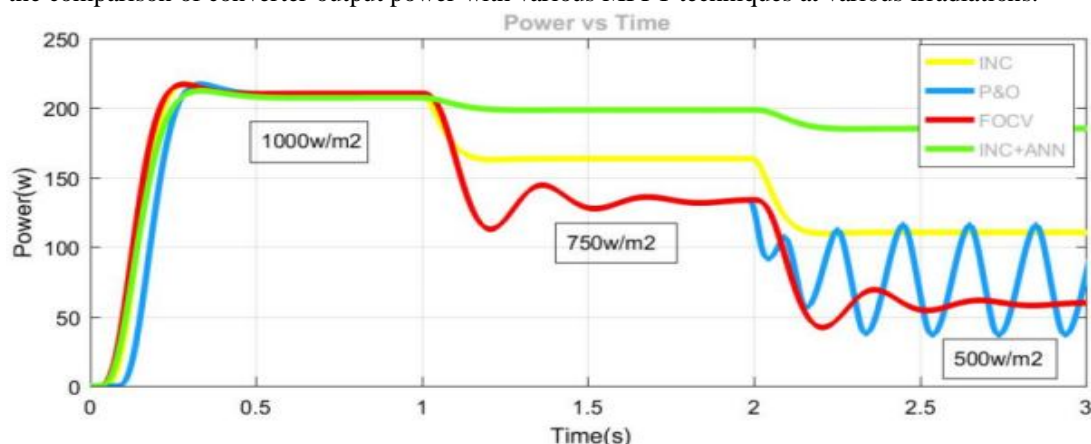


Fig 7: Converter Output Power with Different MPPT Techniques at Various Irradiances

Figure 8(a) and 8(b) shows the output power, output voltage and output current of converter by Incremental Conductance with ANN MPPT controller.

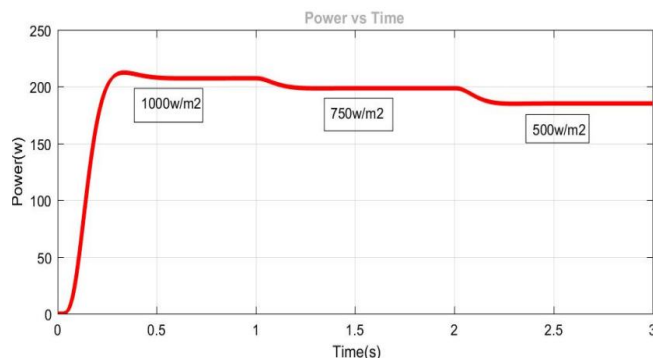


Fig 8(a): INC with ANN output power at various irradiances

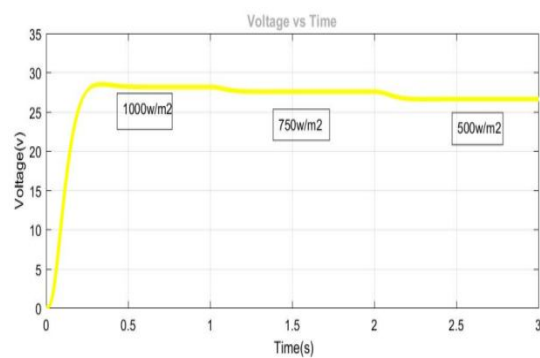


Fig 8(b): INC with ANN output voltage at various irradiances

MPPT algorithm based on Incremental Conductance with ANN controller provides efficient and accurate tracking efficiency to extract maximum possible power from PV array as shown in figure 8(a).

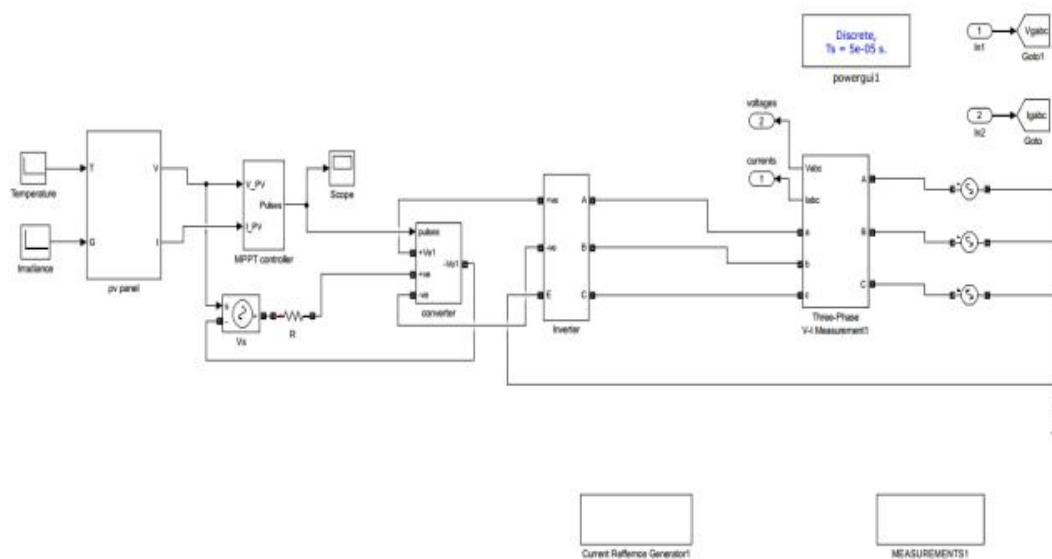


Fig 9(a) simulation diagram of Grid Integrated Photovoltaic system

Grid utility side voltage source converter control strategy perfectly matching the voltage and current at the grid.

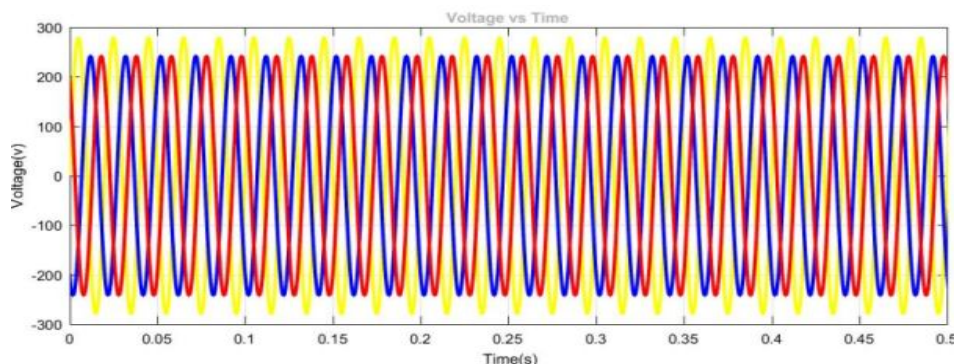


Fig 9(b) Grid side voltages

## VII. CONCLUSIONS

The control strategies for performance enhancement of grid connected photovoltaic system is proposed and evaluated by Simulink. The control scheme consist for operation of MPPT based on incremental conductance with ANN controller extract the maximum possible power from PV array with good tracking efficiency. Hence the proposed control schemes enhance the performance of whole system and overcome the challenges associated with integration of renewable energy to the utility grid.

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