International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-7 Issue-2, December 2017

Optimization of Power Generation and Reliability Enhancement of Photovoltaic System

M. K. Naga Mounika, N. Bhupesh Kumar

Abstract: ***In this paper a PV array mathematical model with different MPPT techniques in a standalone mode is validated. The PV array characteristics are highly non-linear as they depend on irradiation and temperature. Therefore it is important to extract the optimum possible power from PV panels with control algorithms. The total efficiency of photovoltaic generation conversion is reduced due to partial shading. PV array along with buck converter and MPPT controller are simulated in MATLAB/Simulink environment. When climatic conditions vary, the parameters of capacitance and inductance of DC-DC converter will change to attain optimal efficiency. The effect of climatic conditions on design of two elements (inductance, capacitance) for buck topology is also discussed. This paper presents different MPPT techniques like Perturb & observe, Incremental conductance, Fractional open circuit voltage, Constant current and intelligent control methods to extract the optimum power from PV panel. This paper proposes differential power converter to overcome the PV partial shading problem along with INC control algorithm.***

Index terms: Maximum Power Point Tracking (MPPT), Perturb & Observe (P&O), Incremental Conductance (INC), Fuzzy Logic Controller, partial shading, Differential power converter.

Nomenclature:

I_{ph}, I = Photo Voltaic & Output current,
I_0, I_{0ref} = Saturation & nominal saturation current,
V_t = Thermal voltage,
a = Emissivity factor,
R_s = Series resistance,
R_{sh} = Shunt Resistance,
G,G_{ref} = Irradiance & Nominal Irradiance,
T,T_{ref} = Actual and nominal temperature of the cell
q = Change of electron
k = Boltzmann's constant
Eg = Energy Band Gap
I_d,I_{sh} = Diode current & current in the shunt resistance

I. INTRODUCTION

Solar photo voltaic systems need to produce reliable, affordable and sustainable energy over the life of the system when it reaches to grid parity [1]. To control the energy obtained from a PV panel power electronic equipment is used which increases the balance of system costs.

Manuscript published on 30 December 2017.
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Solar energy is not an attractive alternative for consumers because of their High initial costs and installation costs. Despite the fact solar cell prices have decreased consequently due to the development in manufacturing process and control techniques [2]. The utilization of solar photovoltaic system as residential and Street lighting, electric vehicles, water pumping, military and space applications, refrigeration etc. all in either stand-alone (or) grid-connected configurations. A PV array has a nonlinear power voltage characteristics and VI characteristic under uniform irradiance condition like shown in the figure 1(a). The characteristics and efficiencies depends on insulation levels, temperature and load conditions. To eliminate these unfavorable conditions we have a MPP on the solar characteristic curves.

If PV panels are connected in series shading is occurred. The total efficiency of PV generation conversion is reduced due to partial shading. This kind of energy waste could bring very serious economic problems considering the high cost of PV investment.

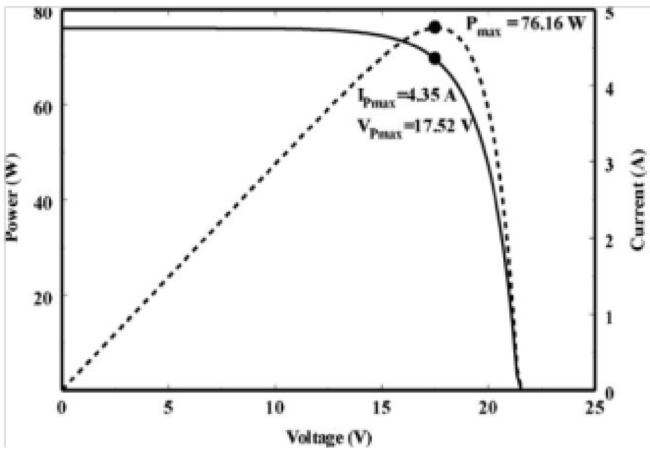

Fig 1 (a): PV Array I-V and P-V Characteristics

The difference between MPPT system and a mechanical tracking system is that the mechanical system physically orients the panel straight at the sun, while the MPPT system electronically control the system so it can change the electrical output of the panel in accordance with changes in irradiation or temperature, so that the solar panel is able to yield the maximum available power.

When a PV module is directly connected to load resistance (R_L).At different values of R_L, the operating point the operating point is varying from A to B as shown in the figure 1(b) , and there is only one maximum power point(MPP) in that range. This occurs when load resistance is equal to the optimal value (load resistance at MPP: RL = Ropt).

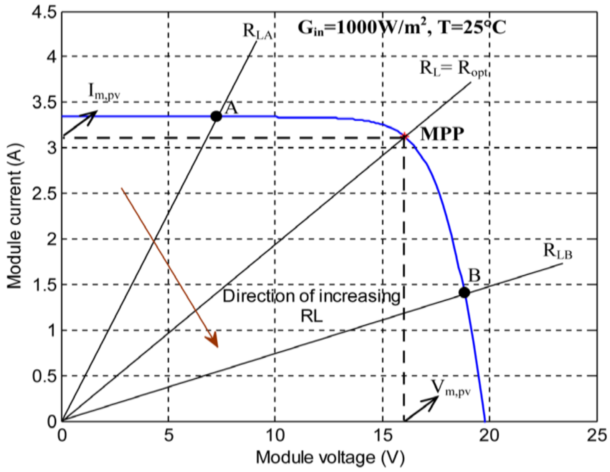

Fig 1(b): Operating point of a PV module with different resistive loads.

In the source side we are using a buck convertor connected to a solar panel in order to enhance the output voltage. By changing the duty cycle of the buck converter appropriately we can match the source impedance with that of the load impedance. In the literature, many maximum power point tracking systems have been proposed and implemented.

To maintain the operating point of PV array at MPP, we need a maximum power point tracker (MPPT). The controlling of MPPT is done by different search algorithms depends on the voltage and current of PV array. Now a days, the research and development is done in the operations of MPPT techniques in terms of convergent speed, complexity, effectiveness of the system, Sensors required for measurement and implementation hardware.

The Different MPPT techniques include lookup table methods, P&O methods [3] – [5] and computational methods [6]. This thesis presents comparison of MPPT techniques like P&O, INC, Constant voltage, Constant current and Fuzzy Logic Control method with buck converter [7]. The proposed differential converter improves the output of PV panel under Partial shading conditions.

II. SIMULATION OF THE PV SYSTEM

The operation of solar panel or solar cell is explained by the process of photovoltaic effect. The theoretical studies give the guidance on losses and solar cell efficiency [8]. In practice, there is no ideal solar cell, so a series and shunt resistance are added to that model. The equivalent circuit is given by,

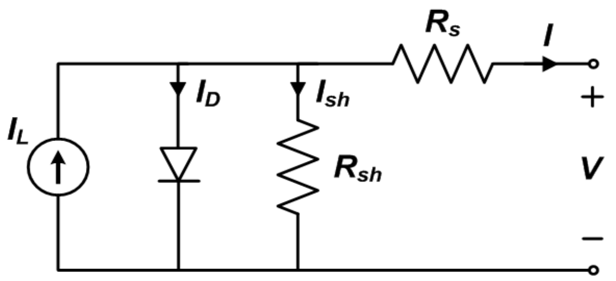

Fig 2: Equivalent Circuit of PV Cell

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

$$I = Iph - Id - Ish \longrightarrow \quad (2.1)$$

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

Diode current

$$Id = I0 * \left(\exp\left(\frac{q*(Vpv+Ipv*Rs)}{aKT} - 1\right)\right) \longrightarrow \quad (2.2)$$

The reverse saturation current, I_0 is varied with temperature and expressed by the following equation

$$I0 = I0ref\left({}^{T}/_{Tref}\right)^3 * \left(\exp\left(\frac{qEg}{K\gamma}\left(\frac{1}{Tref} - \frac{1}{T}\right)\right)\right) \longrightarrow \quad (2.3)$$

$$I0ref = \frac{Isc}{\exp\left(\frac{Voc}{a}\right) - 1} \longrightarrow \quad (2.4)$$

The photo current, I_{ph} depends on the solar radiation (G) and temperature (T)

The equation can be expressed as

$$Iph = \frac{G}{Gref}\left(Iref + \mu(T - Tref)\right) \longrightarrow \quad (2.5)$$

The current flowing in the shunt resistance is

$$Ish = \frac{V+I*Rs}{Rsh} \longrightarrow \quad (2.6)$$

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

$$I = Iph - I0 * (\exp\left(\frac{q*(Vpv+Ipv*Rs)}{aKT} - 1\right) - \left(\frac{V+I*Rs}{Rsh}\right) \longrightarrow (2.7)$$

To simulate the PV array from the above equation, the mathematical model contains and Np cells in parallel and Ns cells in series.

Assuming that the solar array has Np equal to 1,

Then the equation is

$$I = Iph - I0 * (\exp\left(\frac{q*(Vpv+Ipv*Rs)}{aKTNs} - 1\right) - \left(\frac{V+I*Rs}{Rsh}\right) \longrightarrow \quad (2.8)$$

The power of the PV array is calculated as follows

$$P=V*I \longrightarrow \quad (2.9)$$

The specifications are shown in table 1

Table 1: Specifications of the PV array

At Temperature=25°C		
Open circuit voltage	V_{oc}	21.0 V
Short circuit current	I_{sc}	3.74 A
Voltage at max power	V_m	17.1 V
Current at max power	I_m	3.5 A
Maximum power	P_m	60 W

III. BUCK CONVERTER

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 [9]. The converter can operate in two distinct modes of operation, the continuous conduction operation (CCO) or the discontinuous conduction operation (DCO). The CCO occurs when inductance current is always greater than zero and is preferred for high efficiency.

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The DCO is not preferred since the dynamic order of the converter is reduced [9-10].The design optimization is based on two principles:

1) For a steady-state operation in a continuous conduction mode, the inductance value for all choppers must be greater than the maximum value of boundary inductance.

2) In order to limit the output voltage ripple of DC-DC converter below a desired value, the filter capacitance must be larger than the maximum value of boundary capacitance.

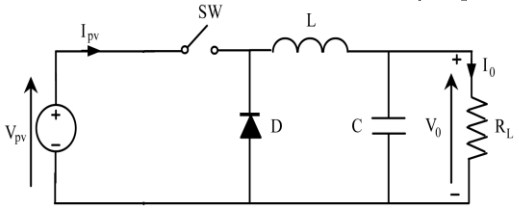


Fig 3(a): Buck Converter

Table 2: Characteristic Parameters of Buck Converter

parameters	A_v	A_i	R_{in}	L_{bo}	C_{bo}
Buck Conv-erter	A	$1/\alpha$	R_L/α^2	$(1-\alpha)R_l$ /2f	$(1-\alpha)V_0$ /8$V_0\Delta Lf$ 2

The equivalent circuit of buck converter and characteristic parameters of buck converter is shown in fig 3(a).

IV. MPPT TECHNIQUIES

A. MPPT by P&O Method:

Perturb and observe method is one of the hill climbing method based on the voltage power characteristics of PV array. This algorithm is mostly used for PV systems because of its low complicated ness and easy to implement.

The power drawn from the PV array is examined by changing the direction of operating voltage. If it increases then the module voltage is further increased in the same direction, if it decreases the direction of voltage module perturbation is reversed. The flowchart of P&O method is shown in figure 4(a).

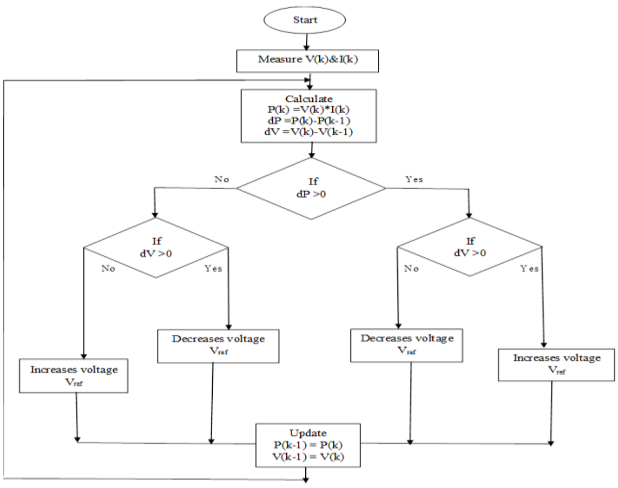


Fig 4(a): Flow Chart of P&O Algorithm

The main disadvantages of this algorithm are oscillations occurred around MPP under steady state conditions and poor tracking capacity under swiftly changing irradiations.

B. Mppt by Incremental Conductance Algorithm:

Incremental conductance algorithm is also a hill climbing method similar to that of a P&O algorithm. This method is more efficient than the P&O algorithm in terms of tracking the maximum power point of PV array correctly.

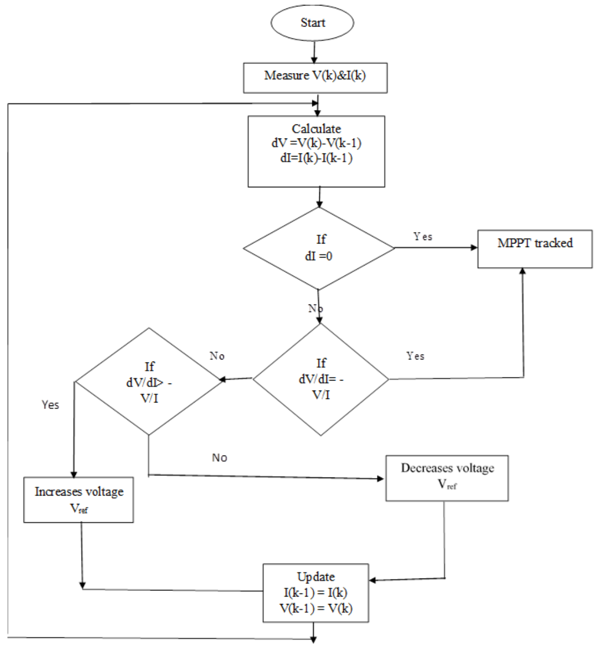
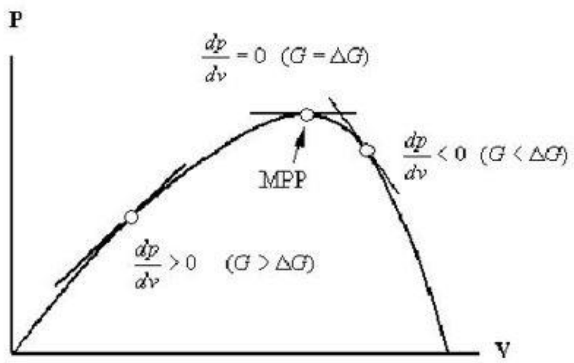


Fig 4(b): Flow Chart of Incremental Conductance Algorithm

This algorithm has a concession between maximum efficiency and reliability of tracking MPP. The flowchart for INC is shown in the figure 4(b).

This method uses conductance for searching the maximum power point (MPP). The output voltage and current from the PV array is sensed and the MPPT controller lean to calculate the conductance and incremental conductance. By comparing both, make its decision to increase (or) decrease the module voltage.



The slope of the power vs voltage (current) characteristics of the PV module is zero at MPP, negative (+ve) on the right of it, and positive (-ve) on the left of it as shown in the above figure.

The incremental conductance method is processed by using MATLAB simulation. The oscillations around the MPP is eliminated by this method.

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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.

$$k = \frac{Vmp}{Voc}$$

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[11].

To operate the PV panel at MPP, then the voltage of PV array is compared with open circuit voltage. Based on the error signal produced, which is used to change the duty cycle of buck converter connected between load and PV array.

The open circuit voltage (V_{oc}) is calculated by disconnecting the load from PV panel means we obtain interruptible power supply.

The flowchart of fractional open circuit voltage is shown in the figure 4(d).

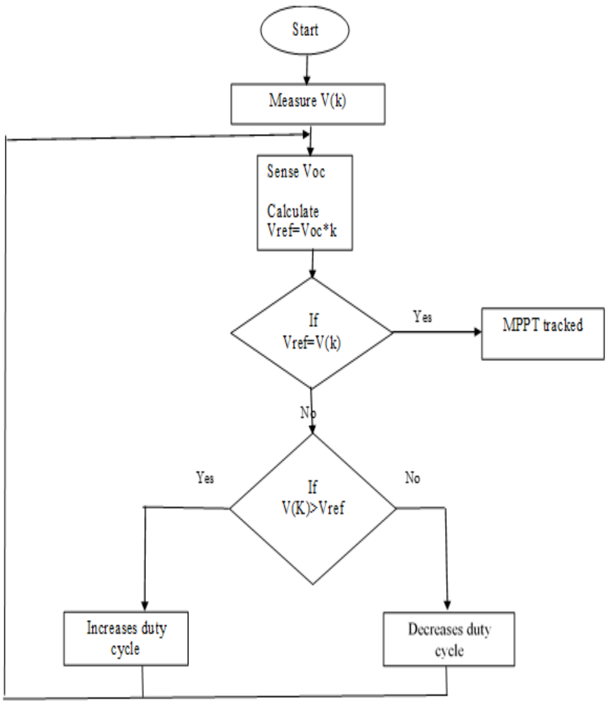

Fig 4(d): Flow Chart of Constant Voltage Algorithm

D. Mppt by Constant Current Method:

In this method also the MPP current has a linear relationship with short circuit current (Isc) of the PV panel.

$$Imp = M * Isc$$

M is a constant current factor, which depends on fabrication of PV array and ranging from 71% to 86%.

The short-circuit current is calculated for a given solar module. Then, it is multiplied with M and obtained value (current) I_{mp} corresponding to Maximum power (P_m) and the algorithm is same as constant voltage algorithm.

This method is not practically possible to short circuit the PV array (i.e; to establish zero resistance across the array terminals).

E. Mppt by Fuzzy Logic Controller:

Fuzzy logic controller does not require the knowledge of exact model. It is robust and relatively simple [12]. The proposed MPPT fuzzy logic controller is shown in figure 4(e) with 2 inputs and 1 output.

The input variables are defined by

$$E=\frac{dP(K-1)}{dV(K-1)}\text{ ; } CE=E(K)-E(K-1)$$

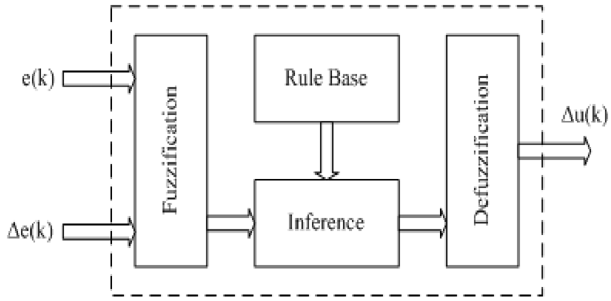

Fig 4(e): General Diagram of Fuzzy Controller

The membership function of inputs is shown in figure 4(f) and figure 4(g).

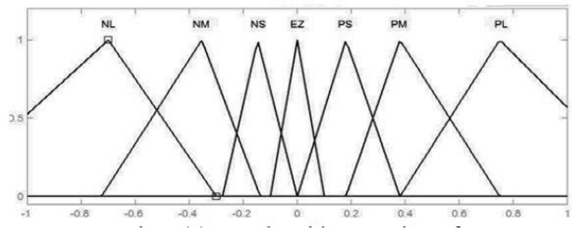

Fig 4(f): Membership Function of An Error

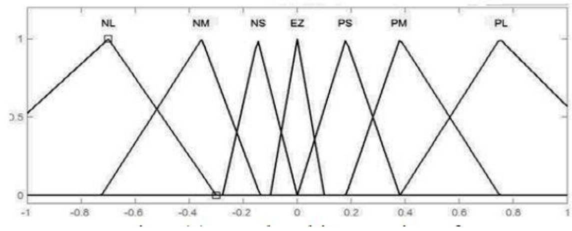

Fig 4(g): Membership Function of Change in Error

The duty cycle is calculated from the change in duty cycle from the equation:

Duty cycle D = dD + dD(k-1)

Where dD is the change in duty cycle. Fig 4(i) illustrates the fuzzy set of change in duty cycle output which contains triangular membership functions.

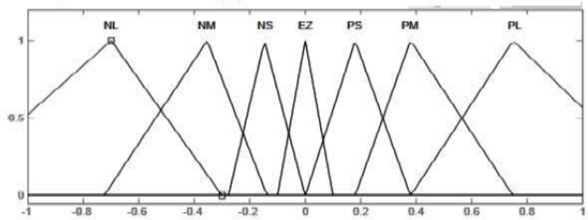

Fig 4(h): Membership function of change in duty Cycle

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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-7 Issue-2, December 2017

V. DIFFERENTIAL POWER CONVERTER

When the MPPs of series PV elements match, the energy produced can be sent directly to an output, without additional processing [15]. Differential converters take advantage of this by only processing power if there is mismatch in the MPP current of the series PV elements.

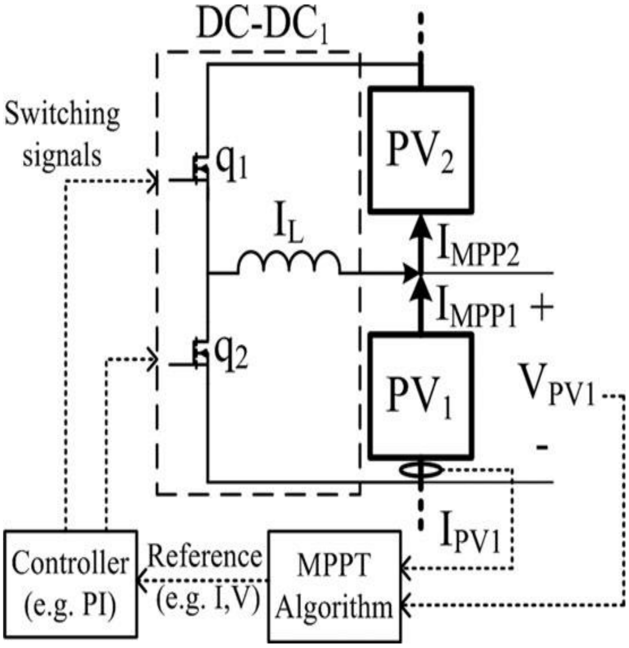

Fig 5: MPPT with Local Information

If MPP currents are matched, differential converters need not operate (i.e., have no output current). Differential power processing can be implemented using a variety of architectures [16] and converter topologies. Isolated or non-isolated converters can be used for energy conversion, depending on configuration.

VI. SIMULINK REPRESENTATION AND RESULTS

In order to access the implementation of all algorithms, a PV module with a maximum output power 60W, short circuit current 3.74AMP and open circuit voltage 21.1V under standard temperature and irradiance conditions was simulated using MATLAB. The basic representation of simulation diagram is shown in the figure 5.

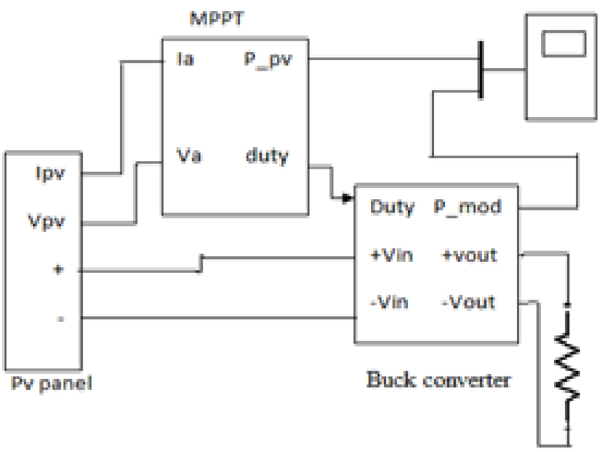

Fig 6: Basic Simulink Representation

Table 3: P_{max} at Constant Irradiation for Different MPPT Techniques.

At irradiation=1000W/m²		
MPPT techniques	Maximum power obtained	Settling time
P&O algorithm	57	Oscillated around its MPP
INC algorithm	59.8	0.43
Constant current algorithm	57.93	0.32
Constant voltage algorithm	59.66	0.36
Fuzzy logic controller	59	0.28

At constant temperature and constant irradiation the maximum power obtained for different MPPT techniques is shown in the table 3.

Figures 7(a),7(b),7(c) shows the PV array output power, output voltage& output current with respect to change in irradiations.

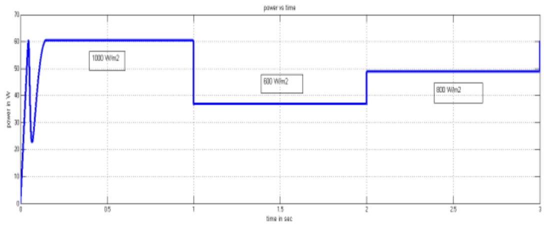

Fig 7 (a): PV Panel Output Power at Various Irradiations

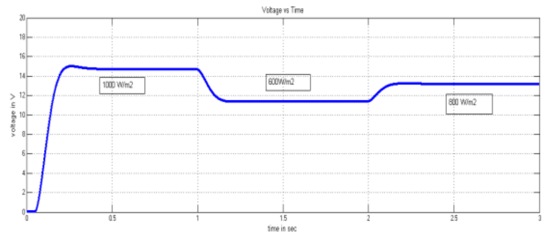

Fig 7(b): PV Panel Output Voltage at Various Irradiations

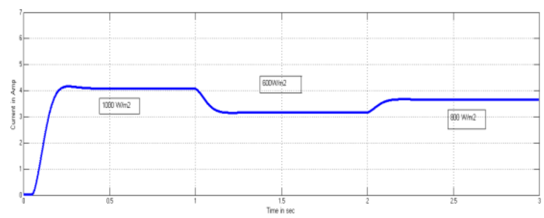

Fig 7(c) PV Panel Output Current at Various Irradiations

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Figure 8 shows the comparison of converter output power with various MPPT techniques at various irradiations.

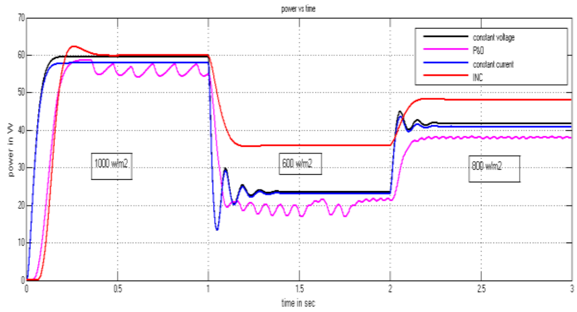

Fig 8: Converter Output Power with Different MPPT Techniques at Various Irradiations

Figure 9(a) and 9(b) shows the output voltage and output power of converter with fuzzy logic MPPT controller.

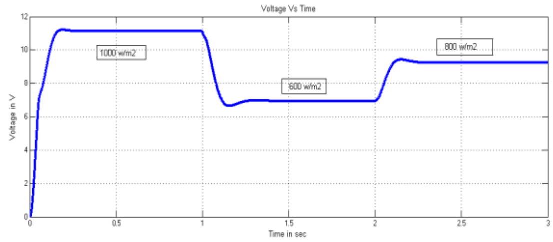

Fig 9(a): Fuzzy Logic Output Voltage at Various Irradiations

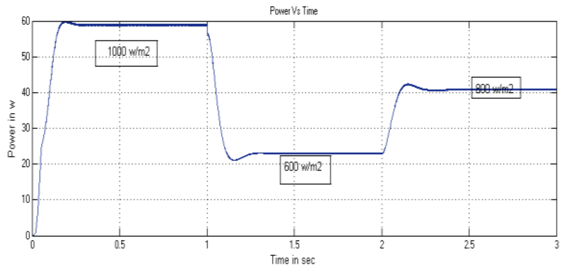

Fig 9(b): Fuzzy Logic Output Power at Various Irradiations

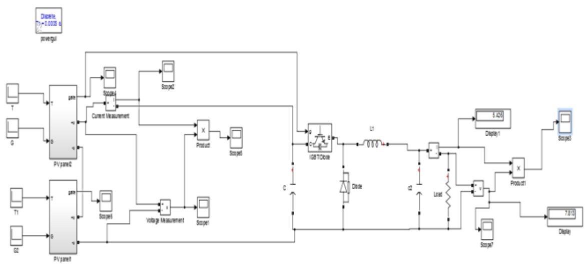

Fig 10(a): Simulation diagram of series PV modules without Differential converters under partial shading

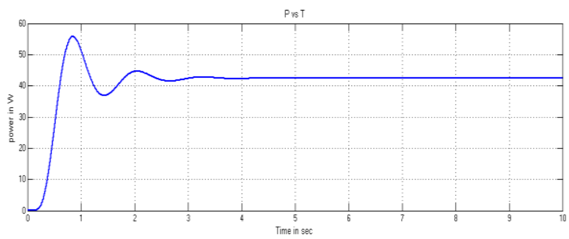

Fig 10(b): Output Power of series PV Panels Without Differential Converters Under Partial Shading

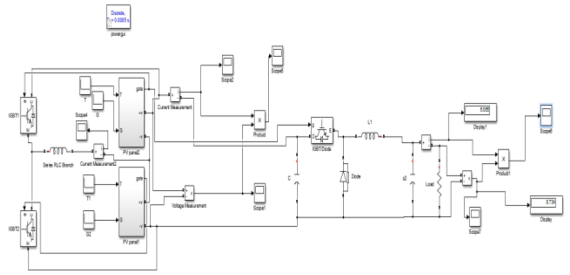

Fig 10(c): Simulation Diagram of series PV Modules with Differential Converters under Partial Shading

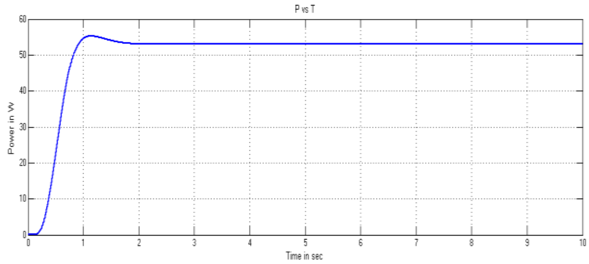

Fig 10(d): Output Power of series PV Panels with Differential Converters under Partial Shading

Figures 10(b),10(d) gives the output power of PV panel under partial shading conditions by with and without differential converter.

VII. CONCLUSION

This paper authorized the simulation model of the Maximum Power Point of photovoltaic array based on MATLAB/Simulink for different MPPT techniques with different light intensities and comparisons are given. From the results pertain to power efficiency; INC and fuzzy method could accommodate a better tracking of MPP with high speed of convergence than other techniques. It produces less oscillations around the MPP and reduces power loss. The differential power converter with INC method gives the best solution for partial shading problem. Tracking step value has a considerable effect on effectiveness of MPPT algorithms. So in the future research, the self-adaptive step size needs to be further optimized in order to reduce the oscillation amplitude of output current and output voltage.

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