

Improving the Performance of PV System by using Fuzzy logic controller and SEPIC Converter under Partial Shading Condition

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ABSTRACT: This paper investigates the comparative study of Photovoltaic (PV) system with maximum power point tracking algorithms (MPPT): Incremental conductance and Fuzzy logic control methods to get maximum power using Different DC-DC converters like boost converter, Buck converter, Buck-Boost and Sepic converter, Among all these combinations we get maximum power output and efficiency of PV system by using Fuzzy logic control MPPT with Sepic converter. Fuzzy logic controller provides advanced features such as fast response, good performance in terms of oscillations and to improve the efficiency. This paper also presents the behaviour of PV system under uniform and partial shaded conditions. This MPPT algorithm's also adjusts the duty cycle of the switch in DC-DC Sepic converter for regulating the input voltage at the maximum power point and provides constant input power load regardless of changing climatic conditions. The proposed system is simulated using MATLAB/Simulink model.

KEYWORDS: Photovoltaic system, incremental conductance method (INC), Fuzzy logic control, Uniform and Partial Shaded Conditions (USC and PSC), Sepic converter, Modelling and Simulation.

I. INTRODUCTION

The renewable energy sources are also called as non-conventional type of energy sources. Which are continuously renewed by natural process. It includes, solar energy, bio-energy - bio-fuels, wind energy, ocean energy, tidal energy and hydropower etc., are some of the examples of renewable energy sources. A renewable energy system convert the energy found in sunlight, falling-water, wind, sea-waves, geothermal heat, or biomass into a usable form, such as in the form of heat energy or electrical energy. The majority of the renewable energy comes either directly or indirectly from sun and it can never be fatigued, and therefore it is called as renewable energy Source.

Nowadays, on a commercial level and on a small scale, individual users are frequently using PV arrays because PV Systems have Specific advantages, it can be used for both low power and high power applications, fuel free etc. but this PV systems suffers from some of the atmospheric conditions like temperature and irradiance so, all are trying to extract a maximum amount of power from PV panel. The output power and the power voltage (P-V) characteristic of PV array are totally dependent on the temperature and solar irradiance. Therefore, if these atmospheric parameters fluctuate rapidly, then the maximum power point of the P-V curve of PV array also fluctuates very rapidly. This rapid fluctuation of the MPP may be, in accordance with the uniform shading of the PV panel or may be in accordance to the partially shaded due to the clouds, tall building, trees, and raindrops.

More importantly, high initial cost and limited life span of PV panels make it more critical to extract as much power from them as possible. Therefore, maximum power point tracking technique of should be implemented in DC - DC converter to achieve maximum power and efficiency of PV arrays.

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II. RELATED WORK

In recent years, a large number of techniques have been proposed for tracking the maximum power point. Maximum power point varies and depends on the temperature of Solar cell or also depends on the preset insolation level. This MPPT with a dc-dc sepic converter is used for tracking or extracting the maximum power from the solar PV module and transferring this maximum power from the solar PV module to the load. There are a large number of algorithms that are able to track MPPs. Some of them are more complicated, such as perturbation and observation or the incremental conductance method and Some of them are simple, such as those based on voltage and current feedback, So we are using such a simple method Fuzzy logic control MPPT with Sepic converter.

This paper also proposed to distinguish between the global peak (GMPP) and local peak (LMPP). The topmost peak is known as global maximum power point and rests all peaks are known as local maximum power point. During partial shading, global and local maximum power points are produced. Once the local maximum is reached, P&O methods fluctuate around that point. To overcome the issue, an innovative method of incremental conductance MPPT has been developed to reduce the oscillations and stabilize the maximum power point. But fuzzy logic controller provides advanced features such as fast response, good performance in terms of oscillations to reaches global maximum point so, fuzzy logic controller is designed and analyzed in this paper and this can be compared with INC Algorithm.

III. MODELING OF SOLAR PV SYSTEM

Solar Cells or Photo Voltaic Cells are devices or simply transducers which convert the energy available from the sun directly into electrical energy which is in the form of a DC i.e. electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. PV cell when placed in the sunlight, photons with energy greater than the band-gap energy of the semiconductor develops electron-hole pairs proportional to the incident irradiation. Solar cells can be connected in series and parallel depending upon the desired voltage or current. This series or parallel connected solar module form a string and the combination of such string in series and parallel gives a solar array. Shows Fig (1) below equivalent circuit of PV cell and the series resistance R_s , which is an existing resistance opposing the flow of current. The parallel the parallel resistance R_p is inversely proportional to the leakage current w. r. t. the ground and this value becomes very small and negligible.

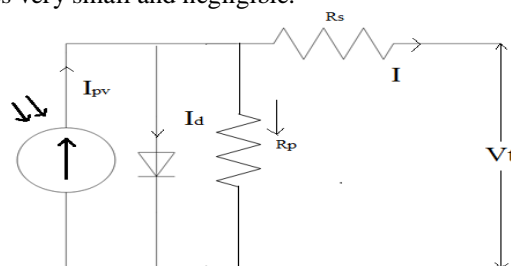


Fig. 1. Equivalent circuit model of PV cell

PV array output current

$$I = I_{pv} - I_d - \left(\frac{IR_s}{R_p} \right) \quad (1)$$

Photo Current

$$I_{pv} = \left[(T - T_{ref}) \left(\frac{S}{S_{ref}} \right) a + \left(\frac{S}{S_{ref}} - 1 \right) I_{sc} \right] \quad (2)$$

Diode current

$$I_D = I_{sc} \left[C_1 \left(e^{\left(\frac{V_{out} - V_d}{C_2 V_{oc}} \right)} - 1 \right) \right] \quad (3)$$

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Voltage across Diode

$$V_d = b(T - T_{ref}) + [(T - T_{ref}) \left(\frac{S}{S_{ref}}\right) a + \left(\frac{S}{S_{ref}} - 1\right) I_{sc}] R_s \quad (4)$$

Where

I =PV array output current in (A)

I_d =Diode current (A)

I_{pv} =Photo current or current generated by the incident of light (A)

Table (1) shown below gives complete specifications of matlab designed PV system. Short circuit current can be found by connecting two output terminals of PV system directly. Temperature of the PV cell is maintained at constant room temperature and the irradiance levels can be changed according to our required output power because the output power may change with respect to irradiance.

Table 1: Specification of PV module

Variable	Name of the variable	Rated values
I_{sc}	Short circuit current	25.44 A
T	Temperature of the PV cell	273 ⁰ C
T_{ref}	Reference Temperature of PV cell	25 ⁰ C
S	Irradiance values	600,400,200(under partial shading)W/m ²
S_{ref}	Reference value of irradiance	1000 W/m ²
R_s	Series resistance	2.2 ohms

IV. PROPOSED MPPT TECHNIQUES

A. Incremental conductance MPPT technique

The MPP can thus be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance ($\Delta I/\Delta V$) as shown in the flowchart in Fig. 2. The incremental conductance method is based on the fact that the slope of the PV array Power curve is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by below equations.

$$\frac{dP}{dV} = 0 \quad \text{At MPP} \quad (5)$$

$$\frac{dP}{dV} > 0 \quad \text{Left of MPP} \quad (6)$$

$$\frac{dP}{dV} < 0 \quad \text{Right of MPP} \quad (7)$$

Since

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V \frac{dI}{dV} \cong I + V \frac{\Delta I}{\Delta V} \quad (8)$$

Equations (5), (6) & (7) can be re written as

$$\frac{\Delta I}{\Delta V} = \frac{-I}{V} \quad \text{At MPP} \quad (9)$$

$$\frac{\Delta I}{\Delta V} > \frac{-I}{V} \quad \text{Left of MPP} \quad (10)$$

$$\frac{\Delta I}{\Delta V} < \frac{-I}{V} \quad \text{Right of MPP} \quad (11)$$

V_{ref} is the reference voltage at which the PV array is forced to operate. At the MPP, V_{ref} equals to V_{MPP} . Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI is noted, indicating a change in atmospheric conditions and the MPP. The algorithm decrements or increments V_{ref} to track the new MPP. Effective way of performing the INC technique is to use the instantaneous conductance and the incremental conductance to generate an error signal

$$e = \frac{I}{V} + \frac{dI}{dV} \quad (12)$$

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We know that e goes to zero at the MPP.

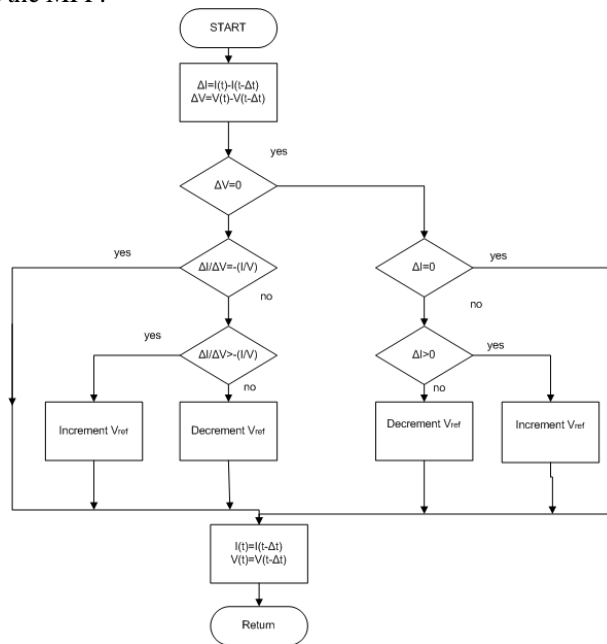


Fig. 2. Flow chart for the Incremental conductance MPPT

Below figure (3) shown MATLAB design of INC MPPT. By using this we can generate gate pulses to the switch in the DC-DC converter and to control output power. This technique can be operated by taking feedback voltage and current from the PV system. It provides the duty cycle according to the maximum power point whether it is positive or negative by comparing the calculated instantaneous conductance with change in conductance.

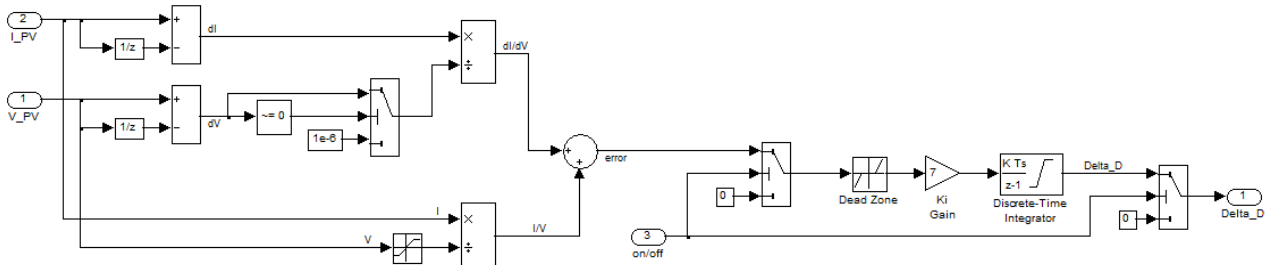


Fig. 3. MATLAB Simulated Algorithm for Incremental conductance MPPT

B. Fuzzy Logic Control

Fuzzy logic control is most popular for MPPT over the last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Fuzzy logic control generally consists of three stages: fuzzification, rule base table lookup, and Defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function similar to Fig. 4 below.

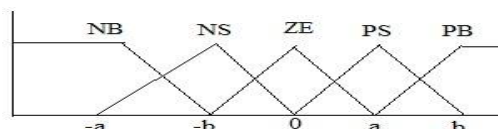


Fig. 4. Numerical variables

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In this case, five fuzzy levels are used: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). In Fig. 4, a and b are based on the range of values of the numerical variable. The membership function is sometimes made less symmetric to give more importance to specific fuzzy levels. The inputs to a MPPT fuzzy logic controller are usually an error E and a change in error ΔE. The user has the flexibility of choosing how to compute E and ΔE. Since dP/dV vanishes at the MPP.

$$E(n) = \frac{[p(n)-P(n-1)]}{[V(n)-V(n-1)]} \tag{13}$$

And

$$\Delta E(n) = E(n) - E(n - 1) \tag{14}$$

Once E and ΔE are calculated and converted to the linguistic variables, the fuzzy logic controller output, which is typically a change in duty ratio ΔD of the power converter, can be looked up in a rule base table such as Table II.

Table 2: Fuzzy rules base table

ΔE \ E	NB	NS	NE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

The linguistic variables assigned to ΔD for the different combinations of E and ΔE is based on the power converter being used and also on the knowledge of the user. If, for example, the operating point is far to the left of the MPP, that is E is PB, and ΔE is ZE, then we want to largely increase the duty ratio that is ΔD should be PB to reach the MPP. In the Defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function. This provides an analog signal that will control the power converter to the MPP. MPPT fuzzy logic controllers have been perform well under varying atmospheric conditions.

V. DC-DC CONVERTERS

There are different types of dc-dc converters. Buck, boost, buck-boost and Sepic converter topologies have been developed in this paper and from these converters sepic converter meets specific demands.

A. Buck converter:

The buck converter is also known as the step-down converter. Buck converters will produce ripples on the PV module side currents and thus require a larger value of input capacitance on the module side. A buck converter using a power MOSFET shown in Fig. 5.

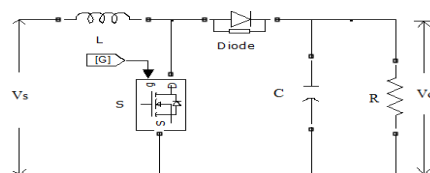


Fig. 5. DC-DC Buck converter

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B.Boost converter:

The boost converter is also known as the step-up converter. In this boost converter the output voltage is greater than the input voltage. Large output capacitor is required to reduce ripple voltage as output current is pulsating. Slower transient response. A boost converter using a power MOSFET shown in Fig. 6.

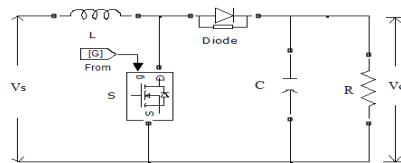


Fig. 6. DC-DC Boost converter

C.Buck-Boost converter:

Buck boost converter requires input filter to reduce current ripple and to meet electromagnetic interference (EMI) requirements as input current is pulsating due to switching of power switch. Also output current is discontinuous and hence large output capacitor is required to reduce ripple voltage. Even though buck-boost converter is able to step up or step down input voltage it gives negative output voltage with respect to ground. Moreover, presence of right half zero in continuous conduction mode makes feedback loop compensation difficult. A Buck-Boost converter using a power MOSFET shown in Fig. 7.

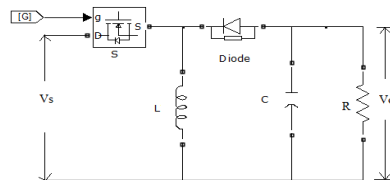


Fig. 7. DC-DC Buck-Boost converter

D.Sepic converter:

To overcome the above disadvantages of all above converters by using Sepic converter. This is the one of the DC-DC converter and This single ended primary inductor converter (SEPIC) can have its output voltage higher or lower than its input voltage unlike boost converter or buck converter Although buck- boost converter is also able to give higher as well as lower output voltage than its input voltage, it's output voltage is negative with respect to ground unlike SEPIC converter, which provides positive output voltage. A Sepic converter using a power MOSFET shown in Fig. 8.

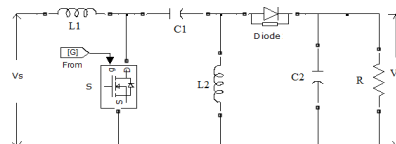


Fig. 8. DC-DC Sepic converter

Table (3) Shown below represents designed Specifications of Sepic converter. Here, inductor and capacitor values are selected carefully to reduce the ripples in the current and to maintain output voltage as constant, i.e. to filter out the ripple content. R value represents load resistance of the PV system. By changing the load resistance we can change the load voltages and currents but here, we need not to change this value i.e. R value becomes constant, because the output power can be changes according to the irradiance levels.

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Table 3: Specification of Sepic Converter

Variable	Name of the variable	Rated values
$L_1=L_2$	Inductance in Henry	0.01H
$C_1=C_2$	Capacitance in Farad	2mF
R	Load resistance in ohms	500 ohms

VI. SIMULINK MODELING OF SOLAR PV SYSTEM

Modelling can be done in MATLAB by many ways; common methods includes by programming and using SIMULINK modelling. Modelling a PV panel using SIMULIK is explained in this section. As explained above, the PV panel is influenced by temperature, Irradiance, etc. Step wise blocks are made and finally, all are combined to get the PV panel. Below figure (9) shown design of PV system to get PV current, this can be done by standard equations and reference values as already mentioned above.

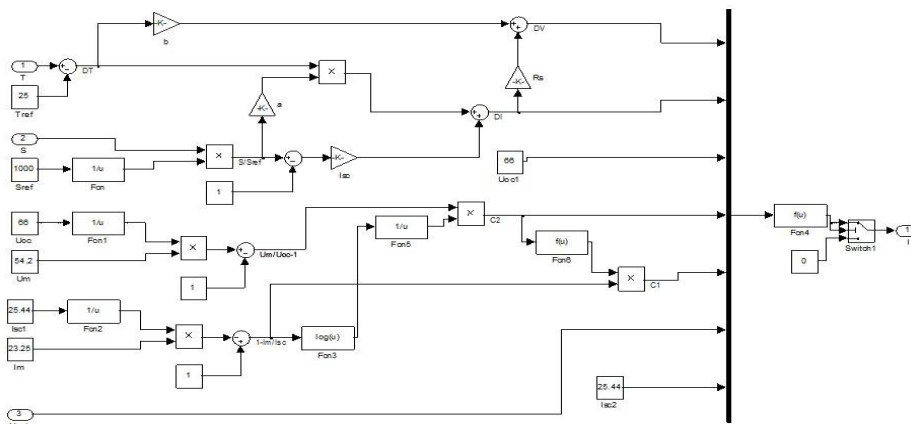


Fig. 9. Calculation of PV Current

Below figure (10) shown represents single PV cell subsystem created for the above figure (9). We can give constant reference temperature of 25°C and irradiance value $400\text{W}/\text{m}^2$. From this single cell we got less value of output current, to overcome this problem by connecting three cells in parallel as shown in figure(11).

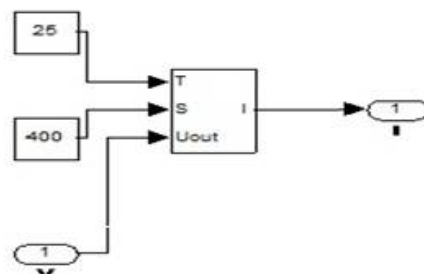


Fig. 10. Single PV Cell

Below Fig. (11) Shows three individual PV cells are connected in Parallel to get a PV module and to collect the total amount of current from this module given to the DC-DC Sepic converter. Here, we can observe Three PV cells are operated at constant temperature of 25°C and constant irradiance ($400\text{W}/\text{m}^2$) for uniform shading condition, this irradiance values can be given at constant blocks represented by S provided at each cell and having same value. For obtaining partial shading effect we maintain constant value of temperature 25°C but provide different values for irradiance like 200,400 and $600\text{W}/\text{m}^2$.

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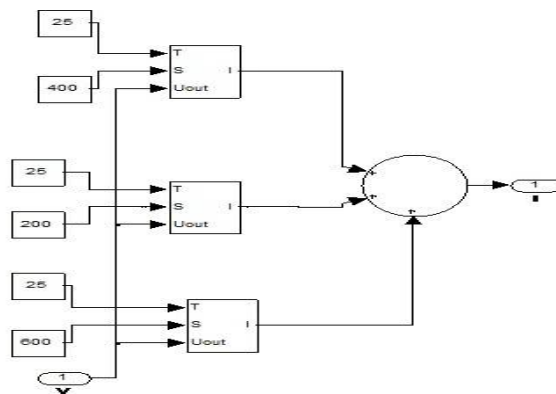


Fig. 11 Parallel Connected PV Module

VII. SIMULATION RESULTS

CASE 1: Uniform shaded Condition

During uniform shading, the PV system is tested under same irradiation levels. Three modules are uniformly Shaded with an irradiance level of 400W/m^2 and constant temperature of 25°C . The power level can be increased by increasing the irradiance value and this can be verified by this simulation. Below figure (12) shown P-V and I-V characteristics under uniform shading. Under this condition we got only one local maximum point, this can be easily tracked by MPPT.

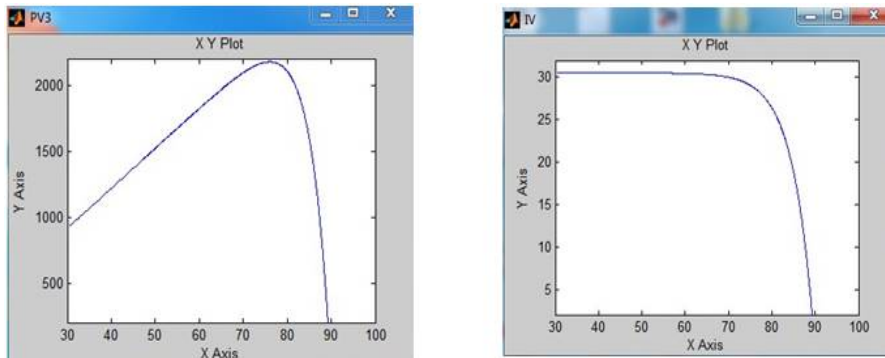


Fig. 12. P-V and V-I Characteristic of solar array with uniform irradiance

CASE 2: Partial shaded Condition

During partial shading, the PV system is tested under different irradiation levels. Three modules are partially Shaded with an irradiance level of $200, 400$ and 600W/m^2 and constant temperature of 25°C . Below figure (13) shown P-V and I-V characteristics under partial shading condition.

In this condition we got multiple maximum power points called as local maximum points, among these points topmost one is the global best maximum point and the PV system can be operated at this point and this can be tracked by using fuzzy logic controller MPPT.

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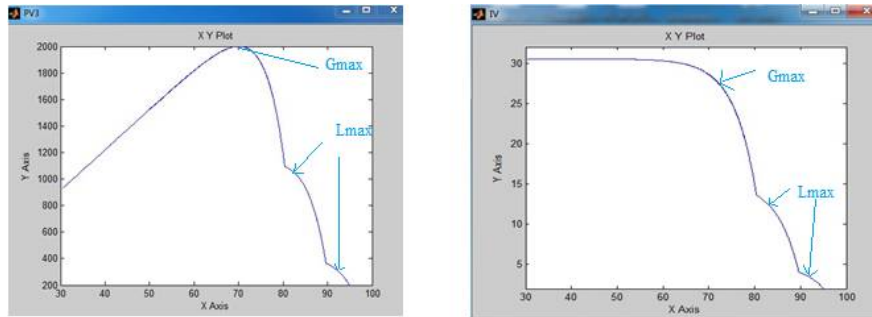


Fig. 13. P-V and V-I Characteristic of solar array with non-uniform Irradiance (Shading Effect)

CASE 3: Simulated outputs with Incremental conductance MPPT Algorithm

PV module is simulated with Incremental conductance MPPT and this PV system output voltage applied to different converters. The output voltages of different converters shown in Figure 14, for constant duty cycle $\delta=0.5$

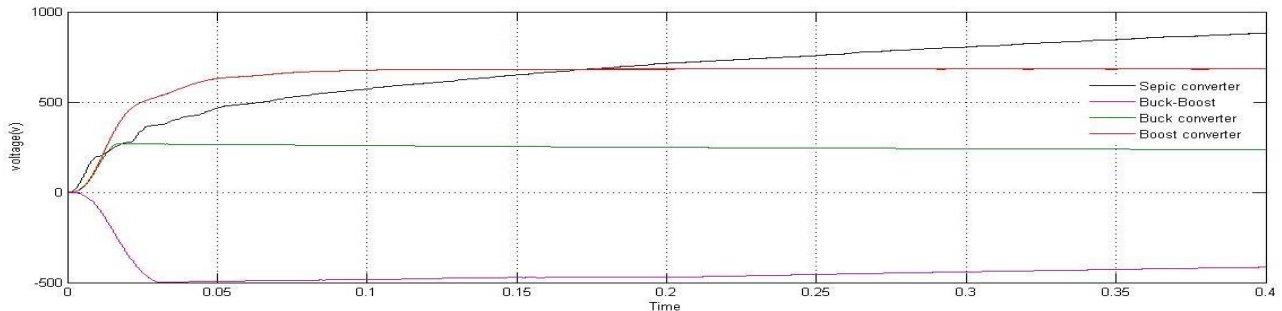


Fig. 14. Output voltages of different converters along with incremental conductance MPPT.

CASE 4: Simulated outputs with Fuzzy logic control MPPT Algorithm

PV module is simulated with Fuzzy logic control MPPT and this PV system output voltage applied to different converters. The output voltages of different converters shown in Figure 15, for constant duty cycle $\delta=0.5$. Observe the below output voltage levels, we got greater positive voltage level with combination of fuzzy logic controller MPPT algorithm and Sepic converter as compared to all other converters and this voltage also greater than the combination of incremental conductance algorithm and sepic converter.

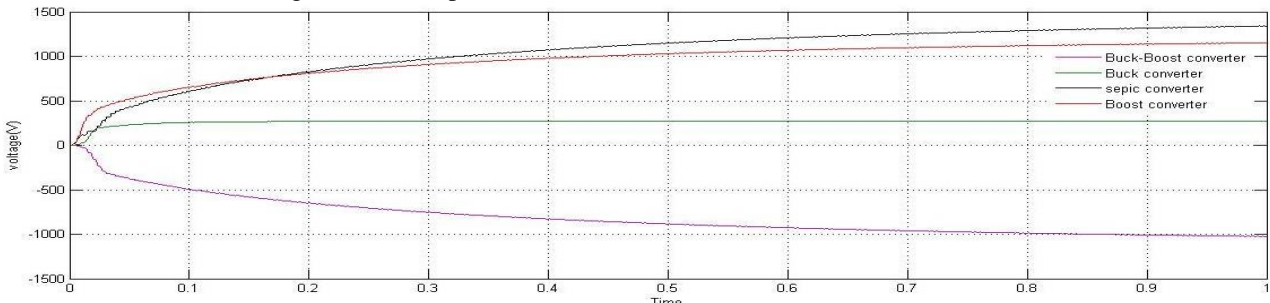


Fig. 15. Output voltages of different converters along with Fuzzy logic controller MPPT.

Continues mode operation of the sepic converter can be decided by current flowing in the inductor L1, it should not reach to zero value in this mode. This can be represented by below Figure 16. In continues mode of conduction, the load current is available at all times to operate the connected load.

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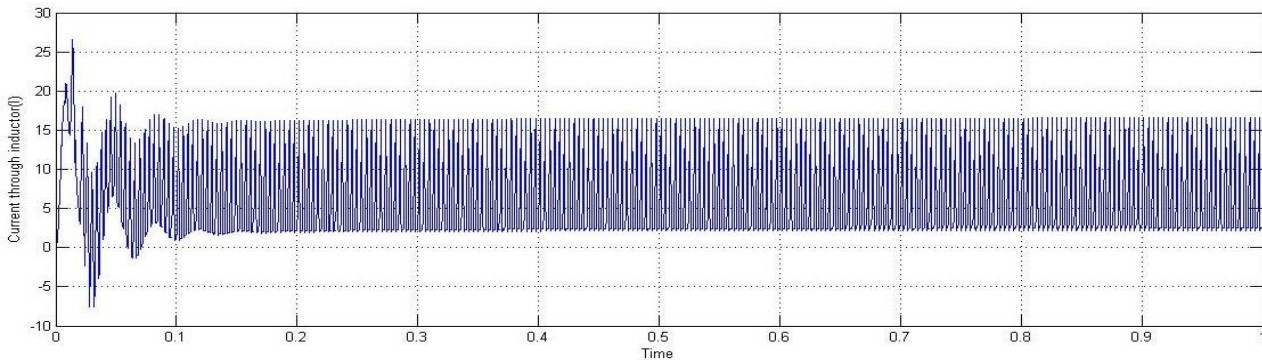


Fig. 16. Current flowing in to the inductor L1 for continues mode operation of sepic converter along with Fuzzy logic controller MPPT.

From the table (4) given below gives comparative analysis of proposed MPPT techniques and this analysis clearly indicates Fuzzy logic control algorithm along with Sepic Converter gives increased positive output voltage and this voltage will reach steady state within the less time i.e. settling time of this combination (Fuzzy logic control with Sepic converter) is very less.

Table 4: Comparison of proposed MPPT Algorithms

Specification	Incremental Conductance Algorithm				Fuzzy logic controller algorithm			
	Boost Converter	Buck Converter	Buck-Boost	Sepic converter	Boost Converter	Buck Converter	Buck-Boost	Sepic Converter
Settling time of Voltage(sec)	0.1	0.05	0.25	0.3	0.6	0.1	0.8	0.4
Output Voltage(volts)	700	240	-500	900	1100	300	-1000	1300
Accuracy	Medium				More			
Tracking Speed	Medium				Fast			
Complexity	More				Less			

VIII. CONCLUSION

The energy conversion of entire system has been designed in MATLAB-SIMULINK environment. By observing the above simulated results we got improved values of voltage with the combination of combination of fuzzy logic controller MPPT algorithm and Sepic converter as compared to all other combinations and this output voltage has less harmonic content. During the simulations, it was confirmed that, with a well designed system including a proper converter and selecting an efficient algorithm, the implementation of MPPT is simple and can be easily constructed to achieve an acceptable Power levels Regardless of changing Environmental conditions. The results also indicate that the proposed control system is capable of tracking the PV array at maximum power and thus improves the efficiency of the PV system due to good dynamic response and good tracking accuracy.

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BIOGRAPHY



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Mr.T.Manmadha Rao completed his graduation in electrical and electronics engineering from JNTUK, in 2011 and received his M.Tech from JNTUK in 2015. He served as an Assistant Professor in various Engineering colleges from 04 years and presently working as Asst.Proffesor in the Department of Electrical and Electronics Engineering in Aditya Institute of Technology and Management, (Autonomous), Tekkali, Andhra Pradesh, India. His areas of interest are Power systems, power electronics and Drives, Electrical circuits, Electrical Machines.