Fuzzy Logic Based Maximum Power Point Tracking For Standalone Photovoltaic System

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Abstract

The paper presents a technique used to optimize extraction of solar power from photovoltaic (PV) system. To increase efficiency, photovoltaic system uses a Maximum Power Point Tracking system (MPPT) which continuously extracts the maximum possible power from solar panel and deliver it to the load. The MPPT maintains the operation of MPP using various tracking algorithm. The existing systems have many drawbacks in terms of efficiency, flexibility, and accuracy. The objective of this paper is to design and implement a fuzzy logic based MPPT techniques. Fuzzy logic naturally deals with nonlinearities and offers higher controller. The model consists of PV panel, a dc-dc converter ie, boost converter and a fuzzy logic based MPPT controller. The fuzzy logic controller is implemented using conventional MPPT techniques such as fuzzy based hill climb technique and fuzzy based incremental conductance technique and comparative results are presented with conventional techniques. The current technique shows improved performance with less oscillation at MPP, fast setting time and sensitivity in parameter variation. The results shows that a significant amount of additional energy can be extracted from a photovoltaic module by using a fuzzy logic based maximum power point tracking system. The results provide better efficiency for the operation which is highly suitable for standalone systems.

Keywords

Solar PV system, MPPT, Fuzzy logic based MPPT, Boost converter, Hill Climb Technique, Incremental conductance Technique

Introduction

Renewable energy is a natural source of energy such as sunlight, tide, wind, rain and geothermal energy. Renewable sources are clean and produce energy without the harmful effects of pollution. Among different renewable energy technologies solar energy plays a major role in recent trends.

Solar energy can be utilized in two ways. The extracted heat can be used as solar thermal energy. Another alternative is the conversion of incident solar radiation to electrical energy, which is used for various applications. This can be achieved with the help of solar photovoltaic cells. Thus the maximum power that can be obtained from these solar panels are tracked using various MPPT techniques. This can be further connected with a boost converter to improve the output power of solar photovoltaic system. Additionally an inverter can be connected to supply ac loads.

Photovoltaic System

Generally, sunlight is composed of packets of energy, called photons. When a photon is absorbed, the photon energy is transferred to an electron of the material under illumination. This energy is higher than the electron binding energy, the electron will be ejected from its ground state and electron hole pair are created. The holes and electrons are then separated by the electric field produced by the p-n junction, this results in a potential difference and a current flow (electricity) through an external circuit if the PV cell is connected to a load.

For obtaining higher power, numerous solar cells are connected in series and parallel circuits on a module area of several square feet. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array.

Equivalent diagram of single PV cell is given in figure 1,

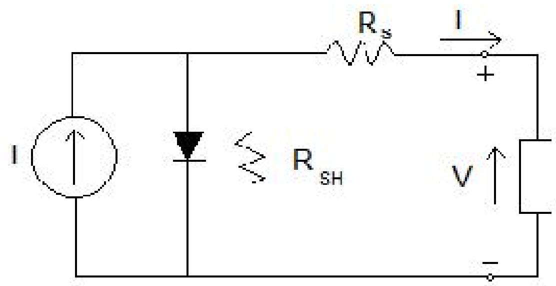

Figure 1: Model of solar PV cell

Typically a solar cell is modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

In this model we consider a current source (I) along with a diode and series resistance (Rs). The value of shunt resistance (RSH) in parallel is very high and has a negligible effect. Hence it is neglected. The output current is

I=Isc – Id (2.1)

Id= Io (eqVd/kT - 1) (2.2)

Where,Io is the reverse saturation current of the diode,q is the electron charge,Vd is the voltage across the diode,,k is Boltzmann constant (1.38 * 10-19 J/K),T is the temperature in Kelvin (K)

From eq. 2.1 and 2.2,

I = Isc – Io (eqVd/kT - 1) (2.3)

Using suitable approximations,

I = Isc – Io (eq((V+IRs)/nkT) - 1) (2.4)

Where, I is the cell current,V is cell voltage,T is temperature in Kelvin,n is ideality factor

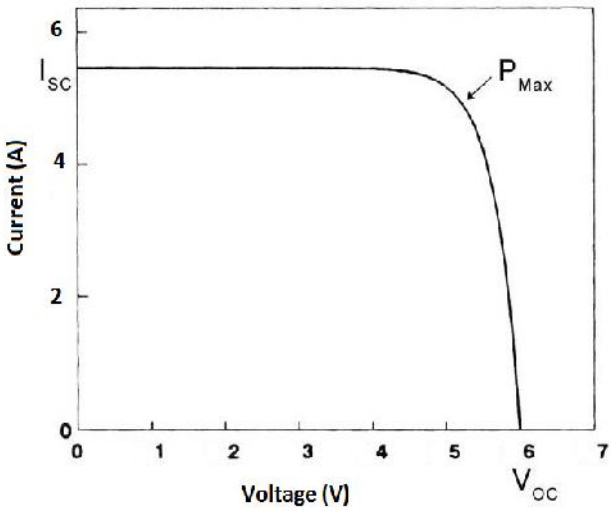

Figure 2: V-I characteristics of a solar panel

The V-I characteristics of a typical solar cell are as shown in the Figure 2.The voltage and the current characteristics are multiplied to get the P-V characteristics as shown in Figure 3.

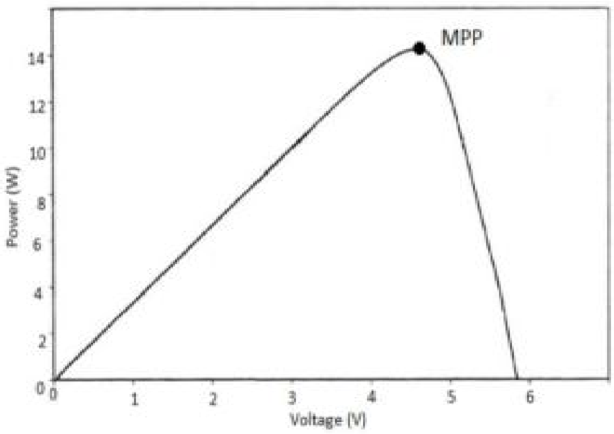

Figure 3: P-V characteristics curve

MPPT Techniques

Maximum power point tracking technique is used to improve the efficiency of the solar panel. Maximum Power Transfer theorem states that the power output of a circuit is maximum when the source impedance of the circuit matches with the load impedance.

In the source side, a boost converter is connected to a solar panel in order to enhance the output voltage. Changing the duty cycle of boost converter, source impedance is matched with the load impedance.

Few of the most popular MPPT techniques are:

1) Perturb and observe method (Hill climb)
2) Incremental Conductance method
3) Neural networks

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4) Fuzzy logic

The choice of the algorithm depends on the time complexity and the time taken to track the MPP, implementation cost and the ease of implementation. This paper provides a detailed study of fuzzy logic based hill climb method and fuzzy logic based Incremental Conductance method.

Fuzzy Logic based MPPT Technique

Recently more focus is done artificial intelligence based MPPT techniques, as they focus on the nonlinear characteristics of the PV array providing a good alternative for basic MPPT techniques. Mostly commonly used technique is fuzzy logic controller.

In general, the PV panel voltage and current are sensed and are fed to the fuzzy logic controller, which in turn calculates the input power. The inputs of the fuzzy logic controller are typically the Error (Er) = ΔP/ΔV or ΔP/ΔI and the change in Error (CEr), are calculated. The fuzzy system takes Er and CEr as inputs and outputs the duty cycle D. Moreover, FLC based systems are capable of performing well under varying atmospheric conditions.

Fuzzy logic controller-Design

Fuzzy logic controller is mainly comprises of
1) Fuzzification
2) Fuzzy rule base
3) Fuzzy inference
4) Defuzzification

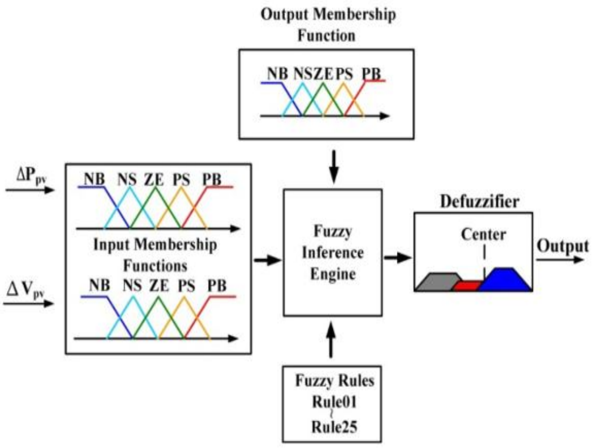

Figure 4: Fuzzy logic controller design

Fuzzification

Fuzzification is the process where the crisp quantities are converted to fuzzy. Fuzzification determines the input variables and does scale mapping technique i.e. converts the range of input variables values into corresponding universe of discourse.

Fuzzy Rule Base

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Fuzzy system consists of expert knowledge based set of linguistic statements. The knowledge base included the knowledge of the system on which fuzzy rules need to be applied. It consists of database and rule base. The database includes definitions that are required to define linguistic control rules and fuzzy data manipulation in FLC and the rule base characteristics the control goals and control policy of the domain experts by means of a set of linguistic control rules.

Fuzzy Inference

Fuzzy inference is the core of a fuzzy logic controller, its main function is to simulate human decisions based on fuzzy concepts and of determine fuzzy control actions by applying the rules of inference in fuzzy logic. In inference engine, fuzzy IF-THEN rules from fuzzy rule base is used to map fuzzy input sets to fuzzy output sets. Mamdani's method is commonly used fuzzy interference method.

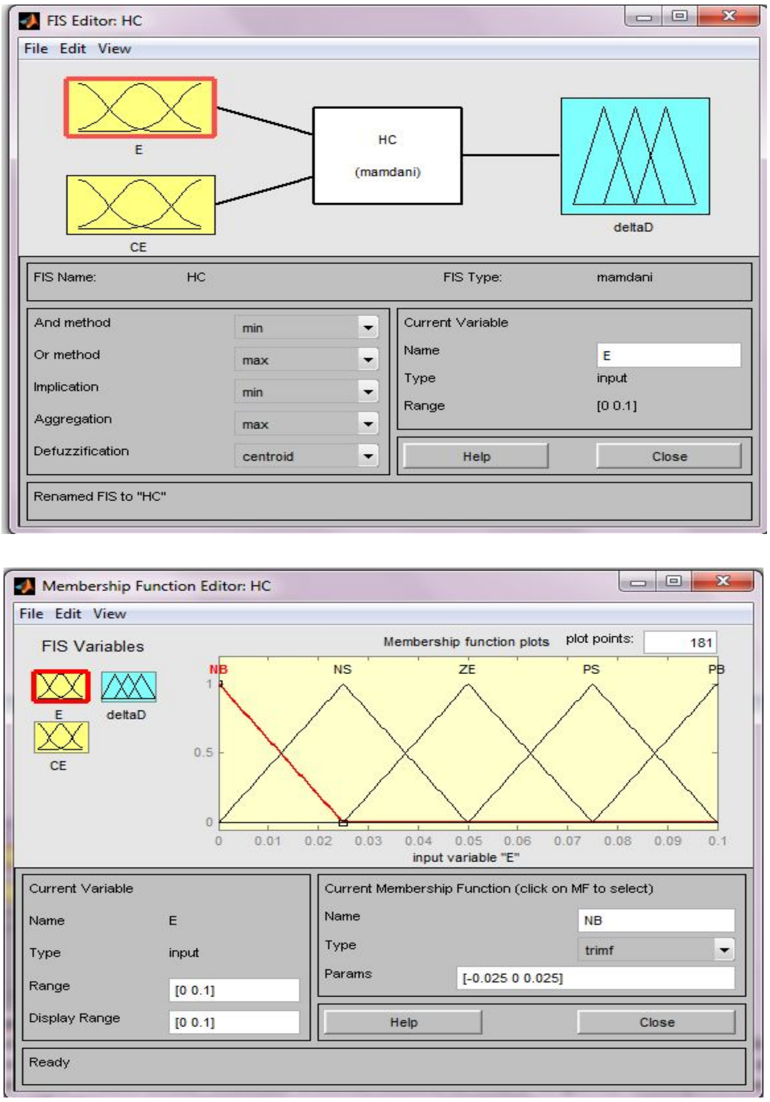

Figure 5: fuzzy membership function

Defuzzification

The defuzzificaztion performs scale mapping i.e. converts the range of values of output variables into corresponding universe of discourse and performs a non-fuzzy control action from an inferred fuzzy control action. Generally Centroid method or Center of gravity technique is used in Defuzzification.

Fuzzy Logic based Hill Climb MPPT Technique

The drawback of conventional hill climb MPPT techniques is that it oscillates when it is close to the maximum power point (MPP) which causes uncertainty and unreliability in output power leads to inaccurate results. To overcome this drawback of oscillations around MPP, a new technique- fuzzy logic based hill climb MPPT control is used. The fuzzy logic controller is connected next to PV panel and it calculates deltaD value from the respective inputs error E and change in error CE .Further the output of fuzzy ie, deltaD is given as input to hill climb algorithm to calculate duty. It is then connected to dc-dc converter and output waveforms are obtained. The Figure 6 shows overall Simulink diagram of fuzzy with hill climb.

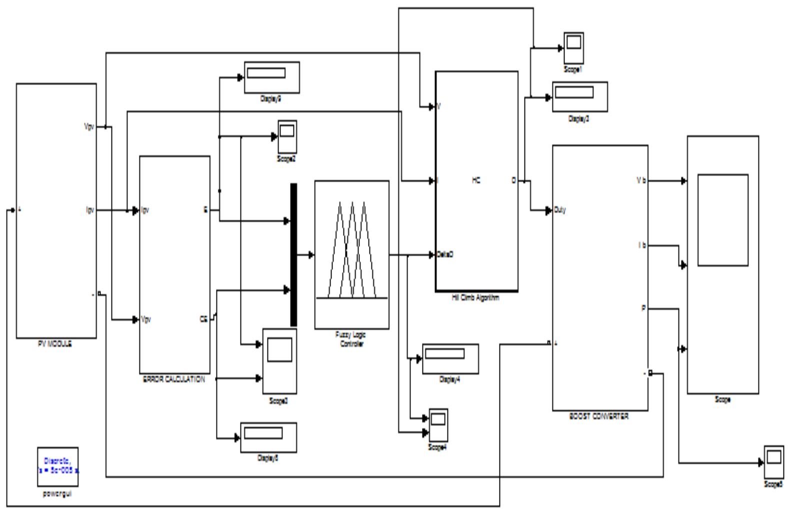

Figure 6: Overall simulink of fuzzy with hill climb

The hill climb algorithm determines the operating voltage of the PV panel, which is perturbed in small increments, the resulting change in power ΔP is positive, then it moves in direction of MPP and keep on perturbing in same direction. ΔP is negative, going away from the direction of MPP.

When we give a positive perturbation, the ΔP becomes negative and imperative to change the direction. The flowchart for the hill climb algorithm is given in Figure 7.
However this algorithm we use only voltage sensor to sense the PV array voltage and hence it is easy to implement and the cost of implementation is very low. The time complexity of this algorithm is also very less and time to reach MPP is very fast when compared to conventional hill climb technique.

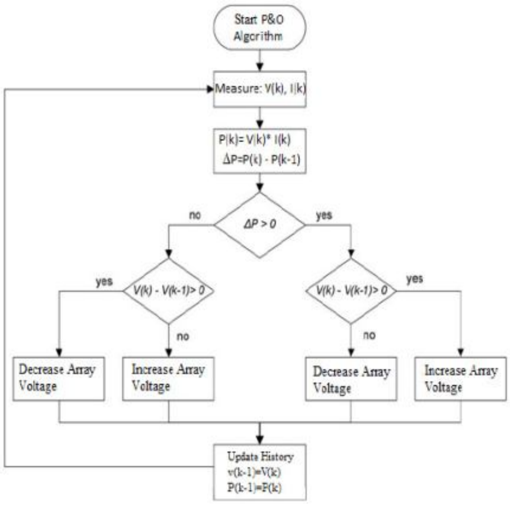

Figure 7: Flowchart of Hill Climb algorithm

Fuzzy Logic based Incremental conductance MPPT Technique

Conventional Incremental conductance method eliminates the drawbacks of the hill climb method, even then it has certain disadvantages which makes it complex. Fuzzy logic controller makes it simpler and reduces the usage of parameters by providing fast response to reach the MPP with less oscillations and more accuracy. Incremental conductance use the derivate of the power with respect to voltage at the maximum power point is zero. Furthermore the derivatives at the left of the MPP is greater than zero and less than zero to the right of the MPP.

The following set of equations describe the incremental conductance algorithm

$$P = V \times I \qquad (2.5)$$

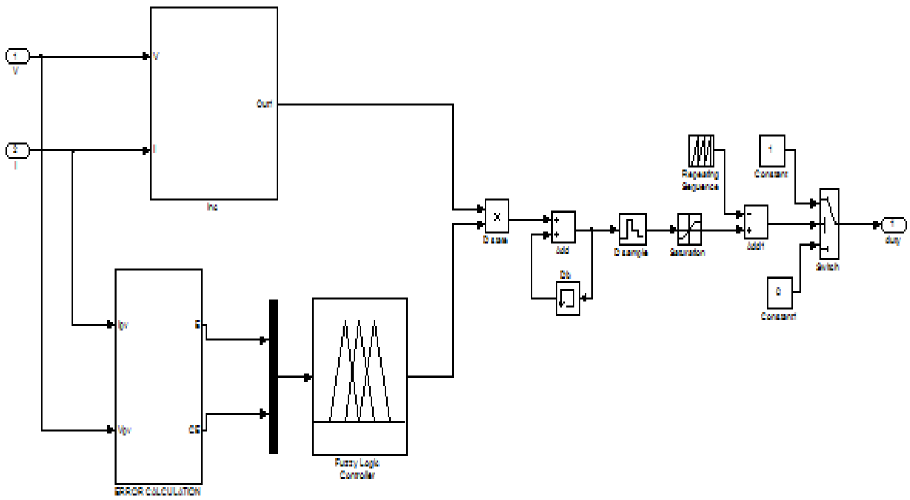

Figure 8: Simulation of fuzzy based incremental conductance MPPT technique

Differentiating Equation (2.5) with respect to V,

dP/dV=d(V × I)/dV
dP/dV= I (dV/dV)+ V (dI/dV)
dP/dV= I + V (dI/dV) (2.6)
Since it is known that
dP/dV=0 (2.7)

At the MPP, Eqn (2.6) and Eqn (2.7) are combined and substituting I/V = G, with G as conductance. The following relationship is given below,
dI / dV=-(I/V)
dI / dV=-G (2.8)

The incremental changes dV and dI is approximated by comparing the most recent measured and approximated to
dV(k)≈V(k)-V (k-1),dV(k) ≈ Δ V and
dI(k) ≈ I(k)-I(k-1),dI(k)≈ ΔI

Finally the algorithm can be summed up in the following set of equations
dP/dV >0 ⇒ G>ΔG (2.9)
dP/dV = 0 ⇒ G=ΔG (2.10)
dP/dV <0 ⇒ G< ΔG (2.11)

Thus fuzzy based incremental conductance can determine that the MPPT has reached the MPP and stop perturbing the operating point. If the condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationships describes in Equation (2.9) and Equation (2.11). The Figure 8 shows the algorithm of incremental conductance.

The advantages of this method is that it can determine when MPPT has reached the actual MPP and time to reach MPP is very fast thus provides efficient utilization of solar power and can track rapidly increasing and decreasing irradiance conditions with higher accuracy than conventional techniques.

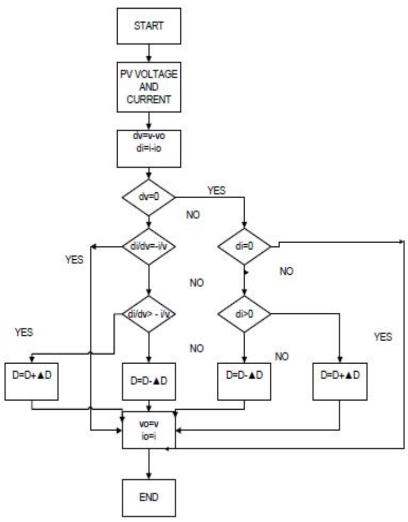

Fig 9: Flowchart of Incremental Conductance algorithm

Simulink Model

The entire system has been modeled on MATLAB/Simulink. The block diagram of the solar PV panel is shown in Figure 10. The solar PV panel input is solar irradiation.

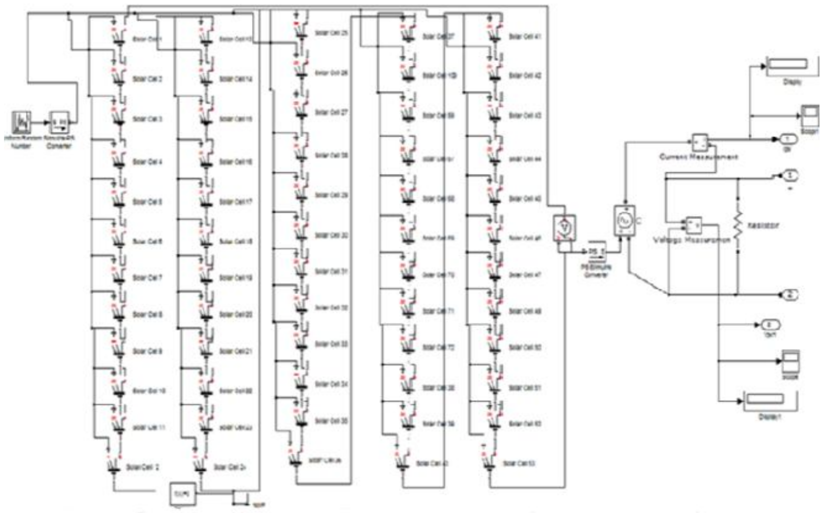

Fig 10: Block diagram of solar PV panel

There are 60 cells connected in series. The simulation is carried out for a cell surface temperature and 5 rows of solar cells in parallel. The irradiation is taken constant.

A controlled voltage source and the current source inverter have been interfaced with the rest of the system. Here the MPPT algorithms – Fuzzy logic based Hill climb algorithm and Fuzzy logic based Incremental Conductance algorithms are simulated in MATLAB Simulink and programmed in Embedded MATLAB function block. The output of MPPT block is duty cycle which is given as input to the boost converter.

The duty cycle required for the switch is provided by the MPPT control block..Under constant irradiation conditions of 1000 W/m^2, the output voltage for PV cell stack is 36 volts and current obtained is 7.34 Amps. This can be analyzed by the voltage waveform given below without MPPT.

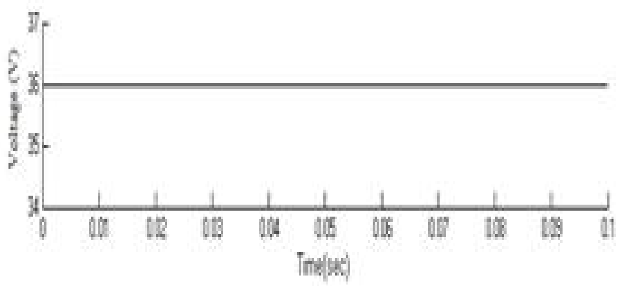

Fig 11: Voltage waveform at constant irradiation

Now the Solar PV stack is connected with MPPT block and a boost converter. The boost converter boosts up the voltage of PV panel from 36 volts to approximately 60 volts by MPPT techniques. The corresponding waveforms of fuzzy based hill climb and incremental conductance method is given below as shown in figure 12 and figure 13. These output waveforms are obtained under loaded conditions.

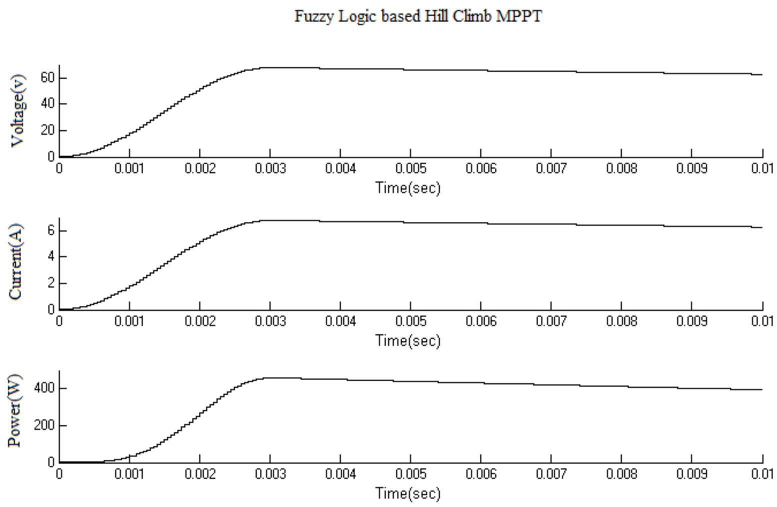

Fig 12: Output waveforms of fuzzy based hill climb MPPT technique

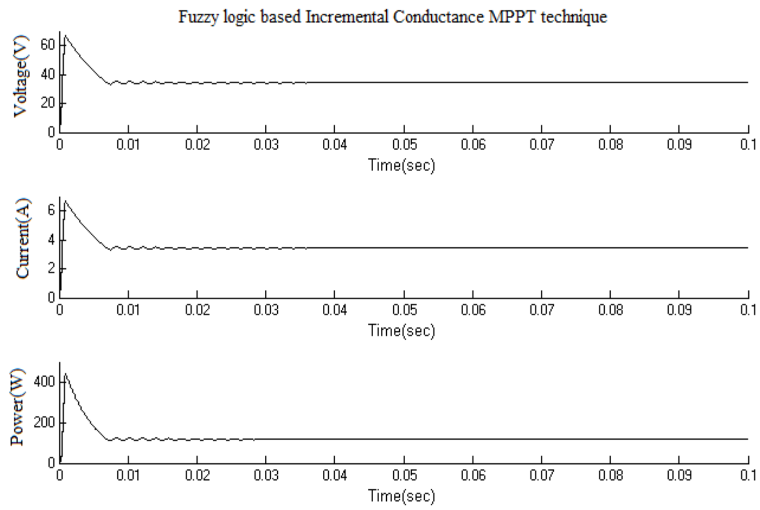

Fig 13: Output waveforms of fuzzy based Incremental Conductance method

Comparison of conventional hill climb and incremental conductance with advanced intelligence fuzzy based hill climb technique and fuzzy based incremental conductance technique are given in the tabulation below.

Content	Voltage (V)	Current (A)	Power (W)	Time to reach MPP(secs)
PV stack	36	7.035	245	-
HC	77.16	7.716	560	0.007
INC	68.08	6.80	470	0.004
FLC	80	8	640	0.006
FLC+ HC	69.5	6.95	483.025	0.0029
FLC+ INc	69	6.9	476.1	0.0009

Table: Results

Conclusion

The PV model is simulated using SIMULINK and MATLAB. The simulation is first made to run without MPPT to obtain the solar panel results. It is seen that the power obtained is around 245 Watts for a solar irradiation value of 1000 Watts per sq.cm without MPPT.
The simulation is then made to run with fuzzy based MPPT. With same irradiation, the PV panel continue to generate 250 Watts approximately and the power obtained at the load side by fuzzy based hill climb was found to be nearly 483 Watts and the power obtained by fuzzy based incremental conductance algorithm was found to be nearly 476 Watts, thus increasing the conversion efficiency of the photovoltaic system. Use of artificial intelligence technique, the time to reach MPP is very fast when compared to conventional technique.

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