SIMULATION OF INCREMENTAL CONDUCTANCE MPPT WITH DIRECT CONTROL AND FUZZY LOGIC METHODS USING SEPIC CONVERTER

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Abstract: T*his paper presents simulation of incremental conductance (IncCond) maximum power point tracking (MPPT) with direct control and fuzzy logic methods used in solar array power systems using SEPIC converter. The main difference of the proposed system to existing MPPT systems includes elimination of the proportional–integral control loop. The IncCond algorithm is used to track MPPs because it performs precise control under rapidly changing atmospheric conditions. A fuzzy logic controller has been developed for interfacing PV array with the load. The controller tracks and feeds maximum power to the load . The linguistic variables have been selected appropriately to modulate the firing angle of the converter for tracking the maximum power. The simulink model of the proposed scheme employing incremental conductance MPPT and fuzzy logic controller has been built using MATLAB – SIMULINK.*

Key words: *Incremental conductance (IncCond), fuzzy logic controller, maximum power point tracking (MPPT), photovoltaic (PV) system, Single ended primary inductance converter (SEPIC).*

I. INTRODUCTION

Recently, energy generated from clean, efficient, and environmentally friendly sources has become one of the major challenges for engineers and scientists [3]. Among all renewable energy sources, solar power systems attract more attention because they provide excellent opportunity to generate electricity while greenhouse emissions are reduced [3],[8],[9]. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique prospective solution for energy crisis. However, despite all the aforementioned advantages of solar power systems, they do not present desirable efficiency [4], [6].

The efficiency of solar cells depends on many factors such as temperature, insolation, spectral characteristics of sunlight, dirt, shadow, and so on. Photovoltaic array (PV) find various applications such as those for the household appliances, for the solar cars, and for the electric aircrafts or spacecrafts. Changes in insolation on panels due to fast climatic changes such as cloudy weather and increase in ambient temperature can reduce the photovoltaic (PV) array output power.

In addressing the poor efficiency of PV systems, some methods are proposed, among which is a new concept called "maximum power point tracking" (MPPT). All MPPT methods follow the same goal which is maximizing the PV array output power by tracking the maximum power on every operating condition.

In the use of solar panels, maximum power point tracking is the automatic adjustment of electrical load to achieve the greatest possible power harvest, during moment to moment variations of light level, shading, temperature, and photovoltaic module characteristics. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the "I-V curve"; it is the purpose of the MPPT system to sample the output of the cells and apply a A new MPPT system has been developed using single ended

resistance (load) to obtain maximum power for any given environmental conditions.
primary inductance converter (SEPIC converter). This converter acts as an interface between the PV module and the load. The controllers are used to track the maximum power of PV array and control action is taken in such a way that the maximum power is tracked in the PV systems thereby improving the efficiency of the systems.

These MPPT systems are controlled using Incremental Conductance and fuzzy logic techniques. Finally the performances of employed converter and controllers are compared. MATLAB Simulink are employed for simulation studies and for result verification.

This paper proposes a novel control scheme, how incremental conductance and fuzzy logic methods are used to track the maximum power generated from photovoltaic panel which is used to drive the load using SEPIC converter.

This paper is organized in the following order. Proposed methodology is described in section II. The photovoltaic model is presented in section III and also the simulink modeling of PVA and the result obtained are shown in section III. In section IV SEPIC converter and the reason for choosing this converter is described. In section V the proposed algorithm is described in detail. Simulation results are discussed in section VI.

II. PROPOSED METHODLOGY

The block diagram of the proposed scheme is shown in Fig. 1.This scheme of power generation consists of PV array, SEPIC converter, incremental conductance/ the fuzzy logic controller. The PV array converts the solar radiation into electrical power. The proposed scheme has been built on a PV array of 60 V, 5 A rating. The power is fed to the SEPIC converter and the trigerring pulse to the converter is given by the fuzzy logic(or)incremental conductance algorithm. Hence the load is maintained to operate at maximum power.

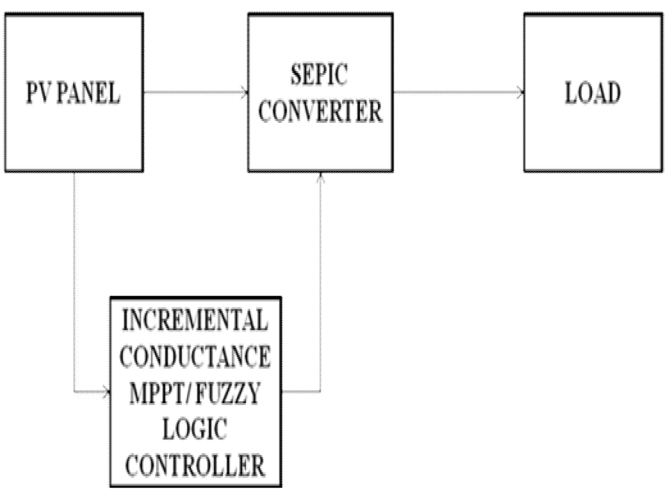

Fig. 1. Block diagram of the proposed methodology

III. PHOTOVOLTAIC MODEL

Photovoltaic array(PV) arrays are built up with combined series/parallel combinations of PV solar cells[13], which are usually represented by a simplified equivalent circuit model such as the one given in Fig.2 and/or by Eqn. (1)

$$V_C = \frac{AK\,T_C}{e} l_n\left(\frac{I_{ph} + I_0 - I_C}{I_0}\right) - R_S I_C \quad (1)$$

During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply it generates a current I_d, called diode (*D*) current or dark current. The diode determines the I-V characteristics of the cell.

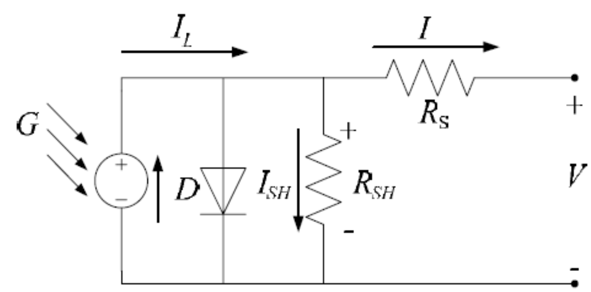

Fig. 2. Simplified equivalent circuit PV model

Where the symbols are given as follows,

e - Electron charge(1.602×10-19C)

k - Boltzmann constant (1.38 × 10-23 J/K)

I_c - Cell output current, A

I_p - Photocurrent, function of irradiation level and junction temperature (5 A)

I_0 - Reverse saturation current of diode (0.0002 A)

R_s - Series resistance of cell (0.001 Ω)

T_c - Reference cell operating temperature (20 °C)

V_c - Cell output voltage, V

A. PVA MODELLING FOR SIMULINK

A general block diagram of the PVA model for GUI environment of Simulink is given in Fig. 3. This block contains the sub models that are connected to build the final model The PVA consists of 6 PV cells all connected in series to have a desired voltage output. Depending on the load power required, the number of parallel branches can be increased to 2 or more. The effects of the temperature and solar irradiation levels are represented by two variables gains. They can be changed by dragging the slider gain adjustments of these blocks named as variable temperature and variable solar irradiation.

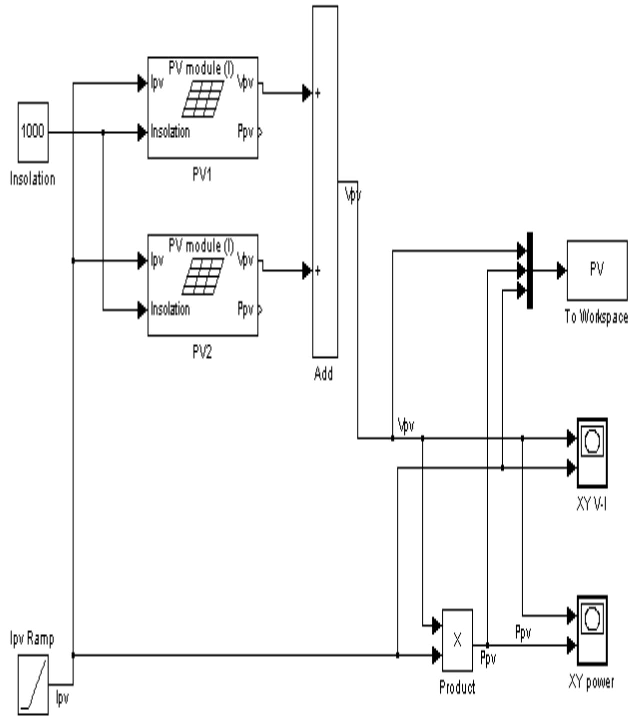

Fig.3. The functional block diagram of the PVA model

B. *SIMULATION RESULTS OF PVA*

In the Fig. 4. Current changes with respect to the voltage. The output voltage across the supply terminals of the photovoltaic array. Initially the voltage is low, suddenly the value increases to a value around 6.2V. The gradual dip of the curve indicates the voltage variations that occur in a practical circuit.

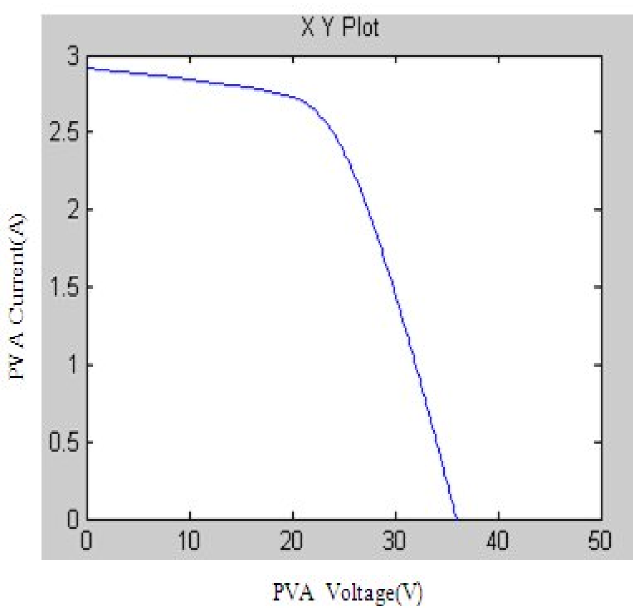

Fig. 4. Current-Voltage (I-V) Characteristics of PVA

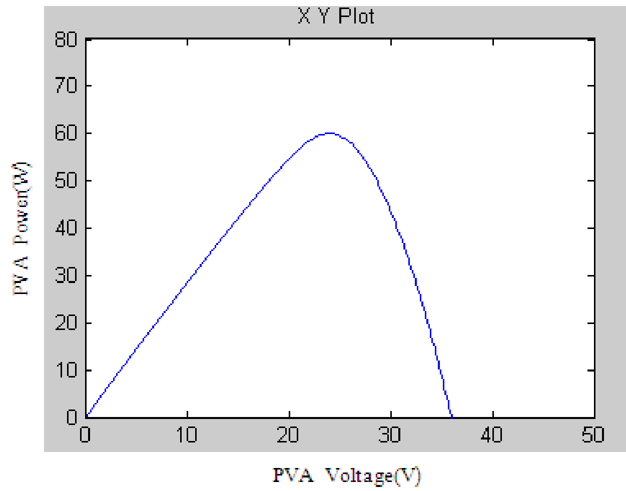

Fig. 5. Power-Voltage (P-V) Characteristics of PVA

In the Fig. 5, it shows the operating point when the reference current is calculated. Initially the curve starts at the zero power output value. Then the power increases to nearly 64W, where the initial short-circuit current is measured. With the adopted MPPT control technique the output power increases gradually to the MPPT power value.

IV SELECTING PROPER CONVERTER

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. The efficiency of switch-mode dc–dc converters is widely used. Most switching-mode power supplies are well designed to function with high efficiency.

Among all topologies available, the single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. It operates in continuous, discontinuous, or boundary conduction mode. SEPIC is controlled by the duty cycle of the control transistor. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output.

As with other switched mode power supplies specifically DC-to-DC converters, the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. A simple circuit diagram of a SEPIC converter is shown in Fig. 6, consisting of a coupling capacitor, C_1 and output capacitor, C_2; coupled inductors L_1 and L_2 and diode.

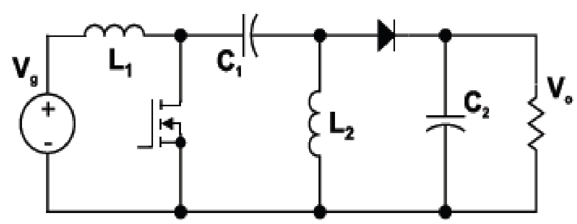

Fig. 6. Simple circuit diagram of SEPIC converter

Fig. 7 shows the circuit when the power switch is turned on. The first inductor, L_1, is charged from the input voltage source during this time. The second inductor takes energy from the first capacitor, and the output capacitor is left to provide the load current. No energy is supplied to the load capacitor during this time. Inductor current and capacitor voltage polarities are also marked.

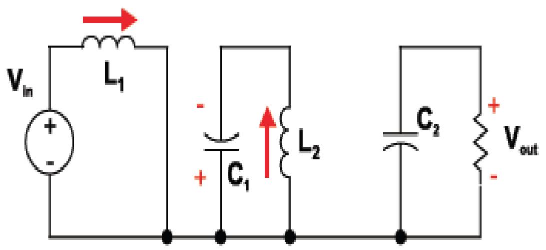

Fig. 7. SEPIC converter when switched ON

When the power switch is turned off, the first inductor charges the capacitor C_1 and also provides current to the load, as shown in Fig. 8. The second inductor is also connected to the load during this time. The output capacitor sees a pulse of current during the off time, making it inherently noisier than a buck converter.

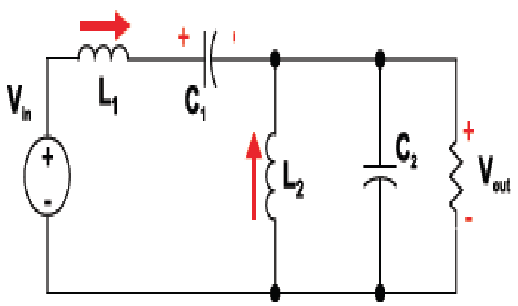

Fig. 8. SEPIC converter when switched OFF

The formulae of duty cycles is given as follows:

$$D_{min} = \frac{V_{OUT} + V_D}{V_{IN(max)} + V_{OUT} + V_D} \quad (2)$$

$$D_{max} = \frac{V_{OUT} + V_D}{V_{IN(min)} + V_{OUT} + V_D} \quad (3)$$

The components for the SEPIC converter used in simulation are selected as follows:

1)Switching frequency, f_{sw} = 1 KHz
2)Minimum input voltage, $V_{IN(min)}$= 55 V
3)Maximum input voltage, $V_{IN(max)}$ = 60 V
4)Output voltage, V_{OUT} = 230 V
5)Diode voltage, V_D = 0.5 V
6)Coupling capacitor, C_1 = 1µH
7)Output current, I_{OUT} = 5 A
8)Duty-cycle $D_{max} = 0.807$, $D_{min} = 0.793$
9)Inductor selection, $L_1 = L_2 = 53mH$
10)Capacitor selection, $C_2 = 1.75mF$

V PROPOSED ALGORITHM

MPPT Methods

There is a large number of algorithms that are able to track MPPs. Some of them are simple, such as those based on voltage and current feedback, and some are more complicated, such as perturbation and observation (P&O) or the incremental conductance (IncCond) method. They also vary in complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima, and their applications [7],[11],[12].

On the other hand, some MPPTs are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects such as fuzzy logic [16] or neural network [14] methods.

MPPT fuzzy logic controllers have good performance under varying atmospheric conditionsand exhibit better performance than the P&O control method [5]. However, the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule-based table. It is greatly dependent on how a designer arranges the system that requires skill and experience.

The IncCond method is the one which overrides over the aforementioned drawbacks. In this method, the array terminal voltage is always adjusted according to the MPP voltage. It is based on the incremental and instantaneous conductance of the PV module [6], [10],[16],[18].

A. INCERMENTAL CONDUCTANCE MPPT

The incremental conductance is derived by differentiating the PV array power with respect to voltage and setting the result equal to zero at the maximum peak power (MPP). This is shown in Eqn. (4)

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} = 0 \quad (4)$$

Rearranging Eqn. (3) gives

$$-\frac{I}{V} = \frac{dI}{dV} \quad (5)$$

Note that the left-hand side of Eqn. (5) represents the opposite of the PV array's instantaneous conductance, while the right-hand side represents its incremental conductance. Thus, at the MPP, these two quantities must be equal in magnitude, but opposite in sign. If the operating point is off of the MPP, a set of inequalities can be derived from Eqn. (5) that indicates whether the operating voltage is above or below the MPP voltage. These relationships are summarized in Eqns. (6,7 and 8).

$$\frac{dI}{dV} = -\frac{I}{V};\ \frac{dP}{dV} = 0 \quad (6)$$

$$\frac{dI}{dV} > -\frac{I}{V};\ \frac{dP}{dV} > 0 \quad (7)$$

$$\frac{dI}{dV} < -\frac{I}{V};\ \frac{dP}{dV} < 0 \quad (8)$$

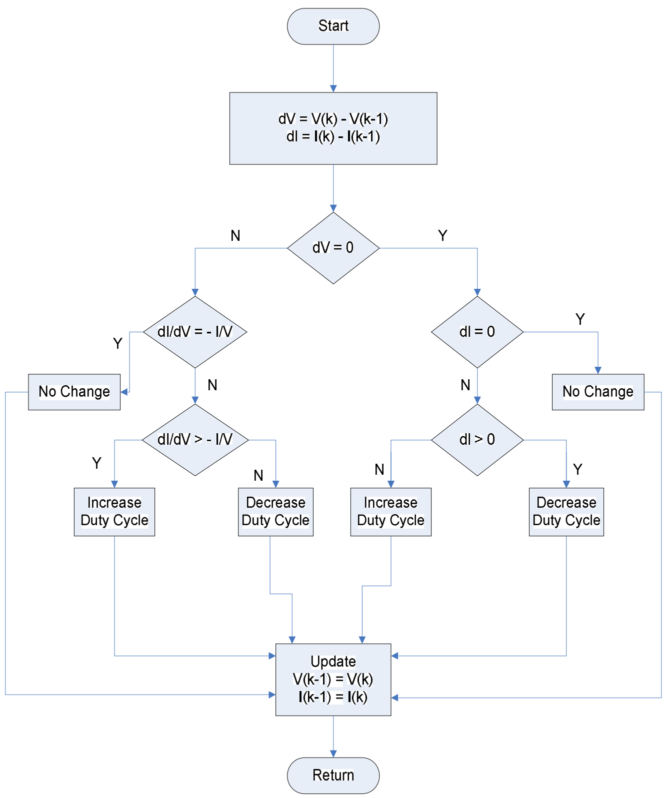

Fig. 9. Incremental conductance algorithm flowchart

Fig. 9 shows a flowchart for the incremental conductance algorithm. The present value and the previous value of the solar array voltage and current are used to calculate the values of dI and dV. The steps involved are:

(i)If dV=0 and dI=0, then the atmospheric conditions have not changed and the MPPT is still operating at the MPP.

(ii) If dV=0 and dI>0, then the amount of sunlight has increased, raising the MPP voltage. This requires the MPPT to increase the PV array operating voltage to track the MPP.

(iii)If dV=0 and dI<0, the amount of sunlight has decreased ,lowering the MPP voltage and requiring the MPPT to decrease the PV array operating voltage.

(iv)If the changes in voltage and current are not zero, the relationships in equation (7, 8) can be used to determine the direction in which the voltage must be changed in order to reach the MPP.

(v)If $\frac{dI}{dV} > -\frac{I}{V};\ \frac{dP}{dV} > 0$ and the PV array operating point is to the left of the MPP on the P–V curve. Thus, the PV array voltage must be increased to reach the MPP.

(vi)Similarly, if $\frac{dI}{dV} < -\frac{I}{V};\ \frac{dP}{dV} < 0$ and the PV array operating point lies to the right of the MPP on the P–V curve, meaning that the voltage must be reduced to reach the MPP.

Herein lies a primary advantage of incremental conductance over the perturb-and-observe algorithm: incremental conductance can actually calculate the direction in which to perturb the array's operating point to reach the MPP, and can determine when it has actually reached the MPP.

B.FUZZY LOGIC CONTROLLER

The Fuzzy Logic tool is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership, the important concept of computing with words. It provides a technique to deal with imprecision and information granularity. The structure of fuzzy controller is shown in Fig 10.

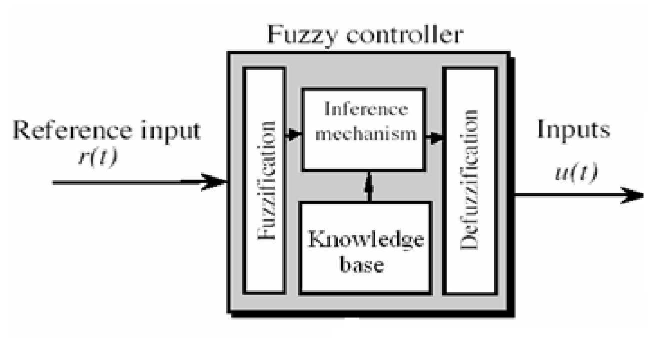

Fig. 10. Structure of fuzzy controller

1) FUZZIFICATION

The values of membership function are assigned to the linguistic variables using seven fuzzy subsets called negative big (nb), negative medium (nm), negative small (ns), zero (zr), positive small (ps), positive medium (pm), and positive big (pb). Variables, change in voltage,dV and change in current,dI are selected as input variables and duty cycle,d is selected as output variable.

2) INFERENCE ENGINE

Inference engine mainly consists of two-sub blocks namely, fuzzy rule base and fuzzy implication. The inputs which are now fuzzified are fed to the inference engine and the rule base is then applied; the output fuzzy sets are then identified using fuzzy implication method. The commonly used fuzzy implication method is MIN-MAX. The consequent fuzzy region is restricted to the minimum(MIN) of the predicate truth while selecting output fuzzy set. The output fuzzy region is updated by taking the maximum(MAX) of these minimized fuzzy sets during shaping of output fuzzy space.

3) DEFUZZIFICATION

After fuzzy implication, output fuzzy region is located. As the final desired output is a non-fuzzy value of control,a defuzzification stage is needed. Center of gravity defuzzification method is used for defuzzification in the proposed scheme. In this method the weighted average of the membership function or the center of gravity of the area bounded by the membership function curve is computed as the most typical crisp value of the union of all output fuzzy sets.

VI SIMULATION RESULT

The diagram of the closed-loop system designed in MATLAB and Simulink is shown in Fig.11 and 12, which includes the PV module electrical circuit, the SEPIC converter, and the MPPT algorithm/fuzzy logic controller. The converter components are chosen according to the values presented in Section IV. The PV module is modeled using electrical characteristics to provide the output current and voltage of the PV module. The provided current and voltage are fed to the converter and the controller simultaneously.

The PI control loop is eliminated, and the duty cycle is adjusted directly in the algorithm. To compensate the lack of PI controller in the proposed system, a small marginal error of 0.002 is allowed.

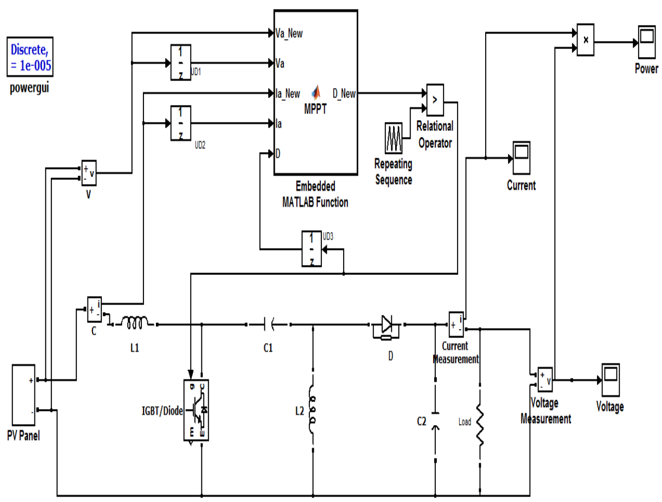

Fig. 11. Simulink block diagram of incremental conductance

In the Fig.11, V_a and I_a stand for the sampling value of the voltage and current; V_{a_new} and I_{a_new} represent the sampling value of the voltage and current in previous cycle.

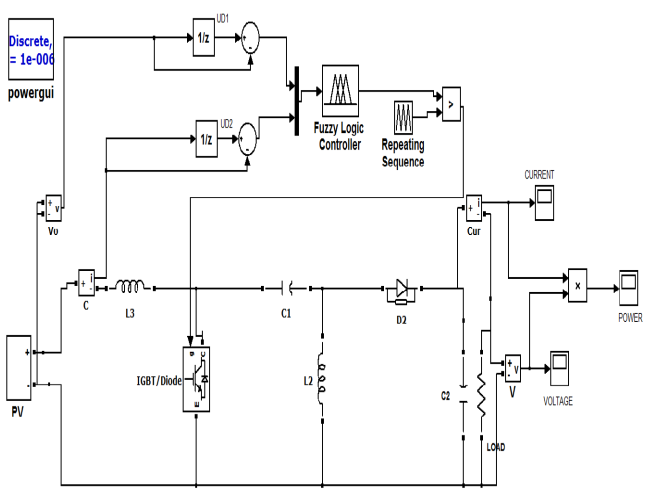

Fig. 12. Simulink block diagram of fuzzy logic method

In the Fig. 12, the input variables to the controller are given as dV and dI. The output variable obtained is the duty cycle,d.

The input from the PV panel is given to the incremental conductance algorithm. The incremental conductance algorithm is derived by differentiating the PV array power with respect to voltage and setting the result equal to zero. It gives the triggering pulse to the SEPIC converter and drives the load at specified voltage. The voltage is maintained constantly at 230 V. The voltage, current and power across the load obtained using the incremental conductance is shown in Fig. 13,14 and 15.

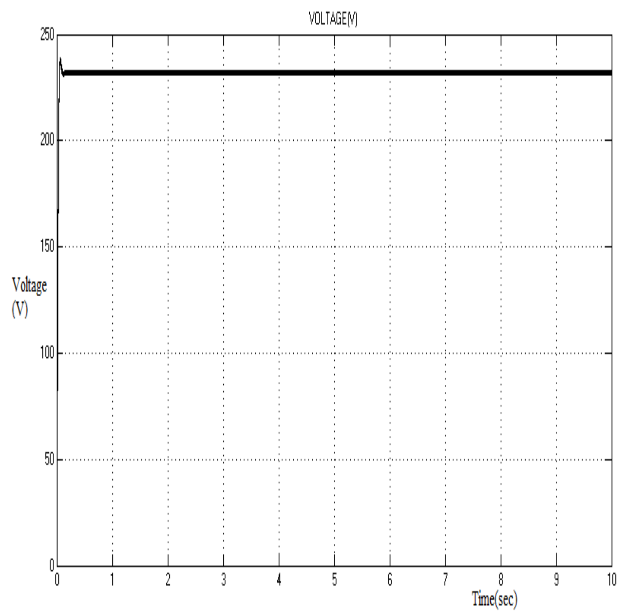

Fig. 13. Output voltage of the load using INC method

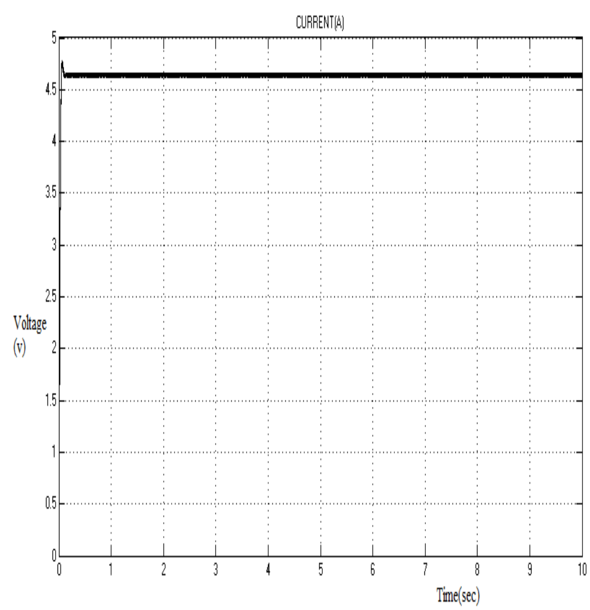

Fig. 14. Output current of the load using INC method

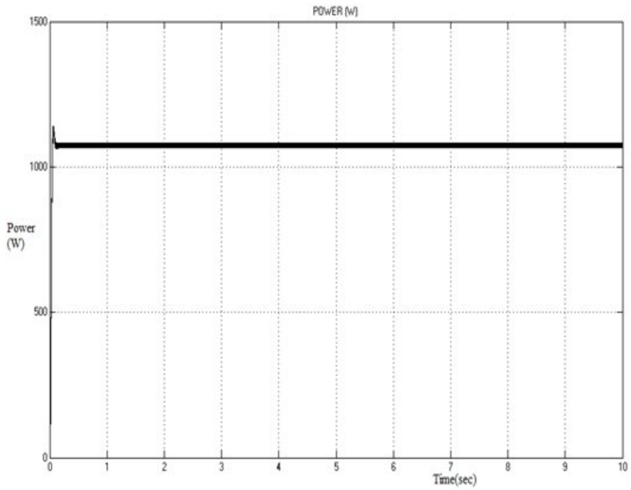

Fig. 15. Output power of the load using INC method

Fuzzy controller is implemented using the rule base which has the ouput as duty cycle. The defuzzification technique used in fuzzy controller is centroid. It is given as triggering pulse to the converter to drive the load. The voltage, current and power across the load obtained using the fuzzy controller is shown in Fig 16,17 and 18.

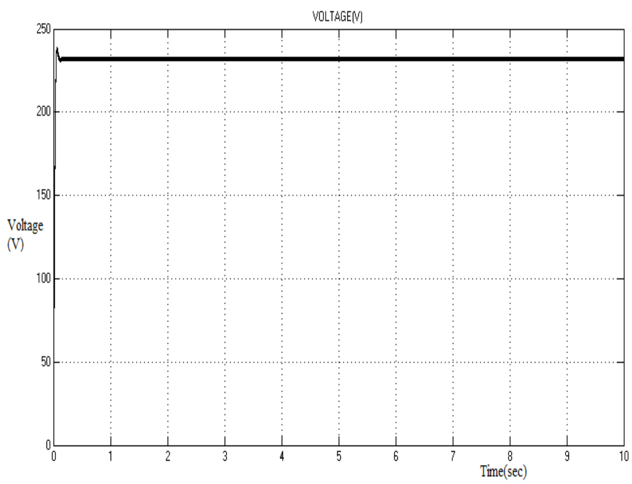

Fig. 16. Output voltage of the load using fuzzy logic method

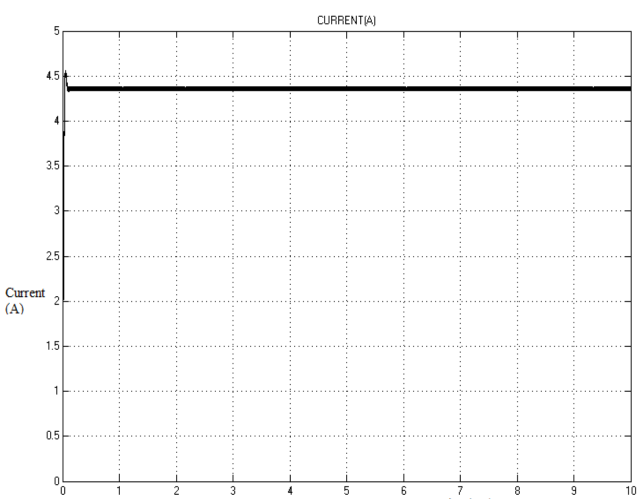

Fig. 17. Output current of the load using fuzzy logic method

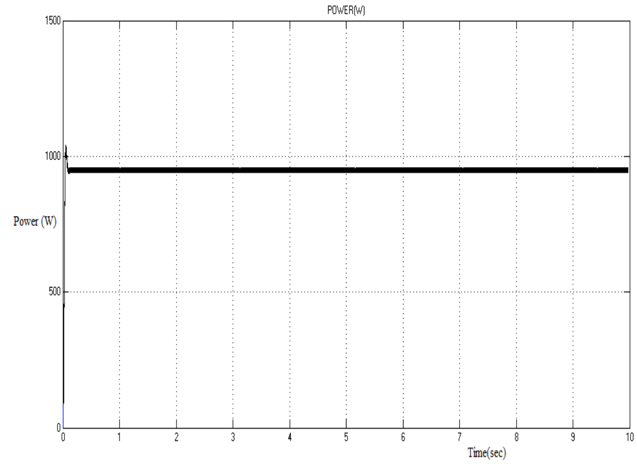

Fig. 18. Output power of the load using fuzzy logic method

VII CONCLUSION

A fixed-step-size IncCond MPPT with direct control method and fuzzy logic is employed, and the necessity of another control loop is eliminated. The proposed system is simulated and the functionality of the suggested control concept is proven. From the results acquired during the simulations, it is confirmed that, with a well-designed system including a proper converter and selecting an efficient and proven algorithm, the implementation of MPPT is simple and can be easily constructed to achieve an acceptable efficiency level of the PV modules. The results also indicate that the proposed control system is capable of tracking the PV array maximum power and thus improves the efficiency of the PV system and reduces low power loss and system cost. In simulation, the system completes the maximum power point tracking successfully despite of fluctuations. When the external environment changes suddenly the system can track the maximum power point quickly.

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