SIMULATION OF MPPT CONTROLLER WITH FUZZY LOGIC AND NEURAL NETWORK FOR SOLAR PV SYSTEM WITH SEPIC CONVERTER

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Abstract— *Design of maximum power point tracking (MPPT) controller to extract power from the solar panel and to supply a single phase Induction motor is presented in this paper. In the proposed scheme the incremental conductance algorithm is employed to track the maximum power from the solar panel. The DC-DC SEPIC converter and a full bridge inverter are employed as power electronic interface. The speed of the motor with proportional integral (PI) controller, fuzzy logic controller and neural network controller has been measured and the comparison results were presented. The entire system has been modeled and simulated using MATLAB/Simulink software.*

Keywords — Maximum Power Point Tracking(MPPT), Incremental Conductance, Photovoltaic (PV), PI controller, fuzzy logic, neural network, SEPIC converter, 1ϕ induction motor.

1. INTRODUCTION

Nowadays, energy generated from efficient, clean and environmentally friendly sources has become one of the major challenges for engineers & scientists [1-2]. PV energy is getting increasing important as a renewable source due to the advantage such as the absence of little maintenance, no carbon emission, the absence of fuel cost and no noise due to the absence of moving parts [3]. Among all renewable energy sources, solar power system attracts more attention because they provide excellent opportunity to generate electricity [4]. The efficiency of solar cells depends on many factors such as insulation, spectral characteristics of sunlight, temperature, shadow, dirt, etc. Changes in insulation on panels due to fast climate changes such as the increase in ambient temperature and cloudy weather can reduce the photovoltaic (PV) array output power.

The maximum power point tracking (MPPT) controller is used to improve the conversion efficiency of the PV system. The frequently used conventional methods of MPPT are Perturb & Observe (P&O) algorithm and incremental conductance algorithm. Also the intelligent control methods such as fuzzy logic and neural network based MPPT also employed in order to improve the efficiency of the system. Both algorithms tune the duty cycle of the DC–DC converter employed in the PV system. The drawback of P&O method is that steady-state oscillation occurs after the MPP is reached, the perturbation continuously varies in both directions to maintain the MPP. This causes power losses in the system. The incremental conductance algorithm determines the gradient of the P–V curve. This method has overcome the disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition. The incremental conductance can determine the maximum power point (MPP) and stop perturbing the operating point or else the relationship between dI/dV & –I/V can be used to determine the direction in which the MPPT operating point must be perturbed.

A dc to dc converter is needed and commonly available converters are the boost, buck, buck-boost, Cuk, SEPIC. In which the single-ended primary-inductance converter (SEPIC) is a DC/DC-converter that provides a positively regulated output and non-inverted output [5]. Buck-boost converters are cheaper because they require only a single inductor and a capacitor. But the drawback is the high amount of input current ripple which create harmonics, in many applications, these harmonics require using a large capacitor or an LC filter. This often makes the buck-boost inefficient or expensive, and that can complicate the usage of buck-boost converters is the fact that they invert the output voltage. Cuk converters solve both of these problems by using an extra inductor and capacitor. However, both buck-boost and Cuk converter operation cause large amounts of electrical stress on the components, this can result in device overheating or failure. SEPIC converter can solve both of these problems.

2. PROPOSED SYSTEM

The block diagram of the proposed system is shown in Fig. 1. Solar panel feeds power to a single phase induction motor by employing incremental conductance maximum power point tracking (MPPT) algorithm. The controller algorithm employs PI controller, fuzzy logic and neural network controllers which varies the duty cycle of the SEPIC converter according to the load and load is always fed with the maximum power. The voltage, current and speed have been measured for the SEPIC converter connected with the motor load. SEPIC converter is designed to step up the voltage obtained from the solar panel (142 to 230) V. A single phase full bridge inverter is employed to convert the DC –AC supply.

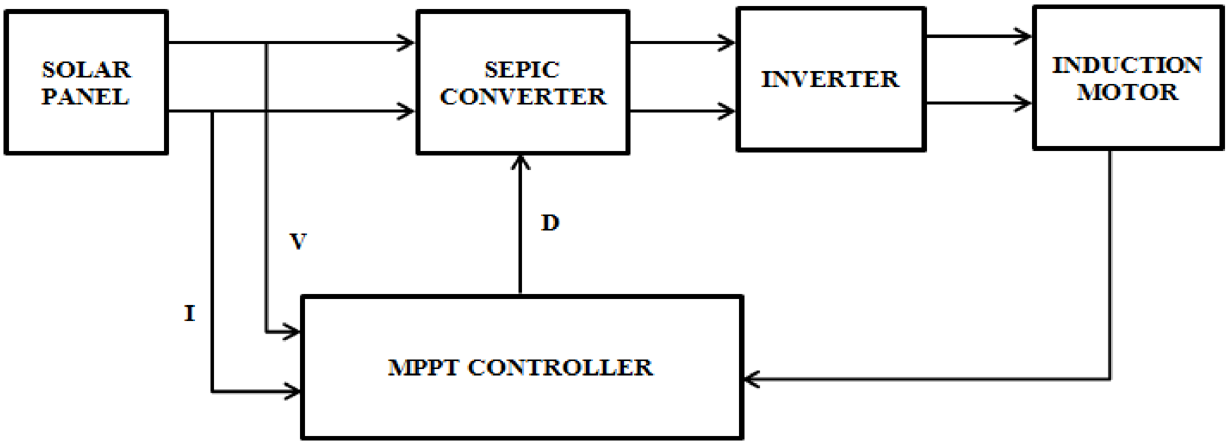


Fig.1. Block Diagram of the proposed system

Table 1. Solar panel specification

Sl. No	Specification	Range
1	Number of cells	72
2	Open circuit voltage (Voc)	44V
3	Short circuit current (Isc)	7.58A
4	Voltage at maximum power (Vmp)	35.55V
5	Current at maximum power (Imp)	7.04A

3. PHOTOVOLTAIC CELL MODEL

Photovoltaic means the generation of electricity from light, here the light source is sun. Solar modules are connected in different combinations which forms the solar array, and a number of solar cells are used to form a solar module. Solar cells are manufactured from semiconductor layers made from silicon crystal [6]. The literature reveals that PV cells are represented by many models have been suggested for PV equivalent circuit. The most commonly used circuit model contains a single diode, the resistances connected in series and shunt [7]-[9]. As given in Fig.2, production of the amount of electrical energy is denoted by the current I_{ph}, which is in direct proportion to the solar irradiation. Internal resistance is represented by the series resistor and the leakage current is represented by the shunt resistance. The PV cell is mathematically represented as follow

$$I_{pv} = I_{ph} - I_D - \frac{V_D}{R_{sh}} \tag{1}$$

Diode characteristics is given as

$$I_D = I_0 (e^{V_D/V_T A} - 1) \tag{2}$$

The voltage of a diode is given by

$$V_D = V_{PV} + I_{PV} R_S \tag{3}$$

Photovoltaic current Iph is expressed by

$$I_{ph} = (I_{SC} + K_1 (T - T_{ref}))\lambda \tag{4}$$

Here I_0 is the saturation current, V_T – thermal voltage of PV modules =kT/q, q is electron charge and is equal to 1.6 x 10^{-19} C, k is the Boltzman constant and is equal to 1.38 x 10^{-23} J/K, T is the junction temperature of p-n diode - Kelvin, A is the diode ideality factor depends on the manufacturing technology, I_{SC} is short-circuit current of the cell at normal test condition of 1000 W/m^2 and 25^{0}C, K_1 is the coefficient of the short-circuit current of the cell, T_{Ref} is the reference cell temperature, λ represents the solar irradiation in W/m^2.

Fig. 2 shows the equivalent circuit of photovoltaic cell.

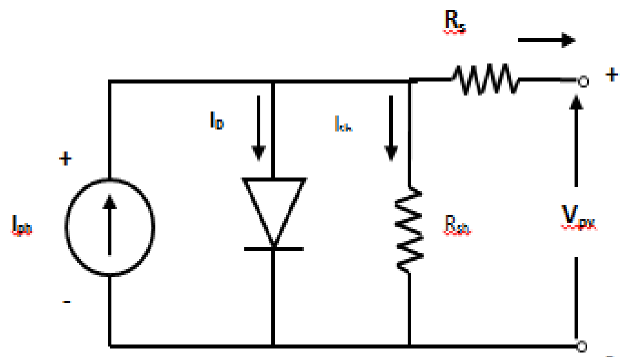


Fig.2. Solar PV cell equivalent circuit

4. PHOTOVOLTAIC CHARACTERISTICS

Photovoltaics have non-linear characteristics and the change of the operating conditions temperature and solar irradiance directly affects their performance and output power. Figs. 3 and 4 shows the P–V and I–V characteristics of a PV array. The above characteristics shows the PV array exhibits non-linearly varying output corresponding to the varying irradiations from the sun. Under the full illumination condition of the sun, the P–V characteristic will have only a single peak. But multiple peaks will be appearing in the PV characteristics during the partial shading conditions.

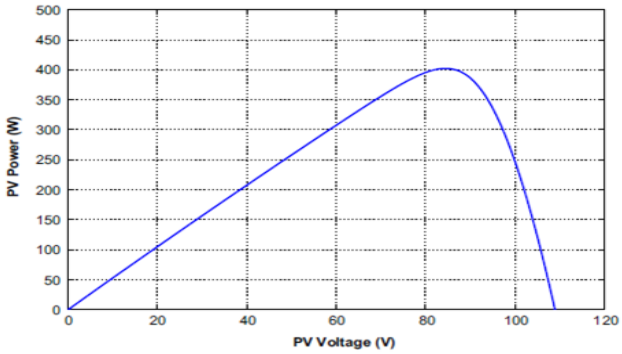


Fig. 3 P-V Characteristics of PV array

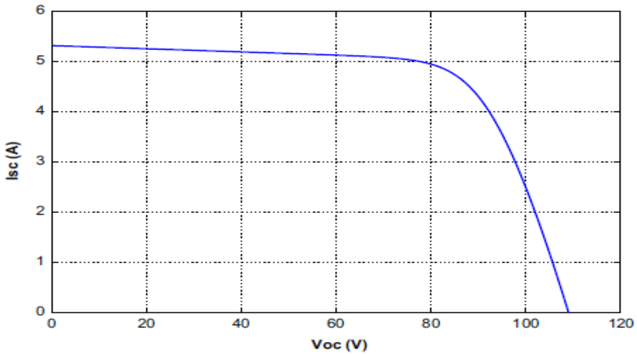


Fig. 4 I-V Characteristics of PV array

5. SEPIC CONVERTER

The power circuit of the SEPIC converter is given in Fig. 5. A SEPIC is a type of DC-DC converter. It consists of boost converter followed by a buck-boost converter. The main advantage of this converter is capable of providing a non-inverted output (i.e. the output has the same polarity as the input) and being capable of true shutdown. Its output voltage must be greater than or less than or equal to the input voltage and it is widely used in battery operated applications. The output voltage is controlled by varying the duty cycle of the switch. MOSFET is used as the control switch in the proposed system is a MOSFET, as it has high input impedance, low voltage drop and lower switching losses. The input inductor L_1 and MOSFET switch leads to a boost topology; and the inductor L_2 acts as a buck-boost topology.

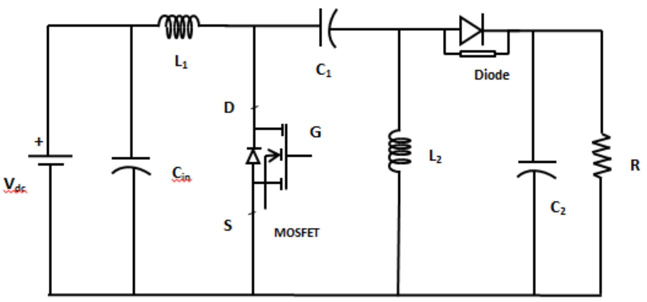
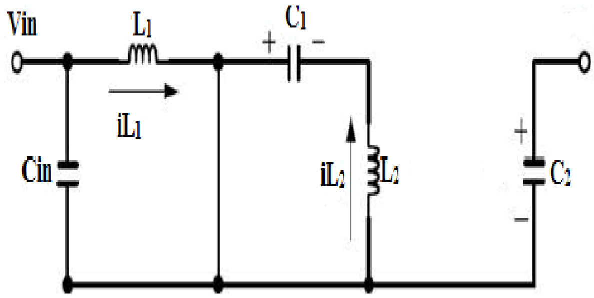
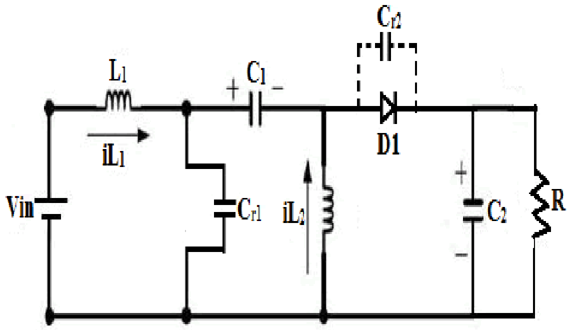


Fig. 5. Power circuit of SEPIC converter

For the SEPIC, when high pulse is given, the MOSFET is on, input voltage charges an inductor 1 and capacitor 1charges an inductor 2. The diode turned off and the capacitor maintains the output. When low pulse is given, the MOSFET is off, the inductors output through the diode to the load and the charges the capacitors. Fig. 6 shows the equivalent circuit of the SEPIC converter under ON and OFF conditions. If pulse tends to be low for a greater portion of duty cycle, the output will be greater.



(a)



(b)

Fig. 6. Circuit equivalent of SEPIC converter (a) when Switch is ON (b) when Switch is OFF

6. MAXIMUM POWER POINT TRACKING

Maximum power point is determined mainly based on atmospheric temperature and solar irradiance. Because of the clouds or shadows of the object the maximum power point will be fluctuating. Maximum power point algorithm is an algorithm which is used to fix the dynamic operating point of the solar panel at the maximum power point by continuously computing the operating point of the solar panel [10]. For obtaining the maximum available power, accurate tracking of the operating point is must under all varying atmospheric conditions by using MPPT algorithm. The MPPT increases the power delivered by the solar panel to the load and the life span of the PV system also increased [11,12]. In the MPPT system, the duty cycle of PWM based dc-dc converter is adjusted to obtain the maximum power point. The significant condition while choosing a MPPT algorithm is the capacity of the algorithm to trace the true MPP among the local peaks taking into consideration of cost and speed of convergence. The various MPPT algorithms considered in this paper for review are shown in Table1. MPPT algorithms are organized under major groups in this paper. One group discusses about the conventional MPPT algorithms. These algorithms show satisfactory working under uniform irradiance. Another group explains the use of intelligent techniques in MPPT algorithms. These exhibits satisfactory operation in both constant irradiance and partial shading conditions.

6.1 Incremental Conductance Algorithm

This algorithm is based on the slope (dP/dV) of power-voltage characteristic, the P-V curve has zero slope at the maximum power point MPP, and is positive on the left side and on the right side it is negative [13]. This method eliminates the drawback of the P&O method which is the oscillation of operating point under varying atmospheric conditions. dP/dV is called as the power gradient. These gradients are summarized as follows:

dP/dV = 0 at MPP

dP/dV > 0 left of MPP

dP/dV < 0 right of MPP

From the characteristics of the PV array (I-V and P-V),

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong V\frac{\Delta I}{\Delta V} \qquad (5)$$

Now the point of dP/dV can be written as

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V}, \text{ at MPP.} \qquad (6)$$

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V}, \text{ at left of MPP.} \qquad (7)$$

$$\frac{\Delta I}{\Delta V} < -\frac{I}{V}, \text{ at the right of MPP.} \qquad (8)$$

In the Incremental Conductance algorithm, the cycle is started by obtaining present value of V and I at V(t) and I(t). The flow chart in Fig. 7 shows that the tracking of MPP done by the comparing the instantaneous conductance (I/V) value and the incremental conductance (ΔI/ΔV) value. The reference voltage, V_{ref}, is either decreased or increased depending on the above comparison output. If V_{ref} is equal to V_{MPP}, then the MPP is reached. This is the stopping condition of the algorithm, the corresponding values will be stored. If any environmental changes then there will be a change in Δ I and at such conditions the algorithm will be recalculated until optimum point is obtained [14]. The speed of MPPT algorithm is determined by the incremental size. If the incremental size is large, then the time taken for tracking is reduced; but, the system oscillates about this point of MPP [15]. This INC algorithm will perform better under quickly changing atmospheric conditions and also oscillations are less. However, the efficiency of the algorithm is somewhat closer to the P&O method. Major drawback identified is that under varying irradiance and also partial shading conditions, the global MPP is not tracked. At last, because of the complexity of control circuits needed for implementing the INC algorithm system cost is high.

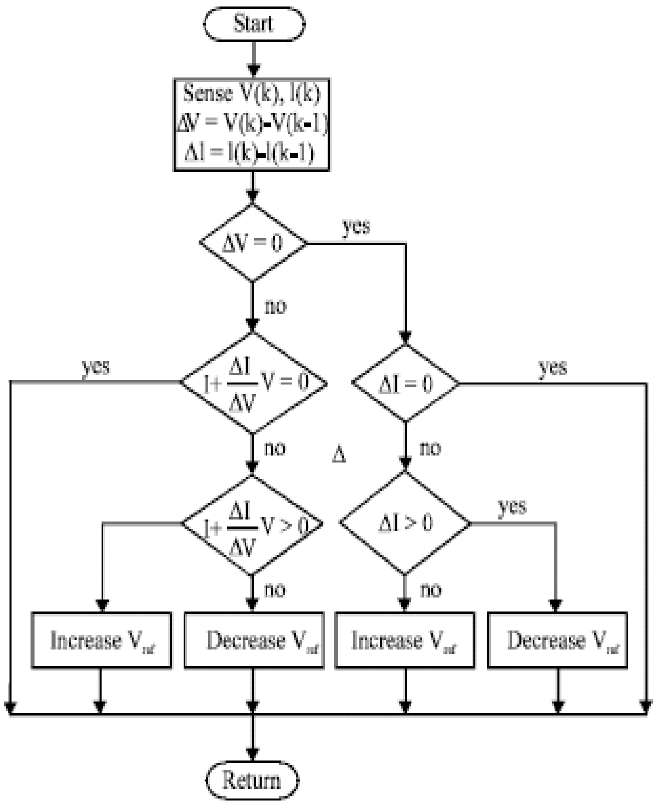


Fig. 7. Flowchart for Incremental conductance algorithm

7. FUZZY LOGIC CONTROLLER

Fuzzy logic depends on the concept of fuzzy set. A fuzzy set is a set with unclear boundary. In fuzzy logic, a curve is defined in which the input space is mapped to a membership value ranging from 0 to 1 is called as a membership function [16, 17]. The input space is also referred as a universe of discourse. To keep the fuzzy values at the extrema, a standard logical operation is used. The logical operations used are AND, OR and NOT. If-then statement rules are used to formulate the conditional statements [18]. The processes involved in the fuzzy logic controller are

1. Fuzzification: During fuzzification, all fuzzy statements are resolved into a degree of membership between 0 to 1.

2. Rule base: To shape the fuzzy output, the degree of support is used. Basically, one rue alone will not be so effective [19]. Each and every rule delivers fuzzy set as output. In this paper, Mamdani base fuzzy inference system is used.

3. Defuzzification: After defuzzification, crisp numerical output values are obtained. For this centre of gravity, method is employed.

Table 2. Fuzzy Logic Rule Table

ce / e	NB	NM	NS	ZE	PS	PM	PB
NS	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NB	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

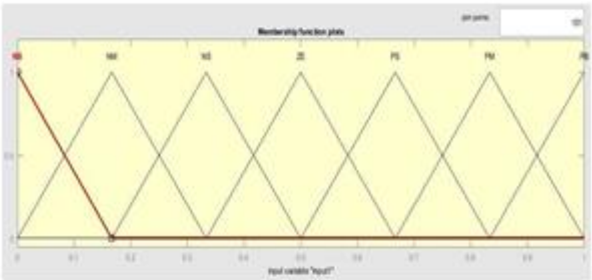


Fig.8.(a) Fuzzy Logic Input 1

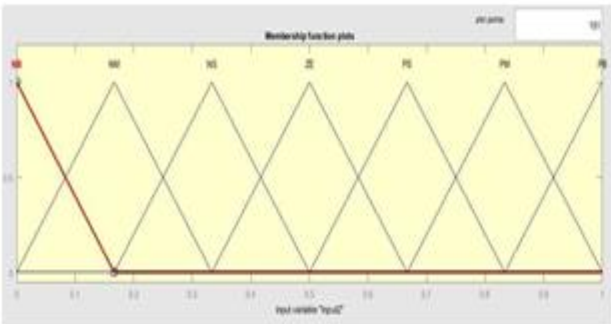


Fig.8.(b) Fuzzy Logic Input 2

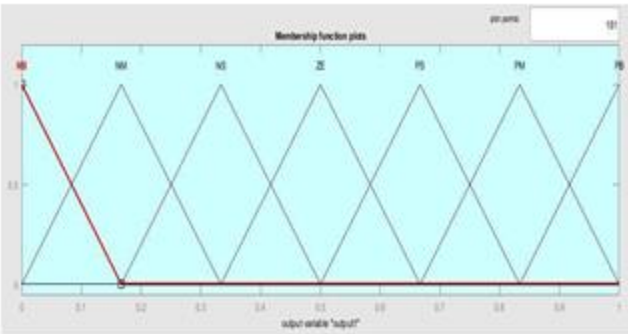


Fig.8(c) Fuzzy Logic Output

8. NEURAL NETWORK MPPT CONTROLLER

(a)

The drawbacks of conventional controllers for MPPT are also overcome by the application of an ANN based MPPT Control technique. The use of ANN improves the system performance and system efficiency to a better rate than traditional methods. Neural network with the multilayer structure in Fig. 9 is employed [20] – [22]. Artificial neural network with offline training based MPPT is added to compute the temperature and irradiance from the PV array.

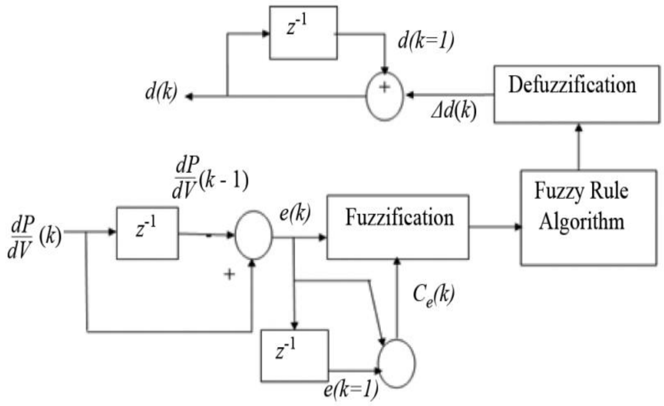


Fig.9. Structure of Fuzzy Logic Controller

Supervised learning is implemented to eliminate the error by providing the required multiplication factors to the weights at the hidden layer. This technique performs better when the environmental conditions are varying rapidly. Here the non- linearities of PV panel are overcome by supervised learning feed forward trained network. Flowchart for artificial neural network based MPPT algorithm is shown in the Figure 10. [23] – [24].

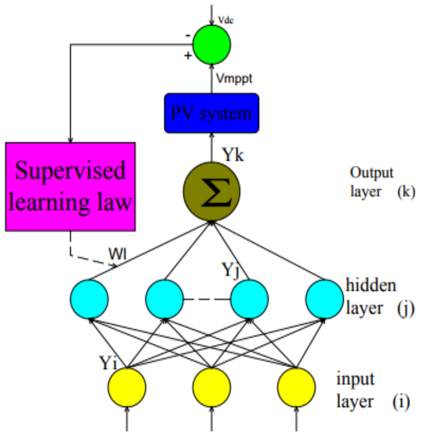


Fig.10. ANN Based MPPT

The artificial neural network (ANN) finds applications in many areas because of the better performance on non-linear tasks. The three layers of ANN are input layer, hidden layer and output layers. The structure of artificial neural network consists of a system to receive an input, data processing, and an output. Input variables can be defined as temperature, solar irradiation and short-circuit current or open-circuit voltage. The system accuracy is decided by the hidden layers and also the process of training. In partially shaded condition, ANN predicts the global MPP voltage and power. The variation of the actual voltage with respect to the reference voltage is given as error for the MPPT controller.

The ANN has two topologies as feed-forward and the recurrent topology. The feed-forward network contains no feedback connections. The recurrent network has feedback connections with short term memory. For better results under partial shading conditions, ANN combined with

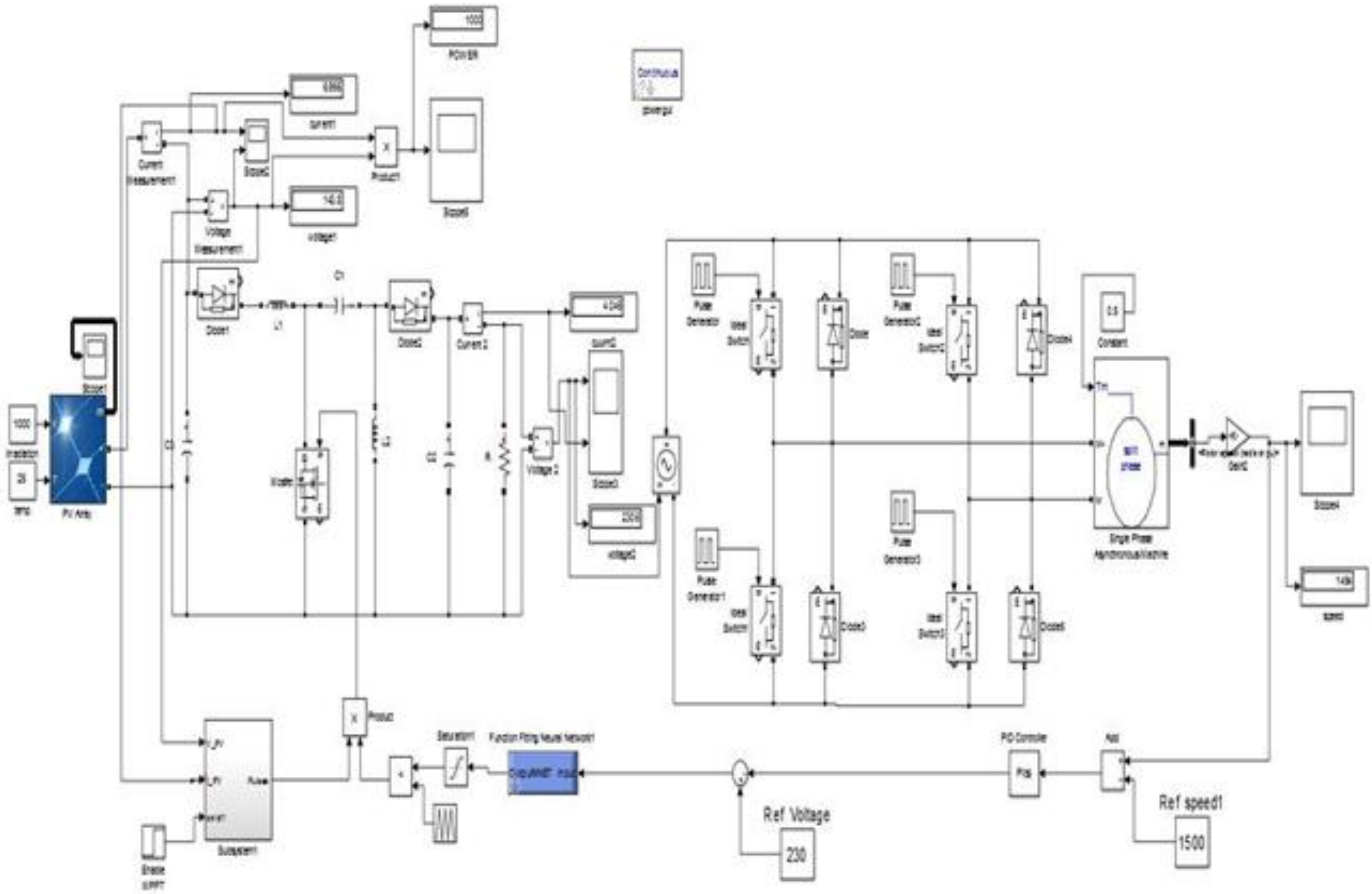


Fig.11. Simulation model of the proposed system

fuzzy logic can be used. The optimum PV voltage can be found out by training three layers of feed-forward ANN. Comparing with P&O, this method shows twice the tracking efficiency.

9. SIMULATION RESULTS AND DISCUSSIONS

The proposed system is simulated in MATLAB/ SIMULINK environment. The results of speed obtained for the system with incremental conductance algorithm using PI controller, fuzzy logic controller and neural network controller were depicted in Fig. 12, 13 and 14 respectively. Fig. 15 represents the result for the system without MPPT.

The results obtained from the system with and without MPPT algorithm are compared and the comparison of these results are depicted in Table 3. The results show that the system with neural network controller seems to provide better results compared with the other controllers. Also the system with MPPT provides better results compared to the system without MPPT.

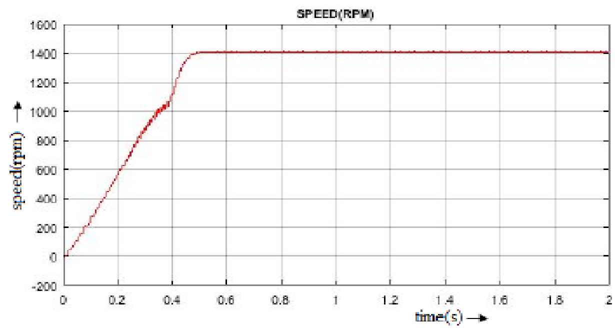


Fig.12. Speed of the motor with PI controller

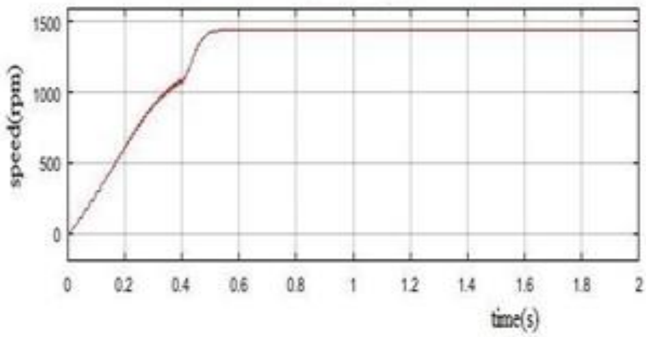


Fig.13. Speed of the motor with Fuzzy Logic Controller

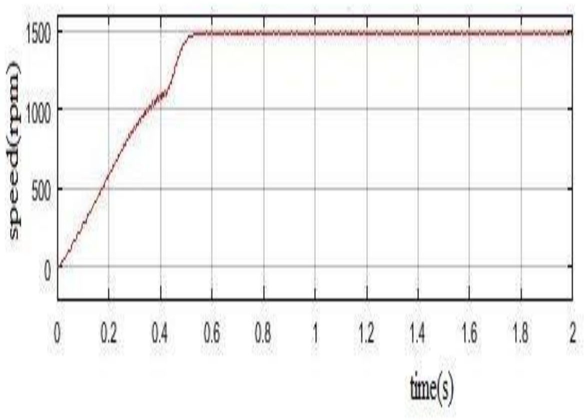


Fig.14. Speed of the motor with neural network controller

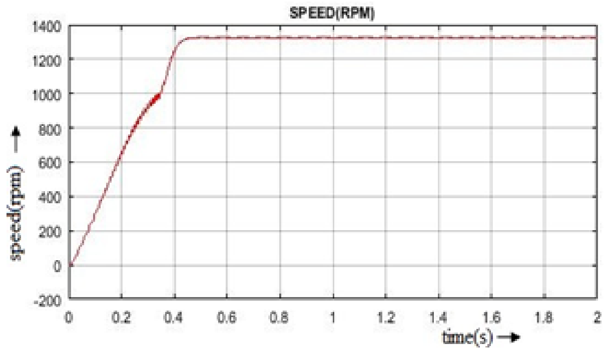


Fig.15. Speed of the motor without PI controller

Table 3. Comparison of output parameters with and without MPPT controller

Parameters	Speed of Motor (rpm)
Without MPPT controller	1330
With MPPT using PI controller	1408
With MPPT using fuzzy logic controller	1442
With MPPT using neural network controller	1494

10. CONCLUSION

Design of incremental conductance algorithm based MPPT controller using PI controller, fuzzy logic controller and the neural network controller for supplying single phase induction motor of the rated capacity of 1HP which is driven by solar energy system is presented. The voltage and current obtained from the solar panel is regulated by SEPIC converter which feeds the single phase inverter and that drives the induction motor. The simulation is carried out with and without MPPT controller. The simulation for the PI controller, fuzzy logic controller and neural network controller has been carried out separately and the results are compared. From simulation results obtained, it is observed that neural network controller performs better than the other two controllers for supplying the induction motor.

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