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STUDY OF INTELLIGENT MPPT CONTROLLERS FOR A GRID CONNECTED PV SYSTEM

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Abstract–*The power available by the photovoltaic system changes with the change in insolation, temperature and load due to the nonlinear V-I characteristics of solar cell.A Maximum Power Point Tracking (MPPT)technique maximises the output power of PV array by continuously tracking the maximum power point. This paper presents comparative analysis of two intelligent algorithms: Fuzzy logic and Artificial Neural Network based MPPT to track the maximum power point from the PV array. Fuzzy logic does not require the exact knowledge of the model and use heuristic reasoning based on experience which deal with the nonlinearity of PV arrays. ANN is trained with PV output voltage and current to analyse the duty cycle of dc-dc boost converter followed by tracking themaximum power point of PV arrays. The designed intelligent algorithms have been compared with Incremental Conductance algorithm based on their dynamic behaviour, efficiency and performance parameters.*

Keywords-PV array, MPPT (Maximum Power Point Tracking), ANN (Artificial Neural Network), FLC (Fuzzy Logic Control), IC (Incremental Conductance), DC-DC boost converter.

I. INTRODUCTION

Generation of electricity using renewable energy sources is becoming popular these days because of increase in demand and depletion of fossil fuels resources. To satisfy these requirements renewable energy sources should be used with non-renewable energy sources. Solar energy is free and abundantly available in nature clean, inexhaustible and produces no harmful gases that affect the environment i.e. it is eco-friendly and requires little maintenance. Solar energy produces variable output power and is not a reliable source since the output power of photovoltaic cell depends upon solar irradiation, cell temperature and load [1-2]. By having an optimal operating voltage and current, the photovoltaic panel extracts maximum power called maximum power point.

The solar cell has non-linear I-V and P-V characteristics due to which it becomes difficult to analyse the maximum operating power point. Maximum power point tracking technique helps in extracting maximum power from the solar module under varying irradiation and temperature. There are many MPPT techniques in the literature [6, 14]. Perturbation and observation (P&O), Incremental Conductance (IC), voltage-feedback methods etc. are the popular MPPT methods. These MPPTs differ in certain factors like complexity, cost, convergence speed, implementation of hardware, range of effectiveness, sensors required. The simplest and the cheapest MPPT controller that operates the PV array at a constant voltage [6] equal to its standard test condition (STC) MPP voltage is provided by the manufacturer. In P&O, perturbation of operating point of the PV array takes place due to increase and decrease of the control parameters by small amount and measurement of the PV array output before and after the perturbation [3].In IC algorithm,

comparison of the instantaneous conductance of PV array with its incremental conductance is done and accordingly decides whether to increase or decrease the control parameters [4]. Due to oscillations in P&O and IC algorithm there is large steady state error around MPP. Both conventional and artificial intelligence methods have their own advantages and limitations.

Conventional methods can be easily implemented and are compatible to operate with any photovoltaic array.These are relatively slower when compared to artificial intelligence methodsand also gives slow response in sudden temperature and variable solar irradiation, hence may fail in tracking maximum power point [6]. On the contrary, artificial intelligence methods gives fast response under any operating conditions, these methods also provides accurate results and can work under instant temperature and variable solar irradiation. But these methods are complicated in designing and need fast processors to be implemented physically otherwise they will run very slowly. For each photovoltaic array type, a separate model should be designed so as to guarantee its performance [6].

Fuzzy logic (FLC) is used as the MPP tracker of PV array because it is robust, simple to design, does not require the exact knowledge of an exact model [3]. Artificial neural network (ANN) is an artificial network that replicates human biological neural network behaviour. It has the ability to learn from environment and to improve its performance through learning [5]. The two inputs given to ANN are the PV array current and voltage whereas to track the MPP an optimised duty cycle is computed.

In this paper, a PV array is modelled using MATLAB/SIMULINK R2015a to simulate behaviour of the PV array. The intelligent MPPT algorithm such as fuzzy logic and artificial neural networkis proposed to control the DC-DC converter followed by voltage source inverter. Voltage source converteris controlled in the rotating frame to inject a controllable three phase AC current into the utility grid [12-13]. A Phase Locked Loop (PLL) locks the grid frequency and provides a stable reference synchronous signal to the inverter control system [13]. Section II presents the configurations and modelling of the PV system, section III presentsthe proposed intelligentMPPT algorithm, section IV presents results and discussions of the paper and the conclusion is provided in section V.

II. PROPOSED SYSTEM CONFIGURATIONAND MODELLING OF PV CELL

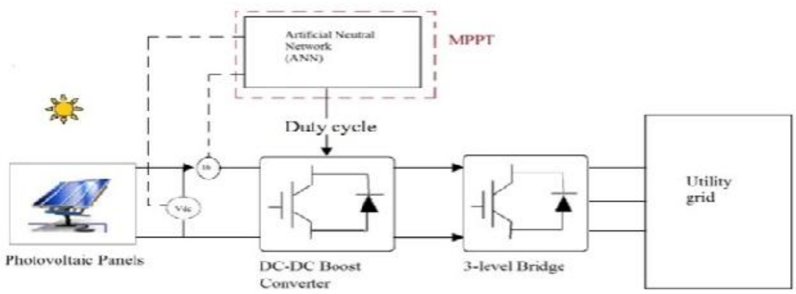


Fig.1. Configuration of proposed system

Solar cell is basically a p-n junction semiconductor diode which is exposed to sunlight to convert it to electricity. A photovoltaic module is the current source which is the combination of number of solar cells connected in series and parallel to obtain required electrical energy. Fig. 1 shows the configuration of the proposed system. PV system exhibits the nonlinear I-V and P-V characteristics with varying irradiation and temperature conditions Fig.2 shows the equivalent circuit of a photovoltaic array.

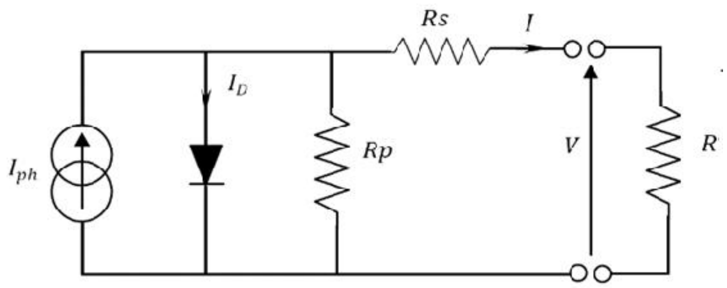


Fig. 2.The equivalent circuit of a photovoltaic array

The mathematical expression for the equivalent circuit model is given by

$$I_p = I_{ph} - I_D - I_{sh} \quad (1)$$

Where $I_{ph}$is the photon generated current, $I_D$is diode current and $R_{sh}$is the shunt resistor. The mathematical equation for the generalized model can be given as

$$I_p = N_p I_{ph} - N_p I_o \left[e^{\frac{q(V_p + R_S * I_p)}{N_S A}} - 1 \right] - \frac{(V_p + R_S * I_p)}{R_{sh}} \quad (2)$$

Where I_{ph}denotes the current generated by incident light, $I_o$is PV saturation current ,$N_p$is cells connected in parallel, $N_s$is number of cells connected in series, V denotes voltage across the diode, T denotes the actual temperature of the cell, A is the ideality factor, R_s is the series resistance, q = 1.6*10^{-19}C, k = 1.381*10^{-23}.

In this paper a 100kW PV array is modelled by connecting 5 Sun Power SRP-305-WHTSolar Panel in series with 66 panel in parallel simulated in MATLAB /SIMULINK (R2015a). Table-I shows the electrical specifications of the designed module on standard test condition.

TABLE I

ELECTRICAL PARAMETER OF SUN POWER SRP-305-WHT SOLAR PANEL

Maximum power (P_{max})	100.7kW
Voltage at MPP (V_{mpp})	54.7V
Current at MPP (I_{mpp})	5.58A
Open circuit voltage (V_{oc})	64.2V
Short circuit current (I_{sc})	5.96A
Number of cells connected in series	96

III. MAXIMUM POWER POINT TRACKING ALGORITHM

PV modules have non-linear current-voltage characteristics depending upon solar irradiation, temperature and load. Hence the operating point corresponding to the maximum output power varies as shown in fig 3. The Maximum power point tracking is used for improving the efficiency of the solar panel. There are different MPPT techniques used in the literature [6] to track the maximum power point of the solar array. In this paper, the two intelligent MPPT algorithms based on FLC and ANN are designed and compared with the IC algorithm.

A. Artificial neural network (ANN) MPPT controller

ANNs are the nonlinear statistical data modelling tool where modelling of complex relationships between inputs and outputs are done. ANN consists of number of interconnected processing elements known as neurons which are again connected by links of the adjustable weights to forward signals to other neurons. The proposed ANN is a Multilayer Feed Forward neural network as shown in fig 3, consisting of four layers- input layer, two hidden layers and the output layer estimating the duty cycle.

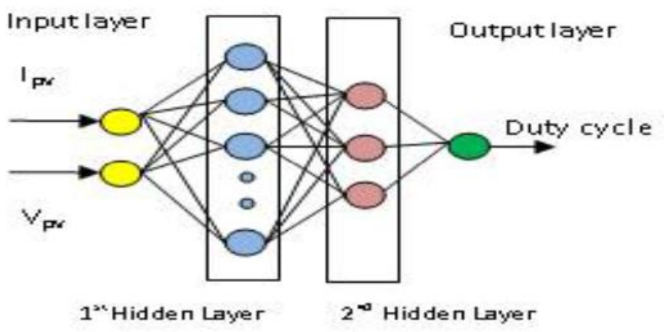


Fig3. Four layer feed forward neural network

The hidden layers consisting 20 neurons in the first hidden layer and 3 neurons in the second hidden layer uses tansig and purelin activation functions. The network is obtained by training with "Trainlm" function according to Levenberg-Marquardt (LM) optimization. Performance function of the network is the mean square error (MSE) that is given by

$$E_p = \frac{1}{2} \sum (T_p - O_p)^2 \quad (3)$$

Where '$_p$'is denoted as the index of the output neuron,T_p is the desired output and O_p is the measured output.

B. Fuzzy Logic (FLC)Based MPPT Controller

The main components of fuzzy logic based MPPT controller are fuzzification, rule-base, inference and defuzzification as shown in fig 4. These consist of two inputs and one output variable. The input control variables E(K) is the slope of P-V curve and CE(K) is the change of slope whereas (D) is the change in duty ratio of the DC-DC converter.

$$E(K) = \frac{P(K) - P(K-1)}{V(K) - V(K-1)} \quad (4)$$

$$C \ (K) = E(K) - E(K) \quad (5)$$

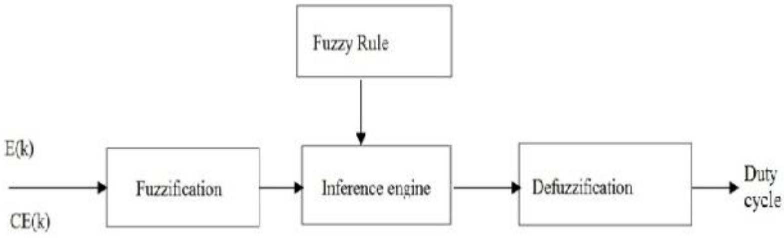
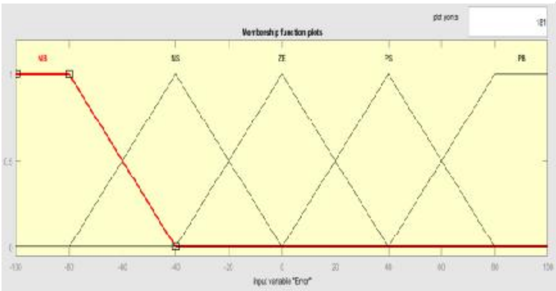


Fig. 4. Fuzzy logic based MPPT for PV array

a. Fuzzifiacation:

In fuzzification actual input variables error (E) and change in error (CE) and output duty cycle are converted into linguistic variables based on their membership functions. These are expressed in seven linguistic variables negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), positive big (PB). The triangular membership function is used in this paper which is shown in fig [5-7].



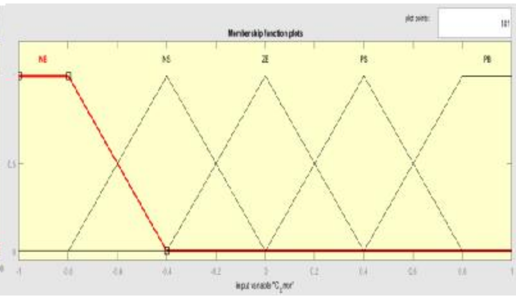


Fig. 5. Membership function of error Fig. 6. Membership function of change in error

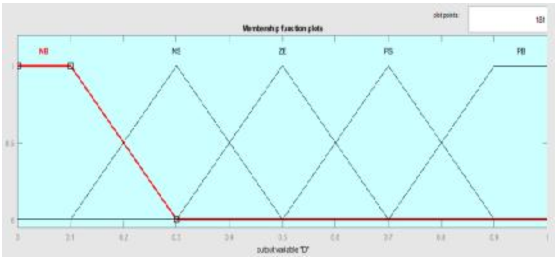


Fig.7. Membership function of duty cycle

TABLE II FUZZY RULES

CE / E	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

b. *Rule base and inference:*

Fuzzy rules are the combination of if-then rules that has information for controlling parameters. Table-IIcontains 49 fuzzy rules which are developed for controlling DC-DC boost converter so that maximum power point is achieved. Fuzzy inference is the mapping process of actual input to an output. In this analysis Mamdani's fuzzy inference method has been used.

c. *Defuzzification:*

Defuzzification is the reverse of fuzzification process i.e. it is the process of conversion of fuzzy set to crisp output values. There are various defuzzification methods out of which Centre of Gravity (COG) defuzzification method is used in this work.

IV. RESULTS AND DISCUSSIONS

A 100kW PV array with 5 Sun Power SRP-305-WHT solar panel in series with 66 panels in parallel has been modelled using MATLAB Simulink under constant and changing irradiation conditions consisting of MPPT controller based on ANN, FLC, and IC algorithm. ADC-DC boost converter converts 272V DC to 500V DC and whose duty cycle is controlled by the (ANN/FLC) MPPT technique. Three level bridge inverter converts 500V DC to 260V AC which is then connected to a 100kVA 260/25kV three phase coupling transformer and utility grid as shown in Fig. 1. The I-V and P-V curve for the designed 100kW panel with varying insolation is shown in Fig 8. The simulink model of ANN based controller is shown in Fig. 9.In this paper the output current and output voltage of PV array is taken as the input data set and the output layer consists of duty cycle which acts as the controlling signal for the boost converter. The samples of training data generated are used for training ANN as shown in table III. The best validation performance MSE is achieved at 0.0020001 at 1000 epochs as shown in Fig 10. The factors analysed for the performance of the MPPT algorithms are settling time, efficiency, transient tracking time, steady state oscillation and dynamic behaviour to track the maximum power point of the PV array.

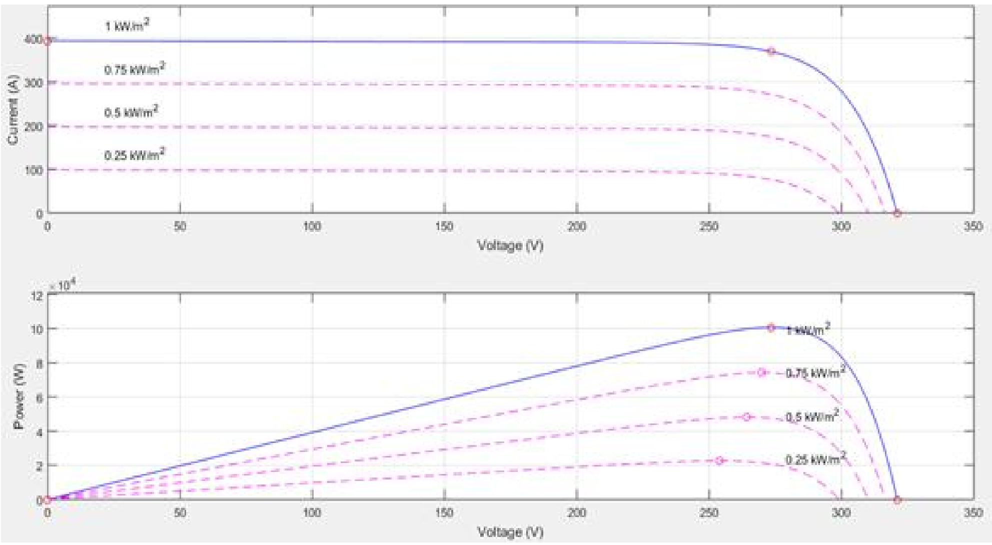


Fig.8. I-V and P-V curve of 100kW PV array

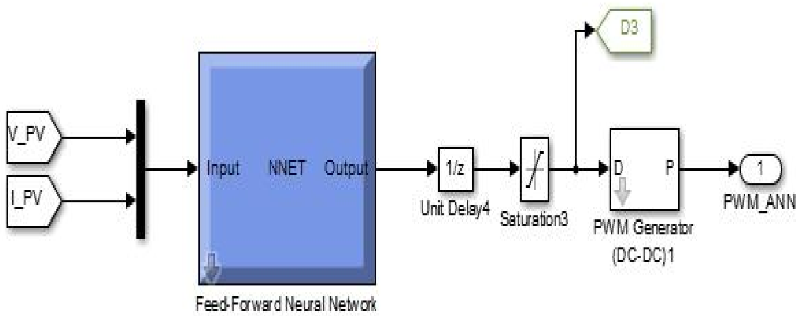


Fig. 9. Simulink model of ANN based controller

TABLE III TRAINING DATA

PV Voltage	PV current	Duty Cycle
176.3500055	391.0108418	0.5
215.3229516	390.4473126	0.5
254.1728794	389.4108069	0.5
292.6010314	383.0269741	0.5
327.4094396	318.1811754	0.450709116

273.0659855	369.6214785	0.450665821
272.9396461	369.6962124	0.450640367
272.7555453	369.8312789	0.450622923

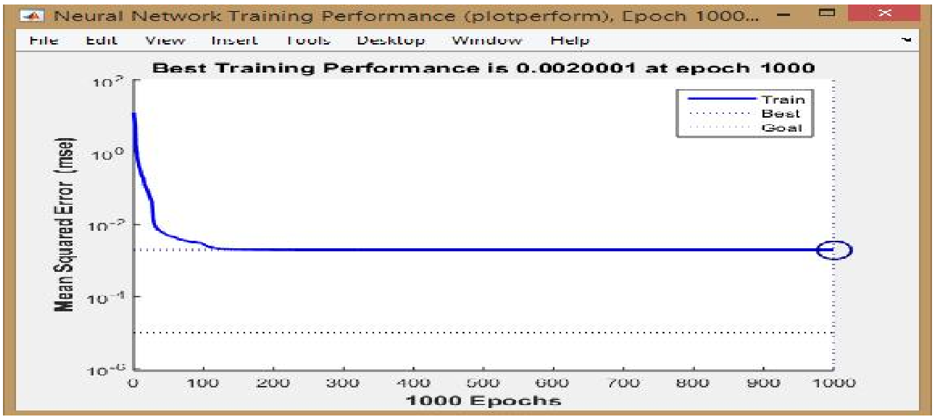


Fig. 10. Performance of ANN

i. *Comparing maximum power point tracking technique:*

Incremental conductance algorithm[20], fuzzy logic algorithm and artificial neural network based MPPT algorithms have been compared based on maximum power achieved from the PV array, steady state power ripple and transient tracking time. In this first the model is operated under nominal operating condition at 25ºC and 1000W/m^2. Secondly the irradiation is kept constant at 1000W/m^2 to 250W/m^{2}and back to 250W/m^{2}again from 2.3 sec to 2.75 sec a fast changing irradiation takes place from 1000W/m^2 to 250W/m^2 and back to 1000W/m^2.

a. *Comparing three MPPT algorithms based on maximum power obtained from PV array*

Power (kW)

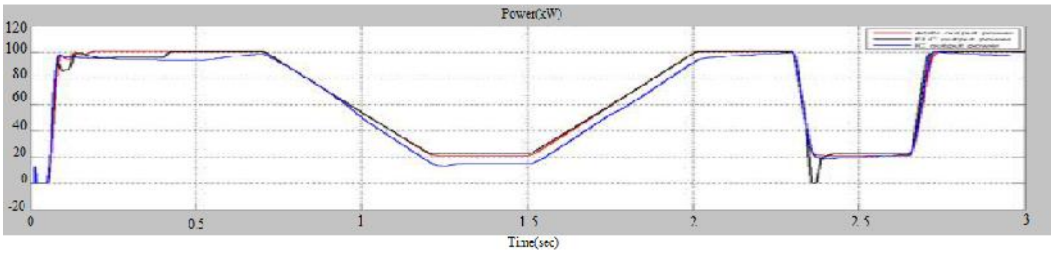
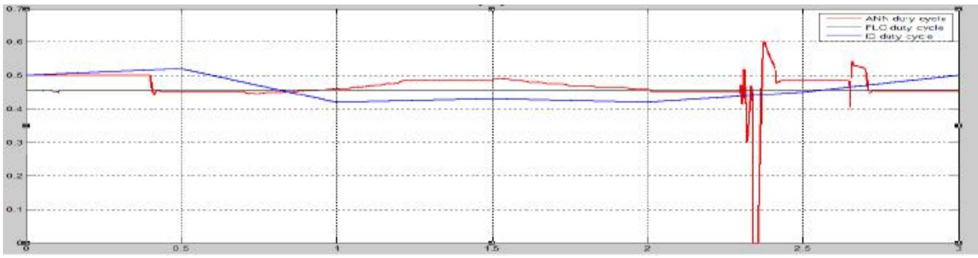


Fig.11. Simulation results showing maximum power obtained from PV array using ANN (red), FLC (black), IC (blue) algorithms.

Duty ratio

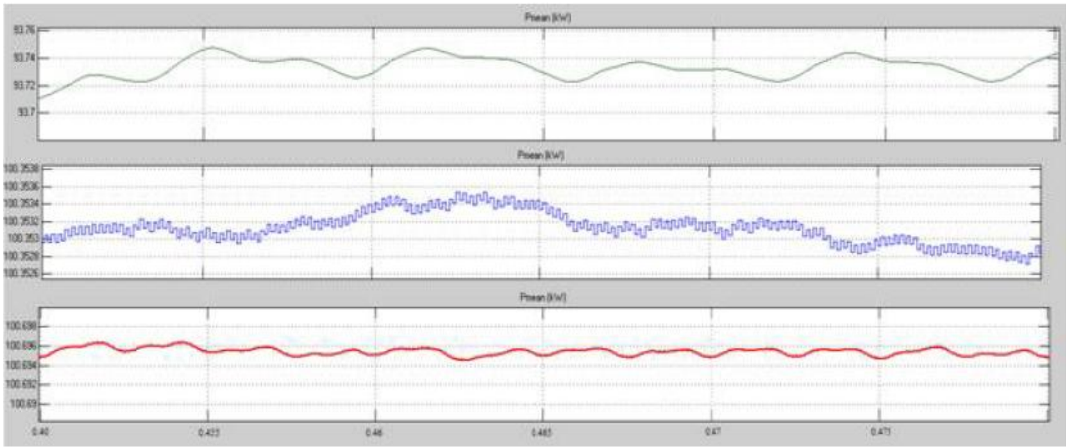
Time (sec)



The maximum power obtained from ANN is 100.5kW while FLC tracks 100.3kW and IC extracts 96.9kW for 1000W/m^2 as shown in figure 11. Figure 12 shows the change in duty cycle for varying irradiation level.

b. Comparing three MPPT algorithms based on steady state power ripple:

Power (kW)



Time (sec)

Fig. 13.Simulation results showing steady state power ripple in ANN (red), FLC (blue), IC (green) algorithms.

As seen from fig.13 at steady state, power ripple at maximum power is tracked at 1000W/m^{2}by ANN is less when compared to FLC and IC algorithm.

c. Comparing three MPPT algorithms based on transient tracking time:

Power (kW)

Power (kW)

Power (kW)

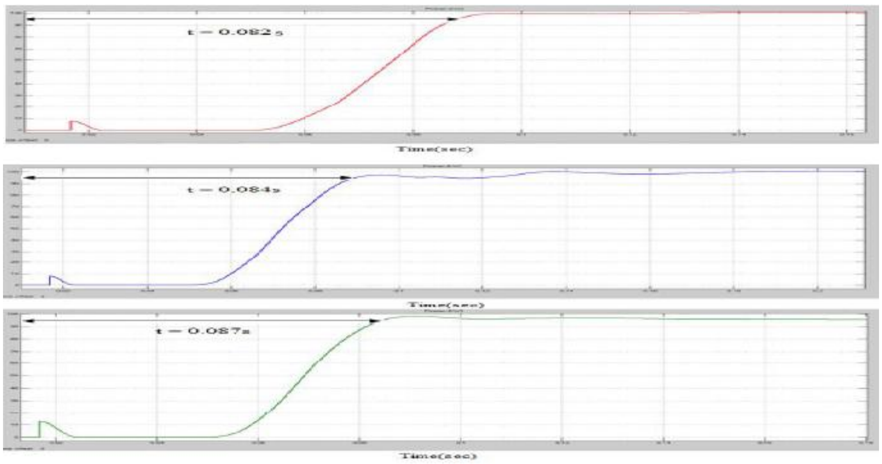


Fig.14. Simulation results for transient tracking time (t) of ANN (red), FLC (blue), IC (green) algorithms.

From fig.14 it is observed that the transient tracking time taken to reach 95% of the maximum average power available for obtaining at MPP by three MPPT algorithms are- ANN required 0.082 sec, FLC took 0.084 sec while IC required 0.087 sec.

V. CONCLUSIONS

This paper presents comparative analysis of two intelligent control techniques- Fuzzy logic and Artificial Neural Network based MPPT to track the maximum power point from the PV array and is compared with Incremental Conductance algorithm based on their dynamic behaviour, transient tracking time, settling time, steady state oscillation, and efficiency.

The controllers are designed and analysed in MATLAB/SIMULINK. The analysis shows the response of the system and is clear that ANN MPPT is better than FLC and IC algorithms, since it is fast and precise in tracking MPP from PV array, and hence increasing the efficiency of the PV system. The efficiency of ANN based MPPT controller is 99.89% with 100.5kW power delivered to the grid, FLC has 99.65% efficiency and 100.3kW power while IC has an efficiency of 96.2% and delivers 96.90kW power to the grid.

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