Efficiency Improvement of Grid Connected PV using ANFIS based MPPT

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Abstract

The Government of India launched the Jawaharlal Nehru National Solar Mission (“JNNSM” or, “National Solar Mission”) which inter alia targets 20 GW of grid connected solar capacity by year 2022.The main purpose of this paper to design high efficient PV integrated with grid. Efficiency of PV is improved by using MPPT technique. ANFIS based MPPT is the proposed method of this paper. This technique is compared with Conventional Incremental Conductance(IC) which is based on fast changing radiation. The ANFIS based MPPT scheme works fast and gives improved results under change of solar irradiation. The simulation study is done using MATLAB/SIMULINK software.
Keywords: Photovoltaic, Mppt, DC-DC Boost Converter, IC, ANFIS, Matlab/Simulink

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I. INTRODUCTION

India has rank 5th in the world in the field of power generation and consumption. Still more than 72% population of villages are without electricity. It is predicted that country's coal reserve won't last beyond 2040-50. Solar energy plays a major role to fulfill the energy needs of India and bridge the energy demand-supply gap. In India 300 clear sunny days are recorded in a year. Almost all parts of India receive 4-7 KWh of solar radiation per square meter[1].

Solar connected with main grid is the most popular solar power solution for houses and commercial establishments. It has advantage of running load directly through solar and selling excess power back to electricity company by feeding the grid. Recently world bank approved $625 million to support grid connected rooftop solar program in India[2]. PV integrated with grid consists of PV array, maximum power point tracking control, DC-DC converter, inverter and smart meters.

The major challenge lies in using the PV power generation systems is to tackle the non-linear characteristics of PV array. The PV characteristics depend on the level of irradiance and temperature. PV array experiences different irradiance levels due to passing clouds, neighbor buildings or trees. The output Power-Voltage(P-V) and current-voltage (I-V) characteristic of a photovoltaic system is affected by environmental factors such as solar irradiance and temperature levels. Finding the maximum extractable power at the nonlinear output characteristic of the PV system is one of the influential factors affecting the efficiency and overall cost of the control unit in a photovoltaic system. The MPPT technique is implemented in DC-DC converters to archive maximum efficiency. Most widely used MPPT techniques are[9] :

Constant Voltage (CV) Method, Open Voltage (OV) Method, Temperature Methods, Incremental Conductance (IC) Methods, Perturb and Observe (P&O) Methods, Three Point Weight Comparison, Short-Current Pulse Method, Fuzzy Logic Method, Sliding Mode Method, Artificial neural network Method(ANN).

P&O, IC, Hill climbing algorithm, short-current pulse, open circuit voltage are simple and easy to implement and suitable for uniform irradiance but they be cannot used under partial shading condition[3,4,9]. Perturbation and observation (P&O), and Incremental conductance (IC) are the most common methods which are frequently used in hardware. Fuzzy logic based MPPT which does not require the knowledge of the PV panel but yields good results in fast change in radiation. ANN method and Artificial Neuro Fuzzy interference system (ANFIS) method are suitable for fast changing irradiation and partial shading but can be implement with those system that can get sufficient training data[5,7]. This paper proposes the ANFIS based MPPT to compute the optimal duty cycle of DC-DC boost converter and compare with IC based techniques.

The paper summarizes as: Section I is the introduction on grid connected PV a literature review, Section II is about system description and mathematical modeling, MPPT control Techniques IC and ANFIS based, in Section III discussion on simulation and results of system and finally Section IV is the conclusion part of the research.

II. SYSTEM DESCRIPTION AND MATHEMATICAL MODELING

The functions of the power converter of a PV system consists of Maximum Power Point Tracking (MPPT), DC/AC power converter, grid synchronization, power quality, active and reactive power control – and anti-islanding detection power converter interface of grid-connected PV system. The system has a PV generation set-up, which can be a single module, a string of series-connected modules, or an array of parallel connected strings. PV inverters nowadays have high demand, which are manufactured in different topologies. The configuration of series/parallel connections of PV modules with 3-ph central string inverter is common for PV plants (10 to 250 kW & more) that gives high efficiency.

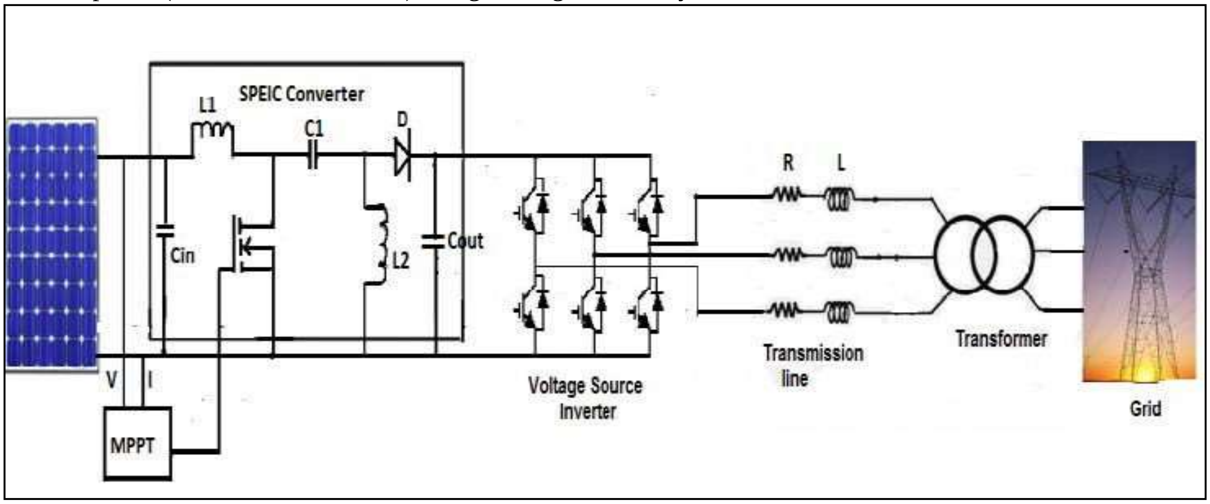

Fig. 1: Three phase grid connected 100KW PV with DC_DC Boost and Inverter

A. PV Array

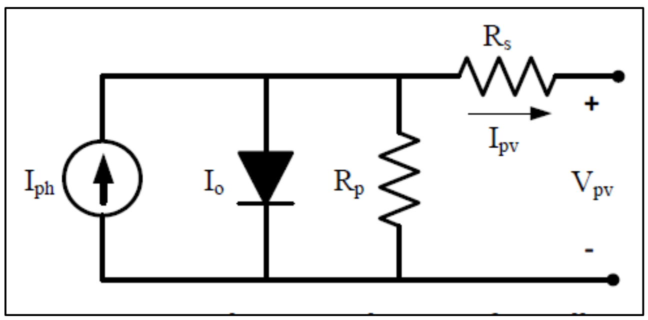

Fig. 2: General circuit diagram of Photovoltaic cell.

The PV system in this study is modeled on the basis of a single-diode model. Solar cells have nonlinear voltage-current (V-I) characteristics due to the p-n junction of diode. Fig. 2 shows a typical voltage current characteristic of solar panel. Since current of solar panel is approximately constant on the left side of maximum power point (MPP), this region can be defined as current source region. On the other hand, voltage range of solar panel is rather a limited on the right side of MPP and this side can be named as constant voltage source[3].

Thus, a solar cell can be modeled by an equivalent circuit that consists of a current source, a reverse-biased diode, and a resistor connected in series, where each part of the model is associated with a specific parameter. The cell's photocurrent is represented by a current source, shown as the solar cell in the model.

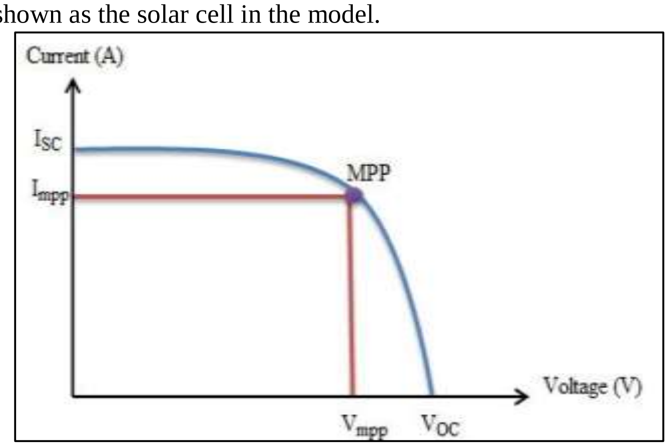

Fig. 3: V-I characteristics curve of PV

Moreover, the output voltage is represented by the reverse-biased diode. The diode's saturation current is represented by a shunt resistance. Finally, the cell's internal losses are indicated by a series resistance.

Under normal operation conditions or in the absence of sunlight, PV cell performance will be similar to a semiconductor diode in the dark. In such a case, this PV cell is represented by a normal diode, where its characteristics (current—voltage) can be expressed as

$$I_D = I_O(\exp\frac{qV_D}{nkT} - 1) \quad (1)$$

$$V_D = V + IR_S \quad (2)$$

Where I is the PV output current, Io is the reverse saturation current of the diode, q is the electron charge equal to 1.602×10−19 C, k is the Boltzmann constant (1.381×10−23 J/K), T is the ambient temperature, V_D is the voltage across the diode terminals, V is the output voltage, R_S is the series resistance, and n is the ideality factor, also known as the quality factor or sometimes the emission coefficient.

On the other hand, an ideal cell is represented as a current generator connected in parallel with a diode when the solar cell is illuminated, and its I–V characteristics are described by with the following equation:

$$I = I_L - I_D = I_L - I_O\left(\exp\frac{q(V+IR_S)}{nkT} - 1\right) - (\frac{V+IR_S}{R_{SH}}) \quad (3)$$

n usually takes values in the range 1–2 (although it might be larger in very few situations), which depends on the construction and semiconductor material. Generally, the proposed PV system model is a five-parameter model, namely, IL, Io,a,Rs and Rh. This model can be used for an individual cell, a module consisting of several cells, or an array consisting of several modules.

Nonetheless, owing to the difficulty in finding an accurate value for n, we assume that

$$C_1 = \frac{q}{nk} \quad (4)$$

$$a = \frac{T_c}{C_1} \quad (5)$$

As a result of this new relation as well as the expected higher shunt resistance, the shunt current becomes modest, and eventually, the new I–V characteristic equation can be simplified as

$$I = I_L - I_O\left(exp\frac{q(V+IR_S)}{a} - 1\right) \quad (6)$$

$$V = a\ ln\left(\frac{I_L - I}{I_O}\right) - IR_S \quad (7)$$

Usually, the photocurrent (IL) is proportional to the value of the solar irradiation, and it is supposed to be linearly dependent on the effective cell temperature (Tc). Consequently, this light generation current could be expressed as

$$I_L = (C_2 + C_3T - C_4)G_T \quad (8)$$

Where are coefficients, is the solar irradiance, and is the temperature of the cell.

$$I_O = C_5T^3\exp(-\frac{C_6}{T}) \quad (9)$$

B. MPPT Control Techniques

1) Incremental Conductance Based MPPT Control

Inc-Con is very popular algorithm running concurrently with solar panel which is based on measurement of voltage and current of solar panel for a certain frequency. According to the measurement results, incremental and instantaneous conductance are calculated and compared. Finally, required control command is generated by MPPT control unit. Fig. 3 shows flowchart of this algorithm.

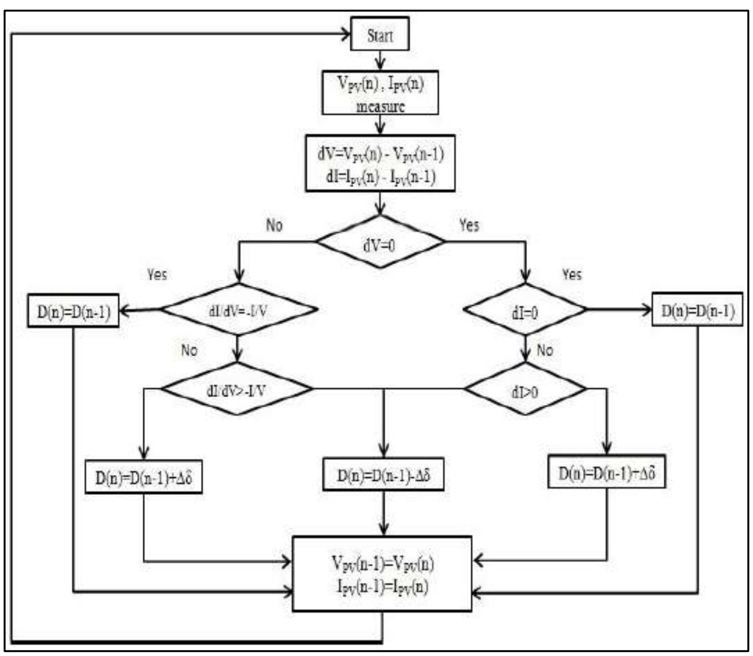

Fig. 4: Flow Chart of IC Algorithm

Equations (10),(11),(12) are the main equations that can be written for this algorithm as given below

$$\frac{dP}{dV} = 0 \rightarrow \frac{\Delta I}{\Delta V} = -\frac{I}{V} \rightarrow MPP \qquad (10)$$

$$\frac{dP}{dV} > 0 \rightarrow \frac{\Delta I}{\Delta V} > -\frac{I}{V} \qquad (11)$$

$$\frac{dP}{dV} < 0 \rightarrow \frac{\Delta I}{\Delta V} < -\frac{I}{V} \qquad (12)$$

2) *ANFIS based Control Technique*

Neuro-fuzzy technique is combining the ANN learning methods and the fuzzy inference system (FIS) [7]. In general the FIS structure consists of three important components: and the rule base one, for rule fuzzy selection, a database, which defines the fuzzy rules MF and a decision generator, that bring up the inference procedure to finally generate an output. The FLC concepts are based on knowledge from expert and in the other hand the neural network models are using a data base. Moreover, neuro-fuzzy approach seems covenant and suitable if both advantages of the tow method are combined. The neuro-fuzzy controller is the called, in this work adaptive network (ANFIS). The structure of the system is an adaptive network running as a first-order Sugeno fuzzy inference system. The hybrid ANFIS learning rule, combine the back-propagation gradient-descent first and second a least-squares algorithm for identification and optimization of the the Sugeno first order system. The the ANFIS working process is simplified by an equivalent ANFIS architecture with two rules are given in Figure below [7].

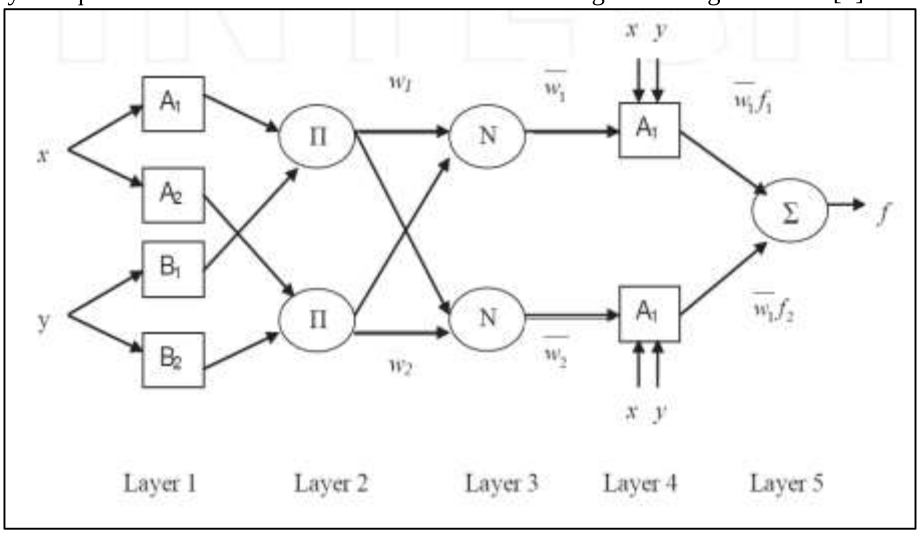

Fig. 5: ANFIS Architecture

The above architecture has five layers and every node in a layer has a similar function. The two fuzzy rules, in which outputs are dressed as linear combinations of their inputs, are [7]:

1) Rule1: if x1 is A1 and y1 is B1 then f1=p1x+q1x+r1
2) Rule2: if x2 is A2 and y2 is B2 then f2=p2x+q2x+r2

- Layer 1: consists of adaptive nodes that generate membership grades of linguistic labels based upon premise signals, using any appropriate parameterized membership function such as the generalized bell function given by :

$$O_{li} = \mu_{A_i}(x)\frac{1}{1 + \left|\frac{x - c_i}{a_i}\right|^{2b_i}}$$

Where output O_{li}i is the output of the ith node in the first layer, x is the input to node i, A_i is a linguistic label (“small,” “large,” etc.) from fuzzy set A =(A1, A2, B1, B2,) associated with the node, and {ai,bi,ci} is the premise parameter set used to adjust the shape of the membership function .

- Layer 2: are fixed nodes designated Π, which represent the firing strength of each rule. The output of each node is the fuzzy AND (product or MIN) of all the input signals:

$$O_{2,i} = \mu_{Ai}(x)\mu_{Bi}(y)$$

- Layer 3: The outputs are the normalized firing strengths. Each node is a fixed rule labeled N. The output of the ith node is the ratio of the ith rule’s firing strength to the sum of all the rules firing strengths:

$$O_{3,i} = \overline{\omega_i} = \frac{\omega_i}{\omega_1 + \omega_2}$$

- Layer 4: the equation gives the rule outputs is:

$$O_{4,i} = \overline{\omega_i} f_i = \omega_i(p_i x + q_i y + r_i)$$

With wi is the firing strength that is normalized from the layer number 3, pi, qi, ri are the node set parameters.

Layer 5: the ANFIS output is given by:

$$O_{5,i} = \sum_i \overline{\omega_i} f_i = \frac{\sum_i \omega_i f_i}{\sum_i \omega_i}$$

The ANFIS controller developed in this section includes ' Ip ' and ' P ' as inputs and 'D’ as output which represent respectively, the PV current, the PV-Power and the converter duty cycle ratio. The input variables allow the ANFIS to generate the converter command. This last is applied to the converter, in order to ensure the adaptation of the power provided by PVG. This controller yields to an automatic fuzzy rules generation based on the Sugeno inference model. The equivalent neural structure of the proposed ANFIS is given in figure 13, figure 14 show the MPPT-ANFIS validation and errors curves.

C. *DC-DC Boost Converter*

DC-DC converters are electronic devices used whenever is needed to change DC electrical power efficiently from one voltage level to another. A DC-DC converter is an adapter controlling the load power through a regulated duty cycle. In order to step up the voltage, the operation consists of switching an IGBT (Figure) at a high commutation frequency, with output voltage control by varying the switching duty cycle (D) [8] and [9]. With the help of this power converter, voltage and current of solar panel are automatically adjusted to MPP value and MPPT operation is provided. As given in Fig. 5, point G is not efficient point. If solar panel operated under this point, capacity of solar panel is not used. By using power converter which is a DC-DC boost converter in this study, optimum operation condition (MPP) is realized by sensing the voltage and current of solar panel.

In MPPT operation, voltage and current are processed and required signal is generated by control unit. The MPPT operating zone for solar PV is dependent on DC–DC converter topology and restricts the value of resistive load for which MPPT become effective. MPPT varies the duty cycle of DC DC converter to match load impedance with input impedance seen by the DC–DC converter, i.e., impedance of solar PV as shown in Figure 5. Rin (the input impedance seen by the converter) and Ro (the output impedance connected with converter) are related with characteristic equation.

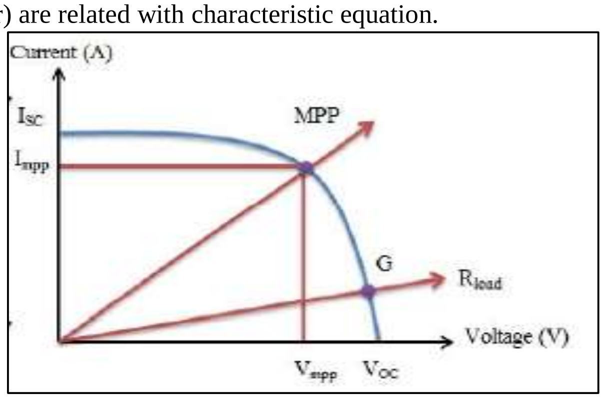

Fig 6: Optimum operation condition and load point

III. SIMULATION AND RESULTS

The MATLAB /SIMULINK model of the MPPT system consists of the 100 KW PV module, IC and ANFIS based MPPT controller, three phase inverter and 25KV grid. PV module is polycrystalline silicon type that produces 305.2 W at 1000 W/ m2 and its parameters are given below. By using this PV module, simulation works were carried out under steady state and dynamic conditions with proposed

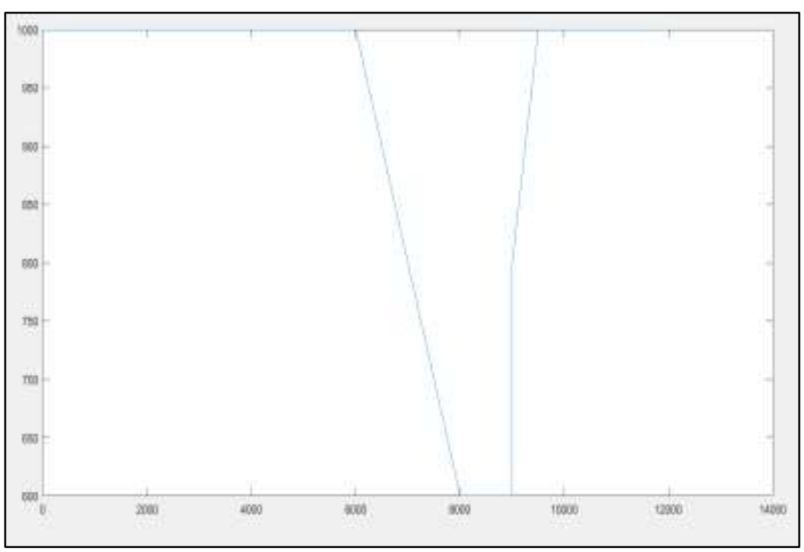

Fig. 7: Plot of Irradiance

ANFIS technique and with conventional IC algorithms, respectively, for evaluation and comparison analysis. The input of dc–dc converter was around 271V, the output was 500 V and the duty cycle of PWM was about 50%. The main importance factors used to analyze performance of each MPPT algorithm are time response, oscillation, overshoot and stability. Fig 6 show a irradiation plot which is constant at 1000w/m2 and changing 1000w/m2 to 600w/m2 at fast rate to show partial shading effect of PV.

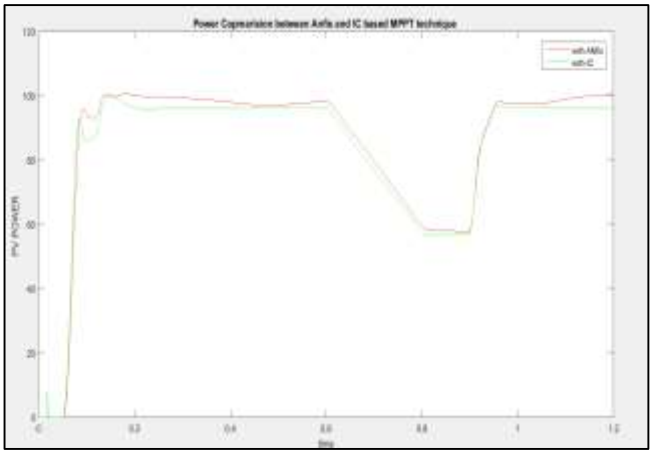

Fig. 8: Power comparison curve with ANFIS and IC

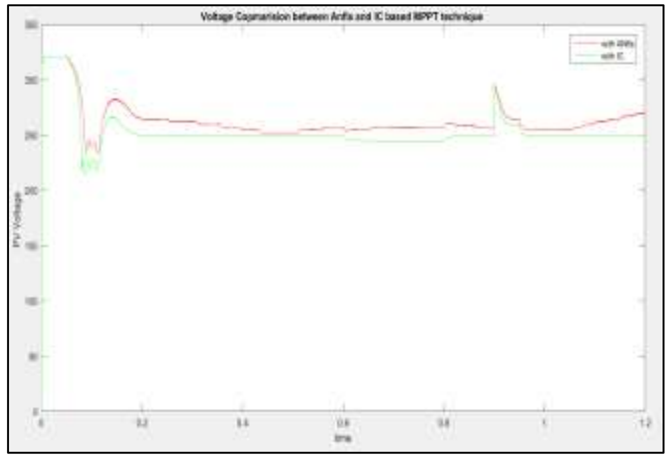

Fig. 9: Voltage Comparison curve with ANFIS and IC

Steady-state test was done for fast change in irradiances . Fig. 7 shows effect of each MPPT algorithm towards the MPP of Power, followed by detailed analysis results as described in Table 3. Fig. 8 shows effect of each algorithm towards the voltage, followed by detailed analysis results as described in Table 4. The time response of IC based MPPT algorithm is 0.0. All algorithms could extract MPP of the PV module. The critical situation was when the irradiation was about 250–1000 W/m2. In specific situation, the conventional IC did not work well with low irradiation and caused power losses. From Table 3, it also contributes to the slowest time response, high oscillation and not that stable. By comparing it with ANFIS as shown in Fig. 7 &8 and listed in Compare Table below, the ANFIS shows that it is much better as compared with IC. The ANFIS also shows a good time response, good efficiency, low oscillation and stable. The efficiency is high, time response is fast, really low oscillation exists and operation is more stable. Despite effect towards MPP, the algorithms should also affect the boost dc–dc converter. The ANFIS performs much better with low overshoot and oscillation. For IC, the time response is about 0.06s before reaching to stable state, overshoot is about 71 V and high oscillation exists. For ANFIS algorithm, the time response is about 0.04 before reaching stable state, overshoot is about 50V and low oscillation is observed. Therefore, from the simulation results, performance of ANFIS algorithm is much better as compared to both conventional MPPT algorithms in terms of time response, overshoot, maximum power ratio, oscillation and stability.

The array consists of 66 strings of 5 series-connected modules connected in parallel (66*5*305.2 W= 100.7 kW). Open the PV-array block menu and look at model parameters. Manufacturer specifications for one module are:
Number of series-connected cells: 96
Open-circuit voltage: Voc= 64.2 V
Short-circuit current: Isc = 5.96 A
Voltage and current at maximum power:
Vmp =54.7 V, Imp= 5.58 A

Table - 1
Comparison Table

Technique	*Based on Power curve*		
	Time response	*Settling Time*	*Efficiency*
IC	*0.06*	*0.20*	*96%*
ANFIS	*0.04*	*0.14*	*100%*

Table – 2
Comparison Table

Technique	*Based on Voltage curve*		
	Overshoot	*stability*	*Voltage*
IC	*71*	*stable*	*249.69*
ANFIS	*50*	*Very stable*	*271*

IV. CONCLUSIONS

In this research PV integrated with grid is studied which is major goal of researcher of this field. PV application of this kind minimizes the cost of energy and encourages the consumer participation. In this paper Incremental Conductance (IC) and Artificial Neuro Fuzzy Interference system (ANFIS) technique based MPPT for grid connected PV are design and presented.

Wide range of irradiation level, constant, fast changing has been discussed. The performance analysis of maximum power tracking (MPPT) algorithms on the basis of time taken to track maximum power point (MPP) and various important factors such as efficiency, stability, settling time, overshoot in power and voltages before reaching MPP are done so that accurate results are obtained. These analysis show that the response of the system when we use ANFIS is better than IC as it is fast and precise in tracking MPP but with more overshooting in voltage and duty cycle during changing irradiation level. Efficiency of ANFIS controller is 100% and while IC has efficiency of 96%.

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