

# IMPROVING PERFORMANCE OF GRID CONNECTED PV INVERTER USING OPTIMAL MPPT CONTROL STRATEGY

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**Abstract:** In this paper, a control strategy for power flow management of a grid connected photovoltaic (PV) based system with an efficient ANFIS based dc to dc converter is presented. The proposed system aims to satisfy the Grid Voltage demand, manage the power flow from different sources, inject the surplus power into the grid, and charge the battery from the grid as and when required. The MPPT technique helps to trim down the hardware setup by means of only one voltage sensor, while increases the array power efficiency and MPPT response time. The simulation results are provided to validate the MPPT algorithm operation as well as the climatic parameters estimation capabilities. An ANFIS based boost DC to DC converter is used to harness power from Solar. The proposed converter architecture has reduced number of power conversion stages with less component count and reduced losses compared with existing grid connected PV systems. This improves the efficiency and the reliability of the system. Simulation results obtained using MATLAB/Simulink show the performance of the proposed ANFIS control strategy for power flow management under various modes of operation.

**Key words:** Grid Connected PV system, MPPT, ANFIS, Wavelet Algorithm .

## I. INTRODUCTION

Rapid depletion of fossil fuel reserves, ever increasing energy demand and concerns over climate change motivate power generation from renewable energy sources. Solar photovoltaic (PV) and wind have emerged as popular energy sources due to their ecofriendly nature and cost effectiveness. However, these sources are intermittent in nature. Hence, it is a challenge to supply stable and continuous power using these sources. This can be addressed by efficiently integrating with energy storage elements. However, they suffer from a relatively low conversion efficiency, which makes their optimization necessary. This is done by extracting their maximum power for fluctuating climatic environments. Well-known “maximum power point tracking (MPPT)” is done through a particular control of a converter. Various techniques have been proposed depending on their complexity, sensors used, convergence, setup, and in further aspects [2]–[8], [22]–[25].

The most common methods are the perturb and observe (P&O), and the incremental conductance (InCond). The first method is popular due to its hardware simplicity. It functions by creating a perturbation in the voltage, which results in variation in the array power [3], [20]. However, the system oscillates around the MP points, which wastes energy while it cannot distinguish between the radiation variation and the tracker’s perturbation. Many solutions are presented based on an adaptive step size or optimization functions [3]–[5], [9], [21], [26]. The second InCond method has a great accuracy with good flexibility to rapidly varying climatic conditions [24]. Therefore, it is possible to recognize when the MPP is achieved within a given accuracy [7], [22] by computing the instantaneous and InConds and verifying if they are identical.

However, it involves an increased hardware and software complexity. Many improvements are proposed using variable and modified step size algorithms [8], [22]–[24]. A sliding mode control has been used to improve tracking accuracy [11] and InCond using reference voltage and direct duty ratio perturbation [12]. Finally, a model-based (MB) control is used [13]. Nowadays, intelligent systems are progressively used due to their human-like capability and ability to adapt and improve their performance [14], [19], [26], [27]. Many neural networks (NN)- and fuzzy logic (FL)-based techniques are proposed. An artificial NN algorithm is developed with climatic conditions as inputs and applied to a boost tracker [28]. Using FL theory, a feed-forward MPPT scheme, a fuzzy controller, and an adaptive P&O-FL control method are proposed [9], [15], [16], [30].

This paper provides an efficient Grid connected PV MPPT method with reduced components. It computes the instantaneous and junction array conductances. The first one is done using the array current and voltage, whereas the second one uses the array junction current, which is estimated using ANFIS cell model presented in a recent paper of the authors [17]. Still, it requires information on the climatic parameters. Hence, it is proposed ANFIS control as an analytical model with a denoising based wavelet algorithm to estimate them, which helps reducing the hardware using only one voltage sensor. The simulation results are provided to validate the proposed ANFIS - PV based MPPT scheme capabilities. This paper is organized as follows: Section II provides an overview of Modelling of PV system. The proposed three phase PV system is developed and explained in Section III. Section IV shows in detail the estimation of environmental parameters. The simulation results based on MATLAB are presented in Section V and Section VII gives a conclusion.

## II. PROPOSED PV ARRAY MODEL

The schematic diagram of a three-phase grid-connected PV system which is main focus of this paper is shown in Fig. 1. The considered PV system consists of a PV array, a DC link capacitor C, a three-phase inverter, a filter inductor L and connected to the grid with voltage  $e_a$ ,  $e_b$ ,  $e_c$ . In this paper, the main target is to control the voltage  $v_{dc}$  across the capacitor C and to make the input current in phase with grid voltage for unity power factor by means of appropriate control signals through the switches of the inverter. The mathematical model of the system is presented in the next subsections. A. PV Cell and Array Modeling PV cell is a simple p-n junction diode which converts the irradiation into electricity. Fig. 2 shows an equivalent circuit diagram of a PV cell which consists of a light generated current source  $I_L$ , a parallel diode, shunt resistance  $R_{sh}$  and series resistance  $R_s$ . In Fig. 2,  $I_{ON}$  is the diode current which can be written as:

$$I_{ON} = I_s [\exp[\alpha(V_{pv} + R_s i_{pv})] - 1] \tag{1}$$

$$\text{where } \alpha = \frac{q}{kATc}, K = 1.3807 * 10^{-23} JK^{-1}$$

is the Boltzmann's constant,  $q = 1.6022 \times 10^{-19} C$  is the charge of electron,  $TC$  is the cell's absolute working temperature in Kelvin,  $A$  is the p-n junction ideality factor whose value is between 1 and 5,  $I_s$  is the saturation current, and  $v_{pv}$  is the output voltage of PV array which in this case is the voltage across  $C$ , i.e., vdc. Now, by applying Kirchoff's Current Law (KCL) in Fig. 1, the output current ( $i_{pv}$ ) generated by PV cell can be written as,

$$i_{pv} = I_L - I_s I_s [\exp[\alpha(V_{pv} + R_s i_{pv})] - 1] - \frac{v_{pv} + R_s i_{pv}}{R_{sh}} \tag{2}$$

The light generated current  $I_L$  depends on the solar irradiation which can be related by the following equation:

$$I_L = [I_{sc} + K_i(T_c - T_{ref})] \frac{s}{1000} \tag{3}$$

Where,  $I_{sc}$  is the short circuit current,  $s$  is the solar irradiation,  $k_i$  is the cell's short circuit current coefficient and  $T_{ref}$  is the reference temperature of the cell. The cell's saturation current  $I_s$  varies with the temperature according to the following equation [19]:

$$I_s = I_{RS} \left[ \frac{T_c}{T_{ref}} \right]^3 \exp \left[ \frac{qE_g}{Ak} \left( \frac{1}{T_{ref}} - \frac{1}{T_c} \right) \right] \tag{4}$$

where,  $E_g$  is the band-gap energy of the semiconductor used in the cell and  $I_{RS}$  is the reverse saturation current of the cell at reference temperature and solar irradiation. Since the output voltage of PV cell is very low, a number of PV cells are connected together in series in order to obtain higher voltages. A number of PV cells are put together and encapsulated with glass, plastic, and other transparent materials to protect from harsh environment, to form a PV module. To obtain the required voltage and power, a number of modules are connected in parallel to form a PV array. Fig. 3 shows an electrical equivalent circuit diagram of a PV array.

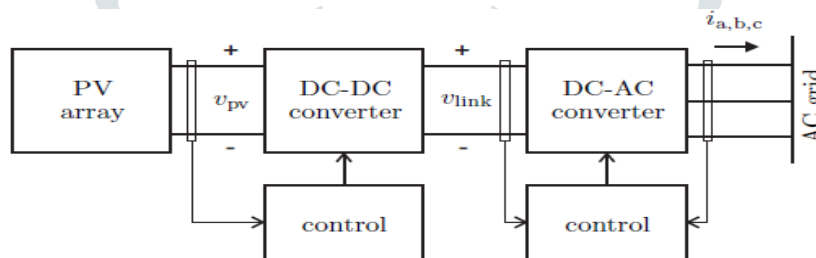


Fig. 1. Block diagram of the PV system.

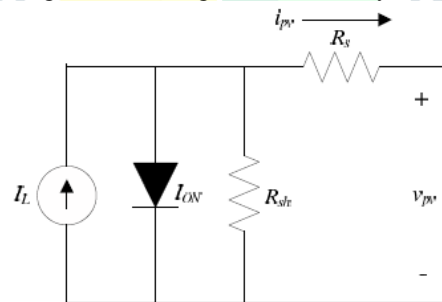


Fig. 2. Equivalent circuit diagram of PV cell.

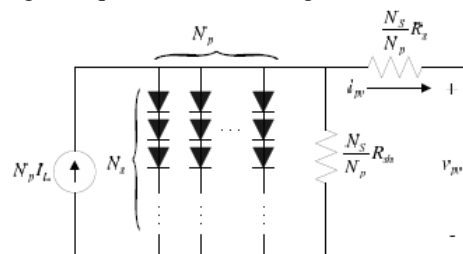


Fig. 3. Equivalent circuit diagram of PV array.

Where  $N_s$  are the number of cells in series and  $N_p$  is the number of modules in parallel. In this case, the the array  $i_{pv}$  can be written as

$$i_{pv} = N_p I_L - N_p I_s \left[ \exp \left[ \alpha \left( \frac{v_{pv}}{N_s} - \frac{R_s i_{pv}}{N_p} \right) \right] - 1 \right] - \frac{N_p}{R_{sh}} \left( \frac{v_{pv}}{N_s} - \frac{R_s i_{pv}}{N_p} \right) \tag{5}$$

### III. PROPOSED MPPT USING ANFIS

The proposed Matlab/Simulink model of ANFIS based maximum power point tracking controller is depicted in Fig. 4. Irradiance level and operating temperature of PV module are taken as the input training data set for the ANFIS. The ANFIS reference model gives out the crisp value of maximum available power from the PV module at a specific temperature and irradiance level. At the same temperature and irradiance

level, the actual output power from the PV module, is calculated using the multiplication growth of sensed operating voltage and current. Two powers are compared and the error is given to a proportional integral (PI) controller, to generate control signals.

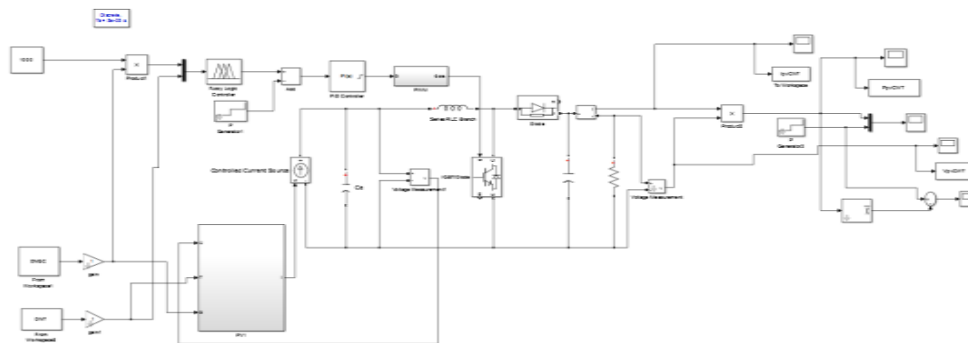


Fig. 4. Matlab/Simulink model of ANFIS based MPPT controller.

The control signal generated by the PI controller is given to the PWM generator. The PWM signal is generated using high frequency of carrier signal as compared to the control or modulating signal. The frequency of carrier signal used is 50kHz. The generated PWM signals control the duty cycle of DC-DC converter, in order to adjust the operating point of the PV module.

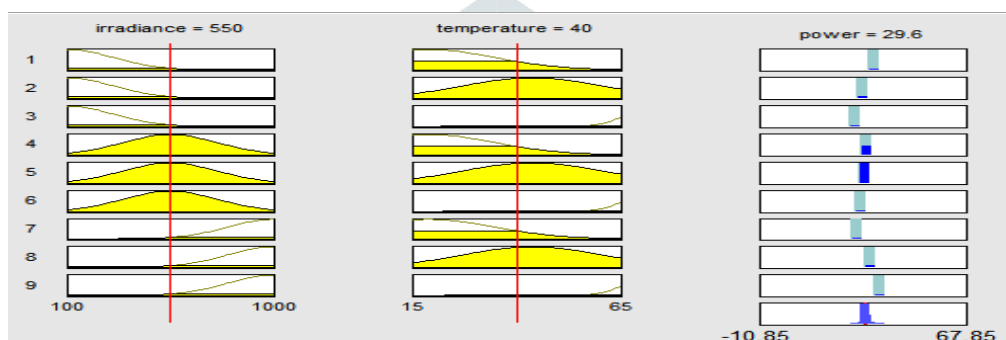


Fig. 5. Output from fuzzy rules for specific value of temperature and irradiance.

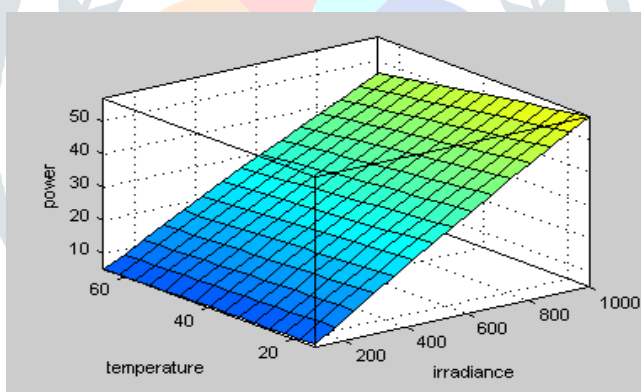


Fig. 6. Surface between two inputs (temperature and irradiance) and one output (maximum power).

Tuning of ANFIS Using the Matlab/Simulink model of PV module, the operating temperature is varied from 15 °C to 65 °C in a step of 5 °C and the solar irradiance level is varied from 100 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> in a step of 50 W/m<sup>2</sup>, to get the training data sets for ANFIS. Maximum available power for each pair of training data is recorded. In total 209 training datasets and 2000 epochs are used to train the ANFIS. By using given input/output dataset, the ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned using the hybrid optimization method of training the FIS. The hybrid optimization method is a combination of the least-squares type of method and the back propagation algorithm. It depicts that the ANFIS output closely matches to the actual output of module even at 6% of training error. It has two inputs (irradiance level and operating temperature), one output and three membership functions for each input. Nine fuzzy rules are derived from six input membership functions. These rules are derived according to the input and output mapping, so as to produce maximum output power for each value of input temperature and irradiance level. The ANFIS generated surface is shown in Fig. 6. It is a 3-dimensional plot between temperatures, irradiance and maximum power.

#### IV. PROPOSED GRID CONNECTED PV SYSTEM

The aim of this paper is to describe the modeling and control design of a three-phase grid-connected converter for photovoltaic (PV) applications. The converter has two stages: an isolated DC to DC Converter (Boost) and a three-phase DC-AC inverter with output current control. The converters are modeled in order to obtain small-signal transfer functions that are used in the design of linear closed-loop controllers based on proportional and integral (PI) compensators. Fig. 2 shows the blocks that constitute the system studied in this paper. The PV array feeds the DC-DC converter, which in turn feeds the three-phase DC-AC inverter. Three controllers are used in the system. The control block of the DC-DC converter contains the controller of the input voltage  $V_{pv}$  of the converter, which is the output voltage of the PV array. The DC to AC control block contains the controller of the DC link capacitor (the capacitor that connects the DC-DC and DC-AC converters) voltage  $V_{link}$  and another for the sinusoidal three-phase output currents  $I_{a,b,c}$ .

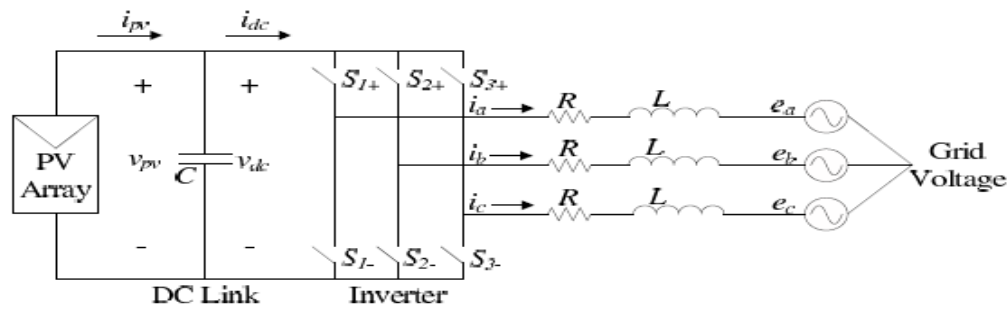


Fig. 7. Three phase grid connected PV system.

The Proposed control system developed to operate a grid connected PV system. First, the structure of the system and its control blocks are introduced. An overview of the sinusoidal PWM technique is presented for their importance in building the inverter control system. The boost DC converter is controlled using an closed loop ANFIS based maximum power point tracking technique in order to achieve fast control response to transients and changes in weather conditions. The control system is assessed based on: the quality of the injected AC current into the grid, as determined by the Total Harmonic Current Distortion (THDI) limits specified by the IEEE Std. 929-2000; and the speed of the control system in tracking the maximum power point as weather conditions, mainly solar irradiation, change. The system was studied under grid code conditions to examine the effect of the transformer less topology selection on the propagation of zero sequence currents to the grid. These currents can intervene with the correct operation of the utility protection relays.

**V. MATLAB SIMULATION RESULTS**

To simulate the performance of the grid connected PV system with Advanced ANFIS controller, a PV array characterized by a rated current of 2.8735. Thus, the total output voltage of the PV array is 30V to 40 V and output current is 1.2A to 6A. The value of DC link capacitor is 400 μF. The line resistance is considered as 0.1 and the inductance is 10 mH. The grid voltage is 440V and frequency is 50 Hz.

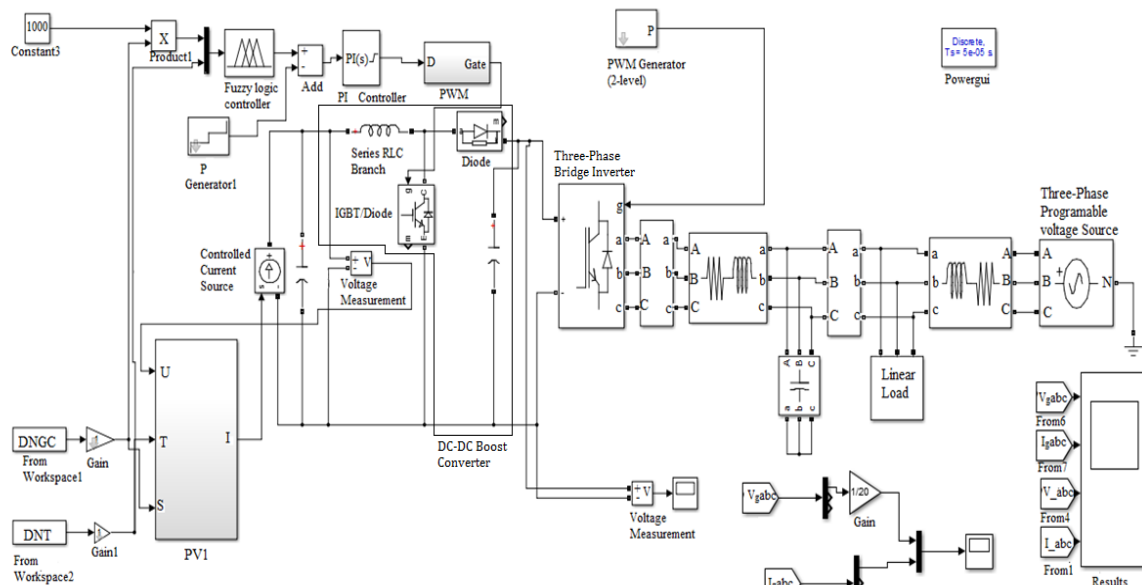


Fig. 8. Completed Matlab/Simulink Model of the Proposed ANFIS based Grid Connected PV Systems.

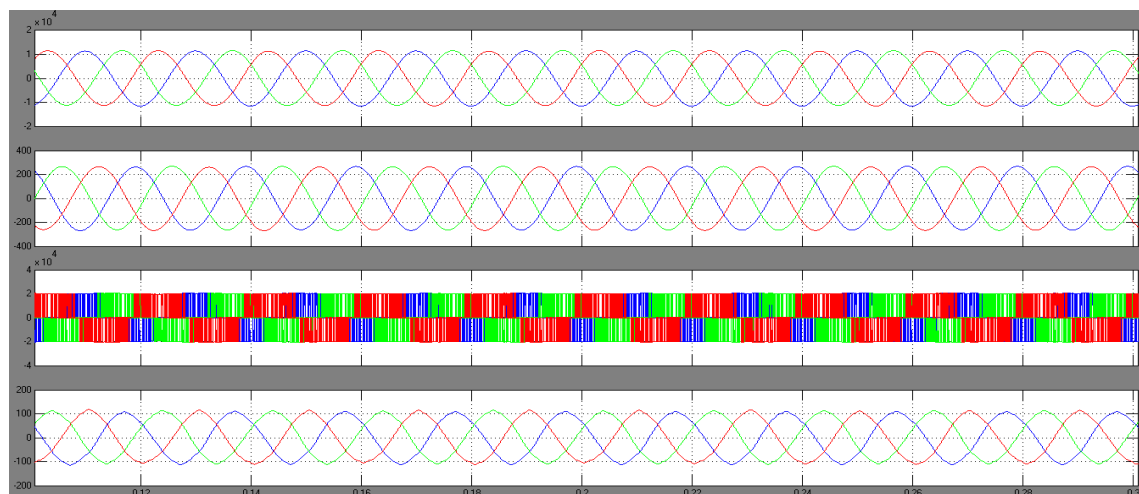


Fig. 9. Three phase waveform of the proposed grid connected PV systems i.e., Grid voltage, Currents & Output Voltage, Currents of the Inverter.

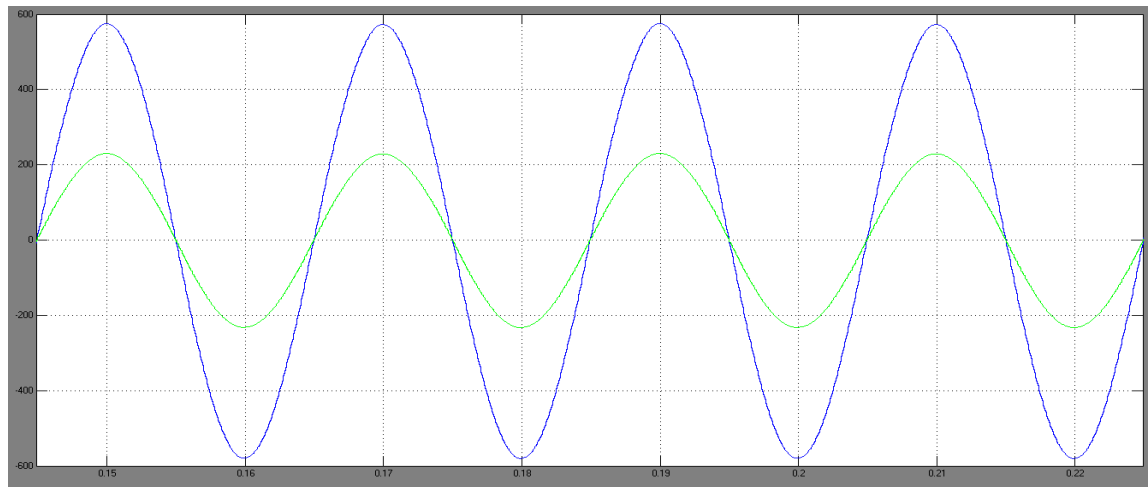


Fig. 10. Grid Voltage & Currents of the phase A.

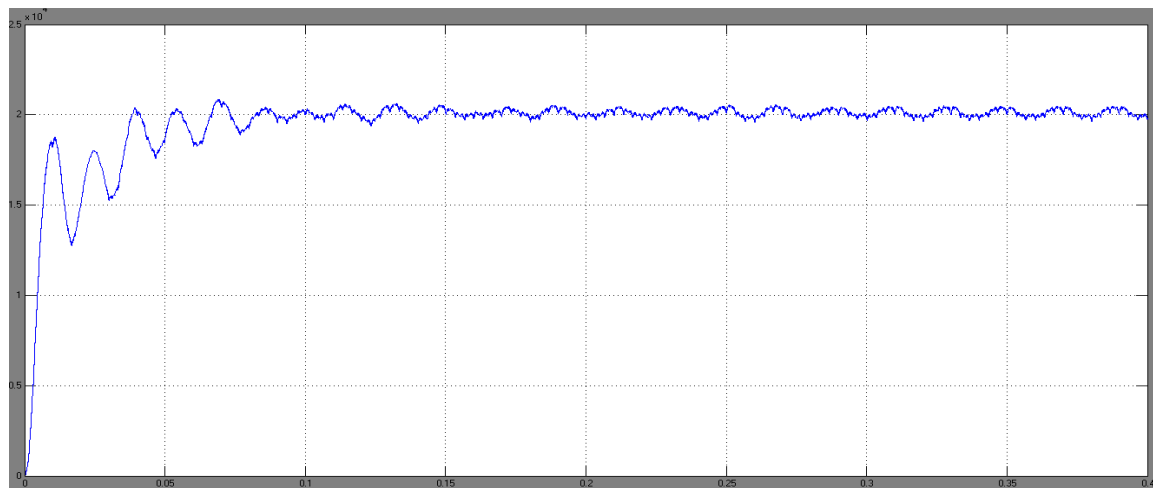


Fig. 11. Dc link Voltage of the proposed ANFIS PV model.

The block diagram representation of the zero dynamic design approach is shown in Fig. 8. From Fig. 9 it is shown that the three phase grid voltages and currents are transformed into the control inputs are again transformed into grid requirements. To make the input signals suitable for switches a PWM is used. All the simulations are done in the widely used MATLAB/SIMULINK environment.

In this case, the system is simulated at different atmospheric condition where the value of solar irradiation is considered as 0.25 kWm<sup>-2</sup>, 0.5 kWm<sup>-2</sup>, 0.75 kWm<sup>-2</sup>, 1 kWm<sup>-2</sup> and the temperature as 30 degrees. At this condition, the output power of PV unit which is shown in Fig. 9 where there is some fluctuation due to the nonlinear characteristics of PV system. The main purpose of the Proposed ANFIS control action is to extract maximum power from the PV unit through MPPT and supply this power to the grid. This can be done by regulating the inverter switches through the proper control scheme when the system is operated at unity power factor. Therefore, to evaluate the performance of the controller, it is essential to analyze the grid voltage and current. The grid voltage and current are shown in Fig. 10 with the proposed control scheme. From Fig. 11, it is seen that the voltage and current are in phase which ensure the operation of grid connected PV system at unity power factor.

S.NO	Grid Connected with Different DER's	Before LC Filter I <sub>gabc</sub> (%)	After LC Filter I <sub>gabc</sub> (%)
1.	Constant DC source	2.14	0.41
2.	ANFIS based PV array without Wavelet	4.79	0.76
3.	ANFIS based PV array with Wavelet	3.90	0.66

**CONCLUSIONS**

In this paper a three phase inverter for photovoltaic applications has been presented and controlled by proposed ANFIS based MPPT technique. The main feature of the presented system is it does not require an intermediate stage of DC to DC control, as the maximum power is set by the inverter itself by means of an ANFIS with Wavelet algorithm. The controller objectives are threefold: i) ensuring the MPPT in the side of PV generator; ii) guaranteeing a power factor unit in the side of the grid, iii) ensuring the global asymptotic stability of the closed loop system. Using both formal analysis and simulation, it has been proven that the obtained controller meets all the grid code requirements.

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