

## ANFIS Controller Based MPPT Control of Photovoltaic Generation System

T. Shanthi and A.S. Vanmukhil  
Department of Electrical and Electronics Engineering,  
Kumaraguru College of Technology, Tamil Nadu, India

**Abstract:** This study proposes an artificial-intelligence-based solution to interface Photovoltaic (PV) array with the three phase ac load and to deliver maximum power to the load. The maximum power delivery to the load is achieved by MPPT controller which employs Adaptive Neuro-Fuzzy Inference System (ANFIS). The proposed ANFIS-based MPPT offers an extremely fast dynamic response with great accuracy. The system consists of photovoltaic module, boost converter, Voltage Source Inverter (VSI) and ANFIS controller to control the duty cycle of boost converter switch as well as the modulation index of VSI. The entire proposed system has been modeled and simulated using MATLAB/SIMULINK Software. The simulation results show that the proposed ANFIS MPPT controller is very efficient, very simple and low cost.

**Key words:** MPPT, ANFIS, boost converter, VSI, Photovoltaic System

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### INTRODUCTION

Photovoltaic (PV) generation is becoming increasingly important as a renewable source. To overcome the incredible power crisis in the country, the best way is to make use of renewable energy sources such as solar and wind. It is inexhaustible and non-polluting. It has the advantages of low running and maintenance cost and also noiseless operation. The voltage power characteristic of a Photovoltaic (PV) array is non-linear and time varying because of the changes caused by the atmospheric conditions. As the Photovoltaic (PV) cell exhibits nonlinear behavior while interfacing the ac load to photovoltaic modules DC-DC converters and inverters are needed. The proposed scheme uses a boost dc/dc converter to boost the wide range of voltage to a constant desired value. When the solar radiation and temperature varies the output power of the PV module is also getting changed. But to get the maximum efficiency of the PV module it must be operated at maximum point. Therefore, it is necessary to operate the PV module at its maximum power point for all irradiance and temperature conditions. To obtain maximum power from photovoltaic array, Photovoltaic Power System usually requires Maximum Power Point Tracking controller (MPPT).

Though it is relatively simple to implement, it cannot track the MPP when the irradiance changes rapidly and it oscillates around the MPP instead of tracking it. The

incremental conductance method can track MPP rapidly but increases the complexity of the algorithm which employs the calculation of  $dI/dV$ . The constant voltage method which uses 76% open circuit voltage as the MPP voltage and the short-circuit current method are simple but they do not always accurately track MPPs.

Artificial Intelligence (AI) based methods are increasingly used in renewable energy systems due to the flexible nature of the control offered by such techniques. The AI techniques are highly successful in non-linear systems due to the fact that once properly trained they can interpolate and extrapolate the random data with high accuracy.

The presented technique utilizes the weather information as the input to ANFIS. The neural network is a powerful technique for mapping the input output non linear function; however, it lacks the heuristic sense and it works as a black box. On the other hand fuzzy logic (Chen and Pham, 2000) has the capability of transforming heuristic and linguistic terms into numerical values through fuzzy rules and membership functions. It also provides the heuristic output by quantifying the actual numerical data into heuristic and linguistic terms. The shortcoming of fuzzy computation is obtaining fuzzy rules and functions which heavily rely on the prior knowledge of the system. The ANFIS integrates the neural network and fuzzy logic.

This study thus uses ANFIS techniques to determine the maximum power of a PV module for variable solar irradiance and temperature condition.

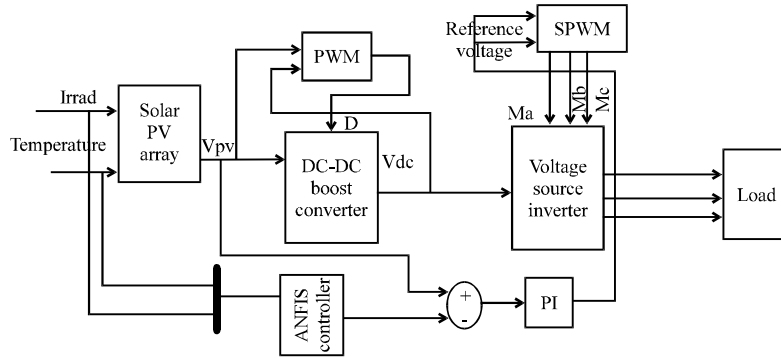


Fig. 1: Block diagram of proposed PV system. D = Duty cycle; Vpv = Voltage of the PV array; M = Modulation index; Vdc = Output voltage of boost converter

**MATERIALS AND METHODS**

Figure 1 illustrates the block diagram of the proposed system. MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the three phase ac load. A DC-DC converter (Walker and Senia, 2004; Quan and Wolfs, 2008) and VSI acts as an interface between the load and the PV module.

Maximum Power Point Tracker (MPPT) used in the proposed system (Yang *et al.*, 2010) tracks the new modified maximum power point in its corresponding curve whenever temperature and/or insolation variation occurs. The MPPT is used to adjust the duty cycle of boost converter and to adjust the modulation index of the VSI (Ho and Cheng, 2005) in order to maintain the power extracted from the solar PV module at maximum point. For a DC-DC boost converter, the input-output voltage:

$$V_0/V_{in} = \frac{1}{1-D}$$

where, D is duty cycle. Since, the duty ratio “D” is between 0 and 1 the output voltage V0 must be higher than the input voltage Vin in magnitude.

The duty ratio is found to increase linearly with increase in cell temperature. When a PV array is connected to a boost converter, increasing the duty cycle increases the average PV array current and as a result, PV array voltage decreases. Thus, an increase in duty cycle result in shifting the operating point to the left on the V-I characteristics of the PV array. Similarly, decreasing the duty cycle decreases the average PV array current and as the PV array voltage increases resulting in shift of operating point to the right. An ANFIS controller is incorporated to automatically vary the duty cycle of the DC-DC converter to obtain constant DC voltage. At constant temperature, the change of solar irradiation will

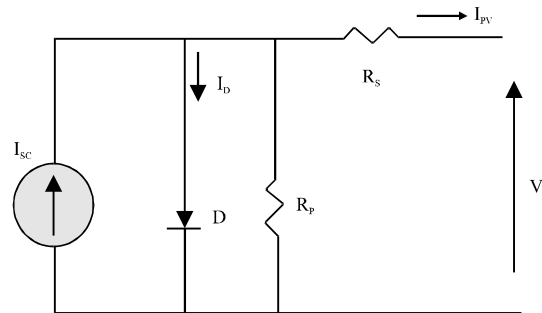


Fig. 2: Solar cell model using single diode with  $R_s$  and  $R_f$

result in a great change of PV current at the Maximum Power Point (MPP) when compared to the resultant change of PV voltage. The MPPT control could ensure a stable. peak dc-link voltage with little variation at a constant temperature. On the other hand, the change of temperature will result in a great change of PV voltage at the MPP when compared to the resultant change of PV current which will make the peak dc-link voltage change greatly.

**Model of a PV array:** A PV cell can be represented by equivalent circuit shown in Fig. 2. The characteristics of this PV cell can be obtained using standard equation.

This cell model includes a current source which depends on solar radiation and cell temperature, a diode in which the inverse saturation current  $I_0$  depends mainly on the operating temperature, a series resistance  $R_s$  and the shunt resistance  $R_p$  which takes into account the resistive losses:

$$I_{pv} = N_p I_{sc} - N_{slo} \left\{ \exp \left( \frac{q(V_{pv} + I_{pv} R_s)}{N_s A K T} \right) - 1 \right\} - V_{pv} + \left( \frac{I_{pv} R_s}{R_p} \right) \tag{1}$$

Where:

- $I_{pv}$  = Photovoltaic current
- $I_0$  = Saturation current
- $N_s$  = No. of cells connected in series
- $N_p$  = No. of cells connected in parallel
- $T$  = Temperature of p-n junction
- $K$  = Boltzmann constant
- $q$  = Electron charge
- $R_s$  = Equivalent series resistance of the array
- $R_p$  = Equivalent parallel resistance of the array
- $A$  = Diode ideality factor

The non-linear equation depends on the incident solar irradiation, the cell temperature and on the reference values. These reference values are generally provided by manufacturers of PV modules for specified operating conditions such as STC for which the irradiance is  $1000 \text{ W/m}^2$  and the cell temperature is  $25^\circ\text{C}$ . Real operating conditions are always different from the standard and mismatch effects can also affect the real values of these parameters (Table 1).

The use of the simplified circuit model for this research makes it suitable for power electronics designers to have an easy and effective model for the simulation of photovoltaic devices (Daniel and Ammasaigounden, 2004) with power converters. The value of the parallel resistance is generally high and hence neglected to simplify the model.

**ANFIS for MPPT tracking:** To validate the proposed control scheme, the simulated model is developed in Matlab/Simulink for the whole system. The PV cell temperature varies from  $10\text{-}70^\circ\text{C}$  in a step of  $6^\circ\text{C}$  and the solar irradiance varies from  $50\text{-}1000 \text{ W/m}^2$  in a step of  $50 \text{ W/m}^2$ . By varying these two environmental factors a set of data is generated in simulation. About 100 sets of obtained data are then used to train the ANFIS network (Abu-Rub *et al.*, 2013) for the purpose of MPPT. The training is done offline using Matlab tool box. The network is trained for 30,000 epochs.

The target error is set to 3.4% and the training waveform is depicted in Fig. 3. The overall neuro-fuzzy structure shown in Fig. 4 is a 5 layers network. The structure shows two inputs of the solar irradiance and the cell temperature which is translated into appropriate membership functions, three functions for the solar irradiance in Fig. 5 and three functions for temperature in Fig. 6.

These membership functions are generated by the ANFIS controller based on the prior knowledge obtained from the training data set. The membership function's

Table 1: PV module specifications

Parameters	Variable	Value
Maximum power	$P_m$	60 W
Maximum voltage	$V_m$	17.1 V
Current at max power	$I_m$	3.5 A
Open circuit voltage	$V_{oc}$	21.06 V
Short circuit current	$I_{sc}$	3.74 A
No. of cells in series and parallel	$N_s, N_p$	36.1

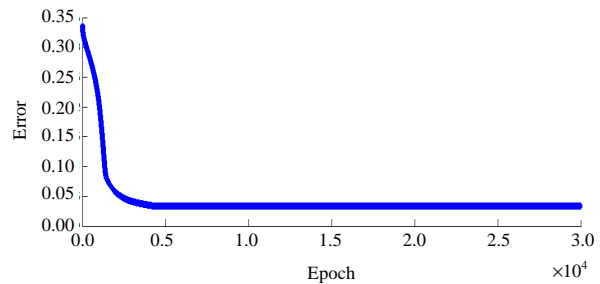


Fig. 3: Training error versus epochs for the ANFIS

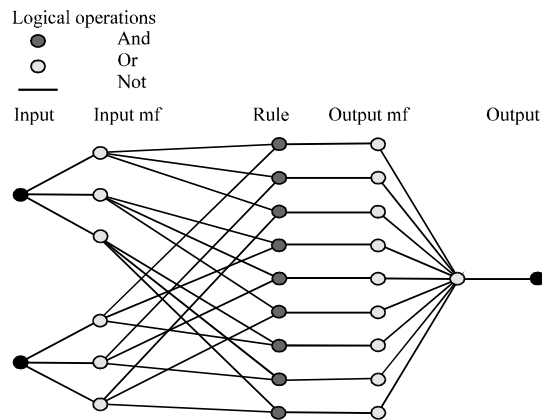


Fig. 4: ANFIS-based MPPT structure

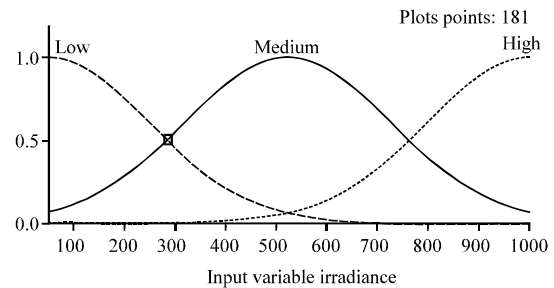


Fig. 5: Membership function of solar irradiance

shape varies during the training stage and the final shape obtained after the completion of the training is shown in Fig. 5 and 6.

They are termed as low, medium and high. The rule depicts the relationship and mapping between the output and input membership function. One particular

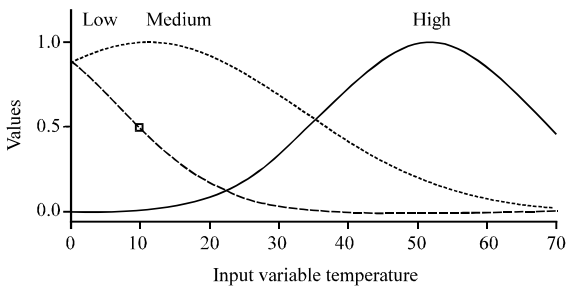


Fig. 6: Membership function of PV cell temperature

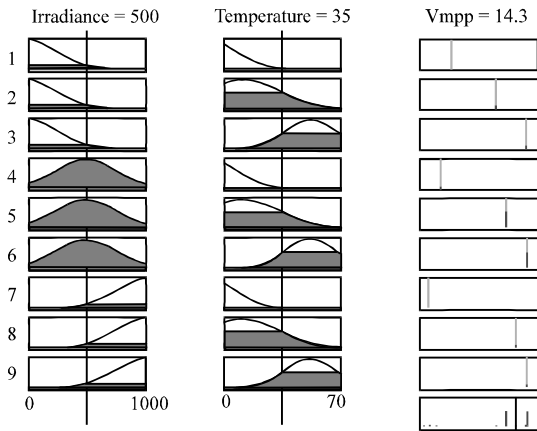


Fig. 7: Rule base of ANFIS controller

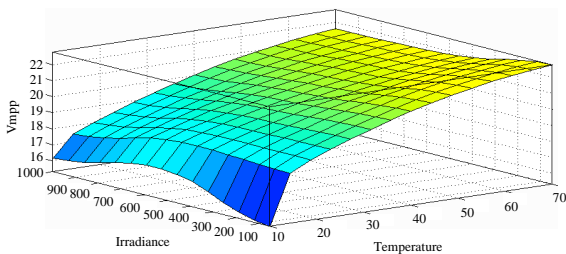


Fig. 8: Surface view created by ANFIS

situation is shown in Fig. 7 when the temperature is at 35°C and the solar irradiance is 500 W/m<sup>2</sup>. By varying the slider on the figure all the conditions can be accessed. It can be seen that the temperature varies from 10-70°C. The solar irradiation varies from 50-1000 W/m<sup>2</sup> and correspondingly the maximum power point voltage varies in the last column.

There are nine rules that can follow the conditions more filled cells means high values and the blank or less filled cells mean low values. Example Rule8 can be read as if temperature input is low and the solar irradiation is medium then the maximum power point voltage is 14.3 V shown in Fig. 7.

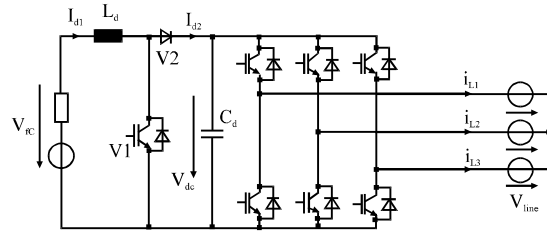


Fig. 9: Circuit diagram of VSI

The rulers (vertical red line) shown in the temperature and irradiance can be moved to check the rules for other operating conditions. The variation of the MPP voltage (Vmpp) with the changes of PV cell temperature and solar irradiance is shown in Fig. 7. The surface shown in Fig. 8 depicts the typical behavior.

The proposed ANFIS based MPPT is more stable and faster than the conventional MPPT algorithms (De Medeiros *et al.*, 1998; Ansari *et al.*, 2010; Aldobhani and John, 2008).

**Voltage source inverter:** The voltage source inverter shown in Fig. 9 converts the boosted dc voltage to ac which is to be fed to the ac load. The three phase inverter is a six step inverter. It uses a minimum of six thyristors or MOSFETs or IGBTs. In inverter terminology, a step is defined as a change in the firing from one device (IGBT) to the next device in proper sequence. For one cycle of 360° each step would be 60° intervals for a six-step inverter. This means the devices would be gated at regular intervals of 60° in proper sequence so that a 3-phase ac voltage is synthesised at the output terminals of a six step inverter.

**Simulation circuits:** Figure 10 shows the overall simulation diagram of the proposed system.

**PV array modeling:** The PV array shown in Fig. 11 is modeled using Eq. 1.

## RESULTS AND DISCUSSION

From the Fig. 12 and 13 it is observed that by increasing the temperature level at constant irradiance, the voltage output from PV array decreases but current output increases slightly with respect to voltage and hence the power output from PV array decreases (Xiao *et al.*, 2004; Hussein *et al.*, 1995).

Figure 14 and 15 shows that by increasing the solar radiation at constant temperature the voltage and current

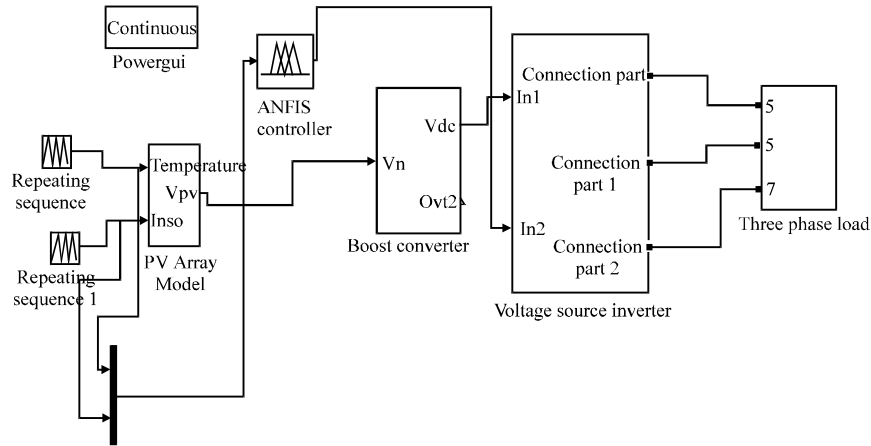


Fig. 10: Simulation Model of the proposed system

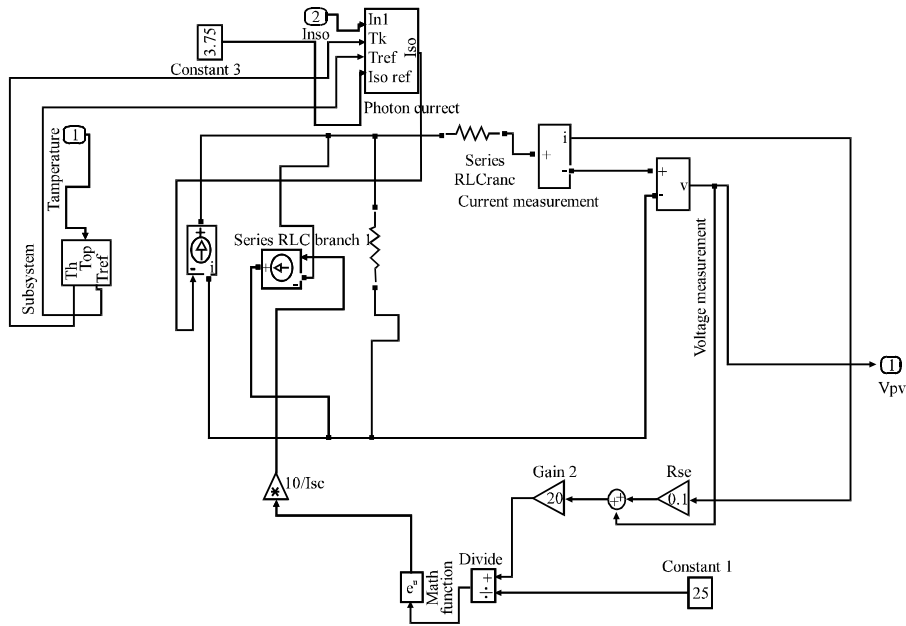


Fig. 11: PV Array Model

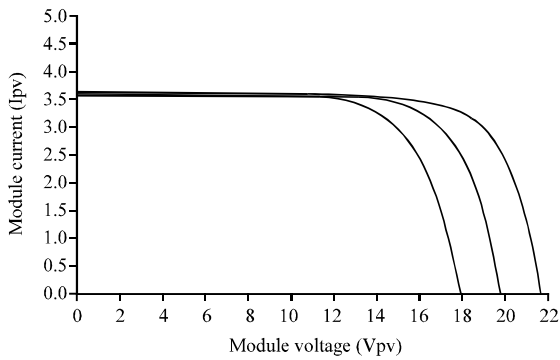


Fig. 12: I-V characteristic for varying temperature and constant irradiation

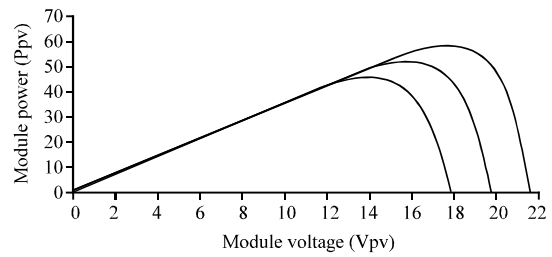


Fig. 13: P-V characteristic for constant irradiance varying temperature

output from PV array also increases. Hence, at higher insolation, researchers can get the required voltage level.

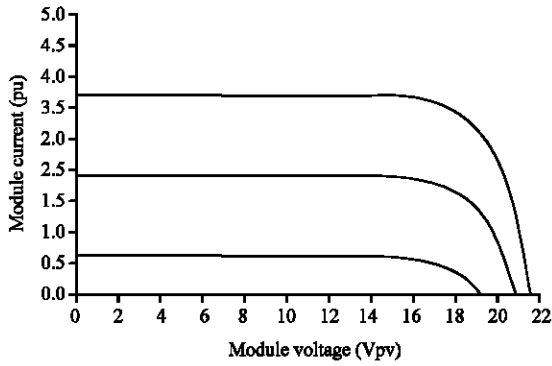


Fig. 14: I-V characteristic for varying irradiance constant temperature

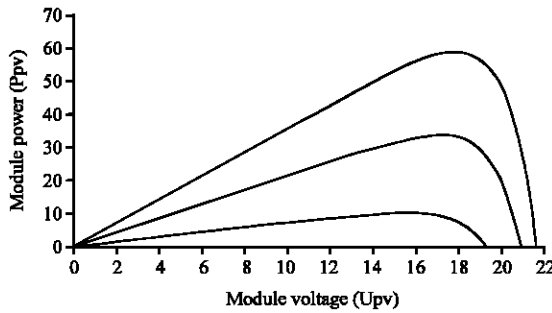


Fig. 15: P-V characteristic for varying irradiance constant temperature

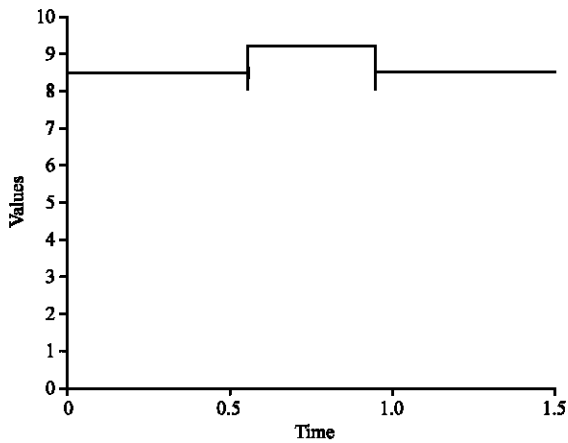


Fig. 16: ANFIS output voltage

Figure 16 shows that the PV output voltage obtained using ANFIS is stable and this technique is faster compared to conventional MPPT algorithms. Figure 17 shows the variation of solar irradiation and temperature during the simulation time.

The gating signals shown in Fig. 18 is given to the switch of the boost converter. The boost converter

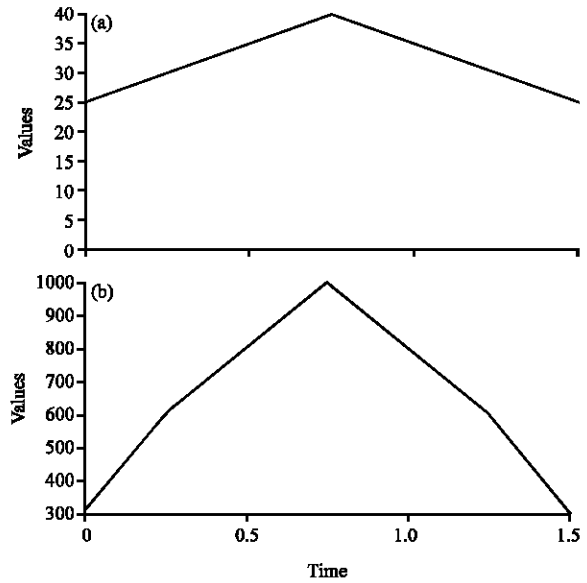


Fig. 17: Curves for varying temperature and solar irradiation

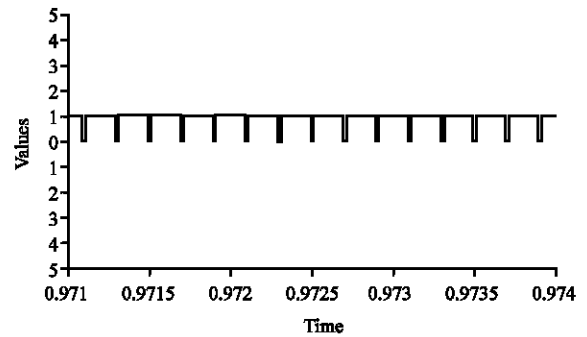


Fig. 18: Gating signals to the switch of boost converter

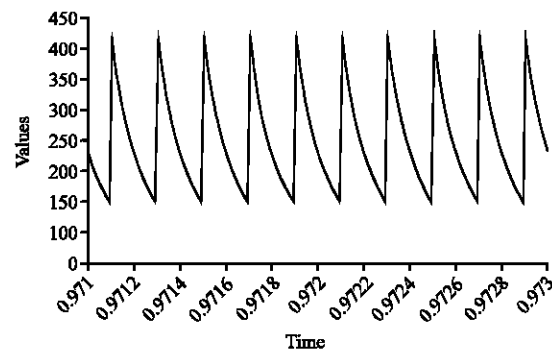


Fig. 19: Boost converter output voltage

boosts the voltage of PV array from 22 to nearly 415 V (Fig. 19 and 20). The boosted voltage is given to the VSI Fig. 21 shows the output voltage without using filter. Figure 22 shows the output voltage of the PV generation

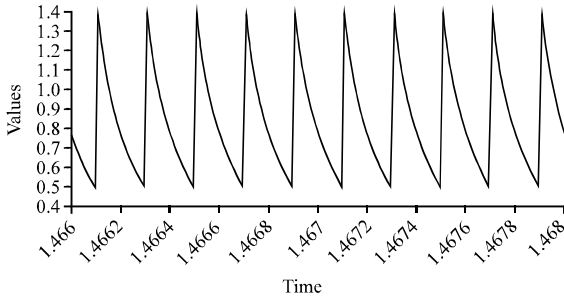


Fig. 20: Boost converter output current

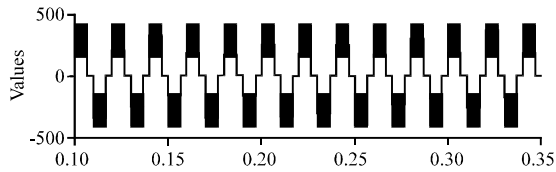


Fig. 21: Output voltage of VSI

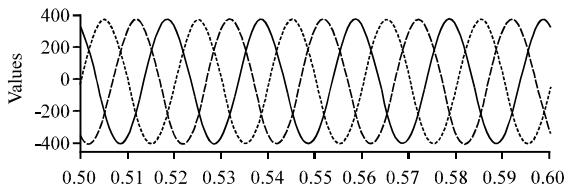


Fig. 22: Output voltage with filter

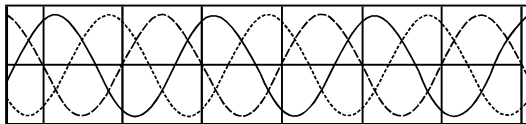


Fig. 23: Output power

system with filter Fig. 23 shows that the ANFIS controller delivers a maximum power of 4 kW to the three phase load.

### CONCLUSION

This study has suggested a PV generation system to interface the solar power to the three phase ac load using ANFIS MPPT controller. The ANFIS controller has been implemented using MATLAB/SIMULINK Software. The interface stage between the generation source and the load is accomplished by a boost converter and a voltage source inverter. The boost converter boosts the output voltage from the PV array of 22 V to about 415 V. The boosted voltage is given to the inverter and then to the three phase load. The maximum power point tracking (Kottas *et al.*, 2006; Hiyama and Kitabayashi, 1997),

voltage boost and inversion are achieved using the proposed system. The simulation has been carried out in MATLAB/SIMULINK environment and the results have been produced.

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