

ANFIS Controller based MPPT Control of Photovoltaic Generation System

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ABSTRACT

This paper 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.

Keywords

MPPT, ANFIS, Boost Converter, VSI, Photovoltaic system

1. 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 nonlinear and time varying because of the changes caused by the atmospheric conditions [1][2]. 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. so 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).

An interface between the PV array and the three phase load is necessary. A power converter can be used as an interface. As the load is a three phase load, the voltage from the PV system must be boosted. The existing power converter topology uses a low frequency step up transformer to interface the low output voltage of the PV array. But it involves some losses. Hence, the proposed scheme uses a boost converter. The boosted voltage is inverted using a voltage source inverter. The existing controllers using fuzzy logic [3] or neural network does not provide maximum power without any prior knowledge and they work as a black box. The proposed system using ANFIS (Adaptive Neuro Fuzzy inference system), the most powerful artificial intelligence technique,

integrates the neural network and fuzzy logic to deliver the maximum available power from the PV system under different weather conditions [8][9].

The paper is organized as follows. The overall architecture of the ANFIS based MPPT system and the modeling of different components of the system is described in section 2 and section 3 respectively. The control strategies of the proposed system are explained in section 4 and the simulation results of the proposed system are included in section 5.

2. PROPOSED SCHEME

Fig.1. illustrates the overall block diagram of the proposed system. The proposed system consists of a PV array [1][2], ANFIS controller, Boost converter, VSI and three phase ac load. The PV power generating system produces different voltages for varying temperature and irradiance [5][6]. By varying temperature and irradiance two hundred sets of data are generated in simulation. These data are used to train ANFIS in offline using MATLAB toolbox for the purpose of Maximum Power Point Tracking (MPPT) [7]. The output voltage from the PV array is boosted using a boost converter. The boosted voltage is given to the voltage source inverter. The inverter feeds the power to the three phase ac load. The output voltage from the inverter is given to the LC filter to reduce the harmonic voltages in the load.

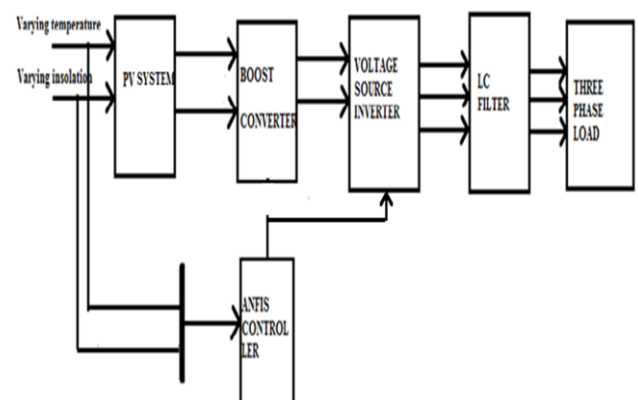


Fig 1: Overall block diagram of the proposed system

3. MODELING OF COMPONENTS OF THE PROPOSED SYSTEM

This section describes the modeling of the major components used in the hybrid system whose results are discussed in section V.

3.1 PV System Model

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 [1][2].

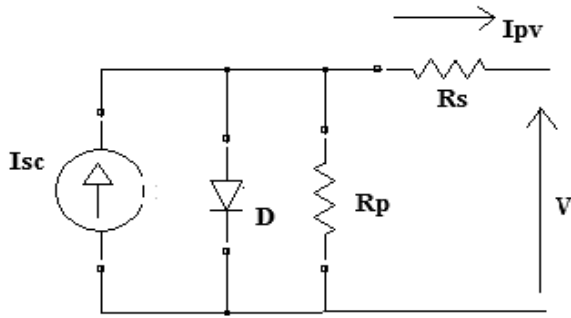


Fig 2: Solar cell model using single diode with Rs and Rp

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.

$$I_{pv} = N_p I_{sc} - N_s I_0 \left\{ \exp \left(\frac{q(V_{pv} + I_{pv} R_s)}{N_s A K T} \right) - 1 \right\} - \frac{V_{pv} + I_{pv} R_s}{R_p} \quad (1)$$

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 nonlinear equation depends on the incident solar irradiation, the cell temperature, and on the reference values [2]. These reference values are generally provided by manufacturers of PV modules for specified operating conditions such as STC for which the irradiance is 1000 W/m² and the cell temperature is 25 °C.

The value of the parallel resistance is generally high and hence neglected to simplify the model [3]. The rated power of the PV module is generally 60W. The simulated PV array is composed of 36 series cells and a single parallel cell which provides an output voltage of 17.1V and an output current of 3.5A.

Table 1. Specifications of PV module

Parameter name	Variable	Value
Maximum power	P_m	60W
Maximum voltage	V_m	17.1V
Current at max power	I_m	3.5A
Open circuit voltage	V_{oc}	21.06V
Short circuit current	I_{sc}	3.74A
No of cells in series and parallel	N_s, N_p	36, 1

3.2 ANFIS for MPPT Tracking

The PV cell temperature varies from 10° C to 70 °C in a step of 6 °C and the solar irradiance varies from 50 to 1000W/sq.m in a step of 50 W/sq.m. By varying these two environmental factors a set of data is generated in simulation. Hundred sets of obtained data are then used to train the ANFIS network [7] 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 which is a five-layer network [8]. The structures shows two inputs of the solar irradiance and the cell temperature, which is translated into appropriate membership functions, three functions for the solar irradiance and three functions for temperature. These membership functions are generated by the ANFIS controller based on the prior knowledge obtained from the training data set [9]. The membership function's shape varies during the training stage and the final shape obtained after the completion of the training is shown in Figs. 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 situation is shown in Fig.7 when the temperature is at 35°C and the solar irradiance is 500W/sq.m

By varying the slider on the figure all the conditions can be accessed .It can be seen that the temperature varies from 10°C to 70°C. The solar irradiation varies from 50 to 1000 W/sq.m and correspondingly the maximum power point voltage varies in the last column.

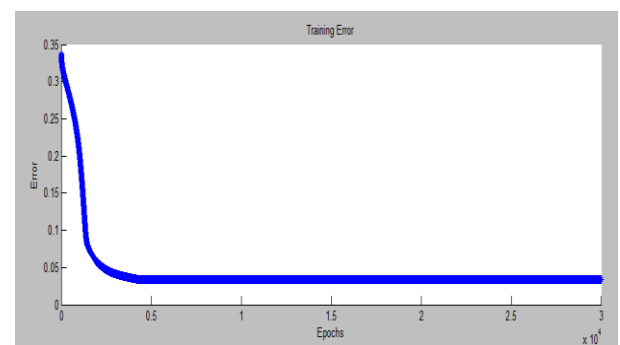


Fig 3: Training error versus epochs for the ANFIS

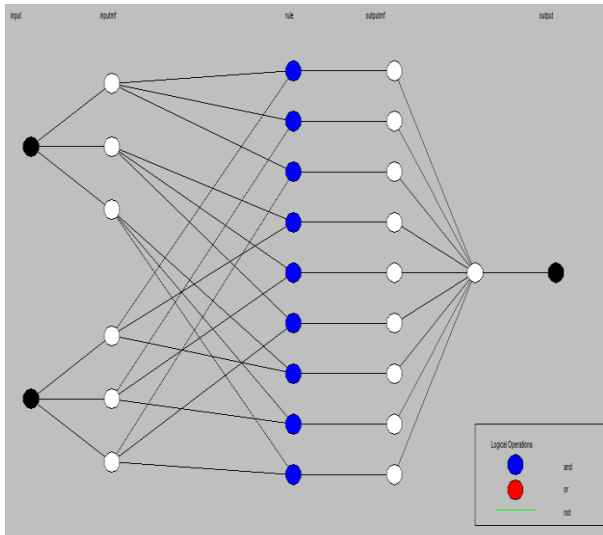


Fig 4: ANFIS-based MPPT structure

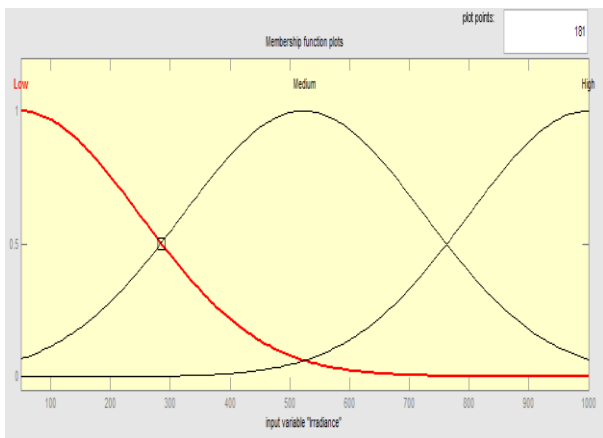


Fig 5: Membership function of solar irradiance

There are nine rules that can follow the conditions, more filled cells mean 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 14.3V shown in Fig.7.

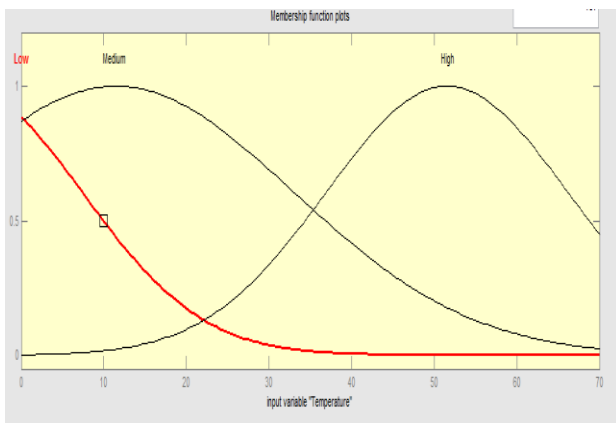


Fig.6. Membership function of PV cell temperature

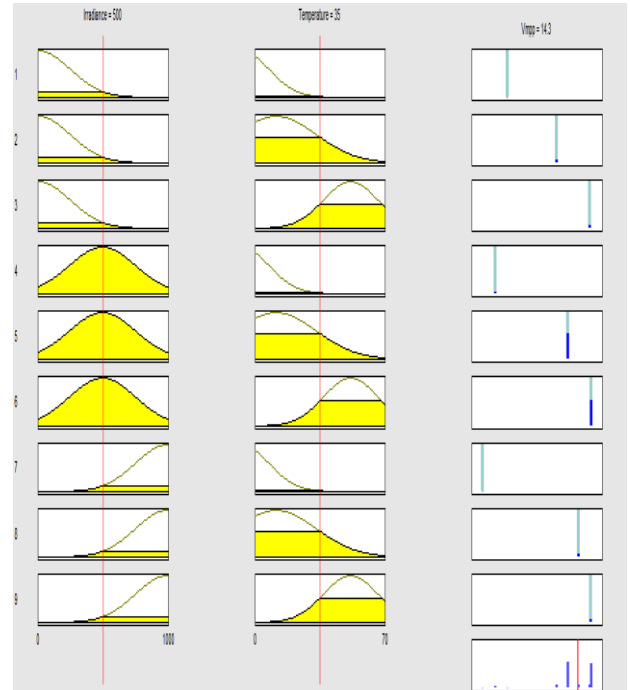


Fig 7: Rule base of ANFIS controller

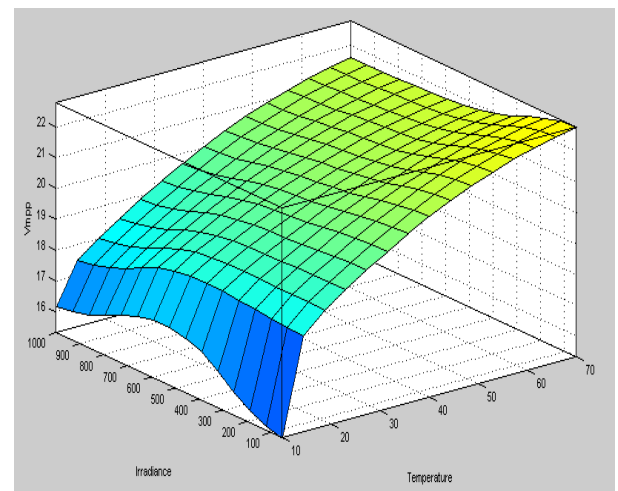


Fig 8: Surface view created by ANFIS

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 (V_{mpp}) with the changes of PV cell temperature and solar irradiance is shown in Fig7. 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 [10][11][12].

4. CONTROL STRATEGIES

This section describes the control strategy involved to achieve the desired objective. Fig.9 illustrates the control scheme diagram involved in MPPT system using ANFIS.

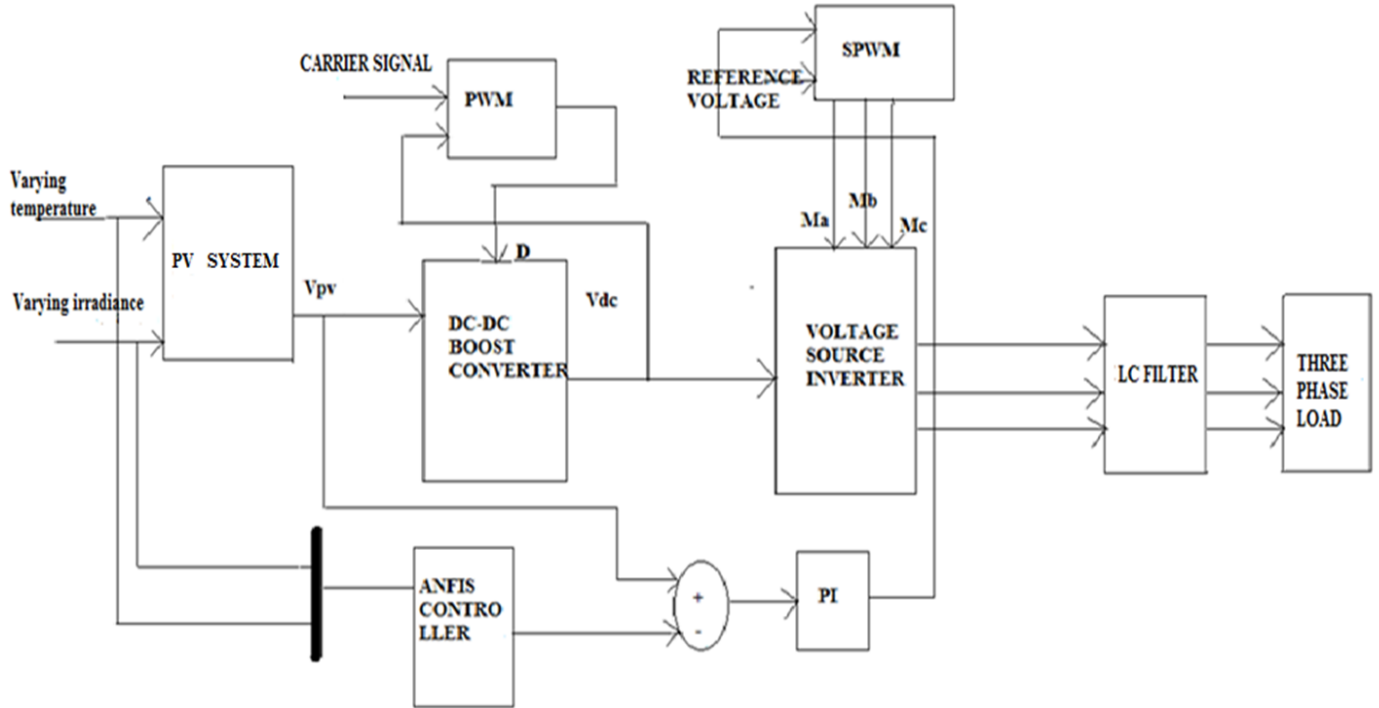


Fig 9: Control scheme

4.1 PWM control

The boosted output voltage of the converter V_{dc} is compared with the carrier signal and the output is given as gating signal to the MOSFET switch of the boost converter.

4.2 Voltage regulation

The voltage obtained from the boost converter is then fed to the three phase voltage source inverter. The gating signals for the devices in VSI are obtained using ANFIS controller. The crisp value of output V_{mpp} of the ANFIS controller [13] is compared with the output voltage of the boost converter. The output signal is given to the PI controller.

A Proportional integral controller is a generic control loop feedback mechanism. The PI controller calculates the error value as the difference between the measured process variable (voltage) and a desired set point. The controller attempts to minimize the error by adjusting the process control outputs. The compensated signal from PI controller is given as the carrier signal for SPWM technique. The pulses obtained using SPWM are given to the three phase VSI and the desired voltage is obtained. Then it is given to the filter and then to the three phase ac load.

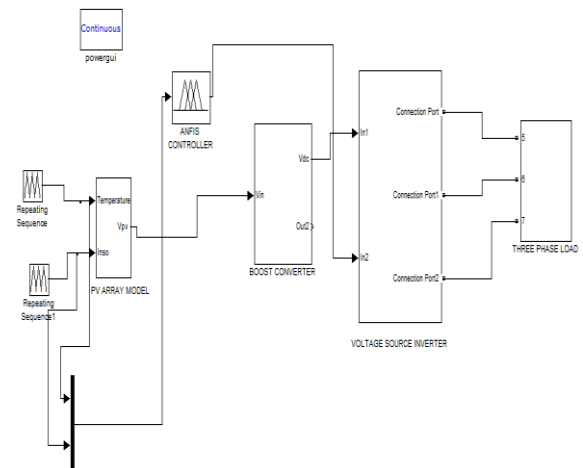


Fig.10.Overall simulation diagram

5. RESULTS AND DISCUSSION

Fig.10 shows the overall simulation diagram of the proposed system. The PV array shown in the simulation diagram is modeled using equation (1) and the specifications mentioned in table 1.

5.1. PV array model

Fig.11. illustrates the simulink model of PV array using the specifications and equation mentioned in section 2. Fig.12 and 13 clearly shows the P-V characteristic curves.

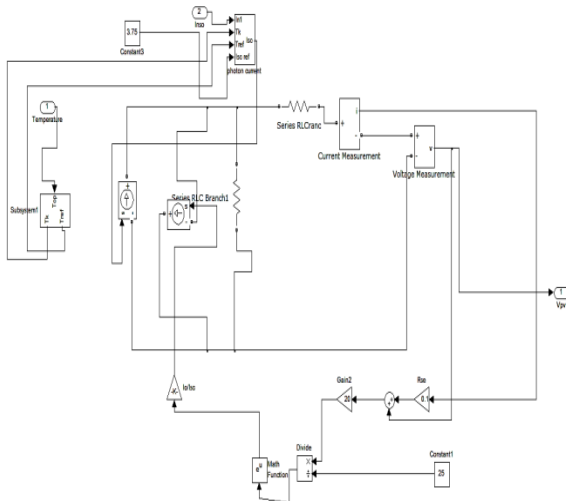


Fig 11: Simulink model of a PV array

From the Fig.12 and Fig 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[12][13].

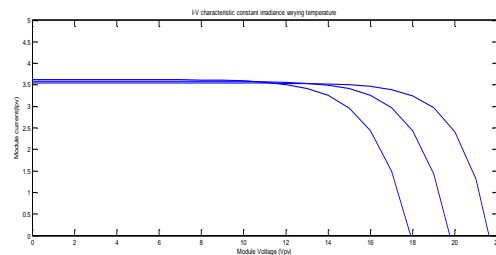


Fig 12: I-V Characteristic for varying temperature and constant irradiation.

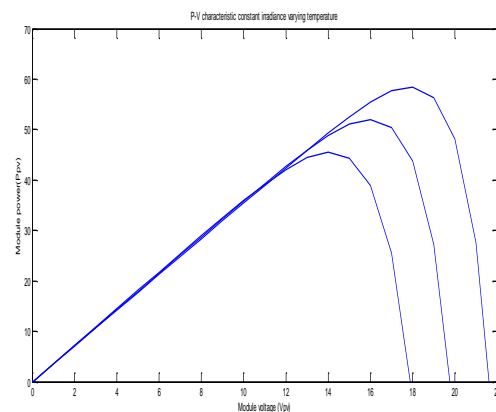


Fig 13: P-V characteristic for constant irradiance varying temperature

The Fig.14 and Fig.15 shows that by increasing the solar radiation at constant temperature the voltage and current

output from PV array also increases. Hence at higher insolation we can get our required voltage level.

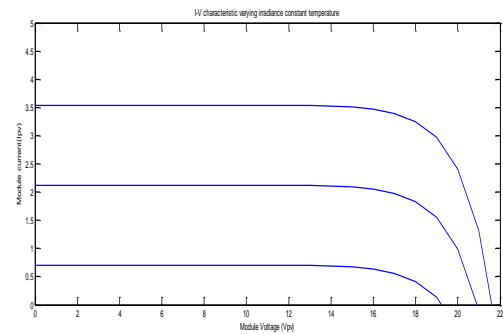


Fig 14: I-V characteristic for varying irradiance constant temperature

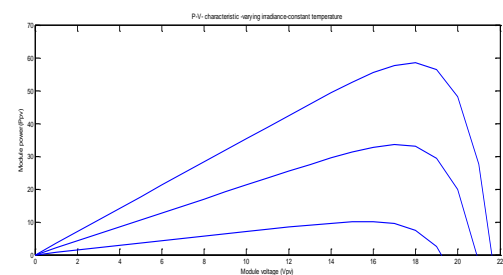


Fig 15: P-V characteristic for varying irradiance constant temperature

The Fig. 16 Shows that the PV output voltage obtained using ANFIS is stable and this technique is faster compared to conventional MPPT algorithms.

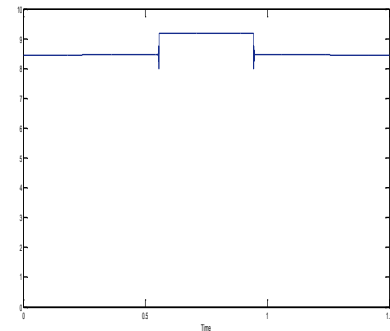
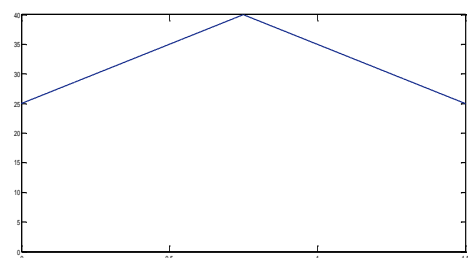


Fig 16: ANFIS output voltage

The Fig.17. shows the variation of solar irradiance and temperature during the simulation time.



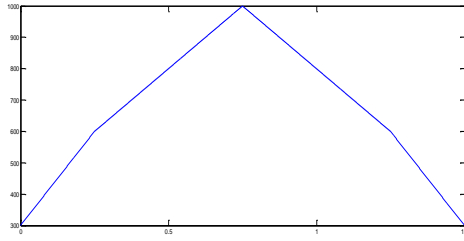


Fig 17 : Curves for varying temperature and solar irradiation.

The gating signal shown in Fig.18 is given to the switch of the boost converter. The boost converter boosts the voltage of PV array from 22 to nearly 415V. The output voltage and the output current from the boost converter is shown in fig.19 and 20.

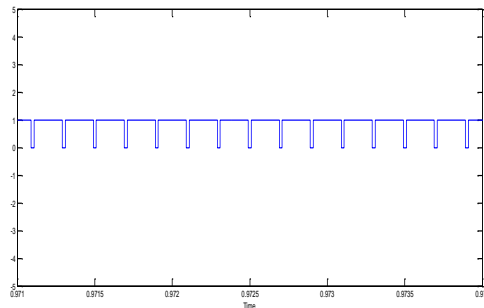


Fig 18: Gating signals to the switch of boost converter

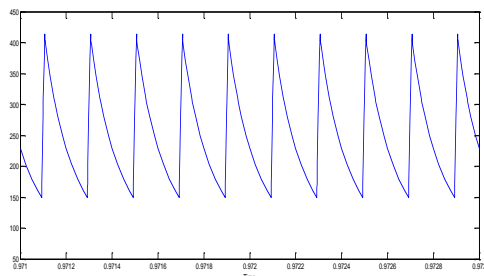


Fig 19: Boost Converter Output Voltage

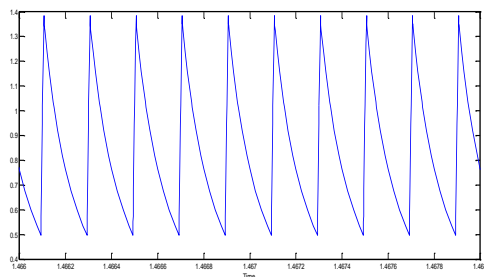


Fig 20: Boost converter Output Current

The boosted voltage is given to the VSI Fig.21.shows the output voltage without using filter. This voltage signal is given to the filter to reduce the harmonics and then it is fed to the three phase ac load. The output voltage from the three phase VSI is found to be nearly 415V.

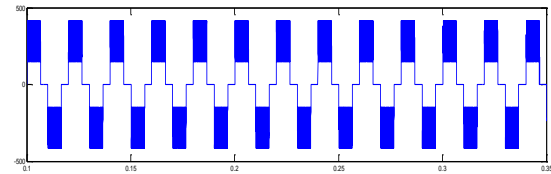


Fig 21: Output Voltage of VSI

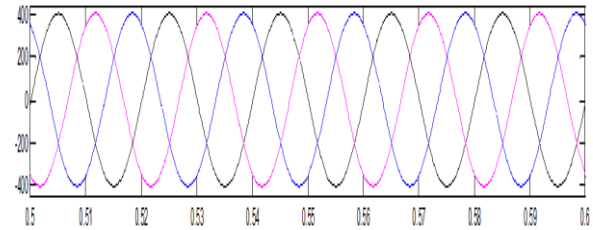


Fig 22: Output voltage with filter

The Fig.22 shows the output voltage of the PV generation system with filter

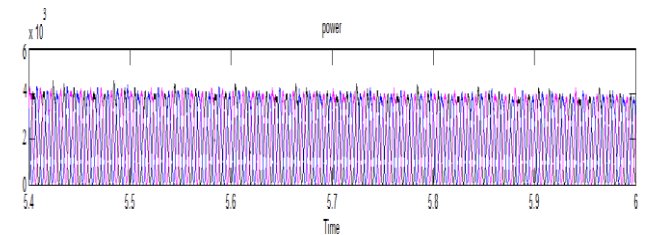


Fig 23: Output power

Fig.23. shows that the ANFIS controller delivers a maximum power of 4 KW to the three phase load.

6. CONCLUSION

This paper 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 415V. The boosted voltage is given to the inverter and then to the three phase load. The maximum power point tracking [14][15] , 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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