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Design and Analysis of ANFIS Controller to Control Modulation Index of VSI Connected to PV Array

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ABSTRACT

This paper analyses the operation of an adaptive neuro-fuzzy inference system (ANFIS)-based maximum power point tracking (MPPT) for solar photovoltaic (SPV) energy generation system. The MPPT works on the principle of adjusting the voltage of the PV modules by changing the duty ratio of the Voltage source inverter. The duty ratio of the inverter is calculated for a given solar irradiance and temperature condition by a closed-loop control scheme. The closed-loop control of the VSI regulates the duty ratio and the modulation index to effectively control the injected power and maintain the stringent voltage, current, and frequency conditions. The ANFIS is trained to generate maximum power corresponding to the given solar irradiance level and temperature. The response of the ANFIS-based control system is highly precise and offers an extremely fast response. The main objective for a grid-connected Photovoltaic (PV) inverter is to feed the harvested energy from PV panels to the grid with high efficiency and power quality.

Key words: Maximum power point tracking (MPPT), Photovoltaic system, Voltage Source Inverter, Modulation index, ANFIS

INTRODUCTION

It is well known that the output power of photovoltaic (PV) panels holds highly non-linear characteristic. For a certain temperature and irradiation, there will be a specific maximum power at certain voltage so-called maximum power point (MPP). The voltage of MPP changes with the irradiation and especially the temperature varying. Thus, the system needs to operate at the MPP of PV array by controlling the inverter, no matter how much irradiation, what temperature or other conditions. Moreover, the generated energy from the PV system, which is mostly provided to the utility grid, not only should be of sinusoidal current, but also must satisfy the requirements of the power grids, such as no DC component of the inverter output current, minimization of the harmonics, as a result of no harmonic pollutions on the power grids, and so on. These requirements impose the inverter with a high-grade control. The challenge is how to meet the above requirements with minimum cost, which has to be faced for the majority of designers. AI based methods are most suitable for improving the dynamic performance of maximum power point tracking. Considering the non-linear characteristics of solar PV module, the AI methods provide a fast, flexible and computationally demanding solution for the MPPT problem. Fuzzy logic controller and artificial neural networks are two main AI methods used for MPPT. In this paper, designing and implementation of ANFIS based MPPT scheme which is interfaced with Voltage Source Inverter presented. ANFIS combines the advantages of neural networks and fuzzy logic and hence deals efficiently with non linear behaviour of solar PV modules. Designing of voltage source Inverter is also carried out which is used for impedance matching and maximum power transfer between load and solar PV module.

Block Diagram of Proposed System

Fig. 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 phases ac load. A DC-DC converter [3-4] and VSI acts as an interface between the load and the PV module. Maximum power point tracker (MPPT) used in the proposed system [5] tracks the new modified maximum power point in its corresponding curve whenever temperature and/or insulation variation occurs. The MPPT is used to adjust the modulation index of the VSI [6] in order to maintain the power extracted. An ANFIS controller is incorporated to automatically vary the modulation index of VSI in order to maintain the power extracted. 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]. 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 load.

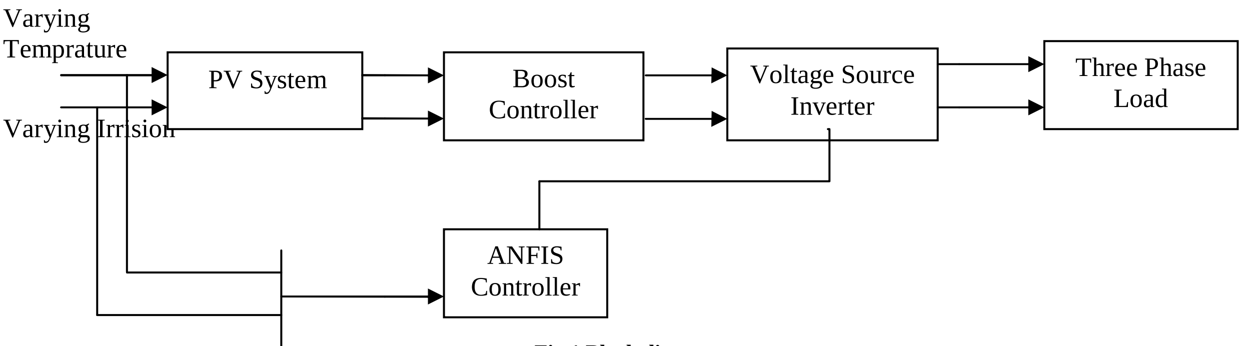

Fig.1 Block diagram

Simulation Models

Fig. 2 is the proposed simulation model which is consisting of PV module, Boost converter, ANFIS controller, Voltage source inverter and three phase load.

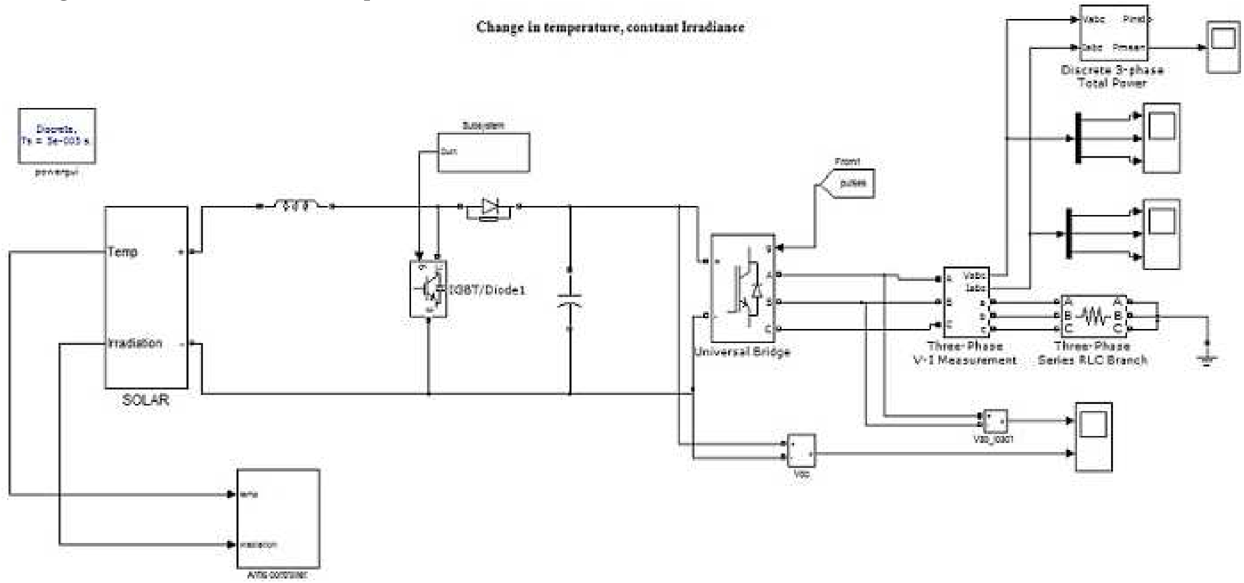

Fig. 2 Simulation Module

PV Module

A PV cell can be represented by equivalent circuit shown in Fig. 3. 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 Io depends mainly on the operating temperature, a series resistance Rs and the shunt resistance Rp which takes into account the resistive losses.

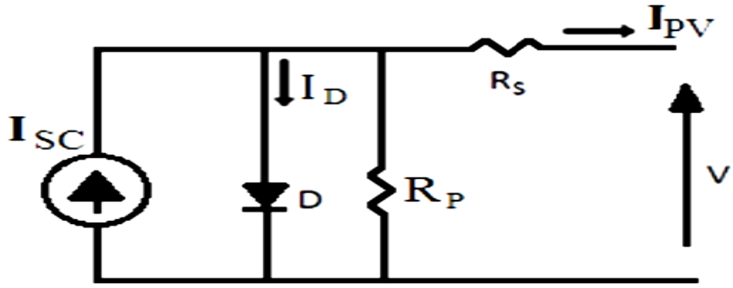

Fig. 2 Solar cell model using single diode with Rs and Rp

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. The overall neuro-fuzzy structure shown in 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].

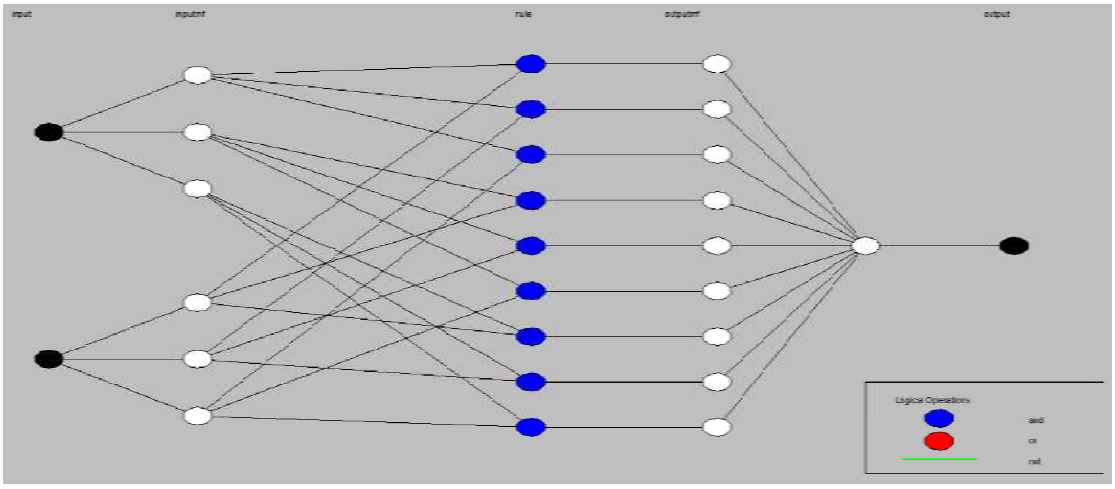

Fig. 4 ANFIS based MPPT Algorithm

Control Strategy

This section describes the control strategy involved to achieve the desired objective. Fig. 4 illustrates the control scheme diagram involved in MPPT system using ANFIS.

PWM Control

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

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 Vmpp 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 to the three phase ac load.

SIMULINK MODELS

PV Array

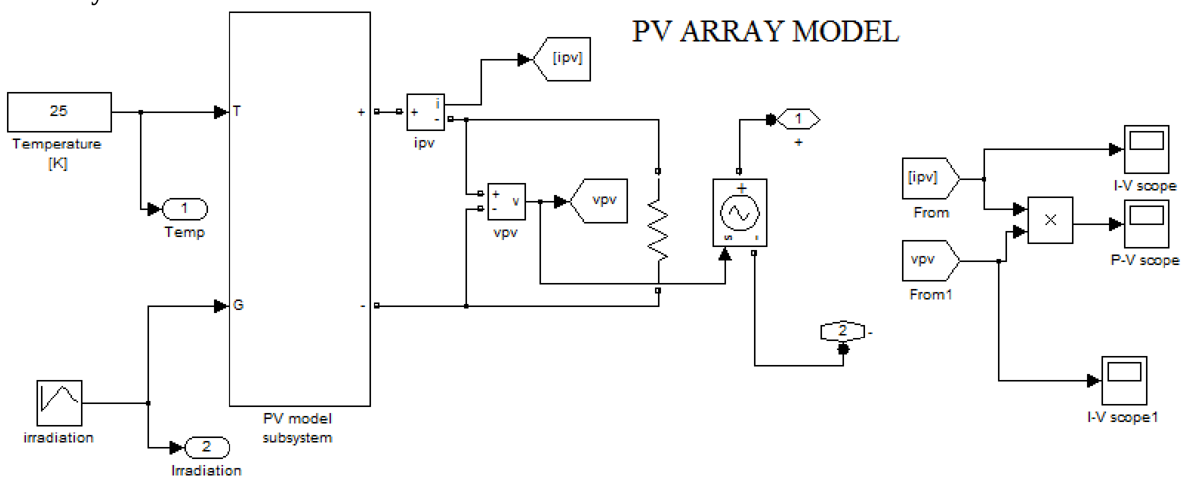

Fig. 5

Model without ANFIS Controller

Fig. 6 depicts that model PV array is connected to boost converter which boost the voltage to required level and the output of converter is fed to VSI and for the gate signal of VSI standard gate signal pulses are used.

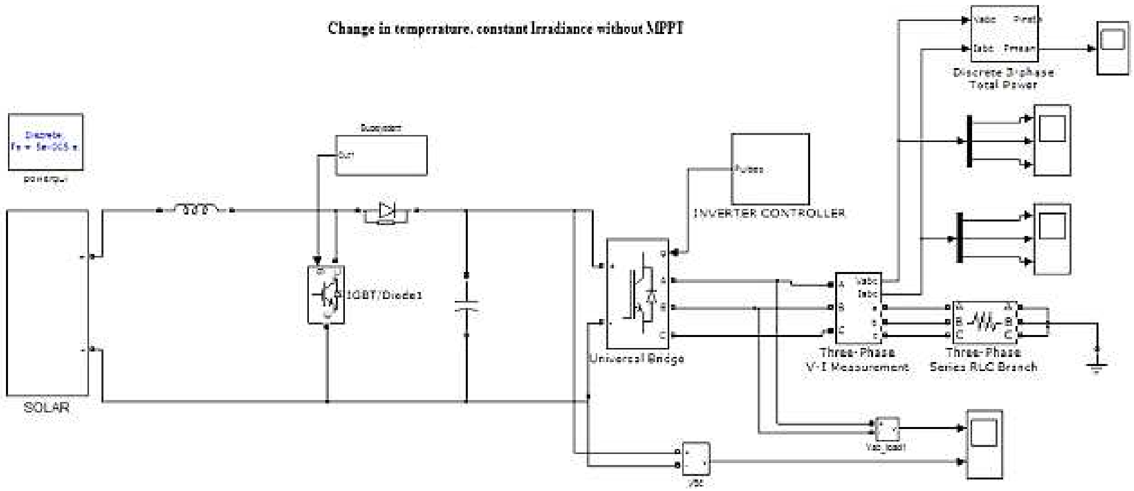

Fig. 6

Model with ANFIS Controller (Change in temperature and constant irradiation)

Fig. 7 depicts that model PV array is connected to boost converter which boost the voltage to required level and the output of converter is fed to VSI to invert the output. And gate signal of VSI is supplied by the ANFIS controller which controls the modulation index of inverter and delivers max power at the output side. During simulation irradiation is maintained constant and temperature is changed.

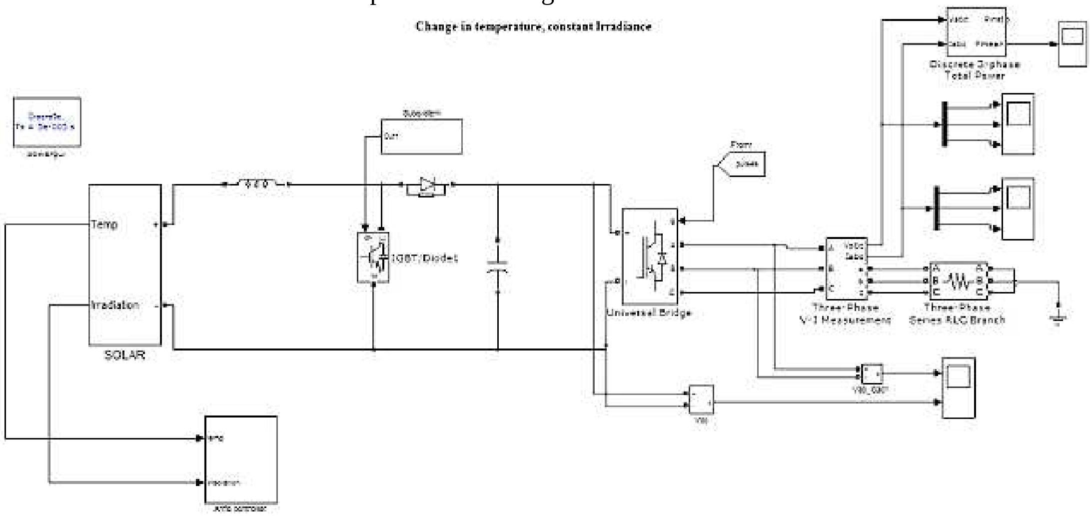

Fig. 7

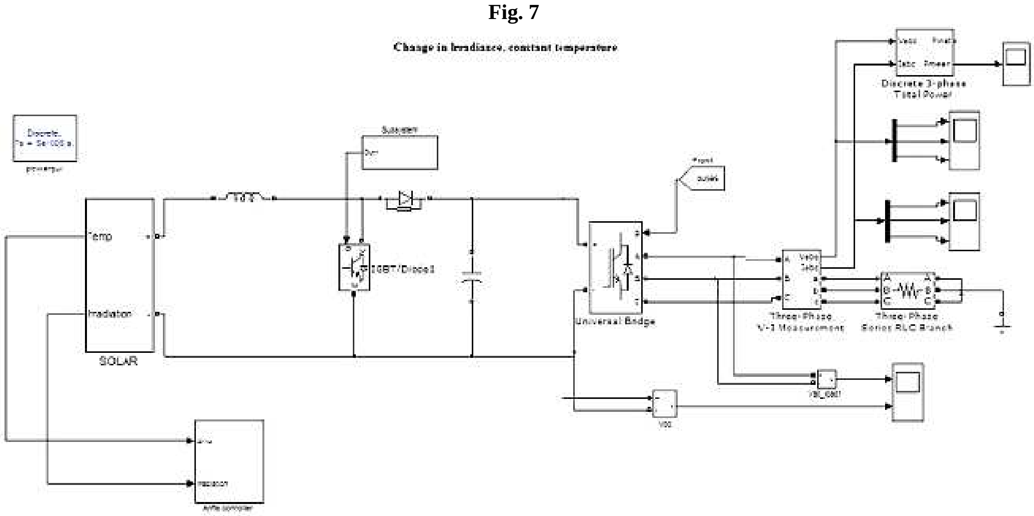

Fig. 8

Model with ANFIS Controller (Change in Irradiation and constant temperature)

Fig. 8 shows that model PV array is connected to boost converter which boost the voltage to required level and the output of converter is fed to VSI to invert the output. And gate signal of VSI is supplied by the ANFIS controller which controls the modulation index of inverter and delivers max power at the output side. During simulation temperature is maintained constant and irradiation is changed.

RESULTS

P-V and I-V Characteristics of PV Module

Fig. 9 shows the PV characteristics of PV module where we can observe the max power point. With MPPT algorithm it is possible to change the operating point of PV panel to maximum value. Fig. 10 shows the I-V characteristics of PV panel in both current source and voltage source mode and (Vmp, Imp). Fig. 11 shows the nonlinear characteristics of PV array (Voltage V/s Time) whereas Fig. 12 shows the nonlinear characteristics of PV array (Current V/s Time). Fig. 13 & 14 shows the waveforms from the simulation results obtained from voltage source inverter with and without ANFIS controller (Line voltage of all three phases).

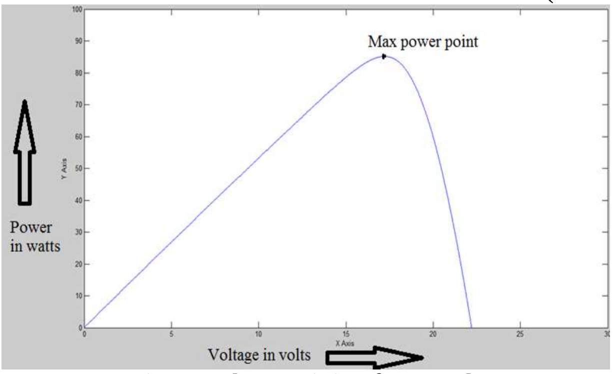

Fig. 9 PV characteristics of PV Panel

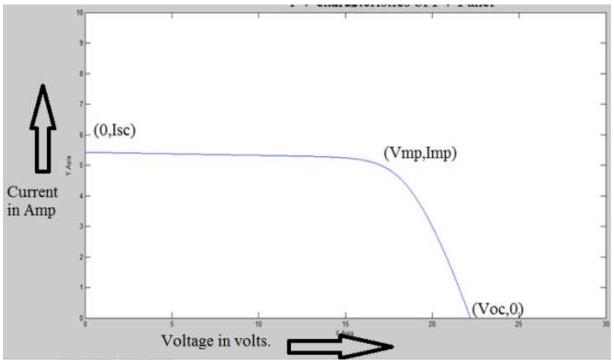

Fig. 10 I-V characteristics of PV panel

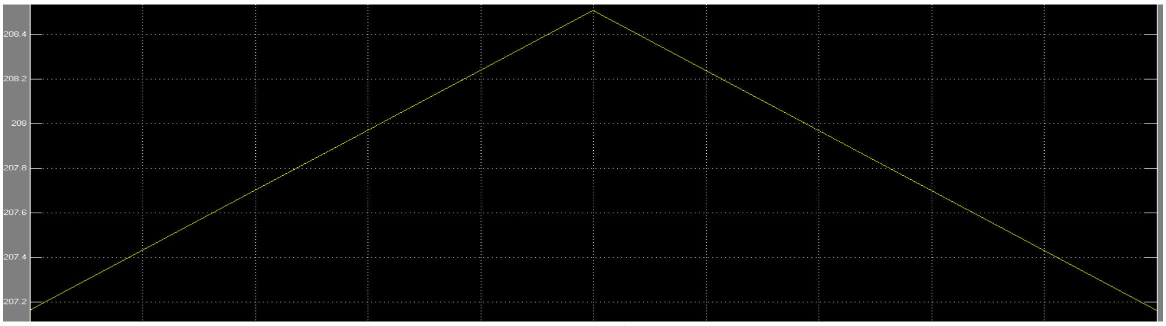

Fig. 11 The nonlinear characteristics of PV array (Voltage V/s Time)

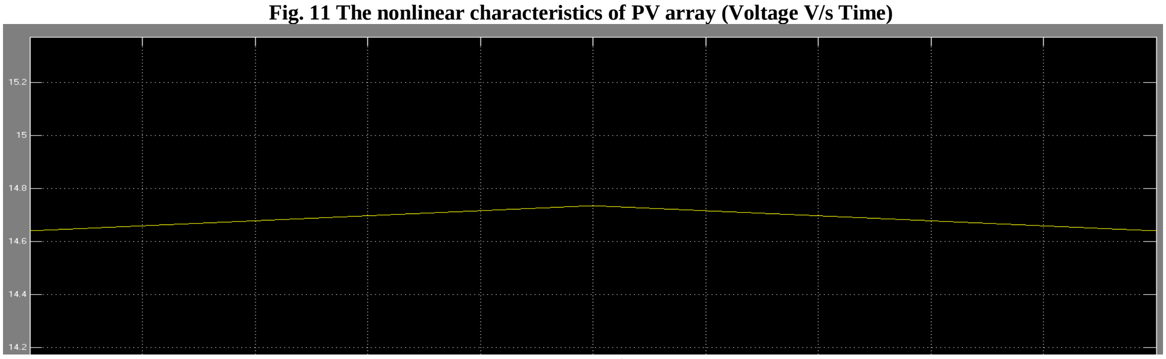

Fig. 12 The nonlinear characteristics of PV array (Current V/s Time)

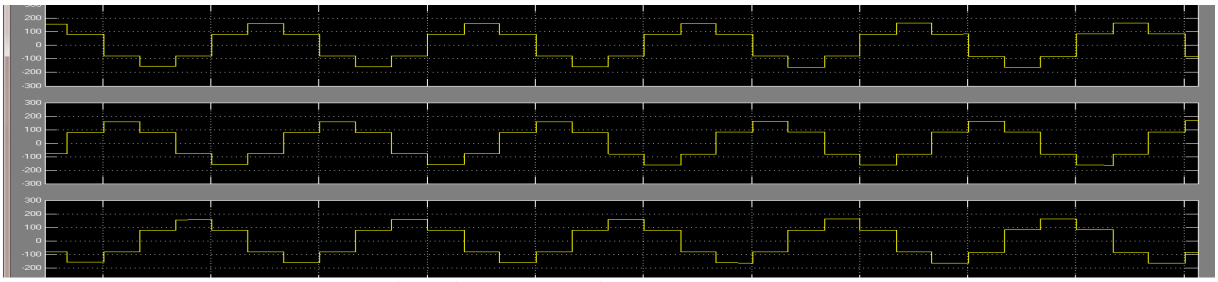

Fig. 13 Simulation results of waveforms obtained from voltage source inverter with ANFIS controller

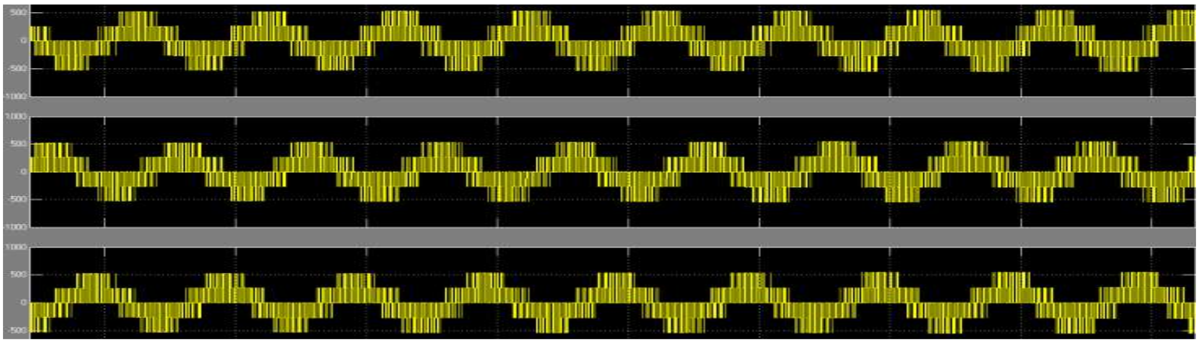

Fig. 14 shows the simulation results obtained from voltage source inverter without ANFIS controller

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

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