Enhancement of Grid Connected PV Inverter using Optimal Maximum Power Point Tracking Algorithm with Climatic Parameters Estimation

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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. AnANFIS 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 increasingenergy demand and concerns over climate changemotivate power generation from renewable energy sources.Solar photovoltaic (PV) and wind have emerged as popularenergy 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 efficientlyintegrating 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 hardwaresimplicity. 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, whichwastes energy while it cannot distinguish between the radiationvariation and the tracker's perturbation. Many solutions are presentedbased on an adaptive step size or optimization functions[3]–[5], [9], [21], [26]. The second InCond method has a greataccuracy with good flexibility to rapidly varying climatic conditions[24]. Therefore, it is possible to recognize when the MPPis achieved within a given accuracy [7], [22] by computing theinstantaneous and InConds and verifying if they are identical.

However, it involves an increased hardware and software complexity.Many improvements are proposed using variable andmodified step size algorithms [8], [22]–[24]. A sliding modecontrol has been used to improve tracking accuracy [11] andInCond 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 totheir human-like capability and ability to adapt and improvetheir performance [14], [19], [26], [27]. Many neural networks (NN)-and fuzzy logic (FL)-based techniques are proposed.

Anartificial NN algorithm is developed with climatic conditions asinputs and applied to a boost tracker [28]. Using FL theory, afeed-forwardMPPT scheme, a fuzzy controller, and an adaptiveP&O-FL control method are proposed [9], [15], [16], [30].

This paper provides an efficient Grid connected PV MPPT method with reducedcomponents. It computes the instantaneous and junction array conductances.The first one is done using the array current andvoltage, whereas the second one uses the array junction current,which is estimated using ANFIS cell model presented ina recent paper of the authors [17]. Still, it requires informationon the climatic parameters. Hence, it is proposed ANFIS control as ananalytical model with a denoising based wavelet algorithm toestimate them, which helps reducing the hardware using onlyone voltage sensor. The simulation results areprovided to validate the proposed ANFIS - PV based MPPT scheme capabilities.This paper is organized as follows: Section II provides anoverview of Modolling of PV system. The proposedthree phase PV system is developed and explained in Section III.Section IV shows in detail the estimation of environmentalparameters. The simulation results based on MATLAB arepresented 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 ea, eb, ec. In this paper, the main target is to control the voltage vdc 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 IL, a parallel diode, shunt resistance Rsh and series resistance Rs. In Fig. 2, ION is the diode current which can be written as:

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

where $\alpha = \frac{q}{AkT_C}$, $k = 1.3807 \times 10^{-23}\ JK^{-1}$ is the Boltzmann's constant, q = 1.6022 × 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, Is is the saturation current, and vpv is the output voltage of PV array which in this case is the voltage across C, i.e., vdc. Now, by applying Kirchhoff's Current Law (KCL) in Fig. 1, the output current (ipv) generated by PV cell can be written as,

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

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

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

Where, Isc is the short circuit current, s is the solar irradiation, ki is the cell's short circuit current coefficient and Tref is the reference temperature of the cell. The cell's saturation current Is varies with the temperature according to the following equation [19]:

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

where, Eg is the band-gap energy of the semiconductor used in the cell and IRS 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
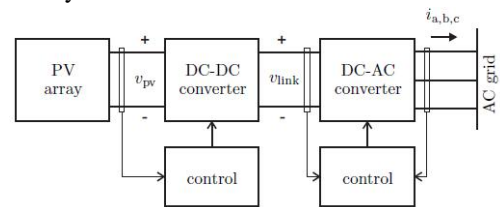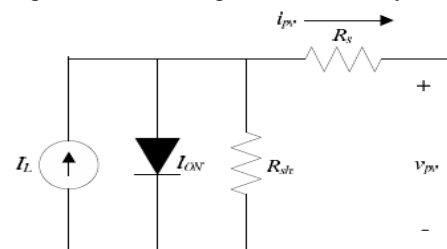

Figure 1: Block diagram of the PV system.

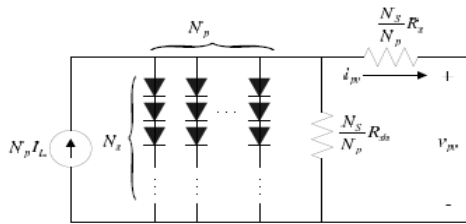Fig. 2. Equivalent circuit diagram of PV cell

Fig. 3. Equivalent circuit diagram of PV array

Where Ns are the number of cells in series and Np is the number of modules in parallel. In this case, the the array ipv can be written as

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

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 powersare compared and the error is given to a proportional integral (PI) controller, to generate control signals.
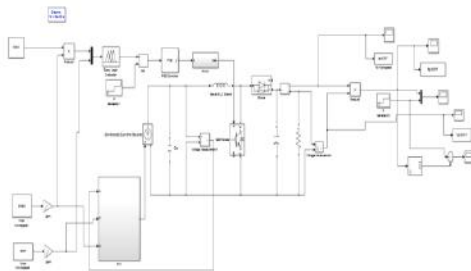

Fig. 4. Matlab/Simulink model of ANFIS based MPPT controller.

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, inordertoadjust the operatingpointofthePVmodule.
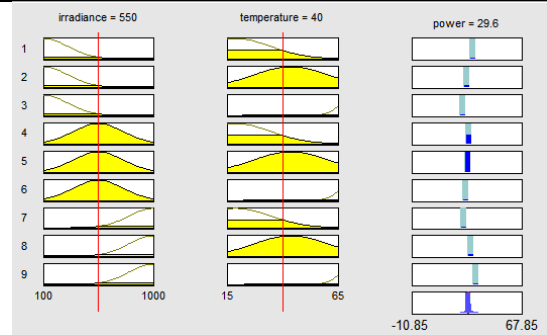

Fig. 5.Output fromfuzzyrulesforspecific valueoftemperatureandirradiance.
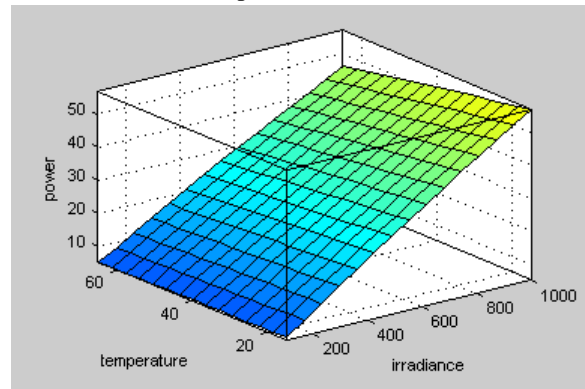

Fig. 6. Surface betweentwoinputs(temperatureandirradiance)andoneoutput (maximum power).

Tuning of ANFIS Using the Matlab/Simulink model of PV module, the operating temperatureisvariedfrom15 1C to65 1C inastepof5 1C andthe solar irradiancelevelisvariedfrom100W/m2 to 1000W/m2 in a step of50W/m2, to get the training data sets for ANFIS. Maximum available power for each pair of training data is recorded. In total 209 trainingdatasetsand2000epochsareusedtotraintheANFIS. By using given input/output dataset, the ANFIS constructs a fuzzy inference system (FIS) who 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. Itis 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 threephase 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 DCDC 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 Vpv of the converter, which is the output voltage of the PV array. The DC to AC control block contains the controller of the DC linkcapacitor (the capacitor that connects the DC-DC andDC-AC converters) voltage Vlink and another for the sinusoidal three-phase output currents Ia,b,c.
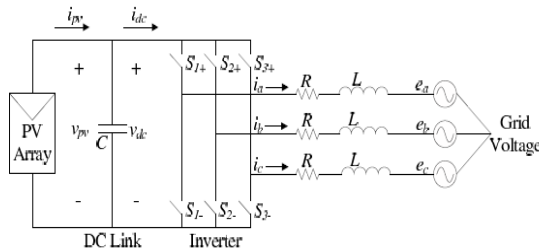

Fig. 7. Three phase grid connected PV system.

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 40V and output current is 1.2Ato 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.
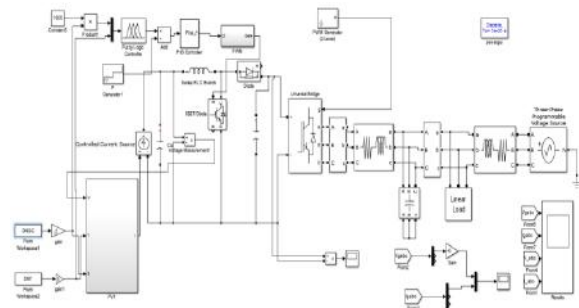

Fig 8 Completed Matlab/SImulink Model of the Proposed ANFIS based Grid Connected PV Systems.
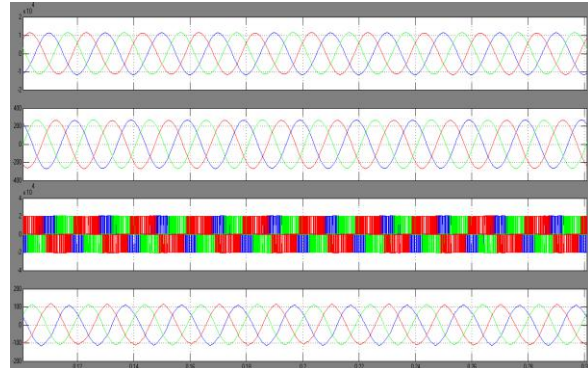

Fig 9 Three phase waveform of the proposed grid connected PV systems i.e., Grid voltage,Currents & Output Voltage, Currents of the Inverter.
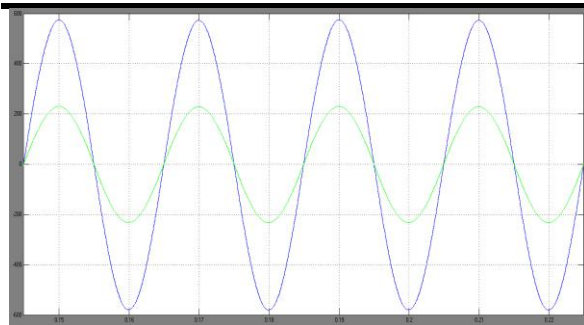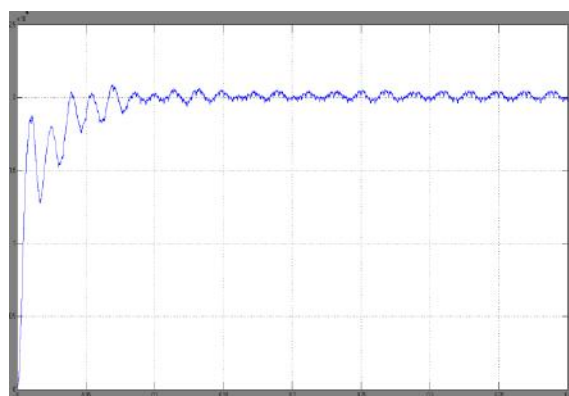
Fig 10 Grid Voltage & Currents of the phase A

Fig11 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 $0.25kWm-2$, 0.5 kWm-2, 0.75 kWm-2, $1kWm-2$ 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 Igabc(%)	After LC Filter Igabc(%)
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 mainfeature of the presented system is it does not require anintermediate stage of DC to DC control, as the maximumpower is set by the inverter itself by means of anANFIS with Wavelet algorithm. The controller objectives are threefold: i) ensuring the MPPT in the side of PV generator; ii) guaranteeing apower factor unit in the side of the grid, iii) ensuring theglobal asymptotic stability of the closed loop system. Usingboth formal analysis and simulation, it has been proven thatthe obtained controller meets all the grid code requirements.

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