# Application of An Adaptive Network-based Fuzzy Inference System to Control a Hybrid Solar and Wind Grid-Tie Inverter

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**Abstract-In this paper, the application of an Adaptive Network-based Fuzzy Inference System (ANFIS) to control a hybrid solar and wind grid-tie inverter in order to reduce power oscillations and enhance power quality is presented. To extract the maximum power from the PV system, a Perturb and Observe (P&O) algorithm is presented that tracks the Maximum Power Point (MPP). Time-domain simulation results of the studied system are performed in MATLAB/SIMULINK under different operating conditions such as changing irradiation and short-circuit faults in the power grid. From the simulation results, it can be concluded that the designed ANFIS controller and the proposed P&O algorithm perform better than the traditional PI controller and improve transient responses under severe operating conditions.**

***Keywords-hybrid; grid-tie inverter; perturb and observe; ANFIS***

## I. INTRODUCTION

Sunlight and wind are the furthermost promising renewable energy sources. Due to the randomness of the solar irradiance and the accessibility of the wind, a combination of solar and wind energy production configuration can be a highly reliable source of electrical energy. A general planning framework for integrating solar and wind energies in a Hybrid Power System (HPS) was proposed to exploit the solar-wind complementarity and to stabilize the combined power output on a case study in Pakistan in [1]. HPS techno-economics for a single-family residence in the region of Yambol, Bulgaria was analyzed in [2] to determine optimum system configuration to minimize the excess energy produced. A hybrid optimization model for electric renewable software and its techno-economic feasibility to develop a hybrid wind-solar model was analyzed in [3]. The benefits of a water pumping power system using HPS in order to supply water to remote areas and rural zones have been studied in [4].

To generate electricity for the power grid, an inverter is required. In [5], a 3-level inverter-based grid-tie hybrid solar and wind energy system was presented with the mitigation of power quality problems. For enhancing the power quality problems caused by the switching of the small-scale grid-tie inverter under the operation states of solar systems, some solutions have been mentioned in [6]. In terms of developing a grid-tie inverter, a Shunt Series Switched Grid Tied Inverter (SSS-GTI) was proposed in [7]. This inverter structure can operate in shunt or cascade-connected mode. Another structure to improve efficiency by reducing the switching losses was introduced in [8]. Research and application of inverter controllers make an important contribution to the quality of the power supplied to the power system. Besides the traditional PI controllers [9, 10], a double closed-loop controller for voltage and current was adopted in [11], using sliding mode control [12]. Also, new and modern control techniques have been applied, such as the fuzzy logic controller [13].

The purpose of this paper is to present the applicability of the Adaptive Network-based Fuzzy Inference System (ANFIS) controller to improve the stability of the hybrid grid-tie inverter.

## II. STUDIED SYSTEM CONFIGURATION

The studied system configuration is introduced in Figure 1. It includes a 5kWp rooftop solar PV system and a 3kW wind turbine system connected to the power grid through a hybrid grid-tie inverter [9, 14]. The mathematical models of the proposed system are described below.

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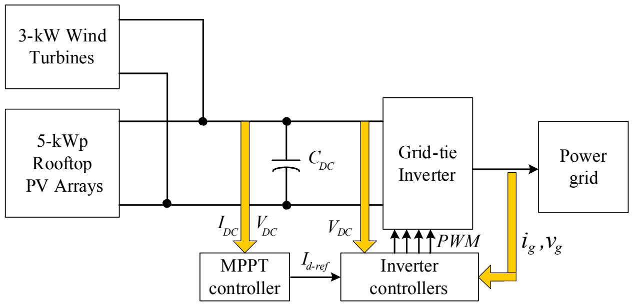


Fig. 1. Block diagram of the studied system.

## A. PV Array Model

An equivalent circuit diagram of the 5kWp PV array is referred to [13, 15]. In this paper, a Sunpower SPR-415E-WHT-D PV panel is selected. The I-V curve for a rated 5kWp PV system affected by irradiance is shown in Figure 2. The rated parameters of this PV panel are:

- Maximum Power: 414.8W
- Cells per module: 128
- Voltage at Maximum Power Point (MPP): 85.3V
- Short-circuit current: 6.09A
- Current at MPP: 5.69A

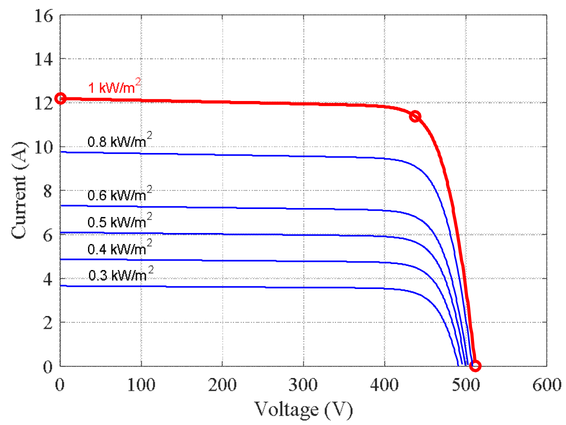


Fig. 2. Irradiance effect on the I-V curve.

## B. The PMSG-based Wind Turbine Model

A small-scale Permanent magnet synchronous generator (PMSG)-based vertical wind turbine was used in this paper. The equivalent voltage equation of the studied wind PMSG in per unit (p.u.) projected to the *dq*-axis was expressed in [16, 17]. In this research, the MSFD5-3.000W wind turbine is selected with the following parameters:

- Rated power: 3.000W
- Max power: 3.500W
- Rated wind speed: 8m/s
- Generator type: Three-phase PMSG
- Working voltage: 192V DC
- Power supply method: Three-phase whole-wave bridge rectifier constant DC charger.

# III. DESIGNED CONTROLLERS

## A. P&O Algorithm for MPP Tracking

For optimizing the efficiency of the PV system, an MPP tracker algorithm using the Perturb and Observe (P&O) controller is applied [18, 19]. Its flowchart can be seen in Figure 3.

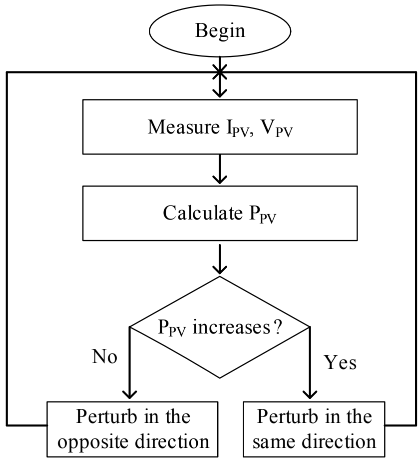


Fig. 3. Flowchart of the P&O algorithm for MPP tracking.

## B. ANFIS Controller for DC Voltage Control

In this section, an ANFIS controller is proposed to replace the PI controller in the DC voltage controller block of the hybrid grid-tie inverter as presented in Figure 4 [20, 21].

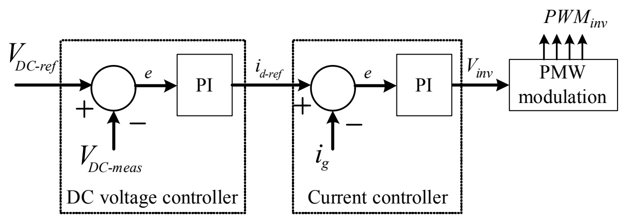


Fig. 4. Controllers for the hybrid grid-tie inverter.

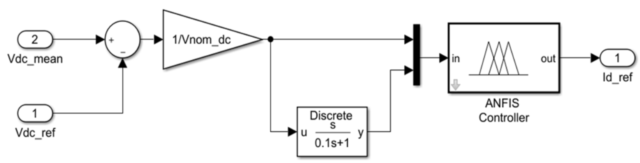


Fig. 5. The designed ANFIS controller for DC voltage regulator.

The structure of ANFIS can be seen in [22-24]. However, for enhancing the accuracy of this controller, besides the error of DC voltage ($e$), additional information from its derivative ($de/dt$) is added to train the ANFIS controller (see Figure 5). As a result, after the training process, the minimal training root mean square error is RMSE = 0.000019. The surface rule is plotted in Figure 6. The selected ANFIS information are:

- Number of nodes: 35
- Number of linear parameters: 27
- Number of nonlinear parameters: 18
- Total number of parameters: 45
- Number of training data pairs: 302.401
- Number of fuzzy rules: 9

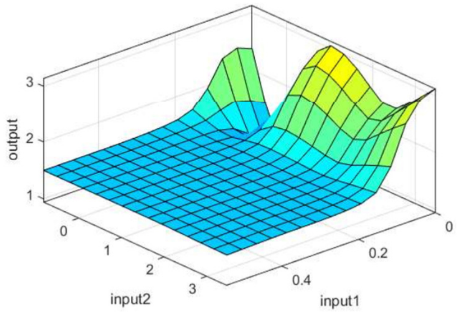


Fig. 6. Surface rule of the designed ANFIS.

## IV. SIMULATION RESULTS

To evaluate the effectiveness of the proposed controller simulations were performed in the time-domain of the studied hybrid solar and wind system under different operating conditions to compare the contributions of the designed P&O and ANFIS controllers to control the hybrid grid-tie inverter and thus enhance dynamic stability. The simulations were carried out in MATLAB/SIMULINK. The mathematical model is shown in Figure 7 and the parameters of the studied system using PI controllers are illustrated in Figure 8.

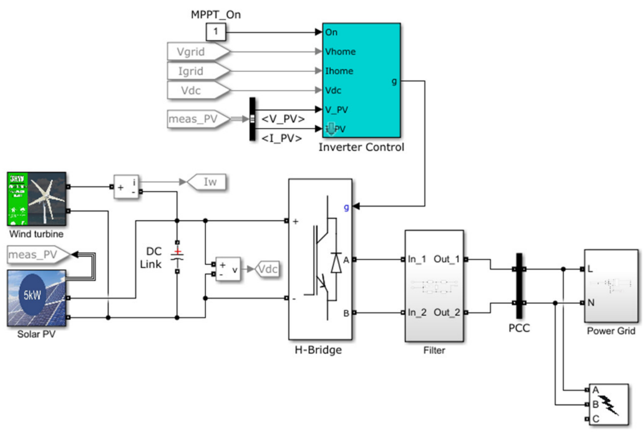


Fig. 7. The mathematical model in SIMULINK.

Figure 9(a) presents the response of the solar PV system when the solar irradiance changes and Figure 9(b) shows the output power of the solar PV system. It is easy to observe that the P&O controller helps keeping the output power of the solar PV system close to the peak value of the maximum power.

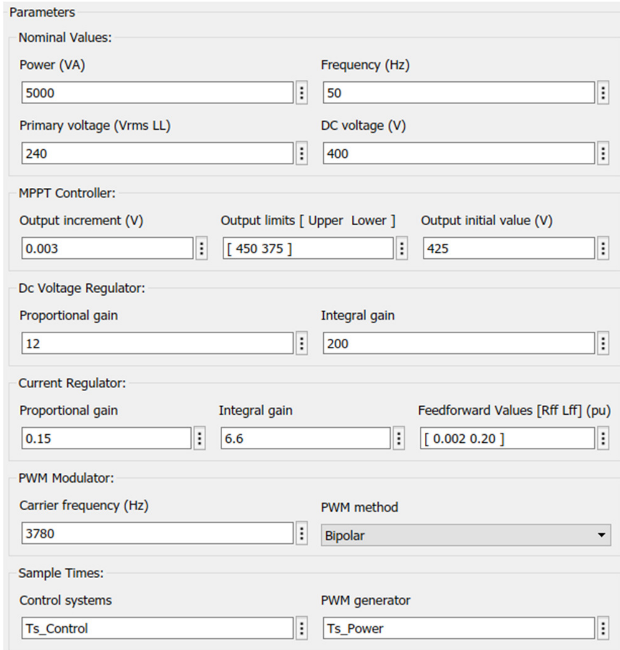


Fig. 8. Parameters of the inverter control block using the PI controller.

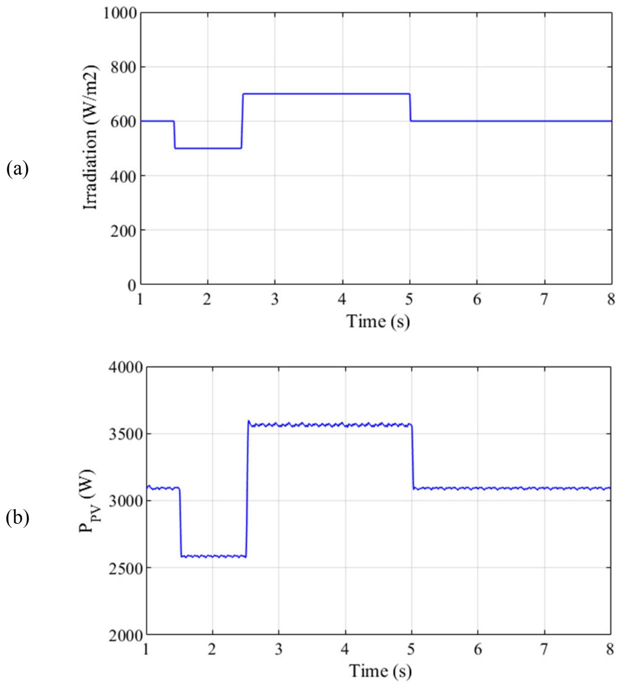


Fig. 9. Responses of the studied system with changing irradiance. (a) Irradiation, (b) active power of the solar PV system.

The fuzzy rules designed in Figures 10-12 show the comparative transient responses in the time-domain of the studied system with the PI controller (red lines) and with the designed ANFIS controller (blue lines) when a single-phase short-circuit fault occurs at the output of the inverter at 3.5s and at the power grid at 6.0s. The wind speed is 6m/s and the irradiation varies from 700W/m$^2$ to 600W/m$^2$.

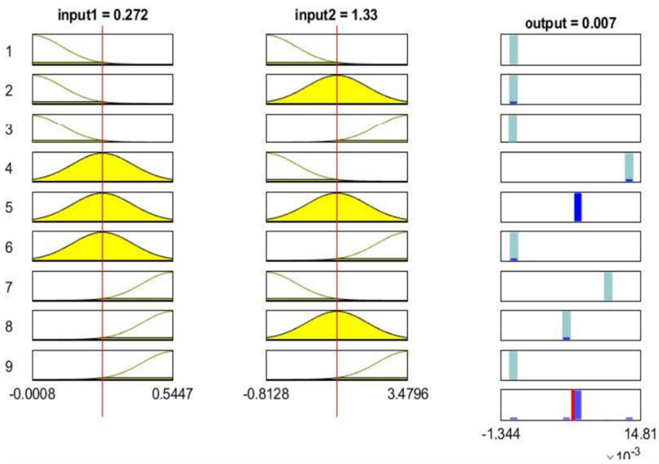


Fig. 10. Relationship between inputs and output of the ANFIS controller in the fuzzy rules.

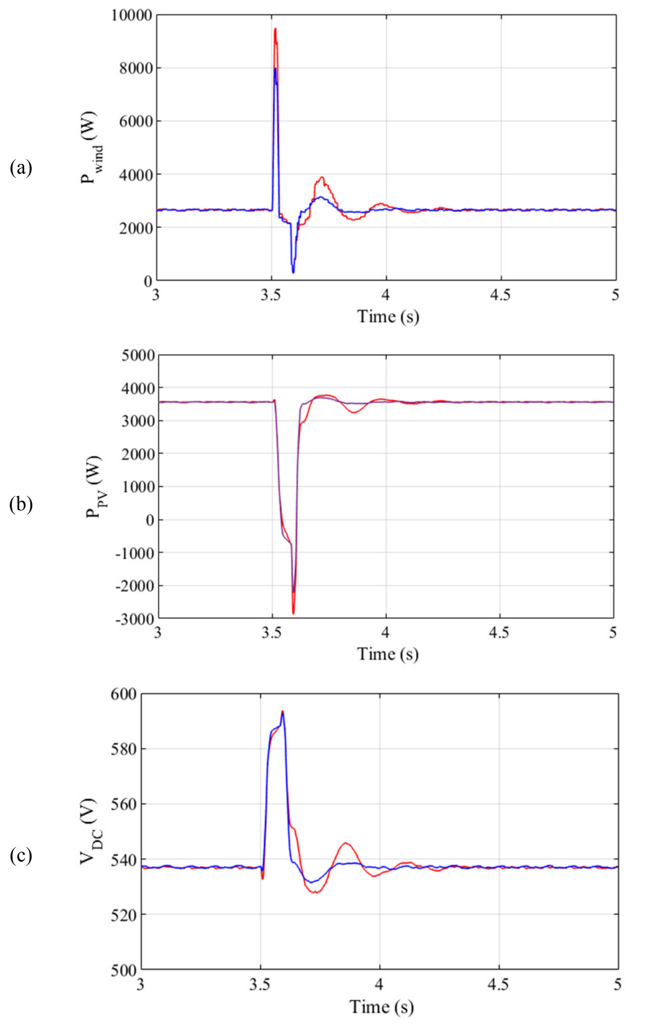


Fig. 11. Response of the studied system when a single-phase short-circuit occurs. (a) Active power of the wind system, (b) active power of the solar system, (c) voltage at the DC-link of the inverter.

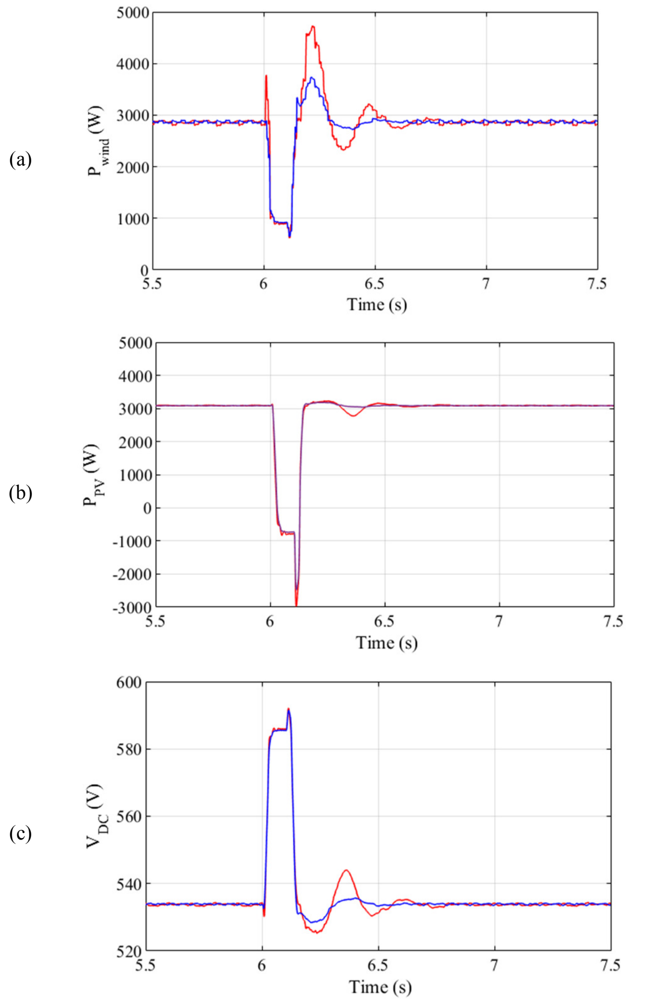


Fig. 12. Response of the studied system when a short-circuit fault occurs at the power grid. (a) Active power of the wind system, (b) active power of the solar system, (c) voltage at the DC-link of the inverter.

It is shown from the comparative results that when the faults occurred, the responses of all parameters oscillated. However, transient fluctuations were better controlled with the proposed ANFIS controller than with the PI controller with regard to overshoot and settling time.

## V. Conclusions

In this paper, the comparative stability improvement of a hybrid grid-connected solar and wind system has been presented. To extract the maximum power from the solar PV system, a P&O controller is proposed for MPP tracking. Furthermore, the ANFIS controller was designed to keep stable the DC voltage of the hybrid inverter. Comparative time-domain simulation results of the studied system under severe faults were performed. It can be concluded from the results that the proposed P&O and ANFIS controller enhances the transient performance of the system with regard to overshoot and settling time reduction of the hybrid grid-tie inverter.

ACKNOWLEDGMENT

This paper was supported by the Ministry-level science and technology program with the title "Application of IoT technology in monitoring, control, and management of integrated electrical systems", grant number CT.2019.04.

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