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Compatibility of Anfis controller and FPGA in solar power generation for a domestic oad

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ABSTRACT. Among other soft computing techniques, the Adaptive Neuro Fuzzy Inference System (Anfis) gives a significant and advantageous result in solar power generation, especially in tracking the maximum power point. Due to the dynamic nature of solar irradiance and temperature, efficient energy conversion is not possible. However, advancements in the areas of artificial intelligence have made it possible to overcome the hurdles. The Maximum Power Point Tracking (MPPT) technique adopting the advantages of Anfis has been proven to be more successful with a fast dynamic response and high accuracy. The complete system is modeled using Matlab/Simulink; the hardware results are validated with the benefits of Field Programmable Logic Array (FPGA) instead of ordinary micro-controllers.

Keywords: solar power generation, MPPT, Anfis controller, DC-AC power conversion, FPGA.

Compatibilidade de Anfis Controller e FPGA em geração de energia solar para uma ocupação doméstica

RESUMO. Entre as outras técnicas de computação moles, Adaptive Neuro sistema de inferência fuzzy (Anfis) dá um resultado significativo e vantajoso em geração de energia solar, especialmente no monitoramento do ponto de potência máxima. Devido à natureza dinâmica da radiação solar e da temperatura, a conversão eficiente da energia não é possível. Mas os avanços nas áreas de inteligência artificial tornaram possível superar os obstáculos. A técnica do máximo Rastreamento Power Point (MPPT) adotando as vantagens de Anfis tem provado ser mais bem sucedido com a resposta dinâmica rápida com alta precisão. O sistema completo é modelado usando Matlab/Simulik e os resultados de hardware são validados com os benefícios da matriz Field Programmable Logic (FPGA) em vez de micro-controladores comuns.

Palavras-chave: geração de energia solar, MPPT, Anfis controlador, DC-AC de conversão, FPGA.

Introduction

Increasing of pollution and rising global temperatures, decreasing reserves of fossil fuels and their increasing cost have led to exploration of alternative energy sources to meet present and future demand. Based on advantages like mass availability and lack of pollution, solar energy is considered to be an inherent source of energy. The principal objective of this paper is to feed domestic load with solar energy in order to ensure the continuity of supply to the load, also using grid power. Due to the dynamic nature of solar irradiance and temperature, energy conversion in solar power generation is not efficient. In order to improve the efficiency, MPPT (Subudhi, & Pradhan, 2013) is used to extract more power from a solar cell. Among the various approaches like Perturb & Observe, incremental conductance, parasitic capacitance, etc., which are available for tracking maximum power from the solar energy, the Anfis (Sumithira, Kumar, & Kumar, 2012; Kalika, Rajaji, & Subash, 2013) approach is a better and more intelligent way to establish the accurate maximum power point even under extreme environmental conditions Anfis, a hybrid platform for solving complex problems, belongs to a class of adaptive neural networks that offer a combination of learning, adaptability, nonlinear, time variant problem solving characteristics of ANN and significant concepts of fuzzy sets theory. Chapter I discusses the general scenario of renewable energy and harnessing methods of photovoltaic energy from the solar source. Chapter II deals with the proposed system and its working principle with the newly developed programmable relay. Chapter III details the Anfis MPPT controller with its adopted algorithm. Chapter IV discusses the various steps in programming the FPGA (Poorani, Urmila Priya, Udaya Kumar, & Renganarayanan, 2005). Chapter V discusses the way of calculating and choosing the values of the filter, which are used in the inverter output. Chapter VI contains the results and the justifications over the conventional ones. Chapter VII contains conclusions.

Proposed system

The suggested system with MPPT and boost inverter is shown in Figure 1.

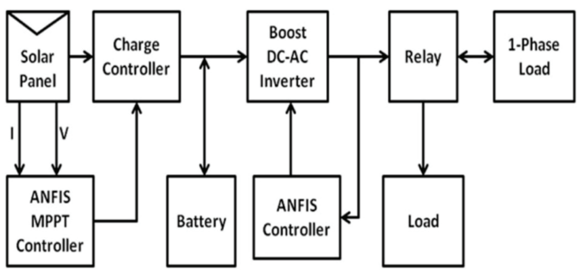

Figure 1. Block diagram of the proposed model.

To ensure the continuity of the power to the domestic load only, grid power is utilized since the solar energy alone is insufficient. The purpose of the programmable relay is to direct the power flow according to the availability of solar or grid energy. When solar energy is sufficient to feed the load, the relay will direct the solar power (or grid power) to the load. Also when load demand is zero, the relay will export the solar energy to the grid. By paralleling the grid and solar energy itself, the purpose of this work is fulfilled; when the grid is at zero potential, solar energy cannot be made to feed the domestic load. The similarities between the results of the simulated model and the hardware model are analyzed, which prove the compatibility of Anfis controller and FPGA for the proposed system.

Anfis MPPT controller

Generally, the MPPT controller tracks the maximum power point by changing the duty ratio of the boost converter and thereby adjusting the voltage of the PV panel. The duty ratio is subjected to change according to the solar irradiance and the temperature. The controller with the Anfis algorithm is trained to generate the maximum power point according to the appropriate solar irradiance and the temperature.

Anfis, a combinational concept of neural network and sugeno model, is a five-layer network, as shown in Figure 2 with different fuzzy rules.

Layer 1: The degree to which the given input satisfies the linguistic label associated with this node, is the output of this node.

Layer 2: This node is known as the Rule node, denoted by T. It calculates the firing strength of the associated rule.

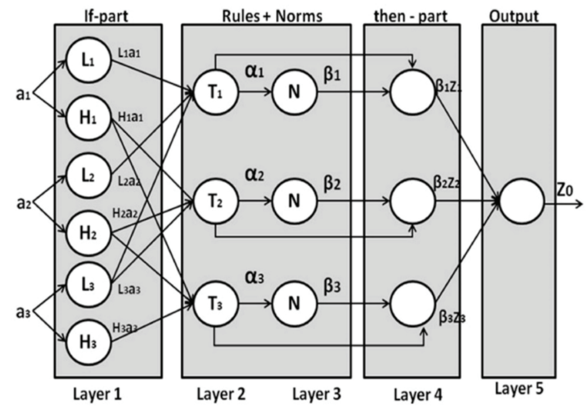

Figure 2. Architectural diagram of Anfis.

The output of the neuron can be calculated by Equations 1 to 3:

$$\alpha_1 = L_1 a_1 * L_2 a_2 * L_3 a_3 \quad (1)$$

$$\alpha_2 = H_1 a_1 * H_2 a_2 * L_3 a_3 \quad (2)$$

$$\alpha_3 = H_1 a_1 * H_2 a_2 * H_3 a_3 \quad (3)$$

Layer 3: The process of normalization takes place in each and every node, denoted by N. Its output is given by Equations 4 to 6:

$$\beta_1 = \frac{\alpha_1}{\alpha_1 + \alpha_2 + \alpha_3} \quad (4)$$

$$\beta_2 = \frac{\alpha_2}{\alpha_1 + \alpha_2 + \alpha_3} \quad (5)$$

$$\beta_3 = \frac{\alpha_3}{\alpha_1 + \alpha_2 + \alpha_3} \quad (6)$$

Layer 4: This layer is generally categorized as the 'then' part; its output is the product of normalization level and the individual rule output, according to the Equations 7 to 9.

$$\beta_1 Z_1 = \beta_1 V B^{-1} . \alpha_1 \quad (7)$$

$$\beta_2 Z_2 = \beta_2 B^{-1} . \alpha_2 \quad (8)$$

$$\beta_3 Z_3 = \beta_3 S^{-1} . \alpha_3 \quad (9)$$

Layer 5: The overall output (Z_0) of the system is computed in this single node as the sum of all the incoming signals, according to the Equation 10.

$$Z_0 = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 \quad (10)$$

Designing steps in FPGA

Step 1: Create Hardware Description Language (HDL) for the proposed model.

Step 2: Generate a netlist file. Netlist files are produced from the HDL description.

Step 3: Netlist files are translated into a Native Generic Database (NGD) file. The NGD file is a single merged file, created by the input design netlists.

Step 4: Native Circuit Description (NCD) file and Physical Constraints File (PCF) are developed. The NCD file represents the physical circuit description of the input design of a specific device.

Step 5: Placement of cells and the routing between them are developed at this stage.

Step 6: Generate bit stream. A bit stream is a stream of data that contains the location information for logic on a device.

Step 7: Upload the bit file into FPGA using a Joint Test Action Group (JTAG) port.

Filter calculations

Based on the proposed simulated model as shown in Figure 3, the hardware setup is used for the experimental analysis and from the resulted hardware waveforms, the inverter frequency (f) is calculated as 49.76 Hz. The cut-off frequency (f_o) should be greater than or equal to 20 times the inverter frequency, according Equations 11 to 14.

$$\text{Cut-Off frequency } (f_o) = 20{*}f = 20{*}49.76 = 995.2 \text{ Hz} \quad (11)$$

$$\text{Therefore, Filter Inductance } (L_f) = \frac{R_d}{2\times\pi\times f_o} = \frac{55}{2\times\pi\times 995.2} = 8.79 \text{ mH} \quad (12)$$

$$\text{Filter Capacitance } (C_f) = 2.5\%\ C_b \text{ F} \quad (13)$$

$$C_b = \text{Base capacitance} = \frac{1}{2\times\pi\times R_d\times f} = \frac{1}{2\times\pi\times 55\times 49.76} = 58.15\mu F \quad (14)$$

$$C_f = 0.025{*}58.15 = 1.45\mu F$$

where:

R_d = Load resistance = 55 Ω.

Results and discussion

Among the various factors, temperature and solar irradiation play a crucial role in deciding the PV output voltage and current. These problems are minimized using neural-fuzzy algorithm in MPPT. The output of the work with Anfis is better than with fuzzy logic control. At steady state, the output from the PV module is 14.1 V as shown in the Figure 4 from which a boosted voltage of 29.5 V as depicted in the Figure 5, is obtained with the help of dc to dc converter. The dc to dc converter is controlled by the ANFIS based MPPT controller. The simulated output when operated from the inverter to the domestic load is 228 V, as shown in Figure 6 which is similar to the output voltage from the hardware model. The peak current taken by the load is 4.1 amps as shown in the Figure 7. Figure 8 shows the load voltage when the load gets energy from the grid in the absence of the solar energy. On observing spectrum analyzer the total harmonic distortion of load current is recorded at 4.80% as shown in the Figure 9 from which it can be decided that it is under the acceptable IEEE standard. The hardware results which are generated from the hardware model shown in the Figure 10 prove the same as obtained from the simulated model.

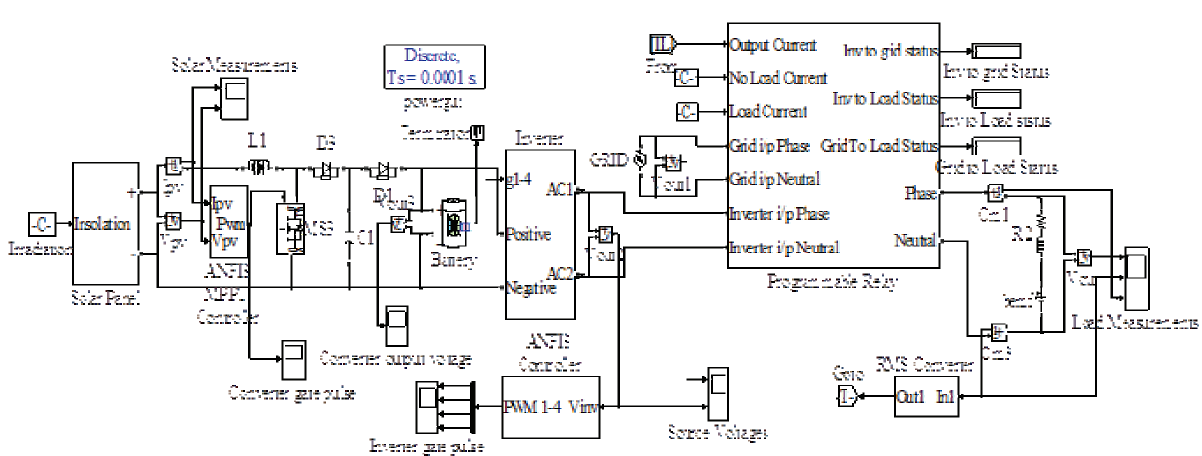

Figure 3. Proposed work in the simulated model.

Generally, change in solar irradiation will cause the PV output current to change considerably but by using the neural-fuzzy algorithm in MPPT, the output voltage of PV module reaches 14.1 V. The duty cycle D is directly proportional to the environmental changes and hence a small change in the environment with solar irradiation or temperature will cause a small change in the duty cycle D. Hence under the standard condition of the environmental parameters, the inverter using the Anfis controller gives a output voltage of 228 V, as shown in Figure 11 of hardware result.

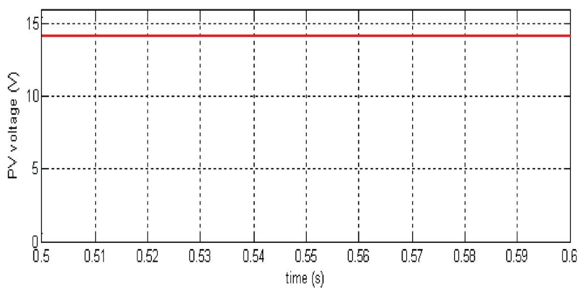

Figure 4. Output voltage of PV module.

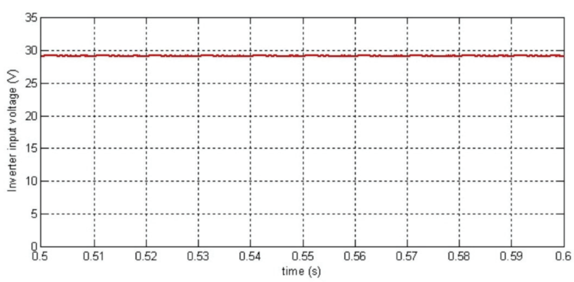

Figure 5. Input voltage to the Inverter.

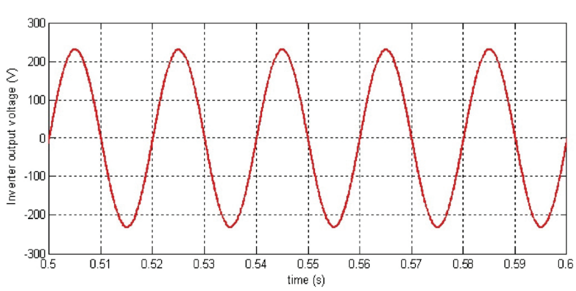

Figure 6. Load voltage when operated from Inverter.

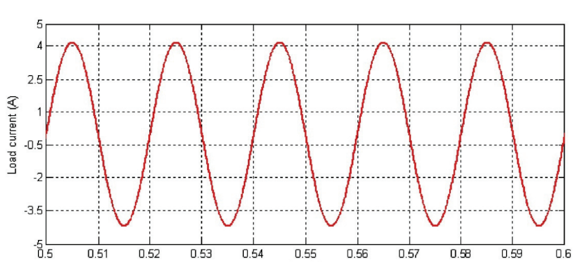

Figure 7. Load current.

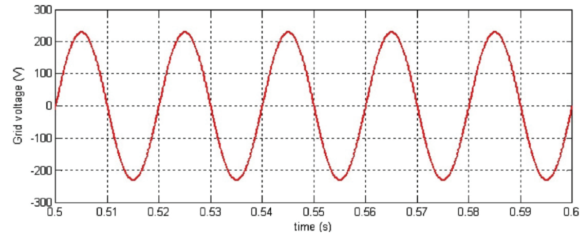

Figure 8. Load voltage when operated from 1 ph AC grid.

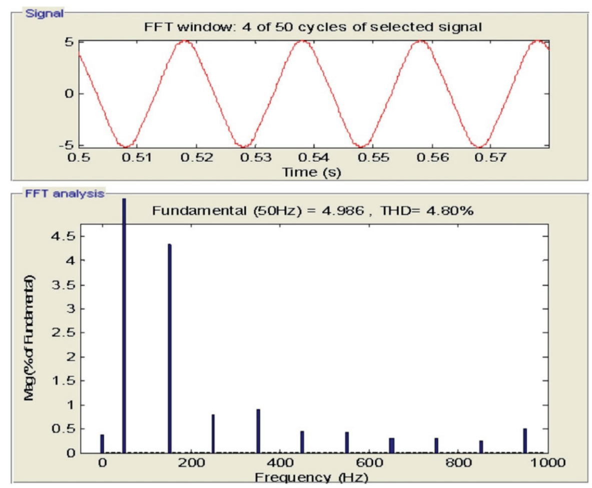

Figure 9. THD spectrum analysis of Inverter output current.

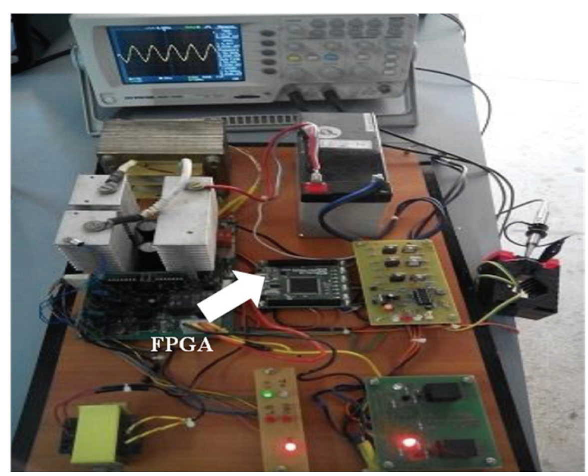

Figure 10. Hardware implementation of the proposed work with Anfis controller in FPGA platform.

Hardware results

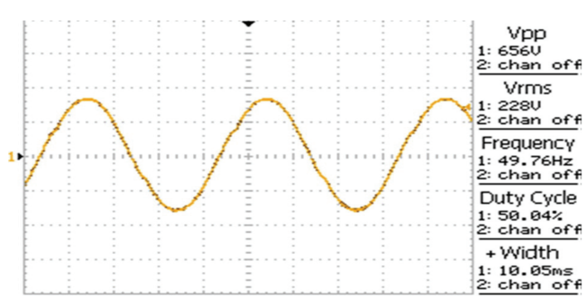

Figure 11. Load voltage when operated from Inverter.

Justifications for using FPGA instead of conventional DSP

i) Easily configurable;
ii) High speed of operation;
iii) Effects of electromagnetic interference can be reduced since hardwires are used;
iv) The operation or data loss will not happen for a long time, even by dangerous alpha and beta radiation.

Justifications for using Anfis over other soft computing techniques

i) Learning duration of Anfis is much shorter than neural network;
ii) Processing large volumes of data is easy with the Anfis technique;
iii) Total error is very small compared to other methods.

Justifications for using programmable relay rather paralleling the solar power and grid power

i) During the grid faces shut down, the energy generated from the photovoltaic panel cannot feed the load, since it will be directed towards the grid;
ii) Likewise if the solar potential is zero, the grid power will damage the solar accessories and batteries;
iii) Hence, to face these problems, the programmable relay is used, since it decides the direction of energy flow according to availability.

Conclusion

The maximum power point technique with the Neuro-fuzzy algorithm in a solar photovoltaic system has been presented in this paper. It gave a better performance even under various environmental changes like solar irradiation and temperature. The overall system has been analyzed, and the performance was studied with Matlab/Simulink. The performance results were validated with the hardware result, with the benefits of FPGA. Even under abnormal temperature and solar irradiation, the system performs well by tracking the maximum power point with help of the Neuro-fuzzy controller.

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