Renewable and Sustainable Energy Reviews 82 (2018) 1313–1319

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Reconfigurable generic FPGA implementation of fuzzy logic controller for MPPT of PV systems

Ayman Youssef[a,*], Mohammed El Telbany[a], Abdelhalim Zekry[b]

[a] Dept. of Computer and Systems, Electronics Research Institute, Giza, Egypt
[b] Dept. of Electronics and Communications, Faculty of Engineering, Ain Shams University, Cairo, Egypt

ARTICLE INFO

Keywords:
Photovoltaic systems
Maximum power point tracking
FPGA

ABSTRACT

In this paper a reconfigurable FPGA implementation for the maximum power point tracking (MPPT) in photovoltaic systems (PV) is presented. The proposed MPPT controller is based on fuzzy logic and operates under variable irradiance and temperature conditions. The fuzzy controller is developed at first using matlab Simulink model. It includes the PV panel, boost converter and MPPT controller. The tested controller is implemented in VHDL. The pro- posed design has the advantage of high flexibility and re-configurability, while maintaining faster response than other hardware implementations. The design has also the advantage of low cost and power consumption. To validate the design, simulation comparison between the Matlab Simulink and VHDL results are provided. The VHDL controller is implemented and synthesized on Spartan 6 field programmable gate arrays FPGA. A graphical user interface GUI is implemented to help the system designer reconfigure the fuzzy controller.

1. Introduction

The sun is one of the most clean and sustainable energy sources. This led many scientists to develop photovoltaic PV systems to harvest the sun energy and convert it to electricity. PV systems however suffer from relatively high installation, and maintenance cost as well as low efficiency. This motivates researchers to search for techniques and methods to increase the system efficiency and hence decrease its cost. MPPT is a technique responsible for match- ing the load resistance to the PV panel resistance to operate it at the maximum power point. There are many classical methods for MPPT techniques introduced in literature. The most widely used algorithm for MPPT is the perturb and observe one [1]. It suffers however from high oscillations in steady state operation. Incremental conductance is a maximum power point tracking algorithm with higher efficiency than perturb and observe [2]. However it has been proven that AI techniques achieve higher efficiency than conventional methods. In [3] artificial neural network with back-propagation learning algorithm is used for MPPT with a high tracking factor. Genetic algorithms are pro- posed also to generate the duty cycle needed for the DC/DC converter. The algorithm is then compared with particle swarm optimization one [4]. The most widely used AI algorithm for MPPT is fuzzy logic one, due to its simplicity, flexibility, and robustness [5]. FPGAs have many advantages over other hardware implementations:

- FPGA implementations offer high flexibility as they can be upgraded by simple re-programming the VHDL code parameters.
- FPGAs offer low cost implementations since various electronic components needed by the controller can be integrated inside one chip or multiple channels can be programmed on a single chip to control different PV systems.

Through our survey process we found that all implementations are fixed designs for specific knowledge base and membership functions or implemented through processors embedded in high cost FPGAs In [6] FPGA implementation of fuzzy logic MPPT controller is proposed, however the imple- mentation depends on embedded processor. This processor is not available in low price FPGAs. Reference [7] provided FPGA im- plementation of a controller for MPPT is proposed. The authors didn't concentrate on the flexibility of the VHDL code.

In [8] a comparative study between AI techniques implemented on FPGA for MPPT is introduced. The designs however needs a knowledge of VHDL to reconfigure for different knowledge bases and membership functions. A new GA optimized Fuzzy logic implementation is presented in [9].

While [10] presented a complete FPGA system for real time simulation and control of grid-connected photovoltaic systems is presented. A review of MPPT based artificial intelligence techniques implemented into FPGA with a complete section on Fuzzy logic is given In [11]. Here,

* Corresponding author.
E-mail addresses: aymanmahgoub@eri.sci.eg (A. Youssef), AbdelhalimZekry@eri.sci.eg (A. Zekry).

http://dx.doi.org/10.1016/j.rser.2017.09.093
Received 22 May 2017; Received in revised form 25 August 2017; Accepted 25 September 2017

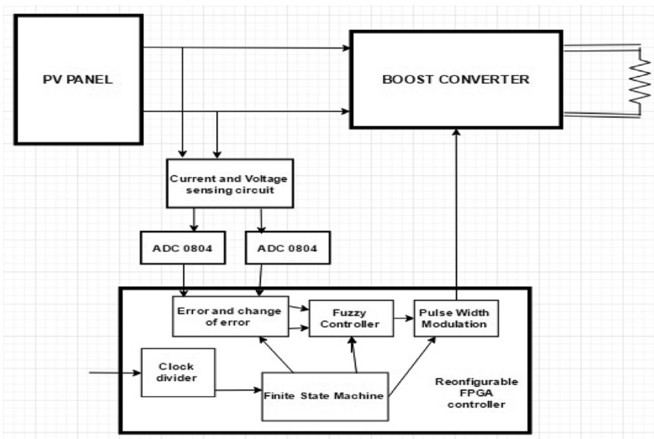

Fig. 1. complete system configuration.

we intro- duce a more general FPGA solution, where introduce a reconfigurable generic all digital hardware implementation of fuzzy logic for the fuzzy MPPT controller. The design can be reconfigured by simple changing of VHDL code parameters. The rest of this paper is organized as follows: Section 2 gives a brief description of proposed system con- figuration. Section 3 describes the Simulink model and software simulations. Section 4 describes the VHDL code of the FLC controller VHDL results and synthesize report. Finally conclusions are presented in Section 5.

2. Proposed system configuration

The proposed system consists as shown in Fig. 1, of PV panels, boost converter, current and voltage sensing circuit and finally the FPGA controller. The current and voltage sensing circuits reads the current and voltage output from the panel. The output is delivered to two external ADC's to convert the sensed values into suitable digital form for FPGA. The FPGA hardware generates the output pulse width modulated pulses controlling the DC/DC converter of the system.

3. Simulink implementation of proposed system

Fig. 2 shows the complete simulink diagram of the proposed system the model contains a model for the PV panel, boost converter, fuzzy controller and pulse width modulation PWM block. In the following sections, the system building blocks will be shortly described.

3.1. PV model

There are three ways to model PV panels:

1. Using experimental data and look up tables, however this method needs sufficient experimental data which may not be available.
2. Simulink blocks, however this method doesn't give the researcher full understanding of the PV panel equations.
3. mathematical model gives the re- searcher full understanding of the PV panel operation with the ability to adjust for different PV panels

A complete mathematical one diode model for the PV panel is implemented and tested in Simulink using equations in [12].

3.2. DC-DC boost converter

This block is responsible of up- converting the input voltage from the PV panel to the desired load voltage. Hence the name boost converter. The design of the boost converter is based on the equations. The critical values of the boost converter coil and capacitor are calculated based on the equations in [13].

3.3. Pulse width modulation generator

The pulse width modulation block is responsible of generating the clock for the boost converter. The clock is controlled by the duty cycle output from the fuzzy con- troller.

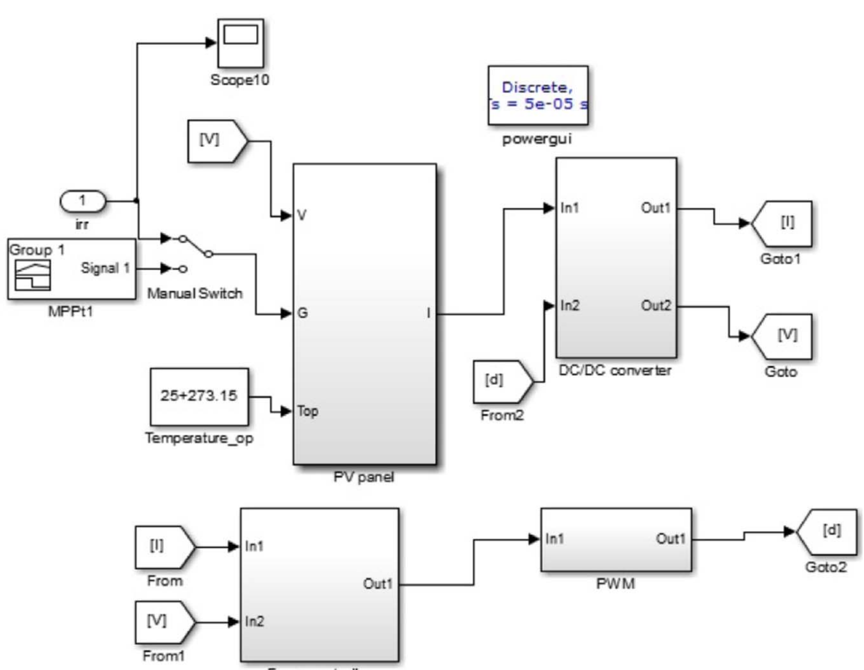

Fig. 2. Simulink model of the system.