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FPGA BASED CONTROLLER FOR FUEL CELL

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ABSTRACT

This thesis primarily focuses on reduction and the complexity of a fuel cell controller and research carried out in the modeling of a renewable energy sources like fuel cell. A fuel cell, one of the recently identified electrical energy resource, provides clean power with high efficiency which undergoes certain chemical reactions to produce electrical power using hydrogen as the fuel and oxygen as an oxidizing agent. Apart from its high efficiency, the fuel cell does not require charging and recharging like batteries since they use the chemical energy without combustion. The goal of this thesis is to examine the possibility of FPGA based hardware prototyping for a complex fuel cell system, so that we can use this system controller efficiently for controlling the voltage. The overall work in this thesis aims to promote professional activity in the area of fuel cell controller and low power electronics used in the modern age, with an important focus on the design, development, simulation, and verification, and to examine the possibility of using Field Programmable Gate Arrays (FPGA) for the rapid prototyping of a PI+PWM digital electronic controller, which is made up of two main component, fuel cell stack and boost converter.

KEYWORDS: PWM, Boost Converter, FPGA, PEM fuel cell.

INTRODUCTION

The specific hardware technology such as Field Programmable Gate Array (FPGA) is an appropriate solution to improve the performance of controllers and work on specific features of circuits with low power consumption. Fuel cells offer numerous advantages over conventional power plants to help them achieve that goal and widespread adoption, such as:

- High efficiency, even at part-load
- Few moving parts resulting in quiet operation, higher reliability, lower
- maintenance and longer operating life
- Fuel diversity
- Zero or low emission of greenhouse gases
- Combined Heat and Power (CHP) capability, without the need for additional
- systems (i.e., low temperature fuel cells can provide district heating while high
- temperature fuel cells can provide high-quality industrial steam) Flexible, modular structure.
- Increased energy security by reducing reliance on large central power plants and oil imports.

MATERIALS AND METHODS

FUEL CELL APPLICATIONS

As a result of the inherent size flexibility of fuel cells, the technology may be used in applications with a broad range of power needs. This is a unique feature of fuel cells and their potential application ranges from systems of a few watts to megawatts.

Fuel cell applications may be classified as being either mobile or stationary applications. The mobile applications primarily include transportation systems and portable electronic equipment while stationary applications primarily include combined heat and power systems for both residential and commercial needs. In the following, fuel cell applications for transportation, portable electronic equipment, and combined heat and power systems are addressed.

PEM Fuel Cell Model

PEM fuel cell is an electrochemical device which generates electricity from the chemical reaction of the species called the fuel (oxidizing species at anode liberate free electrons) and the oxidant (reducing species at cathode accept free electrons) to produce water. The electrons liberated at the anode by the oxidizing species are made to flow through the external circuit, which constitute the current, by making the electrolyte (a polymer membrane) impermeable to electrons, but permeable to the protons. The electrons from the external circuit and protons passing through the electrolyte react at the cathode to form water.

Fuel Cell system Implementation in system level language

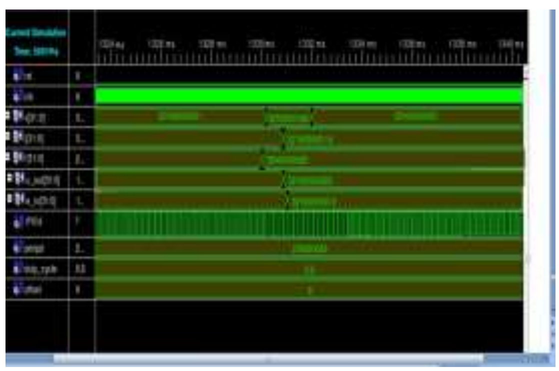
This thesis describes holistic modelling of the fuel cell different techniques of the voltage converter, and different techniques of digital controller design, and hardware prototyping of a 2.4 kW fuel cell energy system for supplying a 96v dc voltage load. There are certain advantages of this thesis, such as: the modelling of fuel cell, parameter evaluation of fuel cell hardware prototyping of the digital controller PI+PWM).

How Fuel Cell Works

Fuel cell is an electrochemical device that azgenerates electricity by the separation of fuel through a catalyst. The protons flow via membrane combines with oxygen to form water, again with the help of the catalyst. In order to create electricity the electrons flow from anode to cathode. A single fuel cell is a piece of plastic between the couple of pieces of carbon plates which are positioned between the two ends which act as electrodes and these plates have channels that distributes oxygen and fuel. Though hydrogen is the most common fuel utilised to power fuel cell, research is performed on new type of fuel cell that handles using methanol and oxygen. The basic physical structure or building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side. A schematic representation of a fuel cell with the reactant/product gases and the ion conduction flow directions through the cell is shown in Fig. 2.1.

Figure:

RESULTS AND DISCUSSION



TestBench Waveform OF The Fuel Cell System Using XILINX ISE Simulator

In the above Test Bench when the resistance has changed, current and voltage has also changed, but voltage settled to its previous value after a short time. In the above test bench waveform u_out and e_in are output and input of the PI controller respectively. We can see that the error signal e_in got scaled with the help of PI controller. Duty Cycle of PWM got changed due to change in the error signal. For above simulation we have taken simple hexadecimal value instead of floating point data, we can take floating point data for a better precision.

Buck Converter working principle

The operation of the buck converter is very simple, with an inductor and two switches (a transistor and a diode) that control the inductor. Two switches come into action and alternate between connecting the inductor to voltage source to store energy in the inductor and discharging it into the connecting load. The inductor L and capacitor C in Fig.3.1 contributes into the filtering to avoid from the current, and voltage ripple respectively. Diode in the figure is a freewheeling diode, to ensure a continuous flow of the current into the circuit. The output voltage of the circuit can be controlled by the duty cycle D given by D +ton .

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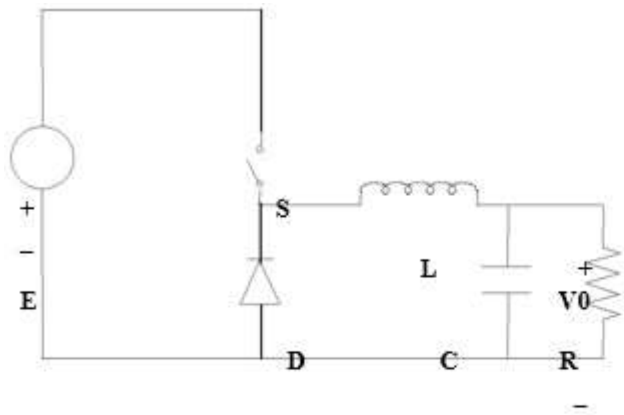
Output voltage vo is always lower than input voltage vi hence, we can also call this converter a "Buck Converter"



Schematic of Buck Converter

Boost Converter working principle

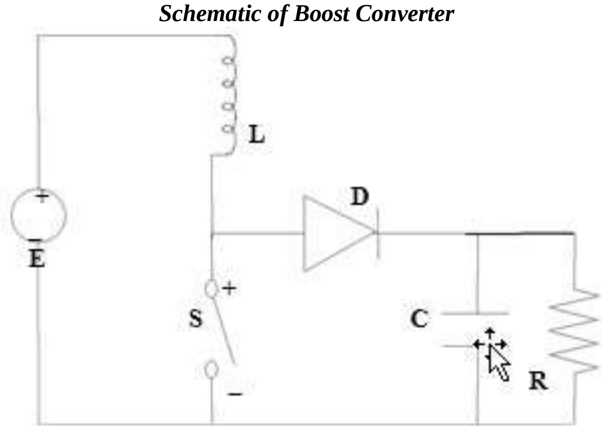
A boost converter (in Fig.3.4) is a dc to dc voltage converter with an output dc voltage greater than input dc voltage. This is an SMPS containing at least two semiconductor switches (a diode which act as freewheeling diode two ensure a path of the current during the off state of other switch and a transistor connecting in series of the source voltage). Filters made of capacitor and inductor is used to reduce the ripple in voltage and current respectively, is used at the output stage of the converter.

Operating principle

The basic operating principle of the converter consists of the two distinct states.

1) In on state, switch is closed, resulting in an increase in the inductor current.
2) In off state, switch is open, resulting in decrease in the inductor current.

Schematic of Boost Converter



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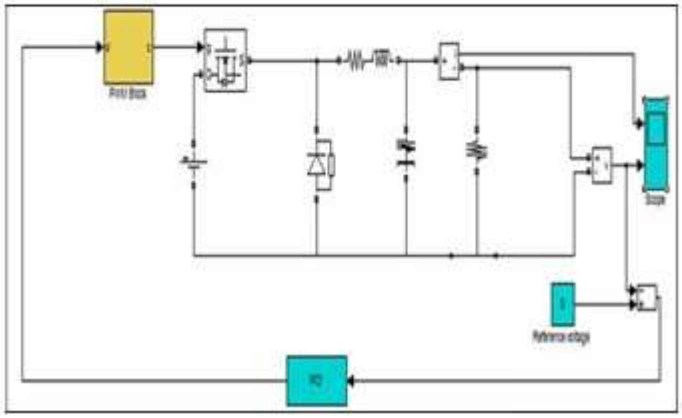
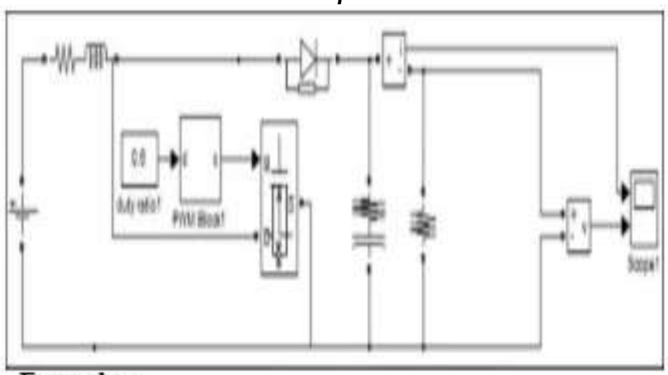
Simulink Model Of Buckt Converter



Simulink Model Of Boost Converter



Formulae:

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Reaction at Anode:

$2H_2 \rightarrow 4H^+ + 4e^-$

Reaction at Cathode:

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

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I.Nernst voltage (ECell):

The overall reaction in a PEM fuel cell can be simply written as

$2H_2 + O_2 \rightarrow 2H_2O$ (5)

CONCLUSION

In order to examine the possibility to implement digital controller based on FPGA prototyping, a new method is proposed and analyzed. The proposed digital controller is able to control the output of any renewable energy sources. A method to synthesized whole fuel cell power system is developed using VHDL. This approach using VHDL is applied to a fuel cell power system of 2.4 kW and 96 v is. The proposed method is simulated, and the results demonstrate appropriate performance of the system and controllers. This thesis presents a very simple and reasonable approach to model a particular PEM (Polymer electrolyte membrane) fuel cell, and its real time debugging using SPARTAN3E board. Initially the system were simulated in Matlab/Simulink, to make a reference for VHDL implementation, after the Matlab/Simulink modeling, fuel cell system model has developed in VHDL by using some approximation and assumption. The work carried out in this thesis has allowed to prototype hardware of fuel cell controller.

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