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Interleaved Boost Converter for Fuel Cell Fed

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ABSTRACT

One of the biggest problems that the world is facing in recent times is a global energy crisis. This is why there has been a massive shift in focus to finding sustainable and efficient alternative energy sources like solar, wind, hydraulic and clean energy like fuel cell. Low cost, high efficiency, compactness, portability and environmentally clean energy has enhanced the research on fuel cell. In this paper, a prototype model of a Proton Exchange Membrane (PEM) fuel cell (FC) based Tiny Power Producing (TPP) unit has been developed and the dynamic behavior are studied. PEMFC has been chosen due its low operating temperature and little start-up time. One of the factor which affects the life time of the fuel cell is ripple content. Boost converter is used in order to supply high voltage and low current applications. The performance and lifetime of fuel cell can be further improved by employing interleaved boost converter. Also the output voltage can be maintained at a particular value through controllers. The conventional PI controller is designed for fuel cell fed interleaved boost converter in order to track the output voltage and to improve the transient time. The results depict the validity of the design procedure and the potential of the proposed method.

Keywords-Conventional PI controller, Interleaved Boost Converter, Fuel Cell.

I. INTRODUCTION

The consumption of electrical energy has increased many folds all over the world due to its several advantageous features. Limited fossil fuels resources and their impact on environment forced the researchers to explore alternative energy sources [1]. The alternative energy source is generally defined as any power source that is not based on fossil fuels or nuclear reactions which includes power generation from wind power, solar energy, geothermal, biomass, plant matter and mini hydropower etc. Alternative fuels also include ethanol from com, bio-diesel made from vegetable crops and methane made from waste [2]. The main advantages of these renewable energy sources (RES) are that they are pollution free, inexhaustible and easily accessible [3]. Among them is the Fuel cells which are not only characterized by higher efficiency than conventional power plants, but they are also environmentally clean, have extremely low emission of oxides of nitrogen and sulphur and have very low noise.

PEM fuel cell is considered to be a promising power sources especially for transportation and stationary cogeneration applications due to its high efficiency, low temperature operation, high power density, fast startup, ultra-low emission, and system robustness [3]. PEM fuel cells are suitable for portable, mobile and residential applications [4]. In most stationary and mobile applications, fuel cells are used in conjunction with other power conditioning converters and a circuit model would be beneficial, especially for power electronics engineers who

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in many cases have the task of designing converters associated with the fuel cell for various load applications [5].

In order to supply a constant of high voltage and low current loads, the output of low voltage and high current from the fuel cell has to be boosted by some DC/DC converter. The DC-DC Converter is an integral part of fuel cell power conditioning unit. The design of DC/DC converter and their controller plays an important role to control power regulation particularly for a common DC bus. The boost converter offers higher efficiency and less component counts compared to other DC/DC converters topologies like push pull, half bride and full bridge etc. which could possibly be used to interface fuel cell system to the load. Using the simple boost converter circuit will introduce more ripple content in input current. Sharp increase and decrease in input current will reduce the performance and also the life time of the catalyst of fuel cell. To avoid this problem interleaved boost converter is employed. Paralleling the N number of boost converter circuit will make an interleaved boost converter. The input current is divided into N number of paths so the ripple at the output side is reduced drastically. When the load is varied or when the input level to the fuel cell is reduced then the output voltage reduced correspondingly. So this setup may not be able to supply for constant load like grid.

This paper proposes the design of the interleaved boost converter and control method to track the output voltage at a particular level using Conventional PI controller. These controllers will track the output voltage to the referred value. This paper is organized as follows. Section II presents the basics of the PEM fuel cell. Section III presents the interleaved boost converter. Section IV presents the basics of voltage mode controllers. Section V presents the mathematical modelling of voltage mode conventional PI controller. Section VI presents the mathematical modelling of smith predictive controller. Section VII presents the simulation results and comparison of both controllers. Section VIII presents the conclusion.

II. PROTON EXCHANGE MEMBRANE FUEL CELL

The fuel cell is an electrochemistry device, which produces electricity directly and efficiently and emits pure water and gases. On the other hand, the power density of a typical fuel cell is 200 to 300 Wh/L which is nearly ten times that of a battery. Therefore, it has received great attention in DG and electrical vehicles. Proton exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells (PEMFC) [3], are a type of fuel cell being developed for transport applications as well as for stationary fuel cell applications and portable fuel cell applications. Their distinguishing features include lower temperature/pressure ranges (50 to 100 °C) and a special polymer electrolyte membrane. PEM fuel cells are the most popular type of fuel cell, and traditionally use hydrogen as the fuel [1], [2].

A. Operation and Basic Principles of Fuel Cell

A fuel cell is a static energy conversion device that converts chemical reaction of fuels directly into electrical energy with some heat and produces water as its by-product [13]. The chemical reaction sustains as long as fuel and oxidant supply is maintained. Fig. 1 shows a simple arrangement of fuel cell system. The chemical reaction involved in the anode, cathode and electrolyte membrane for the production of electricity is given below:

Anode reaction $H_2 \Rightarrow 2H^+ + 2e^-$ (1)

Cathode reaction $\frac{1}{2}O_2 + 2H^+ + 2e^- \Rightarrow H_2O$ (2)

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Overall reaction $H_2 + \frac{1}{2} O_2 \Rightarrow H_2O$ (3)

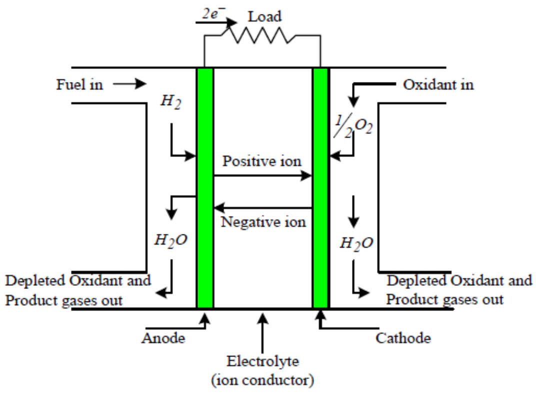

Fig. 1. Schematic of an Individual Fuel Cell

For both these reactions to proceed continuously, electrons produced at the anode must pass through an electrical circuit to the cathode. Also, H+ ions must pass through the electrolyte. An acid is a fluid with free H+ ions, and so serves this purpose very well. Certain polymers can also be made to contain mobile H+ ions and are called Proton exchange membrane, as an H+ ion is also a proton.

B. Losses Presents in Fuel Cell

1. Activation losses

These are caused by the slowness of the reactions taking place on the surface of the electrodes. This voltage drop is highly non-linear.

2. Fuel crossover and internal current

This energy loss results from the waste of fuel passing through the electrolyte.

3. Ohmic losses

This voltage drop is the straightforward resistance to the flow of electrons through the material of the electrodes and the various interconnections, as well as the resistance to the flow of ions through the electrolyte.

4. Mass transport or concentration loss

These result from the change in concentration of the reactants at the surface of the electrodes as the fuel is used. The reduction in concentration is the result of a failure to transport sufficient reactant to the electrode surface, this type of loss is also often called mass transport loss.

C. Polarization Curve

Stack voltage of the PEMFC is given by the following equation [3],

$V_{stack} = V_{reversible} - V_{activationloss} - V_{ohmicloss} - V_{concentrationloss}$ (4)

where, $V_{reversible}$ = Reversible voltage.

$V_{activationloss}$ = Activation loss.

$V_{ohmicloss}$ = Ohmic loss.

$V_{concentrationloss}$ = Concentration loss.

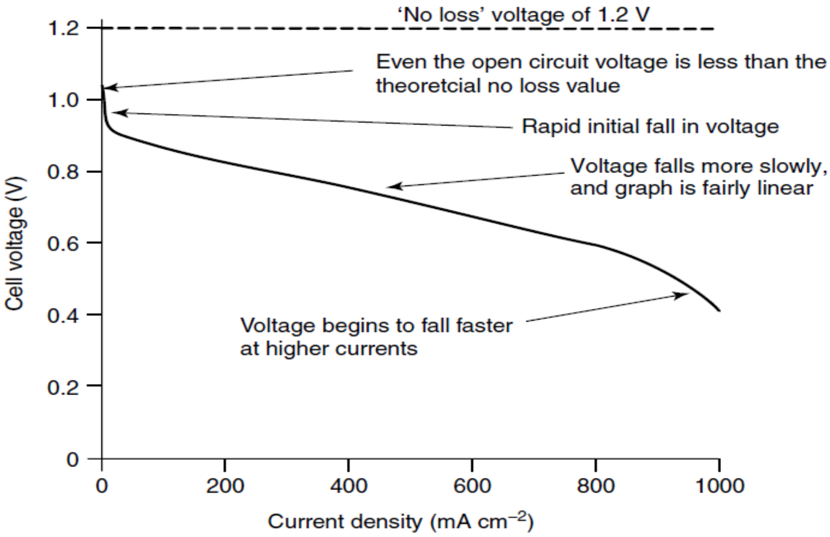

Fig. 2. VI Characteristics of Fuel Cell

III. INTERLEAVED BOOST CONVERTER

Number of boost converters connected in parallel is called as interleaved boost converter. It shares the common source and common load. That is the source current is shared between the numbers of converters connected in parallel [9], [10].

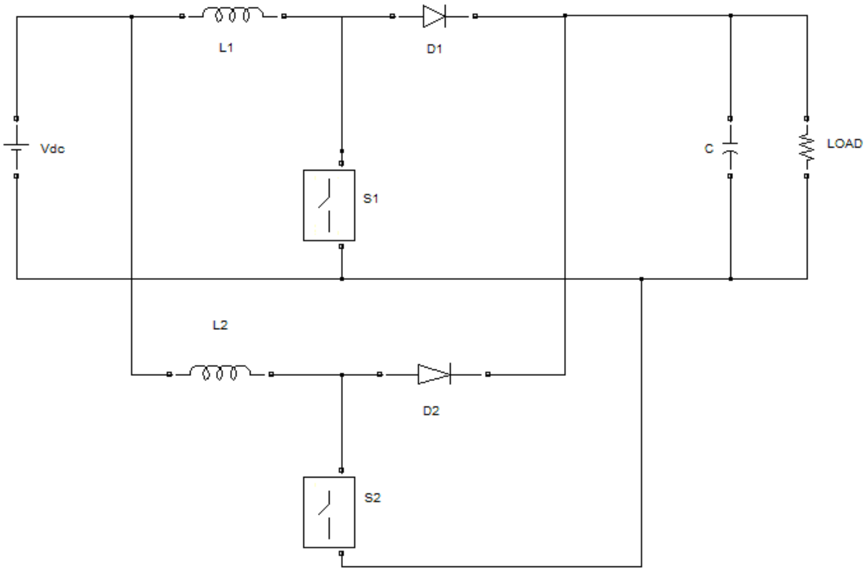

Fig. 3. Interleaved Boost Converter

So the current stress on the single converter is reduced by interleaving. Therefore the ripple at the current is reduced automatically by providing the phase shift between the numbers of converters connected in parallel. Where n is the number of converter connected in parallel. And each converter is rated for equal power rating.

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TABLE: 1 INTERLEAVED BOOST CONVERTER PARAMETERS

Parameters	value
L	161.95 µH
R	10 Ω
C	220 µF
F	100 kH
V_{in}	24 V
D V_o	53 % 48 V

Fig.4. Basic block diagram of the system

IV. VOLTAGE MODE CONTROLLER

To track the output voltage at a particular referred value, output feed controllers has to be implemented [12]. The first step in designing the conventional PI controller is to get the error signal by comparing the output voltage with the reference value. And the controlled error signal is obtained by passing the error signal to the conventional PI controller.

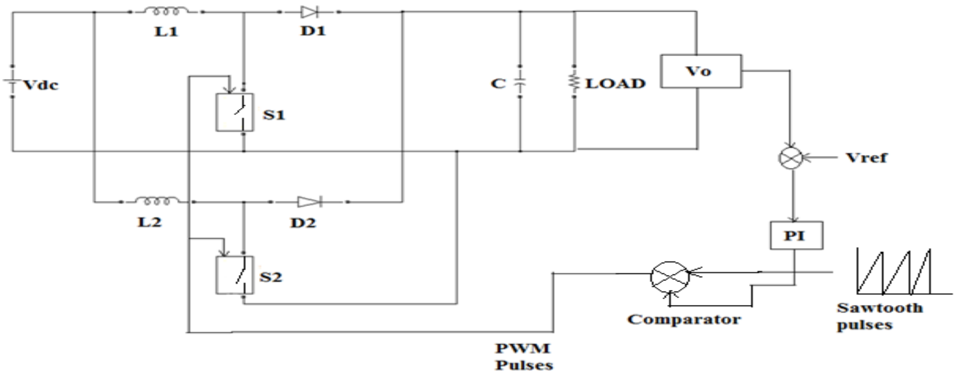

Fig. 5. Closed loop control of ILBC

The error amplifier may be any type of controller like P, PI, PID. This error amplifier produces the control signal which is then compared with the constant amplitude of saw tooth waveform in order to generate the PWM pulse signals to the switch. The duty ratio of PWM signal depends on the value of the control voltage. The frequency of the PWM signal is the same as frequency of the saw tooth waveform.

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V. SIMULINK MODEL

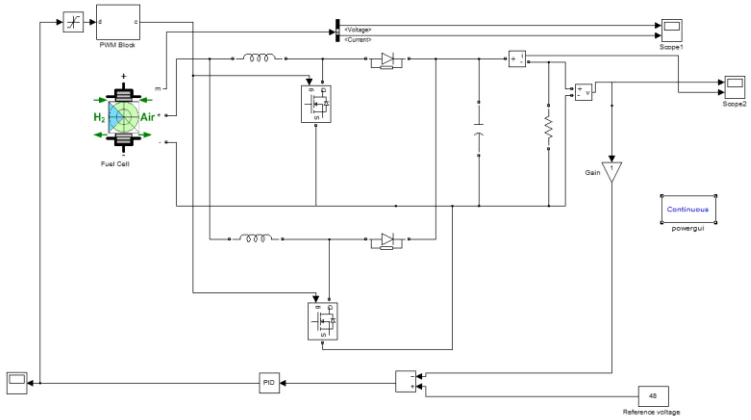
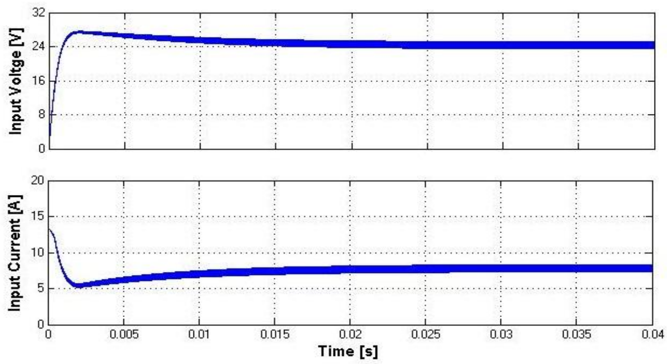


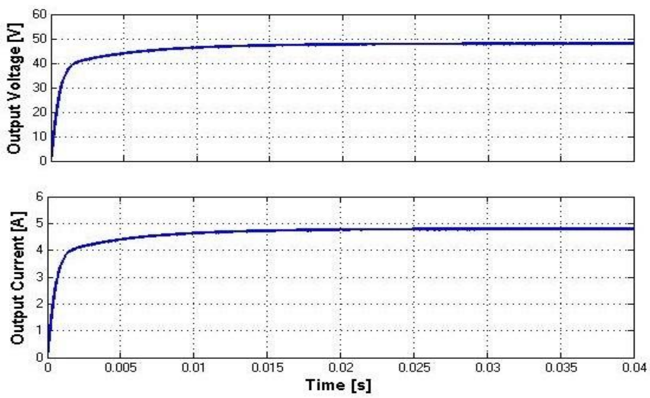
Fig. 6. Model of closed loop control of fuel cell fed ILBC system

VI. SIMULATION RESULTS

A. Voltage mode conventional PI controller for fuel cell fed ILBC system



(a)



(b)

Fig.7. (a) fuel cell voltage and current waveforms (b) output voltage and current waveforms

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B. Function of ILBC is expressed by the following graph

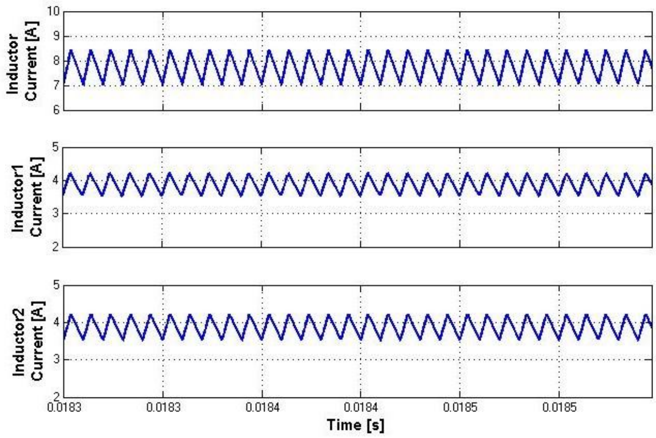

Fig. 8 The current gets divided equally between the inductors.

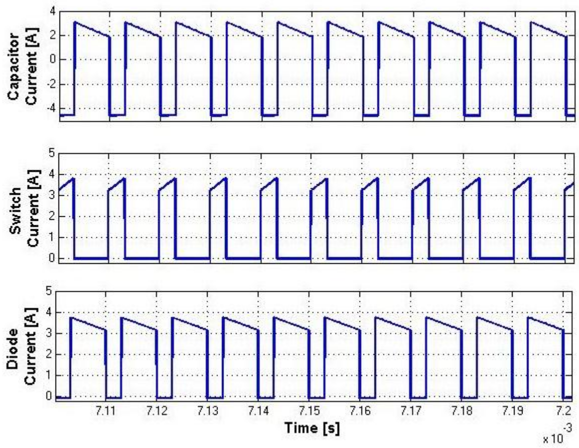

Fig.10 The current through various devices

VII. CONCLUSION

This paper gives an exhaustive description procedure of a controller applied for interleaved boost converter. Design of voltage mode controller for ILBC system is obtained by using the PID control. And this method overcomes the problem of conventional boost converter design. Ripple current and stress on the devices has been reduced considerably.

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