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Implementation of Three Phase High Voltage Gain Boost Converter for Fuel Cell

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ABSTRACT

Generally, the power generating from the Fuel cell is an electrochemical reaction between H2 and oxygen and it generates electric energy, and the by-product is water vapour. However, the output from the fuel cell systemsis very low, then it becomes necessary to connect more number of cells in series to improve the output. The proposed method electrically divides the fuel cell stack into different sections, and each stack is powered by a direct boost inverter. This paper proposes a concept of high voltage dc-dc boost converter topology for a three phase systemto a typical output voltage from the fuel cell as a stand-alone supply. The main advantage of the proposed boost inverter method include ability to deliver the operations of both boosting and inversion of the power in only one stage, compactness, and economical. The output voltage from the fuel cell is a voltage controlled method and output from the battery is a current controlled method. Analysis, and Simulation are taken from a 1kW prototype.

Index Terms: *Fuel cell stack, remote area power supply, three-phase boost-inverter, Battery Storage system.*

INTRODUCTION

In the present scenario, generally the increasing electrification of daily life causes growing electricity consumption, rising number of sensitive/critical loads demand for high-quality electricity, the energy efficiency of the grid is desired to be improved [1]. The output from the Fuel cells are obtained by electrochemical reaction between H2 and oxygen.Generally, the fuel cell stacks are obtained by series connection of several individual fuel cells, which are equivalent to series connection of general voltage sources, with its internal impedance.

In order to eliminate the disadvantages of Fuel Cell power controlling systems a single phase fuel cell energy system with single power conversion based on the single stage boost inverter is proposed. This paper compared with different types of dc–dcConverters and dc–ac inverters, including voltage source and current source, e.g., a boost converter followed by a voltage source based inverter, single-stage current source based inverter, and z-source inverter. Specifically, CSI and z-source inverters provide boost and inverter functions in a only one and a wide input voltage range, while limited input voltage lower than the peak grid voltage and insufficient voltage gain are considered. In [2] three-phase boost-inverter topology was proposed including sliding mode control technique and small signal analysis. However, this paper also introduced the boost-inverter topology in the context of a complete three-phase stand-alone energy conversion system based on such topology and sourced by an FC while addressing specific converter and overall control design requirements of the FC that needs to be supported by a battery based back-up unit [3]. For instance, the proposed three-phase stand-alone FC power supply can be used as a remote area power supply.

PROPOSED FC ENERGY SYSTEM

The main objective of this paper is to propose a 3-phase FC stand-alone power supply having only single energy conversion converter along with a back-up unit is shown in Figure 1. The cost of this proposed system is reduced by making the multi stage conversion system with a single stage system, i.e. boost-inverter due to this the switching losses and conduction losses are also reduced.

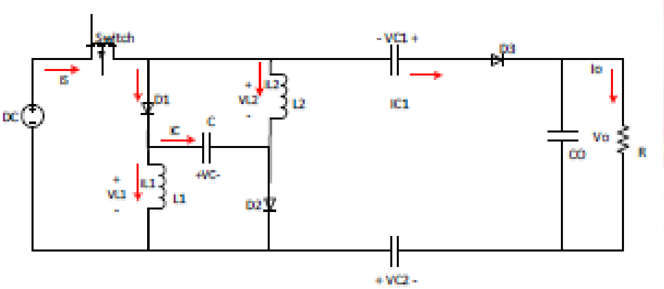

Figure 1: FC sourced based on the three-phase boost-inverter

Generally, the diagram shown in Figure 1 shows thatboost converter is followed by the Fuel Cell and the back-up energy storage system, these two converter are connected at the same bus and output from the boost inverter is a three phase AC and it is connected to three phasebalanced star connected resistive load [4].The Fuel Cell system hasoperated in current mode controlled bidirectional converter for battery converter to support the Fuel Cell.

Boost Converter Using Voltage Multiplier Circuit:

Typically, during day time, electrical load in Indonesia islower compared to peak load. Therefore in order to improvegeneration efficiency, during day time energy from the grid isused to generate hydrogen through electrolyzer. Then, storedhydrogen is required to generate electricity for the peak load.To achieve a high converter output the boost converter circuit,it is combined with a voltage multiplier circuit. The advantagesof this circuit boost converter is a simple system circuit so thateconomically reduce the cost of construction and able togenerate high gain with decreasing MOSFET rating as theautomatic switch. Disadvantages of this converter circuit areless efficient level and the number of power losses that occurin the circuit. Fig. 1 shows a series of a boost converter with avoltage multiplier.

In this proposed concept the 3-ø boost inverter is separated to three individual converter for three phase arms and connected to three individual balanced loads, as shown in Figure 1. The dc-biased three phase output voltages are described by

$$V_a = V_{dc} + A_o \cdot \sin\theta$$
$$V_b = V_{dc} + A_o \cdot \sin\left(\theta - \frac{2\pi}{3}\right)$$
$$V_c = V_{dc} + A_o \cdot \sin\left(\theta + \frac{2\pi}{3}\right)$$

In the above equation Ao is the peak amplitude of line-to-neutral voltage and Vdc is dc voltage across each converterwhich is greater than Ao + V_{in}. In this boost converter generates ac output voltage with dc bias, so that the output voltage generated from the boost converter is greater than the input voltage from the fuel cell and have equal magnitudeThe dc components are canceled in the [5]

Three-phase three-wire balanced output and the expression for line to line voltages are

$$V_{ab} = V_a - V_b = \sqrt{3}A_o \cdot \sin\left(\theta + \frac{\pi}{6}\right)$$
$$V_{bc} = V_b - V_c = \sqrt{3}A_o \cdot \sin\left(\theta + \frac{5\pi}{12}\right)$$
$$V_{ca} = V_c - V_a = \sqrt{3}A_o \cdot \sin\left(\theta - \frac{5\pi}{12}\right)$$

However, the line to neutral voltages are expressed as,

$$V_{an} = \frac{2}{3}V_a - \frac{1}{3}V_b - \frac{1}{3}V_c = V_a$$
$$V_{bn} = \frac{2}{3}V_b - \frac{1}{3}V_a - \frac{1}{3}V_c = V_b$$
$$V_{cn} = \frac{2}{3}V_c - \frac{1}{3}V_a - \frac{1}{3}V_c = V_c.$$

This paper also proposes the concept of double closed loop control system for controlling boost inverter. Specifically, this control method provides stable operating condition using direct current control of the inductor even in special conditions such as nonlinear loads, load variations, and transient short circuits.

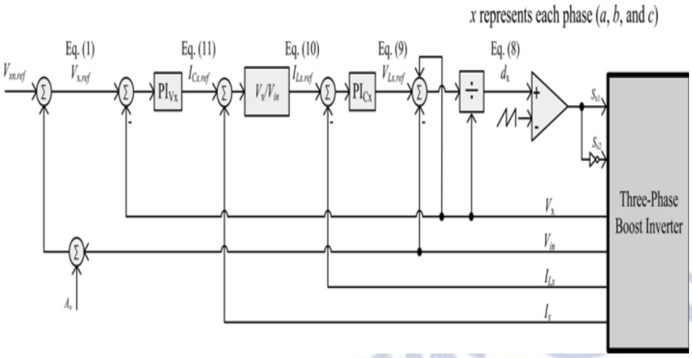

Figure 2: Control block diagram of the three-phase three-line boost-inverter

Figure. 2 shows the control block diagram of the three-phase boost-inverter including the voltage and current control loops [6]. The voltage errors are obtained by the comparison of combination of dc offset voltage with ac amplitude and the output actual three phase voltages. These voltage errors are processed by PI controller to generate capacitor current references. When the capacitor current references and the output current are applied with the block (Vx /Vin) and each reference currents of the inductorare compared with the feedback currents of the inductors (Lx) to produce the current errors [7]. Then, the inductor voltage references are provided using PI controller for current with the current errors. Finally, the duty cycles determined for boost inverter circuit.

BATTERY STORAGE BACK-UP UNIT

The battery energy storage system are in the form of electrochemical and is most widely used for energy storage purpose in variety of applications. Forobtaining the mathematical model calculations for observing the performance, the configuration of battery is represented in [8] by its equivalent electrical circuit shown in the Figure 3.

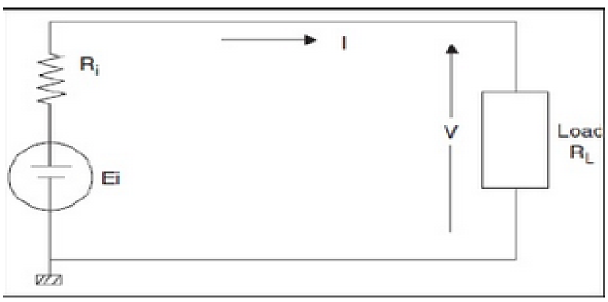

Figure 3 single line diagram for battery internal voltage and resistance

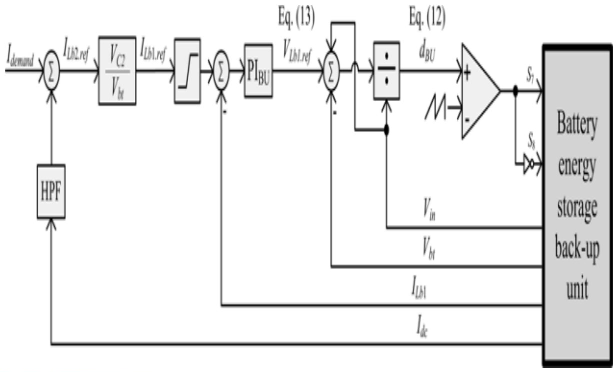

Figure 4: Control Diagram for Battery Energy Storage system

The closed loop control diagram for the battery energy storage system is shown in [9] Figure 4. The duty cycle for the back-up unit based on the averaging concept can be expressed by using

$$v_{\text{in}} - v_{Lx} = (1 - d_x) \cdot v_x$$

SIMULATION DIAGRAM AND WAVEFORMS:

The experiments for the fuel cell system along with boost inverter is obtained by the Figure shown in 1.These experiments are verified in Matlab/Simulink and the parameters considered for this system is shown in table 1. In this case study we considered the input voltage from the fuel cell is nearly 42V and the ac line to line output voltage obtained is 210V. The Simulation diagram for this system is shown in Figure 5.

PARAMETER	RANGE
AC OUTPUT VOLTAGE	210V, 50Hz
Switching Frequency	20kHz
Rated Power	1kW
La=Lb=Lc	700 micro H
Lb1=Lb2	700 micro H
Ca=Cb=Cc=C1=C2	20 micro F

Table 1: System Parameters

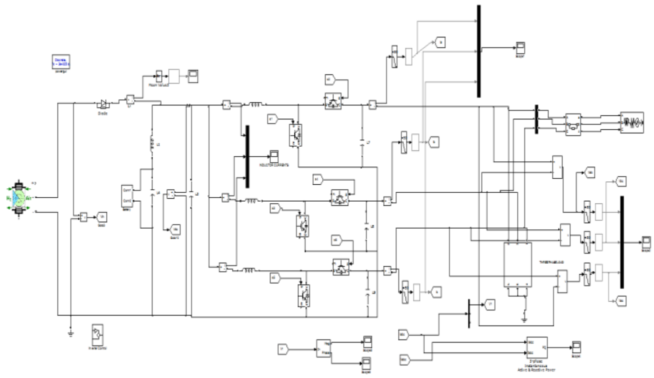

Figure 5: Simulation Diagram for grid connected Fuel Cell system based high Voltage DC-DC Boost-Inverter

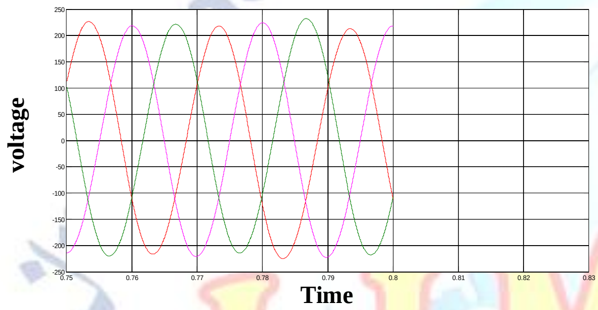

Figure 6: Simulation result for three Phase line-line output voltage

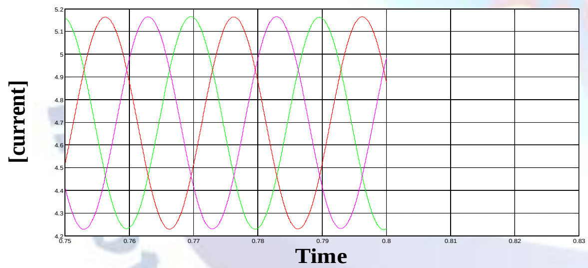

Figure 7: Simulation result for three phase output current

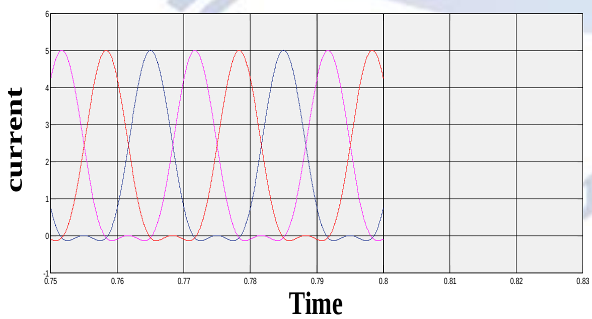

Figure8: Simulation result forInductor currents

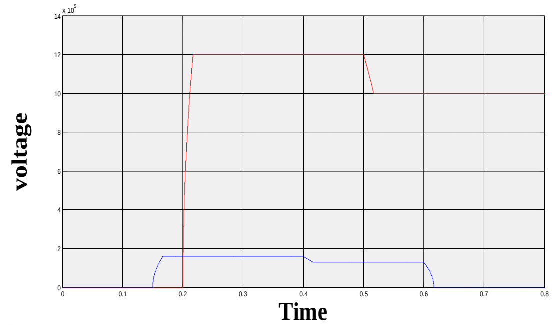

Figure 9: Simulation result forActive and reactive Powers

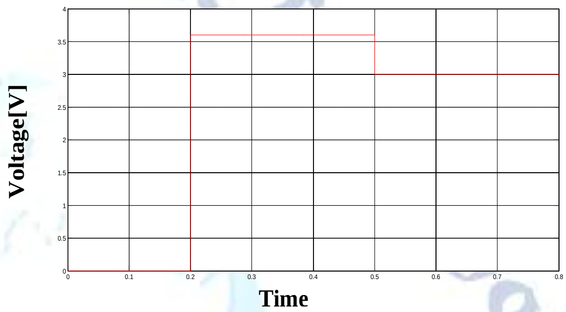

Figure 10: Simulation result forVoltage variation

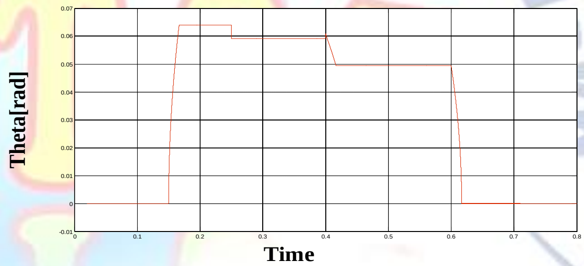

Figure 11: Simulation result forDelta variation

The Simulation experiment is done for the fuel cell system with three phase boost inverter and verified the results. The Simulation results of the three phase output voltage of the boost inverter is shown in figure 6. Figure 7 shows the simulation result for three phase output currents. In this system we considered only pure resistive load. Therefore, the output current is proportional to voltage. Figure 9 shows the output active and reactive power variations under system variation in system conditions. And finally the figure 10 and figure 11 shows the variations in system voltage magnitude and phase angle respectively.

CONCLUSION

A stand-alone 3-ø Fuel Cell power supply based boost converteralong with a battery energy storage system has been successfully proposed. With these Simulation results the operational characteristics of FCBI has been understand. The results of the proposed 3-ø FC supply have confirmed its satisfactory performance in delivering boosting and inversion functions in one conversion stage to generate 210 Vacat rated power. The back-up unit key function is to support the slow variations of the Fuel Cell. Finally, the efficiency of this proposed boost inverter fuel cell system is improved with its single stage conversion process and from economical point of view it is better than all other conventional converters. It is in compact size because of usage of less number of switching devices.

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