International Journal of Scientific & Engineering Research, Volume 4, Issue 6, June-2013 2384
ISSN 2229-5518

Analysis of Fuel Cell System including Inverter Control Strategy

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Abstract— Renewable Energy has been playing an important role in the world over the last few years. Due to massive increase in prices of fossil fuels as well as alarming rate of environmental pollution, researchers and scientists are paying good number of attentions towards this energy and technology. Among various sources of renewable energy, fuel cell technology is becoming quite popular now a days. This paper presents a comprehensive analysis of fuel cell system using inverter control strategy. The results of this control strategy have been verified by the time domain simulation model developed in MATLAB/SIMULINK

Index Terms— fuel cell, PWM Generator, simulation, voltage source inverter, z source inverter.

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1 INTRODUCTION

FUEL cell systems are new sustainable energy sources compared to other technologies. Fuel cells have a good number of advantages like high efficiency, modularity, high power, low noise etc. Another advantage of this technology is they can be placed on any part of the distributed system. Among fuel cells PEMFC is used in different applications. Proton exchange membrane fuel cell (PEMFC) has a number of advantages. This type of fuel cell is generally used for low temperature and transportation. Grid-tied application is now major concern. Nowadays PEMFC based power system design and other electronic designs are developed to meet the power demand. Fuel cell has already been proved for transportation and in space shuttles due to their light weight and compact size [1]. The most promising technology is to connect fuel cell systems in the grid with other types of renewable energy sources and finding its feasibility and stability. For low noise, waste free output and grid reinforcement application fuel cell systems are being proven promising. Few works have been done on the control of fuel cell inverter [7-9]. Works on new types of inverters like Z-source inverter have also been done [6]. However, fuel cell connected with grid has not been reported much yet. Especially grid connected fuel cell model with the Z-source inverter control strategy is a rare one.

This paper focuses on the fuel cell system including control of output voltages. There are three sections:

1. In the modeling section fuel cells and their uses are described.
2. In the inverter modeling section inverter with controller modeling are described.
3. In the last part simulation results are analyzed

2 FUEL CELL APPLICATIONS

2.1 Principle

Fuel cells convert chemical energy of fuel into electrical energy. The fuel cell used for modeling is termed as Proton exchange membrane fuel cell (PEMFC). In figure 1 the schematic diagram of PEM fuel cell is given. It is fed with hydrogen and air. There are few assumptions in the modeling. The electrode channels are assumed to be small enough that the pressure drop across them is negligible. The ratio of pressures between the inside and outside of the electrode channels is large enough to assume choked flow. The temperature of the fuel cell is stable. The gases are assumed to be ideal [4].

The typical anode and cathode reactions for a hydrogen fuel cell can be described as follows:
In the anode section, hydrogen gas oxidizes releasing electrons and creating H^+ ions.

Anode equation:

$$2H_2 = 4H^+ + 4e^- \tag{1}$$

At the cathode, oxygen reacts with electrons from the electrodes and H^+ ions from the electrolyte and form water. Here water is the waste product and taken out from the cell.

Cathode equation:

$$O_2 + 4e^- + 4H^+ = 2H_2O \tag{2}$$

$$O_2 + 2H_2 = 2H_2O + heat + electricity \tag{3}$$

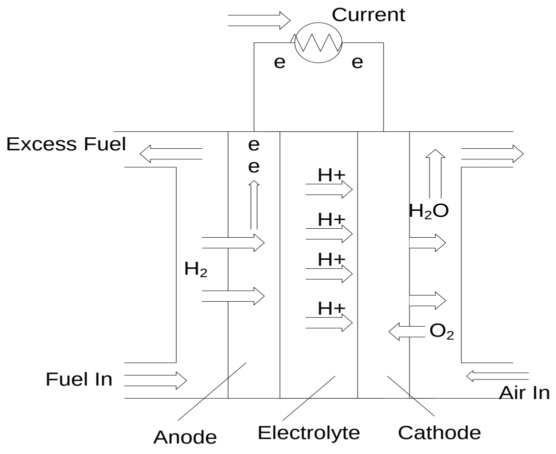

Fig. 1. Fuel Cell schematic diagram

The general voltage-current relationship of 65 v dc PEMFC is shown in figure 2. We can see the voltage decreases with the increase of the current.

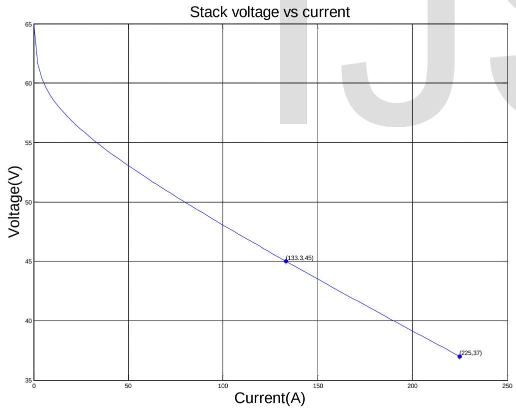

Fig. 2. Fuel Cell V-I characteristic

2.2 Inverting Strategy

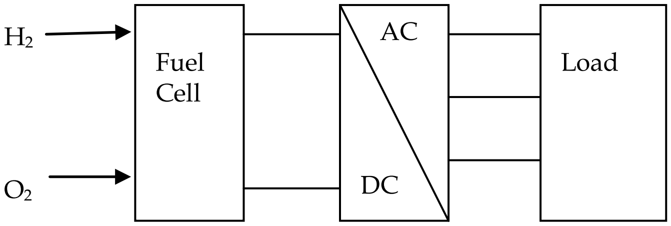

Fig. 3. Fuel cell connected to the load

In Fuel cell systems the load needs higher voltage than the dc source voltage. Dc-dc boost converter is generally used for this purpose. When the power requirement is high then the voltage stress on the switch is high. So in such applications VSI is not good. Voltage-fed full-bridge converter for step-up applications display low voltage spike on the switches at the primary side. Thus, lower voltage rated MOSFETs can be used in voltage-fed converter. But the transformer of the voltage-fed step-up full-bridge has high leakage inductance and parasitic capacitance [3]. Also, high currents through the switches on the primary side and voltage ringing on the rectifier diodes are the other disadvantages of the voltage-fed full-bridge converter.

The parasitic capacitances of the switches are too small compared to the amount of the transferred energy to them. This fact decreases the reliability of the converter. The reliability problem can be solved in the current-fed full-bridge converter by using Z source structure instead of a single inductor.

3 INVERTER MODELING

The typical block diagram of the fuel cell system with inverter and output is shown below

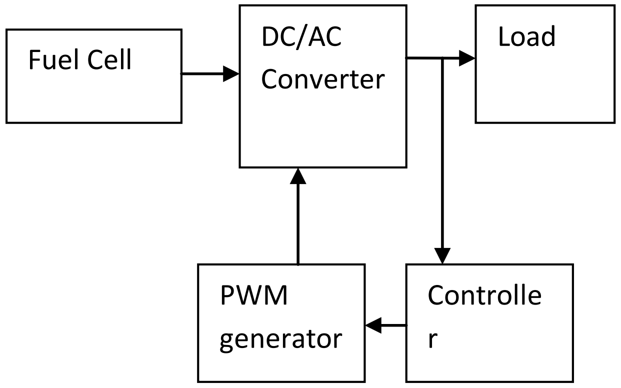

Fig. 4. Block diagram of fuel cell control strategy

Different types of inverter can be modeled for fuel cell. In many cases the voltage produced needs to be boost. For that reason boost converter is used.

3.1 Voltage Source Inverter

The topology of standard three-phase VSI is discussed in this section. There are eight valid switch states for traditional VSI. Shorting the load terminals by both the upper and lower switching devices of any phase leg is forbidden in the traditional inverters. In order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them produce zero ac line voltages. The inverter moves from one state to another in order to generate a given voltage waveform. Modulating technique is used to select the states in order to generate the given waveform. Modulating technique ensures the use of the valid states only.[4]

3.2 Current Source Inverter

Current-fed converter is more suitable for high voltage applications than the voltage-fed converter because of the semiconductor losses, transformer dimensions and the voltage stress on rectifier diodes.

But the parasitic capacitances of the switches are too small compared to the amount of the transferred energy to them. The switches are damaged because the voltage spike exceeds the break down voltage. This fact decreases the reliability of the converter. The reliability problem can be solved in the current-fed full-bridge converter by using Z source structure instead of a single inductor.

3.3 Z-Source Inverter

We need a new type of inverter to solve the problems of two-stage power conversion and low efficiency. High cost for the extra converter can be eliminated by the z source inverter. The problems of EMI noise and start up problems z-source inverter is a new type of power conversion technology [5].

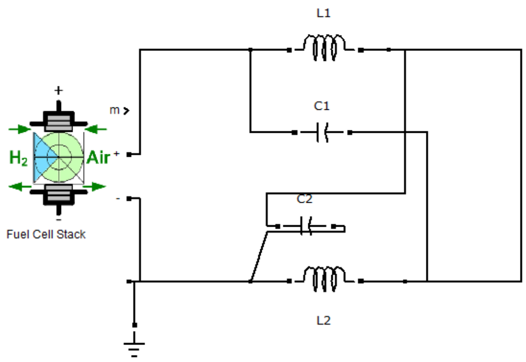

Fig. 5. Z-source Network

The ZSI has two inductors and two capacitors in X- shape,. Whether the traditional VSI that has eight switching states, the ZSI has nine permissible switching states. Like the traditional VSI, the ZSI has six active states when the dc voltage is impressed across the three-phase load, and two zero states when the load terminals are shorted through either the lower or upper three switching devices, respectively. But when the load terminals are shorted by both the upper and lower switching devices of any phase leg which is forbidden in the traditional inverters to avoid ST fault, the shoot-through state occurs. This ST state is actually the third zero state. The ST state can be achieved by seven different ways: ST via any phase, combinations of any two phase legs and all three phase legs. In ZSI, the traditional PWM techniques (Sine PWM) can be used with slight modification to the zero states due to the fact that the ZSI uses the traditional eight states as in traditional inverters with an extra state. The ST states are inserted only into the zero states while the active states remain unchanged and hence the ac output voltage of the inverter remains similar to a traditional inverter. This shoot-through zero state gives a unique buck-boost feature to the inverter, which makes it distinct from a traditional VSI or CSI.

Table 1 describes the advantages of Z-source inverter over voltage source inverter.

TABLE1. COMPARISON OF VOLTAGE SOURCE AND Z-SOURCE INVERTER

VSI	*ZSI*
Two-stage power conversion.	Provides the buck-boost function by one stage conversion.
Difficult to start up (in-rush).	Has low or no in-rush current compared with the V-converters.
Vulnerable to EMI.	Is immune to EMI noise and misgating.
Traditional Sine PWM used.	Traditional Sine PWM used with modification to zero states (shoot through inserted).
Unwanted shoot through can cause damage to inverter.	ZSI can handle unwanted shoot through. Shoot through deliberately inserted and causes no damage.
No self-boost.	ZSI can boost itself which is it's unique feature.
Efficiency low.	Efficiency comparable at high loads.
Modulation index and Boost factor are not directly dependent.	Modulation Index (M) and Boost factor (B) are directly dependent on each other, a higher M, reduces B.

Control of dc link voltage is simple.	Control of dc link voltage is complex because dc link voltage is pulsating.
Large Capacitor & inductor is required if boost converter is used.	Two small capacitors & two small inductors are required for Z-network.

3.4 Controller

PID controller reduces the steady state error and also increases the stability. PI controller does not change anything in the stability. But now-a-days PI controller is also selected for some ac to dc application. PI controllers have two tuning parameters to adjust. So these parameters are easy to control than PID controllers.

3.5 Modeling of converter with controller to generate PWM pulses

PWM control is incorporated within the inverters. Among all the method SPWM is very popular in industrial applications. In multiple-pulse modulation, all pulses have the same width. But in SPWM, the pulse width is varied according to the amplitude of a sine wave.

The magnitude ratio of Ac/Ar is called the modulation index (M) where Ac is carrier and Ar is reference or modulating signal.

M controls the harmonic content of the output voltage waveform. The magnitude of fundamental component of output voltage is proportional to M [4].

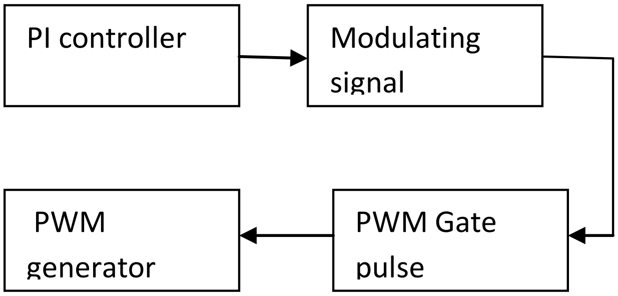

Fig. 6. Controller and PWM generator

4 Simulation Results

The simulation result is carried out for a proposed small scale model of 6 kW 45V dc fuel cell connected with the grid. No of cells in the stack is 65 and nominal stack efficiency is assumed to be 55%. The system frequency is 50Hz.

4.1 Voltage Output

The output voltage of the grid connected fuel cell system must be ac. The simulations are carried out through the Matlab. For easier understanding all the output voltages are calculated in p.u.

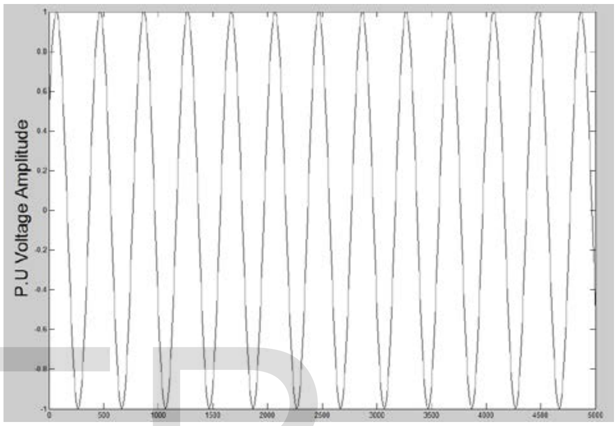

Fig. 7. Output voltage of phase A

Fig. 8. Output voltage of phase B

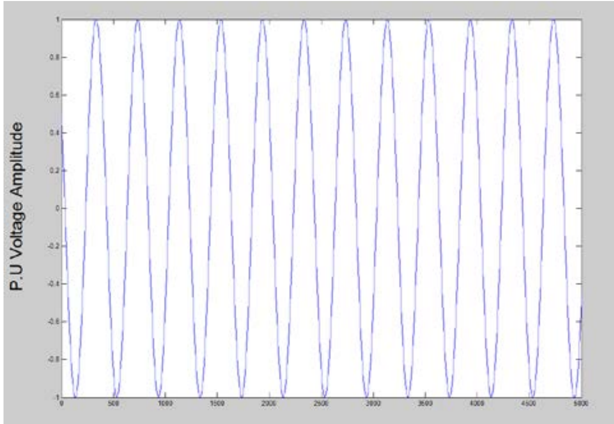

Fig. 9. Output voltage of phase C

4.2 Reference signal

Reference signal for PWM generator compares with the carrier wave to generate the pulses. The frequency of the carrier used is 1080 Hz. The pulses are found to be modulated for 6 switches.

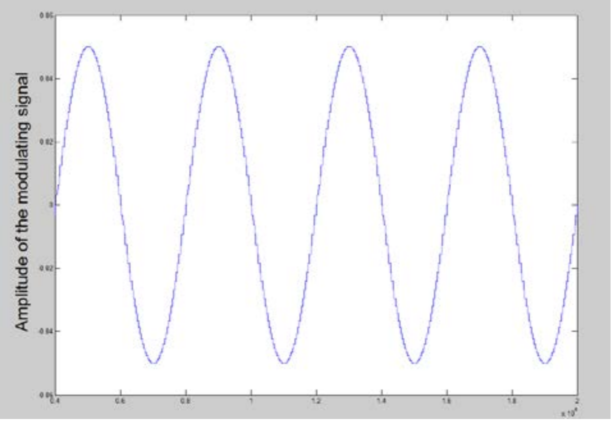

Fig. 10. Modulating or reference signal for PWM generator

4.3 Inverter Output

This inverter output is filtered to find the output voltage. The output is not a pure sinusoidal wave. LC filter is used to find the actual sinusoidal wave.

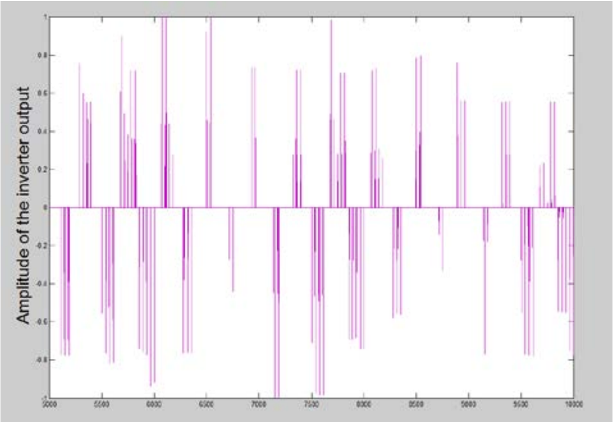

Fig. 11. Inverter output before filtering

Voltage of the fuel cell is not always a constant dc. The fluctuation of the voltage due to various reasons makes very hard to convert the dc voltage to ac. Boost converters are generally used for this kind of topologies. But the converters must be able to boost the necessary voltage in all the cases of the switch states. ZSI solves this problem without using any kind of additional converters. The results of the proposed scheme show the stability and reliability of the fuel cell system with the best control strategy of the inverter

5 CONCLUSION

This work investigates how electricity can be generated from fuel cells with the best integration in energy systems suitable for domestic application. Power electronic converters provide the electrical interface between the sources, storage, and loads, and the availability of reliable, low-cost and efficient. Pressure on fossil fuels will be reduced greatly if the contribution of renewable energy sources can be increased by a great amount. Fuel cell can play an important role in this case. The challenge in front of us is to find a more convenient, more cost effective way to convert the DC power available from the fuel cell to AC & supply it to the grid converters will produce current wave shapes exactly what the grid requires.

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