IJCTA
Vol.8, No.1, Jan-June 2015, Pp.306-314

Three Phase Fuel Cell Inverter Design Based on Hybrid Modulation Technique

K. Sindhu[1], Shri. Ch.N. Narasimha Rao[2] and Shri. A.Sriharibabu[2]
[1]M.Tech Student, Department of EEE, Vignan's University, Vadlamudi, Guntur – 522 213 (A.P.)
[2]Assistant Professors, Department of EEE, Vignan's University, Vadlamudi, Guntur – 522 213 (A.P.)
Email:-sindhuk65@gmail.com; narsi.cherukuri@gmail.com;

ABSTRACT

Fuel cells have achieved global attention as alternative power sources due to the environmental concerns. The prime focus of this paper is to design a three phase inverter fed with hybrid modulation technique suitable for fuel cell applications. Hybrid modulation technique comprises two different modulation schemes. Unlike conventional sinusoidal pulse width modulated inverter this inverter needs only one third modulation of switching devices reducing the switching losses. The proposed hybrid modulation has a unique single reference signal which reduces the control complexity. Interleaving is presented so that even if a bridge fails, the other bridge will maintain six pulse information generating balanced three phase voltage waveforms. It is therefore robust and offers higher reliability. Analysis of the fuel cell inverter with RL load and induction motor is presented and the results are compared with conventional sinusoidal pulse width modulated inverter in terms of inverter output voltages, currents, rotor speeds, electromagnetic torques and total harmonic distortion using MATLAB/simulink environment. Simulation results demonstrate the effectiveness of the proposed modulation scheme.

Keywords: Fuel cells; hybrid modulation; three phase inverter; isolation

1. INTRODUCTION

"IN the future, many local energy sources, such as photovoltaic units, fuel cells, small turbines, small hydro electric plants, and other dispersed sources will become a larger fraction of our electrical supply". A fuel cell uses the chemical energy of hydrogen to cleanly and efficiently produce electricity, with water ad heat as by products. Fuel cells are unique in terms of variety of their potential applications; they can provide energy for systems as large as a utility power station and as small as a laptop computer. Fuel cells have several benefits over conventional combustion based technologies currently used in many power plants and passenger vehicles. Output of fuel cell is a variable dc hence a converter is needed to regulate the fuel cell output voltage and power flow. Both permanent magnet and induction motor machines for fuel cell generation require high voltage at high speed and high power. Thus to achieve high speed and high power, the inverter and the motor must be oversized if only a traditional pulse width modulated (PWM) inverter is used as a power converter. In addition the fuel cell has a relatively slow response and unidirectional power flow. Therefore an energy storage device is always needed to handle load dynamics and regenerative braking. The present prototype has no energy storage device, battery or ultra capacitor and thus cannot handle load dynamics and regeneration. Frequent start up of the fuel cell presents a huge challenge at low voltage, high current for successful continuous generation of electricity. This is almost impossible for the traditional PWM inverter. The voltage boost function is particularly preferable during freeze start. Providing a large amount of boost was prohibitive due to the large device stresses and parasitic circuit elements. Therefore boot topology utilizing high frequency transformer was considered.

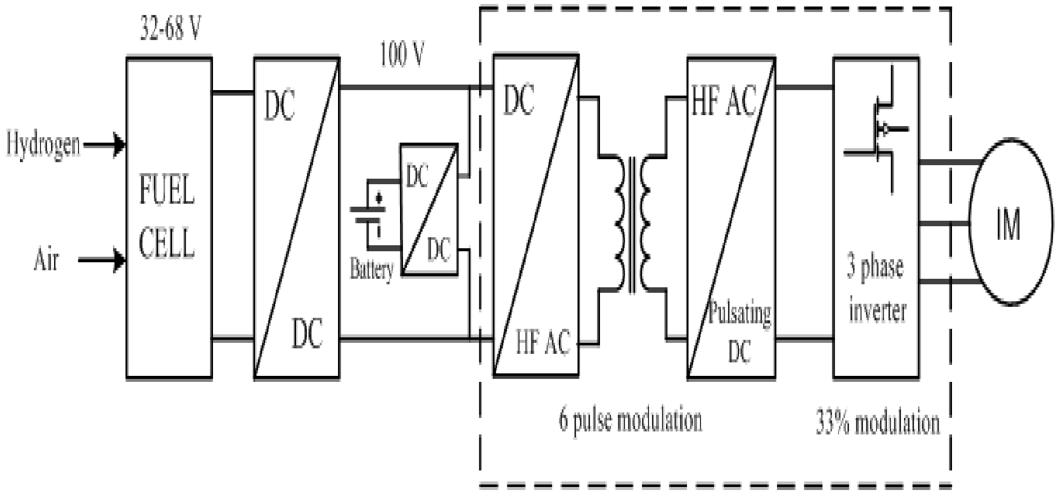


Fig .1. Block diagram of fuel cell inverter system

Even though this environmentally friendly, highly efficient energy resource is promising, the high cost of installing a fuel cell power plant is one of the main obstacles hindering its widespread deployment. Currently, fuel cell production costs are decreasing, and have nearly achieved energy costs that are competitive with local utility rates. To further assist the reduction of cost, the price of the inverter portion of the fuel cell system must also decrease, while at the same time increasing efficiency, increasing reliability, and maintaining suitable power quality levels. This low cost inverter approach will help to enable small-scale fuel cell system commercialization and will in turn encourage the development and advancement of distributed power systems. The proposed inverter consists of two stages, a front end dc/dc converter and a three phase inverter as shown in Fig. 1. This paper proposes a hybrid modulation technique that comprises two different modulations for the two stages of inverter. *Single Reference Six Pulse Modulation* (SRSPM) is proposed to control front-end full-bridge dc/dc converter to produce HF pulsating dc voltage having six-pulse information. Second modulation is *33% (or one third) modulation* adopted for a three-phase inverter that produces balanced three-phase voltage. In *33% modulation*, only one leg is modulated at a time. It reduces the average switching frequency and limits the switching losses to 33% of the conventional value. High frequency modulation is adopted to achieve compact, low cost, and light weight systems. The topology overview is presented in section II.

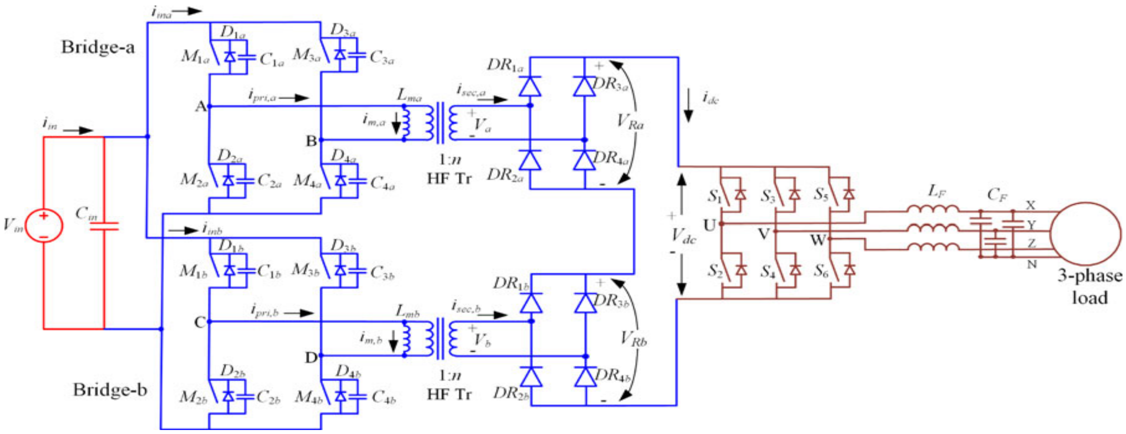


Fig.2. proposed fuel cell inverter system

The operation and analysis of the hybrid modulated fuel cell inverter, presented in section III. The design of the inverter is explained in section IV. The analysis, design has been verified by simulation results using MATLAB/simulink environment and the results are compared with conventional inverter in section V to validate the effectiveness of the hybrid modulated inverter.

2. TOPOLOGY OVERVIEW

A. fuel cell stack

Single fuel cell produces enough electricity for only the smallest applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. Fuel cell stack is heart of the fuel cell power system. A typical fuel cell stack may consist of hundreds of fuel cells. It generates electricity in the form of direct current (DC) from the chemical reactions that take place in the fuel. The fuel cell specified for this design is 2.4KW, 48V open system. Its voltage- current characteristics are shown in Fig.3

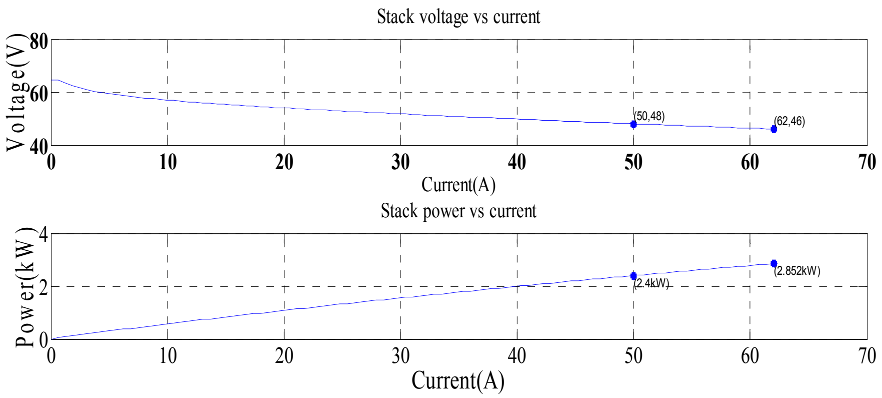


Fig. 3.VI characteristics of 2.4 KW, 48V fuel cell

B.Boost converter

Boost converter is also called as step up converter. When the switch CH is on the input current from the fuel cell flows through the inductor L_b and the switch and the inductor stores the energy during this period of t_{on}. When the CH is off the L_b current cannot die down instantaneously. This current is forced to flow through the diode and the load for a time of t_{off}. As the current tend to decrease polarity of the emf induced in the L_b is reversed. As a result voltage across the load is the sum of the fuel cell output voltage and inductor voltage and it is greater than the fuel cell output voltage. Fig illustrates the step up chopper

$$V_0 = \frac{V_s}{(1-\propto)} \qquad (1)$$

Where, V_0 is output voltage

V_s is input voltage from fuel cell

$\propto$ is duty ratio

C. Dc-dc Converter

Dc-dc converter proposed in this paper consists of two full bridge converters, high frequency transformer and a diode bridge rectifier. Full bridge converters are interleaved at the front end in parallel input and series output. Interleaving doesn't affect the modulation implementation further it increases the power handling capacity. Both full bridges are modulated using identical six -pulse modulation producing high frequency pulsating dc voltage which is fed to the three phase inverter. The transformer isolates the low voltage side and high voltage side, boosts voltage, and the leakage inductance of the transformer is used as an energy storage and transfer element.

3. OPERATION AND ANALYSIS OF THE CONVERTER

The following assumptions are made for easy understanding of the analysis of the converter: 1) All semiconductor devices and components are ideal and lossless. 2) Leakage inductances of the transformers have been neglected. 3) Dc/dc converter cells are switched at higher frequency compared to the inverter.

A. Modulation scheme

The switch pairs M_{1a}–M_{2a} and M_{3a}–M_{4a} are operated with complementary signals. The gating signal of M_{1a} and M_{3a} is phase shifted by DT_s , where D is defined as the duty ratio of the switch. By varying D, voltage at the rectifier output can be varied linearly. In the proposed modulation, D is generated by comparing reference signal with carrier signal. Reference signal V_{ref} is a six-pulse waveform that is obtained from the rectified output of three-phase line-line voltage. As the name suggests, the reference voltage is having frequency of 6× ac line frequency. These six equal pulses (segments) are flagged as T_1 to T_6 . During each of these pulses, only one leg of the inverter is modulated at HF whereas remaining two legs are steady at their switching state. The modulating sequences of the inverter switches S_1−S_6 are given in Table I, which are compared with carrier waveform to get gating pulses for the devices. During time interval T_1, S_4 and S_5 are ON, and S_3 and S_6 are OFF. S_1 and S_2 are modulated at HF by using V_{ab}/V_{cb} as modulating signal.

Table – I Modulation Signals For Inverter Switching

	T_1	T_2	T_3	T_4	T_5	T_6
$S_1, \overline{S}_2$	V_{ab}/V_{cb}	1	1	V_{ac}/V_{bc}	0	0
$S_3, \overline{S}_4$	0	0	V_{bc}/V_{ac}	1	1	V_{ba}/V_{ca}
$S_5, \overline{S}_6$	1	V_{cb}/V_{ab}	0	0	V_{ca}/V_{ba}	1

In the proposed method, exact modulating signals are calculated by considering variation in average dc-link voltage in six-pulse fashion. This modulation technique is very easy to implement by using three-phase line–line voltages as references shown in Fig. 4. Six-pulse modulating signal is obtained from maximum of absolute value of three-phase references, i.e., rectification of balanced three-phase sine ac signals. This reference along with the carrier waveform decides gating signals for switches M_{1a}−M_{4a}. Interleaving at front-end is easy to scale the power transfer capacity due to the proposed modulation. Switches are modulated in similar fashion with same value of D. The modulation given in Table I is implemented for inverter by selecting modulating signal in the given sequence.

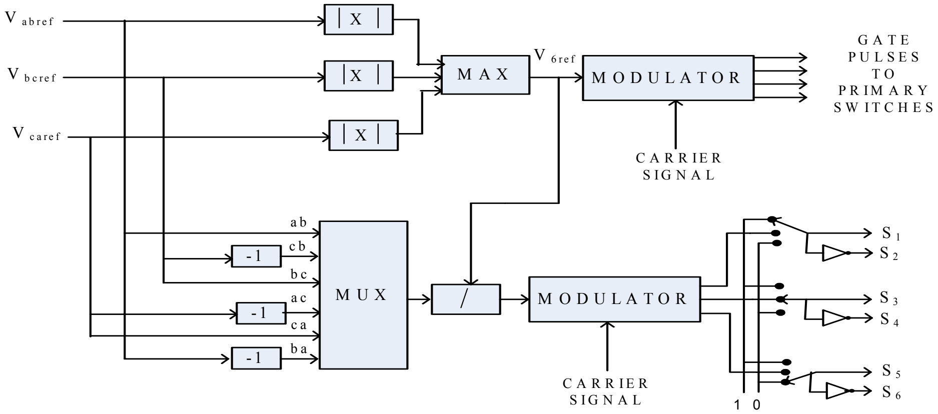


Fig: .5. Schematic of complete modulation implementation

B. *Steady state operation*

Whenever the diagonal switch pairs of the front end converter are ON input voltage V_{in} appears across the transformer primary and nv_{in} appears across the secondary of the transformer .It is then converted into unipolar using full bridge rectifier. Rectifier output from two cells is connected in series to add the voltage level. The average value of rectifier output voltage at dc link over a switching cycle is given by

$$V_{Ra} = V_{Rb} = 2.D.n.V_{in} \quad (2)$$

$$V_{dc} = V_{Ra} + V_{Rb} = 4d.n.V_{in} \quad (3)$$

The maximum value of voltage obtained at V_{dc} corresponds to the peak of line to line inverter output voltage is obtained at D_{max} and is obtained as

$$V_{XY,\text{peak}} = 4D_{\max} \cdot n \cdot V_{in} \quad (4)$$

where $V_{XY,\text{peak}}$ is the peak of line-line output voltage. Magnitude of output voltage can be varied by varying the reference voltage V_{ref} , which changes the range of operating duty ratio D_{min} and D_{max}.

4. DESIGN OF THE INVERTER

1. Input voltage V_{in} = 100 V, output phase voltage V_O = 440 V at f_O = 50 Hz, rated power Po = 1000 W, switching frequency of dc/dc converter f_{SC} = 100 kHz, and of inverter f_{SI} = 40 kHz.
2. The turns ratio of the transformers are designed by considering the operating duty ratio of the full-bridge converter as 0.4–0.425.

$$V_0 = \frac{V_{dc}}{4.n.Vin} \quad (5)$$

The turns ratio of 1.6 is selected allowing the safe margin oin case of decrease in input oltage below 100V.

3. Filter design: Filter inductance is calculated such that the voltage drop across the inductor is less than 2% of the nominal voltage during the full-load condition. For the given specifications, L_F is obtained as 10mH. Filter capacitance is calculated from the cut-off frequency of the low-pass filter. For this application, one tenth of the inverter switching frequency f_{SI} is selected as the cut-off

frequency. For f_C = 4 kHz, where f_C is the cut-off frequency of the filter. The capacitor *CF* is obtained as 0.16μF.

5. SIMULATION RESULTS

The proposed hybrid modulated fuel cell inverter has been simulated using MATLAB/simulink environment using rl load as well as induction motor. Results are illustrated in Figs. 6 to 9

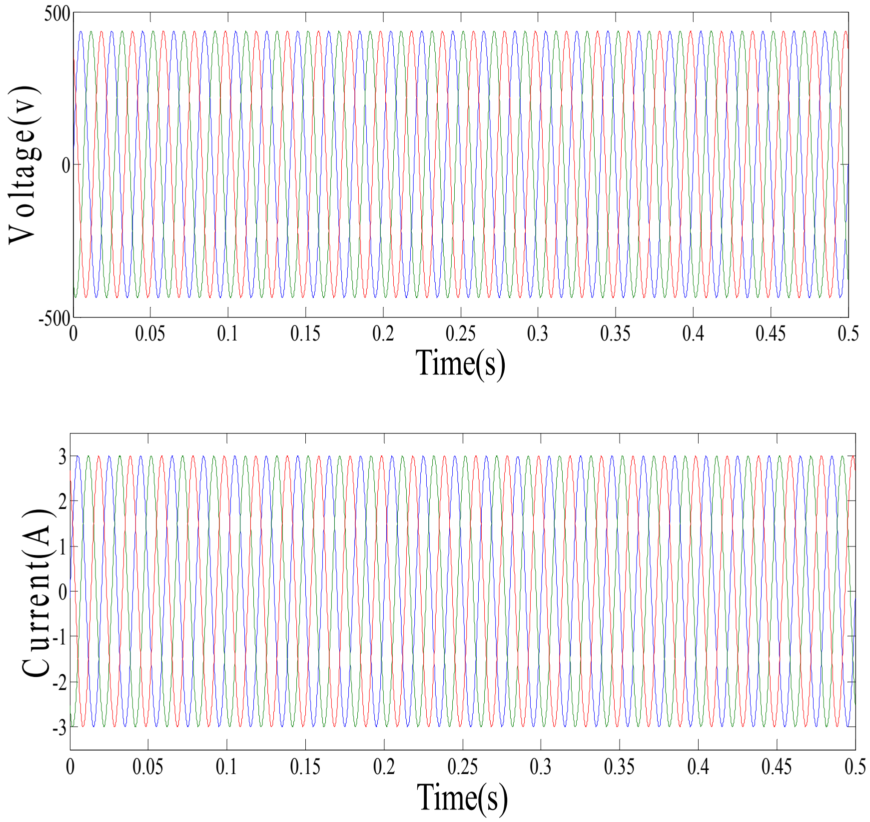
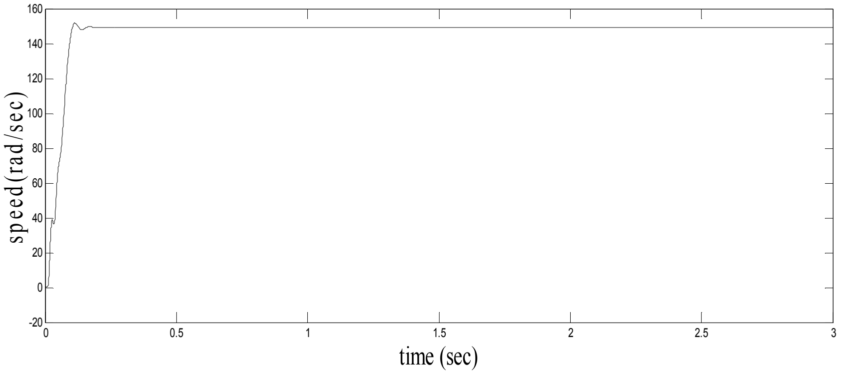


Fig. 6. Simulation results showing output voltages and currents for 0.5kw rl load using fuel cell inverter



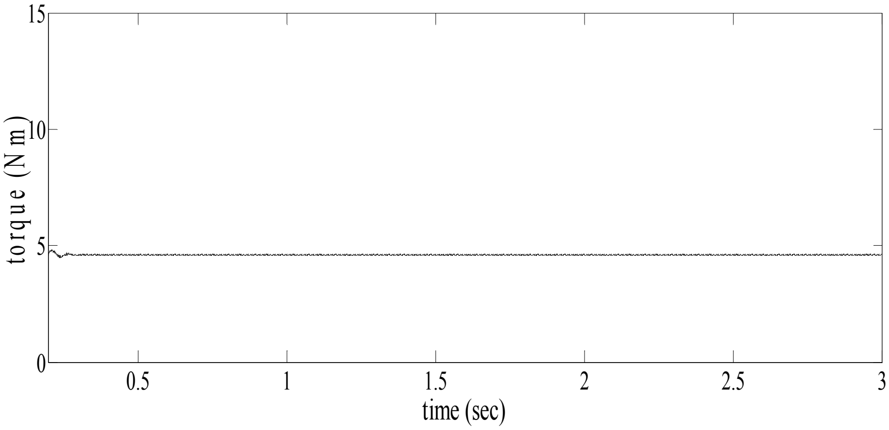


Fig.7. Simulation results showing speed and torque 0.8kw induction motor load using fuel cell inverter

Similarly simulation of inverter with normal sinusoidal PWM modulation scheme is done and the results of both are compared in TABLE II as follows

Table – II Comparision Of Outputs

	Hybrid modulated inverter	Sine PWM inverter
RL load	Output voltage 440v	300v
	Output current 3A	2.25A
Induction motor with a load	Torque 4.79 Nm	3Nm
	Speed 154.4 rad/sec	130 rad/sec

6. CONCLUSION

Fuel cells are becoming lucrative solution toward sustainable low carbon clean mobility owing to zero emission .This paper proposes a novel modulation technique named SRSPM to control front-end full-bridge converter to generate HF unipolar pulsating voltage waveform at dc link having six-pulse information if averaged at HF cycle over line frequency. Six-pulse is meant for six-pulse waveform that results after rectification of three-phase balanced ac waveforms at 6× of line frequency. The proposed modulation technique eliminates the need for dc-link capacitor and feeds directly HF pulsating dc voltage to a three-phase inverter. This pulsating waveform is utilized to generate three-phase output voltage at reduced average switching frequency (one third of the inverter switching frequency) or 33% commutations of inverter devices in a line cycle. The steady-state operation and analysis of the two stage HF inverter controlled by the proposed modulation scheme have been discussed. Simulation results are shown to verify the effectiveness of the converter.

REFERENCES

1) U.R.Prasanna and A.K.Rathore, " A Novel Single reference six pulse modulation technique based interleaved high frequency three phase inverter", IEEE Trans. Power Electron., vol. 28, pp. 5547–5556,no. 12, dec.2013.
2) S. J. Jang, C. Y. Won, B. K. Lee, and J. Hur, "Fuel cell generation system with a new active clamping current-fed half-bridge converter," IEEE Trans. Energy Convers., vol. 22, no. 2, pp. 332–340, Jun. 2007.
3) S. K. Mazumder and A. K. Rathore, "Performance evaluation of a new hybrid-modulation scheme for high-frequency-ac-link inverter: Application for PV, wind, fuel-cell and DER/storage applications," in Proc. IEEE Energy Convers. Congr. Expo., 2010, pp. 2529–2534.
4) R. Huang and S. K. Mazumder, "A soft switching scheme for multiphase dc/pulsating-dc converter for three-phase high-frequency-link pulse width modulation (PWM) inverter," IEEE Trans. Power Electron., vol. 25, no. 7, pp. 1761–1744, Jul. 2010.
5) A. Khaligh and Z. Li, "Battery, ultra capacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in hybrid electric vehicles: State of the art," IEEE Trans. Veh. Technol., vol. 59, no. 6, pp. 2806–2814, Jul. 2010.
6) Nitin Goel,P..R .Sharma,Suman Bala, "Performance analysis of SPWM inverter fed 3-phase induction moyor drive using matlab/simulink",IJATES trans.vol no.2,issue no 06,june 2014.
7) C.S.Sharma and Tali Nagwani, "Simulation and Analysis of PWM inverter fed induction motor drive",IJSETR vol no 2,issue 2,Feb 2013.