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Single Phase Inverter with Fuel Cell for Non-linear Load Applications

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ABSTRACT: The paper aims to design a fuel cell-based single phase inverter topology to run with nonlinear AC loads. We are considering the fuel cell in standalone mode to feed an AC load with the single stage conversion of the electrochemical energy from the fuel cell to pulsating DC. Then using the inverter with controller to cope-up with slow dynamics of the fuel cell and then convert the DC output to AC at a required frequency. To utilize the fuel-cell energy, we consider the require design, operation, and control for a standalone 10kw fuel-cell, maintaining constant frequency i.e. 50 kHz. Here we have considered a low-temperature PEMFC fuel cell. This model is a functional prototype for further development, as in improvements it is providing a backup storage system along with power conversion technique and store the power that generated from the fuel cell. It can be furthermore improvising by choosing super capacitor or backup storage device to provide uninterruptible power supply. As we know the requirement of alternative resources is increasing day by day, the only reliable as well as efficient sources, as per the economic considerations are non-conventional energy sources i.e. photovoltaic cells and fuel cells. This paper represents a proposal of single-phase power system with the utilization of fuel cell for the domestic and commercial purpose. It controls the active as well as the reactive power of the source according to the requirements of the load. All the simulations are done using MATLAB and Simulink with the defined data.

KEYWORDS: Fuel cell; Full wave Bridge Inverter; PI controller; Band pass filter; MATLAB simulation.

I. INTRODUCTION

Electrochemical-based fuel cell converts its stored chemical energy to electrical energy to fulfil the load demand. To get the demanded cell voltage, fuel cells are then connected in series combination and it create a stack of fuel cell [1]-[5]. If liquid type electrolyte used in the fuel cell, such as phosphoric acid and alkaline fuel cells, then the electrolytes of cells is shared through a common process. This may result the presence of shunt current in the system. Similarly, while water is used for cooling of polymer electrolyte fuel cell, shunt current is also present there. To understand the electrical processes of liquid electrolyte fuel cell stacks, here we are proposing an electrical circuit based model and simulate it and critically analyze the results. The fuel cell considered here is a 72 cell PEMFC with a single cell output of 0.6 to 0.7 volts [5]. The characteristic output voltage of the low-power FC is mostly low and it is variable with respect to the load current. For example, while considering the current-voltage characteristics of a 72-cell proton exchange membrane FC (PEMFC) power module, the voltage varies in between the range of 39 to 69 V. These values depend on the level of the output current. Moreover, the hydrogen and oxidant cannot respond straightaway the load current changes due to the process behavior of various components such as fuel-processing unit, pumps and heat exchangers etc.

II. RELATED WORK

Previously the boost- inverter was used as a building block for a single phase grid connected fuel cell offering low cost and compactness[5]. In addition battery based energy storage and a dc-dc bidirectional converter to support the slow dynamics of FC. Fuel cells and batteries both convert chemical potential energy into electrical energy and also, as a by-product of this process, into heat energy. Battery holds a closed store of energy within it also but once this is depleted the battery must be discarded, or recharged by using an external supply of electricity to drive the electrochemical

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reaction in the reverse direction. A fuel cell, on the other hand, uses an external supply of chemical energy and can run indefinitely, as long as it is supplied with a source of hydrogen and a source of oxygen (usually air)[1]. The source of hydrogen is generally referred to as the fuel and this gives the fuel cell its name, although there is no combustion involved. Oxidation of the hydrogen instead takes place electrochemically in a very efficient way. During oxidation, hydrogen atoms react with oxygen atoms to form water; in the process electrons are released and flow through an external circuit as an electric current. Fuel cells can vary from tiny devices producing only a few watts of electricity, right up to large power plants producing megawatts. The single phase boost inverter was voltage mode controlled and the dc-dc bidirectional converter was current mode controlled[8] . The system could operate on either in a grid connected or stand-alone mode. In grid connected mode boost inverter was able to control active and reactive powers.

III. METHEDOLOGY

The proposed system is as shown in the block diagram the inverter output signal is used as the actuating signal for the controller accordingly the reference points are set and thus the duty of the bridge circuit is varied with the help of the controller. The controller is the most important part of the circuit so as to vary the output of the inverter. In this circuit we are considering a voltage control topology for the output control of the inverter [7]. It can also be done using a current controlled topology as per the requirement of the application.

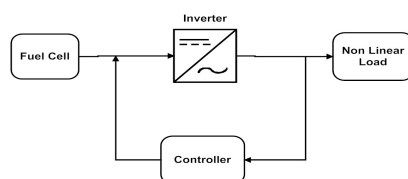


Fig 1. Block Diagram

Load considered here is nonlinear load, basically all the heavy loads can be considered as that of being inductive in nature as the application are considered to be motor i.e. fans, blowers, compressors, and the other being heaters i.e. furnace, boilers etc [2]. Loads are considered to be non-linear types when its impedance values changes with the applied voltage. That means the current drawn by it is not sinusoidal type.

Now while consideration of a PEMFC the advantages are:

- Pressurized versions have high current density
- Relatively quicker startup
- Only pure H₂O as output / spillage
- Multiple options for bipolar plate
- Suitable for small vehicle / portable power applications

The objective of FC system is to maintaining constant power operation by adjusting the input voltage with time being. The threshold limit of voltage and current unit of any particular FC stack must be protecting. The stack must be execute with a converter to protect it from damages. Moreover, the power has to be ramped up and down so that the FC can react applicably, escaping transients and prolonging its lifetime [5]. Meantime, the converter must come across the maximum ripple current requirements of the FC. Fig 2 shows the Proton exchange Membrane Fuel Cell.

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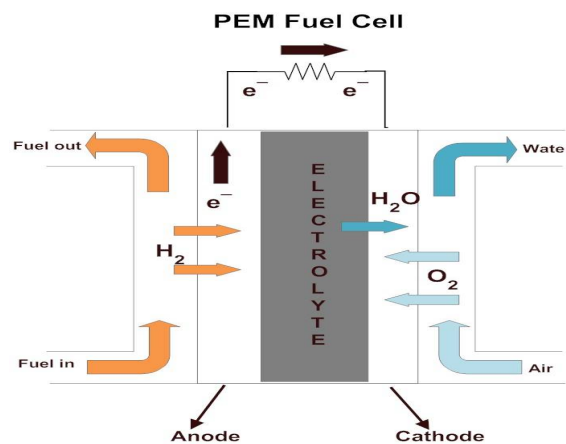


Fig 2. Proton Exchange Membrane Fuel Cell

IV. INVERTER TOPOLOGY

The inverter topology used here is a full wave bridge configuration for single-phase loads. [8]-[13] Capacitive full bridge circuit is engaged to convert fuel cell output to AC output voltage. The capacitor acts as filter to remove the ripples in the input and for the effective cancellation of the DC offset

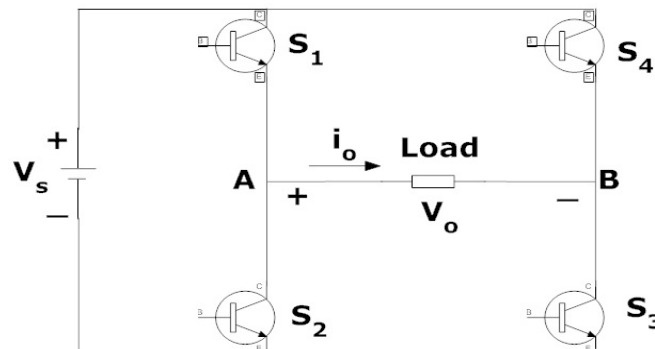


Fig 3. Single-phase full wave bridge inverter

The fig. 3 shows the circuit configuration of single phase full wave bridge inverter. V_s is the DC supply voltage and V_o is the output voltage taken across AB. During the first half cycle S_1 and S_3 are triggered due to which the load current will flow from A to B. And in the next half cycle these thyristors are commutated and the thyristors S_2 and S_4 are triggered due to which the load current will flow from B to A. This is how we will get a sinusoidal wave. If the load is under damped then we will get a pure sine wave.

V. CONTROLLER

Proportional plus integral controls are provided for the conditioning of the inverter output. The proportional control causes the decrease in the damping ratio (ζ) by $\sqrt{k_p}$ [14]. It also increases the peak overshoot but reduces the steady state error. The integral control increases the order by one. The overall P-I controller improves the steady state

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response. It also improves the type and order of system along with reduced noise level[14]-[17]. It increases error constant and thus the bandwidth reduces.

Basically a PI controller consists of k_p and a constant for integral control but in addition to that a band pass filter is used [19]-[20]. The controller adds the functionality as PI controller deals with the change in the peak overshoot and the peak time, rise time is also significantly affected by the use of proportional as well as the integral controls and thus a need of band limited signal occurred in the system, to have a maximum tolerable limit for the frequency variation and thus the this need is met with the help of a band pass filter defining the maximum tolerable limit of frequency accordingly the performance of the load is affected as per the Indian system we consider a tolerance band of 1.5 Hz for a domestic supply same is the case for the inverter controller blocks thus generating a suitable AC supply system for the considered load [4].

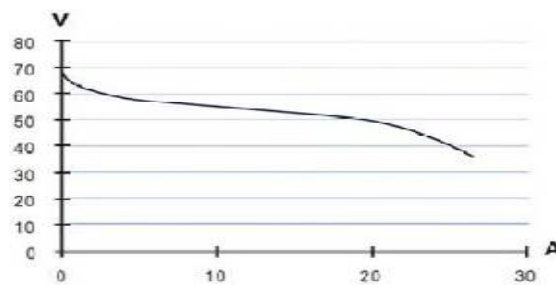


Fig. 4 V-I Characteristics of 72 cell PEMFC.

Voltage-Current characteristic in Fig. 4 showing the DC output voltage ranges from 39V to 69V across the operating range [5]. In this simulation model, we have considered the equivalent circuit of an AC motor. An induction motor of typical ratings to get the output variations and further it can be enhanced and calibrated by carrying out the transient analysis of the provided system just as to meet the efficiency requirements and the power swing and the speed torque specifications. Thus for the occurrence of the transient conditions the output of the supply is needed to be controlled thus defining the behavior of the system and effects on the system due the overloading and surges thus the controller is further modified.

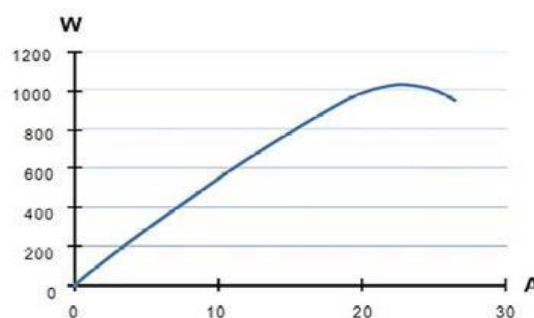


Fig. 5 P-I Characteristics of 72 cell PEMFC.

Power- Current characteristic showing the output power ranges from zero when being idle to 1000W at rated output power [5].

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Proposed System:-

Output voltage:

$$v(x) = \sum_{n=1,3,5,\dots}^{\infty} \left(\frac{4V}{n\pi} \sin n\omega t \right) \quad (1)$$

Output current:

$$i(x) = \sum_{n=1,3,5,\dots}^{\infty} \left(\frac{4V}{n\pi Z} \sin n\omega t \right) \quad (2)$$

Where, Z= load impedance at frequency:

$$Z = \sqrt{R^2 + (n\omega L - \frac{1}{n\omega C})^2} \quad (3)$$

Phase angle:

$$\phi = \tan^{-1} \frac{(n\omega L - \frac{1}{n\omega C})}{R} \quad (4)$$

Total Harmonic distortion:

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2}}{V_1} \quad (5)$$

VI. SIMULATIONS AND RESULTS

The suggested FC system (Fig. 1) has been analyzed, designed and simulated to validate its overall performance. The simulations work has been carried out in MATLAB to confirm the analytical results [21]. The AC output voltage of the system was 220V, while the DC input voltage varied in between 43V to 69V.

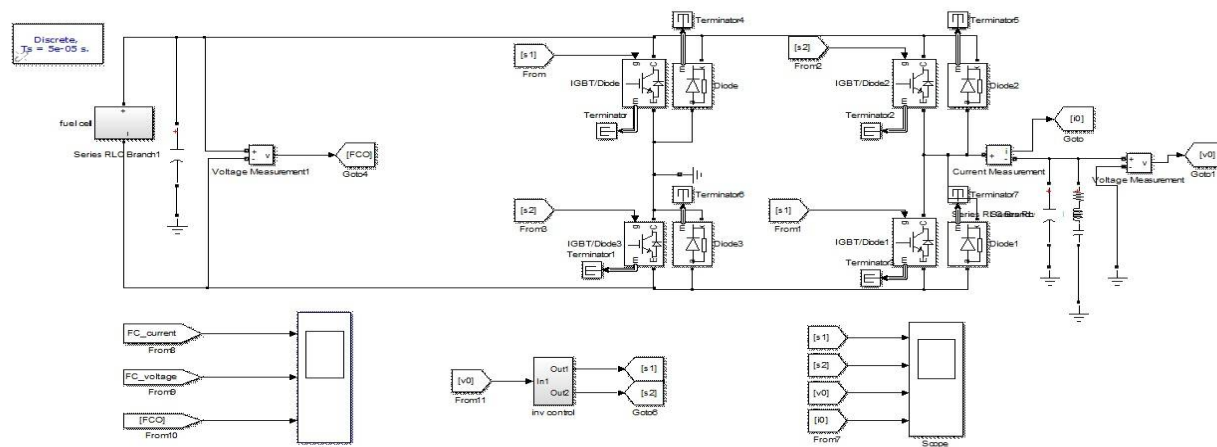


Fig 6. Proposed System

The simulink of the proposed system is drawn in fig 6 used to carry out simulation work in MATLAB.

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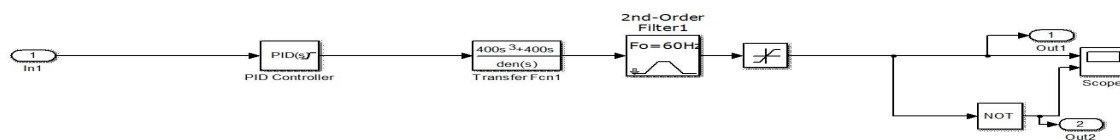


Fig 7. Proposed controller

Simulink of the proposed controller is shown in fig 7. In Table I, all the parameters of the recommended FC system for the simulation are shortened.

TABLE I
Fuel Cell Specifications

FC output voltage	39-69V(72 cell PEMFC)
AC output voltage	220V, 50Hz
Switching frequency	20kHz
Rated power	1.0kW(43V at 23.5A)
Power stack	SEMISTACK-IGBT
Controller	DSP TMS320F28335
Voltage transducers	LEM LV25-P
Current transducers	LEM HAL50s
Energy storage	Two 12V-24Ah lead acid batteries
$L_1=L_2$	700 μ H
$L_{b2}=L_{b1}$	150 μ H
L_f	5mH
$C_1=C_2=C_3=C_4$	20f
PR1	K_p :0.1, K_f :10
PR2	K_p :1, K_f :1000
PI1	K_p :0.1, K_f :100
PI2	K_p :1e-6, K_f :1e-3
PI3	K_p :5e-5, K_f :0.2
PI4	K_p :0.5, K_f :0.03

The simulation result describes the operation of the fuel cell, single-phase inverter and controller. The Fig. 8 shows the output of the single-phase inverter and Fig. 9 shows the output of the controller. The pulses generated from the controller are fed to the gate terminal of the IGBT's used in the single-phase inverter. The output waveform of the single-phase inverter will show the two gate signals provided to the IGBT's, the output voltage and the output current. By controlling the time period of the gate signal we can control the output voltage and current.

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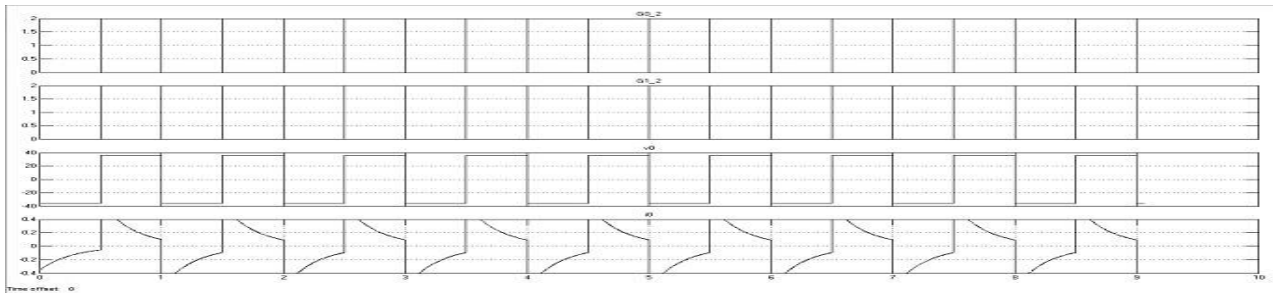


Fig 8. Output of inverter

The attained experimental efficiency of the proposed system is about 93% at the peak point and 83% at rated output power.

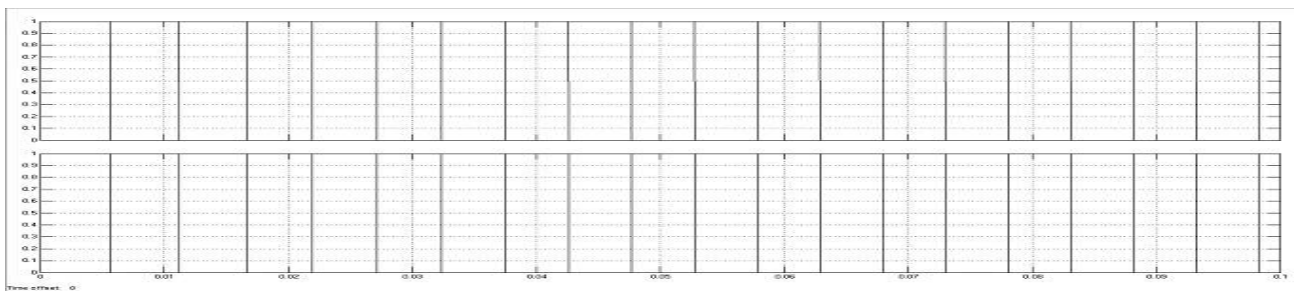


Fig. 9. Output of controller

The output of proposed fuel cell system shown in Fig 10. The output of the FC is a pulsating DC and its frequency is about 20 kHz, which is a very high frequency due to which the pulsating DC look like a constant DC.

The proposed model can be further improved by adding a backup unit to provide the storage of the generated power and supplying power during high load conditions. The ripples of the fuel cell can be removed by using suitable filters to make it exactly equal to constant DC.

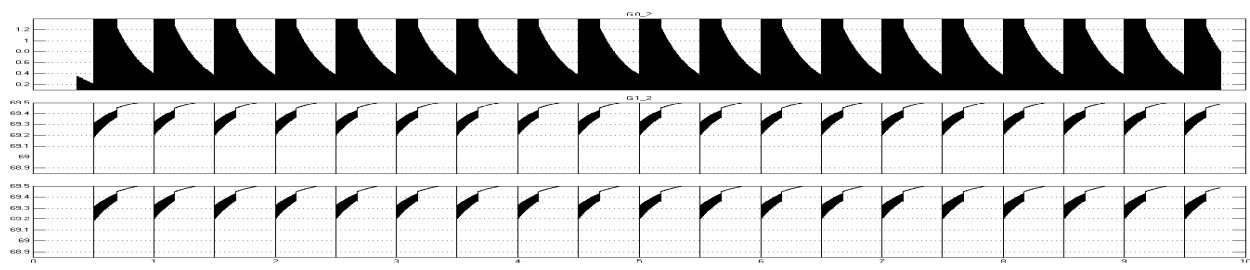


Fig 10. Output of fuel cell

VII. CONCLUSION

A fuel cell based single-phase inverter system for nonlinear AC load has been suggested in this paper. We used the simulations outcomes to verify the operating characteristics of the projected FC system. In swift, the proposed FC system brings several of striking features, such as single power stage operation with good efficiency, simplified the

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electrical circuit, less cost. This system is also able to operate in stand-alone as well as grid-connected mode. Moreover, the further modifications can be done to improve its performance. A backup unit can be connected to provide the necessary storage unit and during the over load conditions. However, it has been noticed that while operating in voltage mode control for the single-phase inverter, the result outcomes are distorted output current if the output voltage includes any harmonic component.

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