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연료전지 응용을 위한 HF Link 전류원 인버터

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HF Link Current-Fed Inverter for Fuel Cell Applications

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Abstract

This paper presents a high frequency (HF) link current-fed inverter for fuel cell applications. The circuit topology, operation and control method of the proposed HF link current-fed inverter are presented. The active cancellation technique of the 120Hz input harmonic current is also considered. The simulation results are provided to show the feasibility of the proposed inverter scheme.

1. Introduction

Fuel cell is a highly promising alternative for a renewable power generation due to its efficiency, modularity and cleanness. One of its applications for medium power is the residential power system, where an isolated low cost inverter is required. Researches on this topic have been presented in recent years [1]-[4].

A high frequency (HF) link converter is attractive for this application because of its compact HF transformer replacing the bulky 60Hz transformer [4][6][7]. A current-fed converter is known as an effective solution for the power conversion from the low to high voltages because it can operate in the buck and boost modes, and provides easy transformer balancing. Moreover, the current-fed converter requires less size of the input filter because the primary inductor is placed in the input side while the voltage-fed converter needs a large capacitor to protect the fuel cell from the input current ripple [3], [4]. However, this current-fed converter still has the input harmonic current of 120Hz that is inevitable in the single phase inverter with an 60Hz output and may impose severe effects to the performance and durability of the fuel cell [5].

This paper considers a low cost HF link current-fed inverter with an active harmonic filter to overcome the above problem. The proposed converter consists of the current-fed HF link inverter and active harmonic filter using the electrolytic capacitor and two MOSFET switches. The proposed HF link current-fed inverter generates a single phase sinusoidal output from the fuel cell powered DC source in a single stage. The active harmonic filter makes the compensation current eliminating the input harmonic current of 120 Hz. In this paper, the operation and control of the proposed inverter are presented and the simulation results are provided to verify the usefulness of the proposed scheme.

2. HF Link Current-Fed Inverter

Fig. 1 shows the proposed HF link current-fed inverter with an active harmonic filter for fuel cell applications. The full-bridge inverter, HF transformer and bi-directional switches generate the sinusoidal output from the fuel cell. The active harmonic filter makes the compensation current eliminating the harmonic current of 120 Hz that appears in the input side.

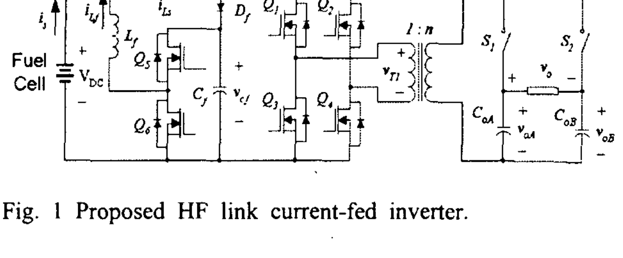
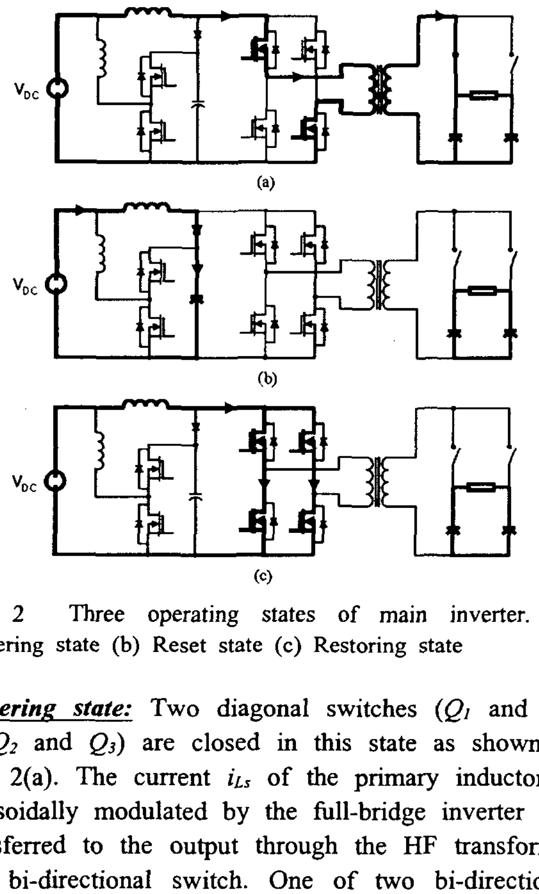


Fig. 1 Proposed HF link current-fed inverter.

The proposed HF link current-fed inverter has a single stage without the buck regulation stage, which consists of the primary inductor (Ls), full-bridge inverter (Q1-Q4), HF transformer, two bi-directional switches (S1 and S2) and output capacitors (CoA and CoB). The diode Df and capacitor Cf in the active filter are also used for the voltage clamping in the main inverter operation without the additional clamping circuit. The full-bridge configuration offers the low switch stress, simple voltage clamping, and simple structure and easy balancing of the HF transformer as compared with the push-pull configuration. Moreover, the secondary side has the simplest structure with only two bi-directional switches and capacitors.

The main inverter has three operating states; the powering, reset and restoring states.



(a)
(b)
(c)

Fig. 2 Three operating states of main inverter. (a) Powering state (b) Reset state (c) Restoring state

Powering state: Two diagonal switches (Q_1 and Q_4, or Q_2 and Q_3) are closed in this state as shown in Fig. 2(a). The current i_{Ls} of the primary inductor is sinusoidally modulated by the full-bridge inverter and transferred to the output through the HF transformer and bi-directional switch. One of two bi-directional switches is closed according to the polarities of the link current and desired output voltage. To minimize the switching losses, the bi-directional switches are turned on/off at the zero link current.

Reset state: Two upper or lower switches (Q_1 and Q_2, or Q_3 and Q_4), or all four switches are opened in this state as shown in Fig. 2(b). The inductor current i_{Ls} flows through the diode D_f and charges the capacitor C_f . The primary inductor is generally reset through a flyback winding in the conventional current-fed approaches, which has the complexity of the inductor and produces a high impact current. These disadvantages are easily overcome in the proposed scheme. The capacitor voltage v_{Cf} can be controlled by the switches Q_5 and Q_6 during the active filter operation and is maintained to be higher than the input voltage V_{dc} and the transformer primary voltage v_{T1}.

Restoring state: Both switches of one inverter leg (Q_1 and Q_3, or Q_2 and Q_4), or all four switches are closed as shown in Fig. 2(c). Thus, the inductor current increases with a rate of V_{dc}/L_s in the restoring mode while decreases with a rate of $(V_{dc}-v_{Cf})/L_s$ in this state.

In order to make sinusoidal output, the inverter should be operated in both buck and boost modes. The main inverter is operated in the reset and powering states for the buck mode, and the restore and powering states for the boost mode.

3. Active Cancellation of 120Hz Input Harmonic Current

The input and output powers of the inverter should be balanced in both average and instantaneous senses. The output voltage and current of the inverter with a sinusoidal output can be expressed as

$$v_o = \sqrt{2}\,V_{rms}\sin wt \tag{1}$$

$$i_o = \sqrt{2}I_{rms}\sin(wt-\phi) \tag{2}$$

where ϕ denotes a displacement factor. The instantaneous power is derived as

$$\begin{aligned} P_o(t) &= v_o(t)i_o(t) \\ &= V_{rms}I_{rms}\cos\phi - V_{rms}I_{rms}\cos(2wt-\phi) \end{aligned} \tag{3}$$

The average power is defined as

$$P_{av} = V_{rms}I_{rms}\cos\phi \tag{4}$$

The input current for a constant input voltage of V_{dc} can be represented as

$$i_s(t) = \frac{V_{rms}I_{rms}}{V_{dc}}\cos\phi - \frac{V_{rms}I_{rms}}{V_{dc}}\cos(2wt-\phi) \tag{5}$$

The second term of the right hand side in (2) is the second order harmonic current defined as

$$i_s(t) = -\frac{V_{rms}I_{rms}}{V_{dc}}\cos(2wt-\phi) \tag{6}$$

The basic concept of the proposed technique is that the capacitor C_f stores the charge Q from the DC source during the negative half cycle of the ripple current and then supplies the stored charge to the output during the positive half. Fig. 3 shows the output power, input current, net capacitor current, and capacitor voltage. The charge Q is equal to the area of the half cycle and can be represented as

$$\Delta Q = \sqrt{2}I_{rms}/60\pi \tag{7}$$

The voltage ripple of the filter capacitor C_f can be calculated from (7) as

$$\Delta v_{cf} = \Delta Q/C_f \tag{8}$$

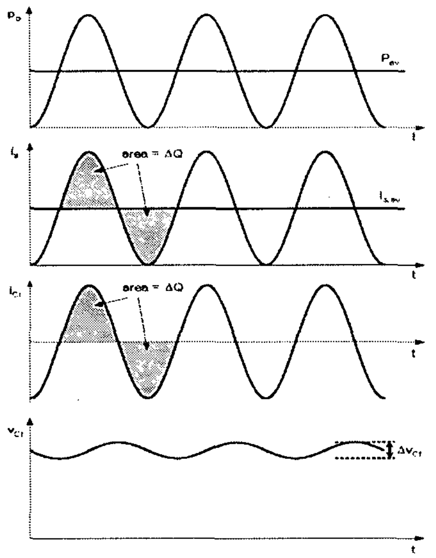


Fig. 3 Output power, input current, capacitor current and voltage waveforms

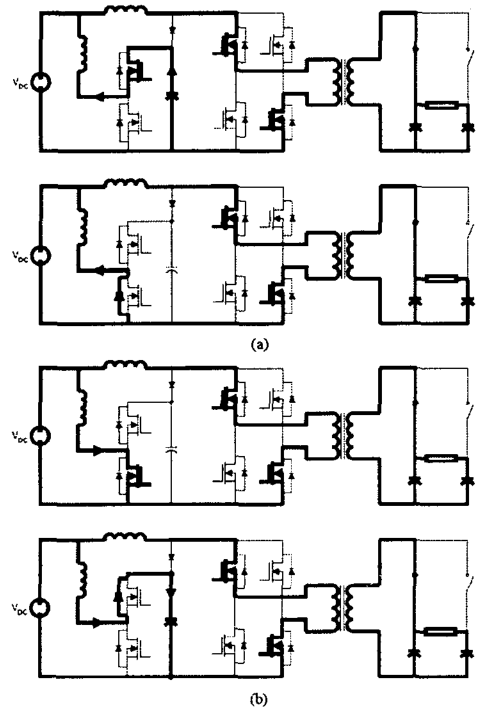


Fig. 4 Operating modes of active harmonic filter. (a) Mode I (b) Mode II

Fig. 4 shows the operation of the active harmonic filter, where it is assumed that the filter capacitor voltage v_{cf} is controlled to be higher than V_{dc} and v_{T1}. Two operating modes can be considered for the active filter operation. In Mode I, the switch Q_5 and diode D_6 operates and the stored charge supplies to the output through the filter inductor L_f. In Mode 2, the current of the filter inductor flows from the source to the filter capacitor and the filter capacitor is charged by the boosting action of the switch Q_6 and diode D_5.

4. Simulations

To verify the usefulness of the proposed converter, the computer simulation is carried out for the actual parameters as follows: V_{dc} = 48V, f_s = 20kHz, L_s = 500uH, L_f = 500uH, C_{oA} = C_{oB} = 50uF, C_f = 5600uF, n = 4, where f_s and n denote the switching frequency and transformer turn ratio, respectively.

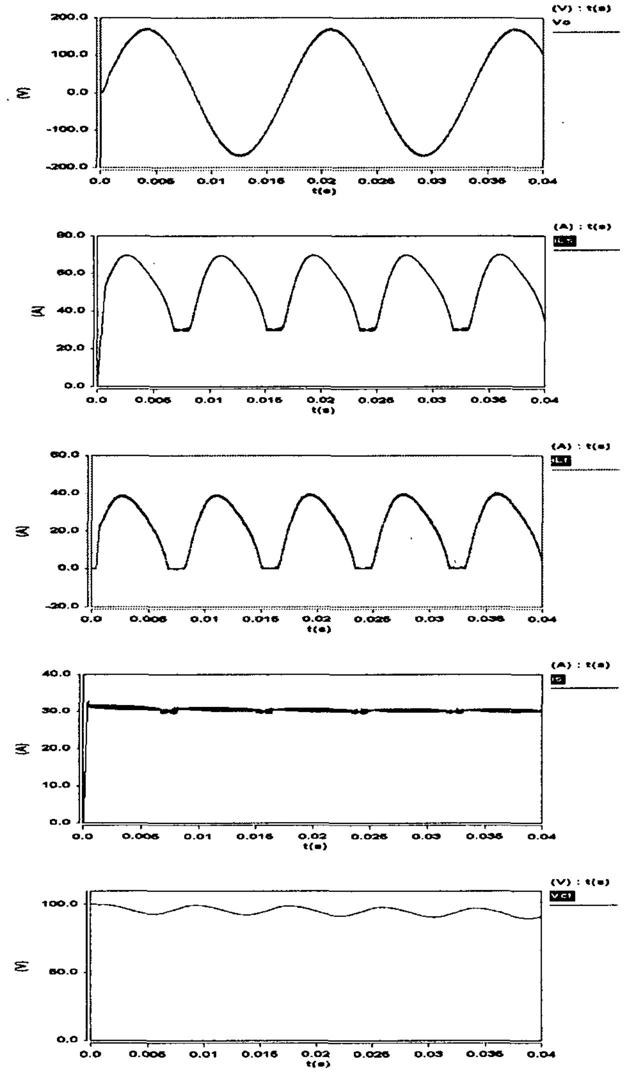


Fig. 5 Simulation results of proposed inverter for resistive load.

Fig. 5 shows the simulation results of the proposed inverter for the resistive load of 10Ω. Fig. 5(a) shows v_{oA}, v_{oB} and v_o, where the voltage reference is $120V_{rms}$ with a frequency of 60Hz. It is shown in this figure that the proposed converter produces the desired output voltages with excellent waveforms. Figs. 5 (b), (c), (d), and (e) represents the operation of the active harmonic filter, and shows the primary inductor current, filter inductor current, input current, and filter capacitor voltage, respectively. It is noted in these figures that the harmonic current of 120Hz is effectively eliminated by employing the proposed active harmonic filter. Fig. 6 shows the simulation results for the *R-L* load, where and the load power factor is 0.8. Figs. 6(a), (b), and (c) show the output voltage v_o, current i_L, and input current. Fig. 7 shows the simulation results for the rectifier load. Figs. 7(a), (b), and (c) show the output voltage v_{oA}, load current, and input current. It can be shown in Figs. 6 and 7 that the proposed inverter also provides a good voltage waveform and the capability of eliminating the 120Hz input harmonic current for the *R-L* and rectifier loads.

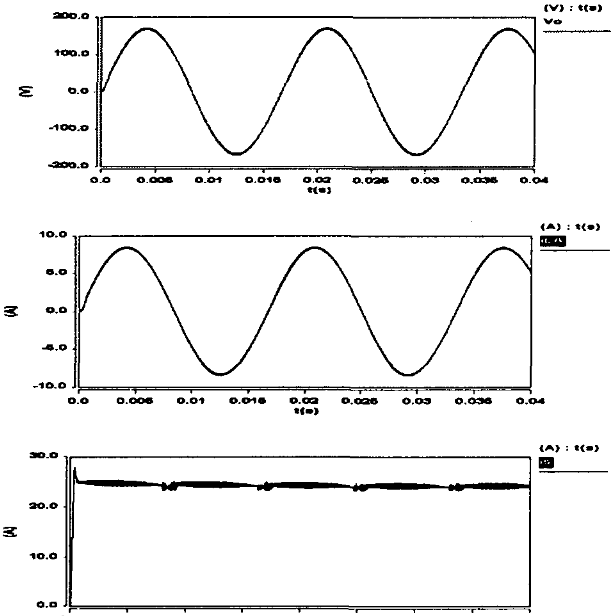


Fig. 6 Simulation results of proposed inverter for *R-L* load.

5. Conclusions

This paper has presented a new HF link current-fed inverter with the capability of the 120Hz harmonic rejection for fuel cell applications. The proposed converter is a single stage approach and has a simple transformer structure. The active harmonic filter consists of the two switches and one electrolytic capacitor, and effectively eliminates the input harmonic current. The operation of the main inverter and harmonic filter has been investigated. The computer simulation was carried out for the actual circuit parameters and the results well verify the validity of the proposed converter with the active filter. It is expected from the results that the proposed scheme is used for the residential fuel cell power systems as an effective low cost solution. The experimental verification is being carried out for the prototype system using the DSP controller.

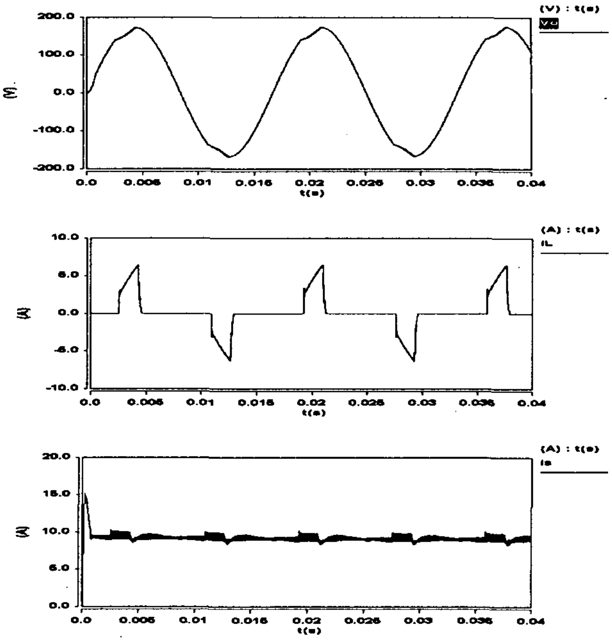


Fig. 7 Simulation results of proposed inverter for rectifier load.

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