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A Novel Three-Phase Interleaved Isolated Boot Converter With Active Clamp For Fuel Cells

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ABSTRACT:

In this paper, a new three-phase high power dc/dc converter with an active clamp is proposed. The converter is capable of increased power transfer due to its three-phase power configuration, and it reduces the rms current per phase, thus reducing conduction losses. Further, interleaved operation of three-phase boost converter reduces overall ripple current, which is imposed into fuel cells and realizes smaller sized filter components, increasing effective operating frequency and leading to higher power density. Each output current of three-phase boost converter is combined by the three-phase transformer and flows in the continuous conduction mode by the proposed three-phase PWM strategy. An efficiency of above 96% is mainly achieved by reducing conduction losses and switching losses are reduced by the action of active clamp branches, as well. The proposed converter and three-phase PWM strategy are analyzed, simulated and implemented in hardware. Experimental results are obtained on a 500W prototype unit, with all of the design verified and analyzed.

INTRODUCTION

Fuel cells are identified as a future energy source due to their efficient and clean energy characteristics; furthermore, they produce low varying dc voltage in the range of 26 ~ 42 V for residential power application. Power conditioning system in the residential use usually consists of a low-voltage fuel cell as the primary source, a dc/dc converter to obtain isolated high voltage, and a dc/ac inverter to connect commercial ac voltage.

Since a dc/ac inverter supplies power into a 220V ac utility, an isolated dc/dc converter has to convert low varying dc voltage to high constant dc voltage at around 370 V. Therefore, a high power dc/dc converter with a high voltage ratio is needed, and a transformer is usually employed for boosting voltage as well as for isolation.

Research has been focused on the three-phase dc/dc converter due to the benefits it can offer, such as high power density and high quality waveforms. However, most of the work thus far has been done on topology and PWM strategy for a voltage-fed dc/dc converter. In recent, a three-phase current-fed dc/dc converter has been studied but it operates in the discontinuous conduction mode in spite of several advantages.

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FUEL CELL

A fuel cell is an electrochemical cell that converts a source fuel into an electrical current. It generates electricity inside a cell through reactions between a fuel and an oxidant, triggered in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained.

DESIGN FEATURES IN A FUEL CELL ARE

- The electrolyte substance. The electrolyte substance usually defines the type of fuel cell.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, which breaks down the fuel into electrons and ions. The anode catalyst is usually made up of very fine platinum powder.
- The cathode catalyst, which turns the ions into the waste chemicals like water or carbon dioxide. The cathode catalyst is often made up of nickel.

PROPOSED 3-PHASE DC/DC CONVERTER

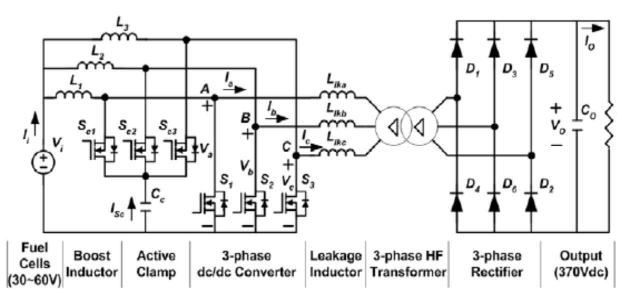

Figure 1. Power circuit configuration of three-phase isolated boost converter with active clamp

Fig. 1 shows the proposed three-phase interleaved isolated boost converter with active clamp. It consists of a three-phase dc/dc converter, whose outputs are connected to a three-phase full-bridge diode rectifier through a delta-delta wound three-phase transformer. The three-phase dc/dc converter is divided into a three-phase boost converter configured as three main MOSFET switches (S1~ S3) for three-phase boost converter, three auxiliary MOSFET clamp switches (SC1 ~ SC3) and common clamp capacitor CC for three-phase active clamp branch, and three dc boost inductors (L1 ~ L3) acting as a current source for each phase. Interleaved PWM operation occurs through the three dc boost inductors L1 ~ L3 of the three phase boost converter and increases effective switching frequency of output current Ii of fuel cells.

Thus, it reduces overall ripple current, which is imposed into fuel cells and realizes smaller sized filter components. The active clamp branch reduces switching losses by zero voltage switching (ZVS) through the use of resonance between leakage inductances of the three-phase transformer and entire capacitances of clamp capacitance, output capacitances of MOSFET switches, and stray capacitances of the transformer.

Furthermore, it clamps voltage across the switches and thus, no ancillary snubber is required in either the primary or secondary sides. The employed three-phase power structure increases input current and output voltage chopping frequencies by a factor of three and thus, reduces size of reactive filter components; lowers rms current through the main switches and transformer windings by distributing currents into three-phase paths; increase power transfer

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capability with the same current rate and voltage rate of switch. In addition, continuous current conduction in three-phase converter output current Ia ~ Ic and input current Ii leads to a highly efficient operation. Due to these characteristics, the proposed converter is highly recommended as the interface between a low voltage high-power fuel cell source and a cascaded inverter stage. It is also suitable for other low-voltage sources, such as batteries and photovoltaic, which supply high-voltage, high-power dc to the next power stages.

PROPOPSED PWMSTRATEGY

Fig. 2 shows a simplified circuit of the proposed three phase isolated boost converter introduced in Fig. 1 and clamp capacitor CC and output capacitor CO are replaced by voltage sources VC and VO, respectively. The boost inductors L1 ~ L3 are also replaced by current sources IL1 ~ IL3 respectively, during each switching period. Fig. 2 includes delta-delta connected three-phase transformer configuration, where iap represents the primary winding current in phase A and ia is output current of boost converter in phase A.

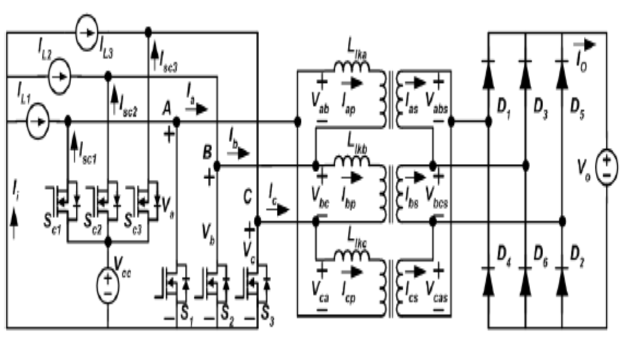


Figure 2. Simplified converter configuration

Fig. 3 shows the ideal current waveforms of phase currents ia ~ ic and transformer primary currents iap ~ icp; the gating signals $v_{G1} \sim v_{G3}$ for main switches S1 ~ S3, resulted phase voltages va ~ vb and line-to-line voltages vab~ vca.

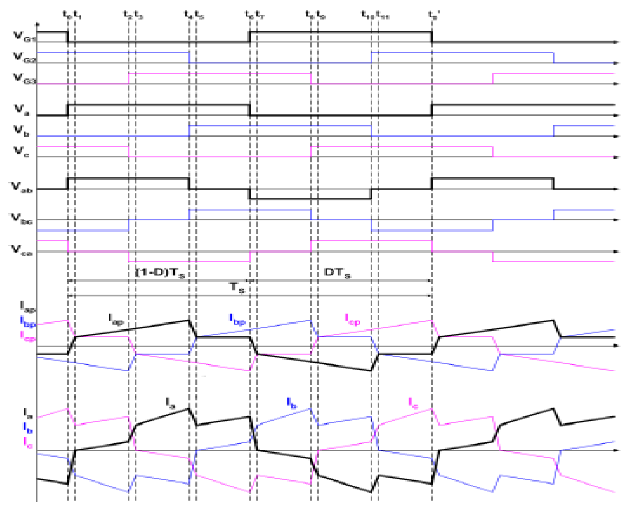
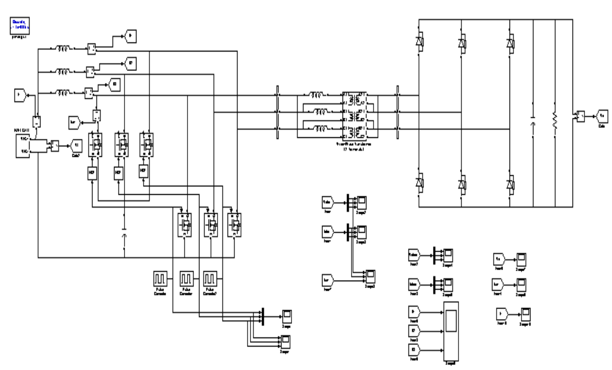


Figure 3. Ideal waveforms of the proposed converters

The operation procedure for the proposed converter is divided into 8 modes. Fig. 4 shows a set of eight topological states in phase A which occur during one switching interval TS and analysis is focused on iap, the primary current of the transformer in phase A. The current paths of input boost inductors which are regarded as constant current sources are not marked to avoid complexity.



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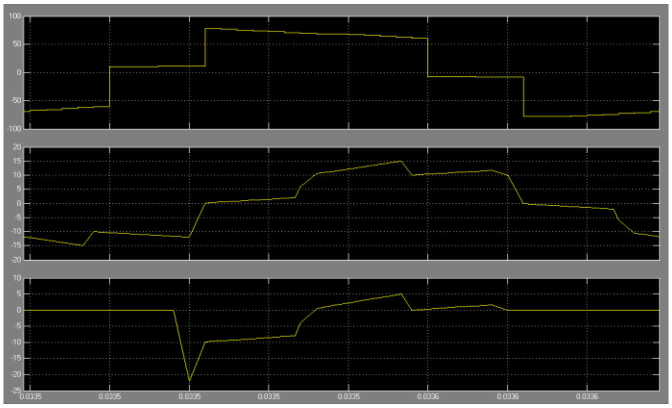

Fig .4 Output wave forms: Vab, Ia, Isc1

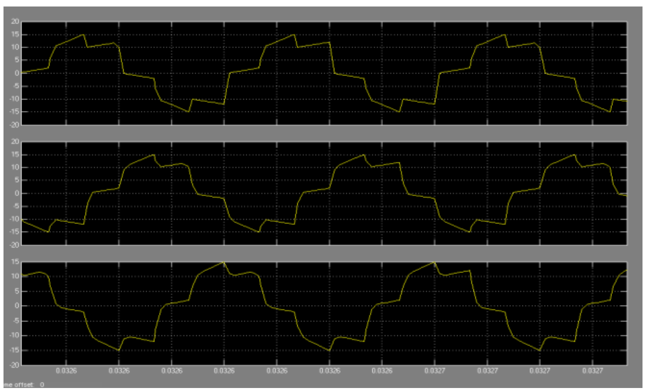

Fig .5 Converter o/p currents: Ia, Ib, Ic

CONCLUSION:

A new three-phase dc/dc converter and three-phase PWM strategy have been proposed in this paper. In the proposed converter, interleaved operation of three-phase boost converter reduces overall ripple current, which is imposed into fuel cells and thus. The interleaved operation increases effective operating frequency and thus, leads to realization of smaller sized filter components. In addition, the proposed three-phase PWM strategy transfers energy in the continuous conduction mode and three-phase paths. Further, three-phase clamp branch mitigates not only switching losses by zero voltage switching but also electromagnetic noises caused by hard-switched voltage spikes. These characteristics of the proposed converter reduce operating losses significantly and result in the whole converter efficiency above 96%. Inherent voltage boost characteristics of the boost converter increase the voltage transfer ratio in addition to the transformer turns ratio. These advantages make this converter suitable for low dc voltage renewable energy sources such as fuel cells and photovoltaic.

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