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Novel Interleaved Bidirectional Snubberless Soft switching Current Fed Full-Bridge Voltage Doublers for Fuel Cell Vehicles

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Abstract— In this paper, initially, a novel secondary modulation technique is also proposed to clamp the voltage across the primary-side switches naturally with zero-current commutation. It, therefore, eliminates the necessity for an external active-clamped circuit or passive snubbers to absorb the switch turn-off voltage spike, a major challenge in current-fed converters. Zero-current switching of primary-side devices and zero-voltage switching of secondary-side devices are achieved, which significantly reduce switching losses. An interleaved design is adopted over a single cell to increase the power handling capacity obtaining merits of lower input current ripple, reduction of passive components' size, reduced device voltage and current ratings, reduced conduction losses due to current sharing, and better thermal distribution. The multilevel inverter is simulated using MATLAB/ SIMULINK software for fifteen levels of step voltages with different DC sources

Index Terms—Fuel Cell, Interleaved boost converter, Carrier Based PWM.

I. INTRODUCTION

TRANSPORTATION electrification has become a clear tendency owing to lower emission, better vehicle performance, and higher fuel economy than conventional internal combustion (IC) engine-based vehicles. Over the past decades, Electric vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, and fuel-cell vehicles (FCVs) are emerging means of transportation to replace the conventional IC vehicle by using a three-phase electric motor for propulsion. With the merits of cleanliness (zero-emission), satisfied driving range, short refueling time, high efficiency, high reliability, FCVs exhibit significant potential in transportation. Several major automotive industries are manufacturing and testing their FCV. The fuel-cell stack converts hydrogen gas stored onboard after reaction with oxygen from air, i.e., oxidization, into electricity to drive the electric motor. As long as continuity of fuel supply is maintained, the electric motor can propel the vehicle quietly, smoothly, and efficiently requiring less maintenance. However, FCVs suffer from slow dynamic response to load variation due to their slow internal electrochemical, mechanical, and thermal dynamic characteristics and, therefore, needs energy storage that can deliver quick power. An auxiliary energy storage system (ESS) such as battery or super capacitor is usually utilized for cold start up, absorbing the regenerative braking energy, and achieving good performance during transient operation. High power bi-directional dc/dc converters are needed for applications such as battery charged dischargers, uninterruptible power systems (UPSs), alternative energy systems, and hybrid electric vehicles. The fledgling nature of many of these application fields may be the main contributing factor for that only limited results are available on this aspect so far. Most of the existing high power bi-directional dc/dc converters fall into the generic circuit topology illustrated in, which is characterized by a current-fed high-frequency (HF) inverter/rectifier on one side, preferably the lower voltage side, of the HF isolation transformer Tr, and a voltage-fed HF rectifier inverter sub topology on the other side. Each of these sub topologies can be a full bridge, a half-bridge or a push-pull circuit, or their variations. The current-fed half-bridge circuit is sometimes also referred as L-type boost circuit, or current-doublers.

II. FUEL CELL OPERATION

A fuel cell is basically fed with hydrogen fuel and air at the anode and cathode, respectively. A low voltage DC is produced at the output, which is applied to an electric

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machine by processing it through a suitable power electronic DC/DC or DC/AC converter. Basically, the electrical machine output is a mechanical output used to drive the wheels of the vehicle. There are 3 major steps involved in the generation of power from a fuel cell. The first step is to achieve purity of the available hydrogen gas. This is done with the help of a fuel processor. A suitable hydrocarbon fuel is fed to the fuel processor, which, in turn, produces a hydrogen rich gas at its output. This hydrogen rich gas is then fed to the anode electrode of the fuel cell. The generation of the DC voltage via the fuel cell makes up the second stage of the power processing unit. Lastly, the power output needs to be properly treated and this is done by passing it through an appropriate power conditioner. Ideally, the power conditioner must have minimal losses leading to a higher efficiency. Power conditioning efficiencies can typically be higher than 80%. As forced to renewable energy systems with various sources becomes greater than before, there is a supreme need for integrated power converters that are capable of interfacing, concurrently, controlling several power terminals with low cost and compact structure. Meanwhile, due to the intermittent nature of renewable sources, a battery backup is normally required when the ac mains is not available.

Fuel cells convert the chemical energy of directly into electric energy by an electrochemical process. Low voltage dc power is produced by using hydrogen or natural gas as fuel. It may be defined as an electrochemical device for the continuous conversion of the portion of the free energy change in a chemical reaction to energy conversion. It is distinguished from a batter in that it operates with continuous replacement of the fuel and oxidant at active electrode area and does not require recharging.

Fuel cell is one pattern of energy converter, which converts chemical energy to electrical energy. As far as PEMFC concerned, it converts oxygen and hydrogen directly into electricity, heat and water in an electrochemical process.

Fuel cells use electro-chemical reactions, rather than combustion (burning a fuel) to produce electricity. The process is the reverse of electrolysis. In electrolysis the action of an electric current decomposes water into hydrogen and oxygen, whereas in a simple fuel cell the two gases can be combined electrochemically to produce electricity, heat and water. In practice, the process is more involved, and each type of fuel cell has its characteristics, operating temperature, materials, and flows. What they have in common are high electrical efficiency, no combustion in the basic reactions, and a clean exhaust stream.

Fueling The Stationary Fuel Cell A fuel cell needs H2 for fuel and some fuel cells such as molten carbonate (MCFC) and solid oxide (SOFC) can also utilize carbon monoxide (CO). Hydrogen may either be directly supplied to the fuel cell or produced from other fuel sources such as natural gas, methanol, propane, bio fuels or non-carbon compounds. A fuel processor or electrolyze (see diagram below) may be used to supply onsite hydrogen to the fuel cell.

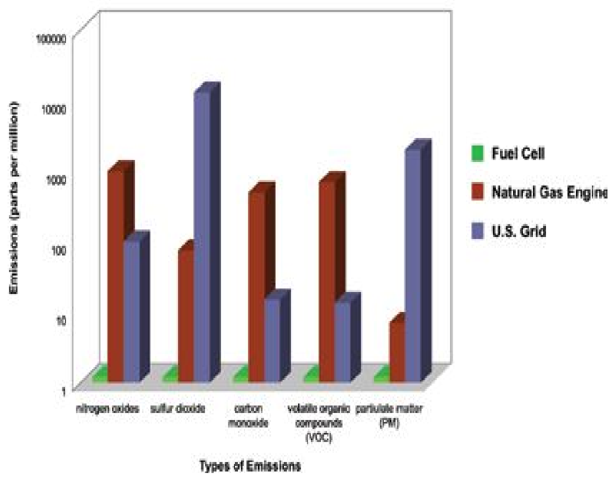

Fig. 1 Types of Emissions

III. WORKING OF THE PROJECT

The typical architecture of a fuel cell car is illustrated the fuel-cell stack converts hydrogen gas stored onboard after reaction with oxygen from air, i.e., oxidization, into electricity to drive the electric motor. As long as continuity of fuel supply is maintained, the electric motor can propel the vehicle quietly, smoothly, and efficiently requiring less maintenance. However, FCVs suffer from slow dynamic response to load variation due to their slow internal electrochemical, mechanical, and thermal dynamic characteristics and, therefore, needs energy storage that can deliver quick power. An auxiliary energy storage system (ESS) such as battery or super capacitor is usually utilized for cold start up, absorbing the regenerative braking energy, and achieving good performance during transient operation. As illustrated by a functional diagram of a typical fuel-cell powered propulsion system in Fig. a fuel cell is connected to a high-voltage dc bus acting as the main source of power. A bidirectional dc/dc converter is utilized to interface the

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auxiliary power source ESS to high-voltage dc bus. This dc/dc converter plays a vital role in coordination with the main power source and auxiliary power source, which needs to satisfy the following requirements:

1) A high step-up ratio to boost low terminal voltage of batteries to variable high-voltage fuel-cell dc bus (150– 300 V);

2) Bidirectional power flow. The converter should be able to supply energy during the cold startup and transition operation in the forward direction and absorb energy during regenerative

Braking in the reverse direction;

3) High power handling power capacity;

4) High-frequency (HF) operation to obtain a compact, lightweight, high power density, and low cost system;

5) High efficiency. It is a general requirement to obtain an efficient utilization of energy and a reduced thermal design.

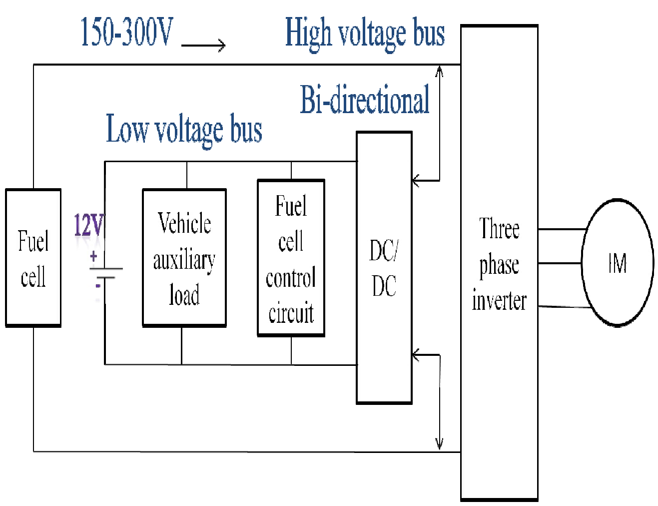

Fig. 2 Block Diagram of fuel cell based interleaved converter

Several bidirectional dc/dc converters for FCV have been proposed in the literature Voltage-fed converters suffer from several limitations, i.e., high pulsating current at input, limited soft-switching range, rectifier diode ringing, duty cycle loss [20], and comparatively low efficiency for high voltage amplification and high input current applications. Compared with voltage-fed converters, current-fed converters have been justified and demonstrated as a suitable option for such applications. One of the very popular topologies is a current-fed dual active bridge converter with a HF transformer. However, the major drawback with such a converter is high voltage spike at device turn-off owing to the energy stored in the leakage inductance. An RCD snubber circuit was employed to limit voltage overshoot.

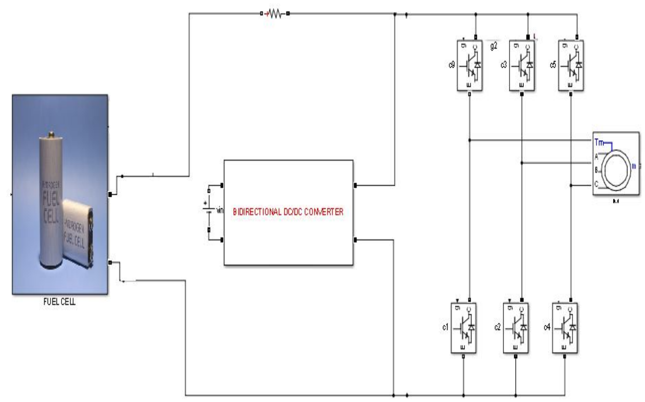

Fig. 3 circuit diagram

A similar approach was applied in with a lossless snubber circuit to reduce the voltage stress of switches. In, an active clamping snubber circuit is used, which consists of an active switch and a capacitor, to clamp the device voltage and achieve ZV ZCS at the same time. However, the disadvantages such as high current stress, higher circulating current at light load, and related thermal issues exist. In this paper, novel secondary modulation-based interleaved soft-switching bidirectional snubberless current-fed full-bridge voltage doublers is proposed, as shown in Fig. 3. The proposed converter consists of two interleaved cells with a current-fed full-bridge switches connected in parallel on the low-voltage side and half-bridge voltage doublers connected in series on the high-voltage side. For this application, interleaved approaches (multicell) are adopted over a single cell to increase the power handling capacity while achieving high efficiency and reduced thermal requirements. A voltage doublers or half-bridge is selected to reduce the number of switches, the transformer turns ratio, and voltage ratings of secondary-side devices.

IV. DC/DC INTERLEAVED CURRENT FED FULL BRIDGE INVERTER

In this section, a steady-state operation and analysis with the ZCS concept has been explained. Before turning-off of a diagonal switch pair (S_1–S_4, S_2–S_3, S_5–S_8, or S_6–S_7) at the primary side, the other pair of the primary-side switches is turned ON. The reflected output voltage V_O /4n appears across the transformer primary. It diverts the current from

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one switch pair to the other pair causing current through one switch pair to rise and the other pair's current to fall to zero. Later, the body diodes across the switch pair start conducting and their gating signals are removed leading to ZCS turn-off of devices. Then, the device voltage rises and is clamped at reflected output voltage. For the simplicity of the study of operation and analysis, the following assumptions are made for the operation and analysis of the converter:

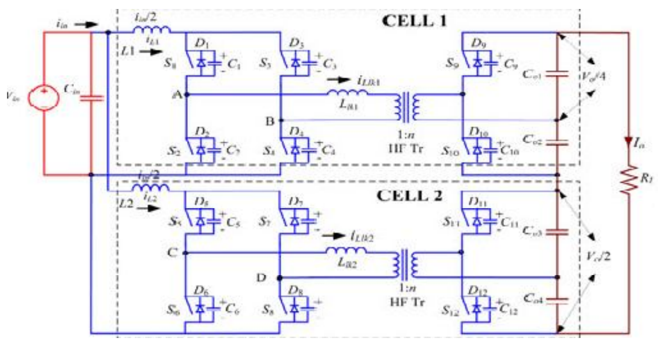

Fig 4. Bi directional dc/dc converter operation

1) Boost inductors L_1 and L_2 are large enough to maintain constant current through them. Output capacitors C_{o1}, C_{o2}, C_{o3}, and C_{o4} are large enough to maintain constant voltage across them;

2) All components are assumed ideal;

3) Series inductors L_{lk1} and L_{lk2} include the leakage inductances of the HF transformers;

4) Magnetizing inductances of the transformers are infinitely large. The steady-state operating waveforms are shown in Fig. The primary switches pairs S_1–S_4 and S_2–S_3 in Cell 1 are operated with identical gating signals phase shifted with each other by 180° and the duty cycle should be kept more than 50%. The same for the switches pairs S_5–S_8 and S_6–S_7 in Cell-2. The phase difference between gating signals of switches pairs S_1–S_4 and S_5–S_8 is 90°. The operation of the converter during different intervals in a one-quarter cycle is explained with the help of equivalent circuits shown in Fig.. For the rest of the HF cycle, the intervals are repeated in the same sequence with other symmetrical devices conducting to complete the full HF cycle.

SIMULATION OF THE FUEL CELL BASED BI-DIRECTIONAL DC/DC CONVERTER As shown in fig 6 an open- loop simulation of the proposed model is performed using MAT lab simulink. pulse width modulation is used to reduce the harmonics and improve the efficiency. The simulation results are shown in fig 7a. The input dc voltage from the fuel cell and the AC and DC load voltages are shown in fig 7b. respectively. The output voltage is boosted as compared with the input DC, with the help of the interleaved boost configuration.

SIMULATION OF FUEL CELL BASED INTERLEAVED BOOST CONVERTER

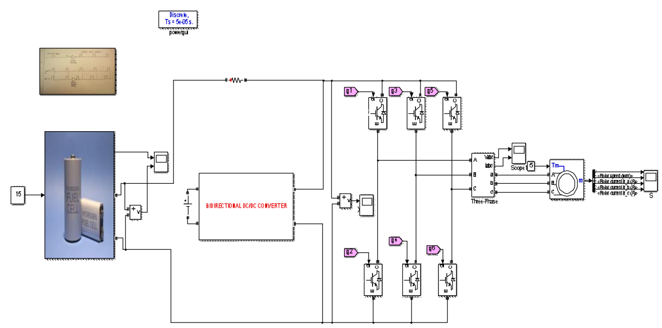

Fig 6. Simulation diagram of the circuit diagram

BI DIRECTIONAL DC/DC CONVERTER

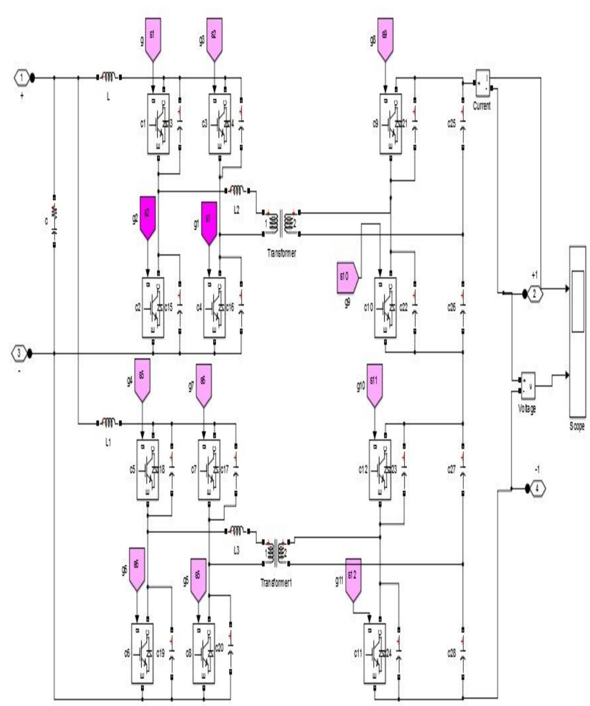

Fig 7. Simulation diagram of bi directional dc/dc converter

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FUEL CELL OUTPUT VOLTAGE

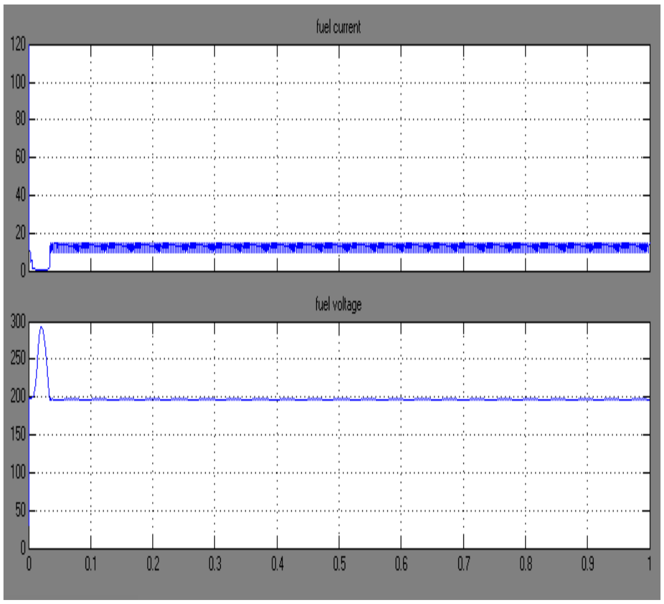

Fig. 7a. Fuel cell output voltage

BI DIRECTIONAL DC/DC CONVERTER OUTPUT VOLTAGE

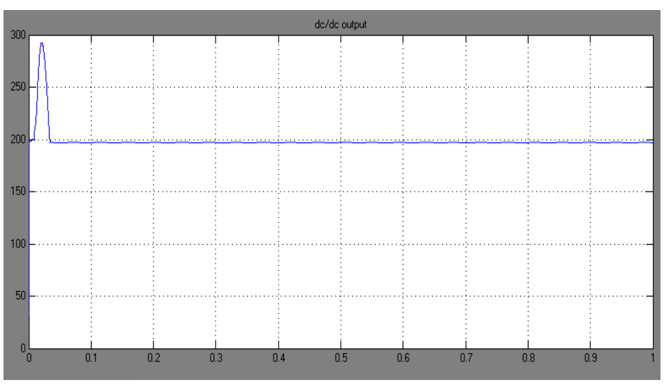

Fig 7b. bi directional dc/dc converter output voltage

THREE PHASE INDUCTION MOTOR OUTPUT RESULTS

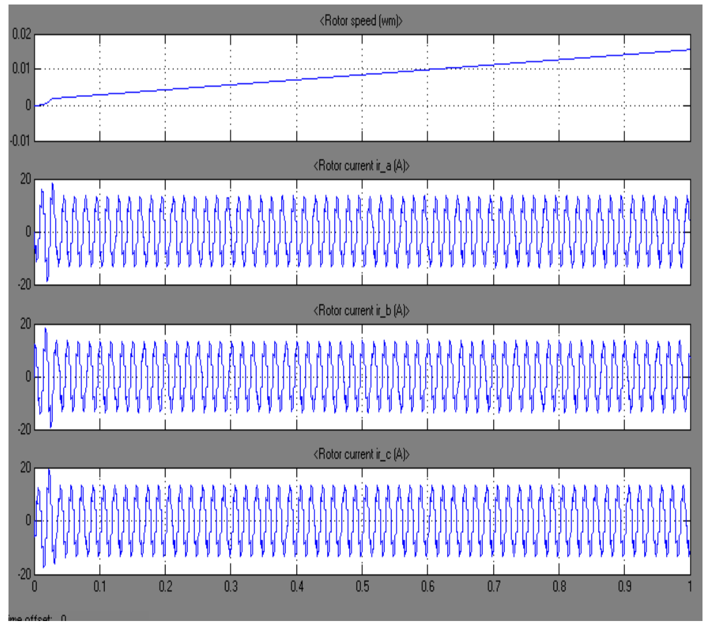

Fig 7 c. Three Phase Induction Motor Output

V. CONCULSION

The proposed converter maintains ZCS turn-off of primary devices and ZVS turn-on of secondary devices throughout the wide variation of output power. Turn-on loss of primary devices is also shown to be low. Hence, maintaining soft-switching of all devices substantially reduces the switching loss and allows higher switching frequency operation of the converter to achieve a more compact and higher power density system. The proposed modulation technique clamps the voltage across the primary-side devices naturally with zero-current commutation and therefore eliminates the necessity for active clamp or passive snubbers required to absorb device turn-off voltage spike in conventional current-fed topologies. An interleaved design is adopted to increase the power handling capacity. Lower input current ripple, reduction of passive components' size, reduced device voltage and current ratings, better thermal distribution are obtained. Usage of low-voltage devices and current sharing between interleaved cells results in low conduction losses in primary devices, which is significant due to higher currents on the primary side. Detailed steady-state operation, analysis, and design have been illustrated. Simulation and experimental results clearly confirm and demonstrate the claimed soft-switching of all semiconductor devices,

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natural clamping, and zero-current commutation of primary-side devices. These merits make the converter promising for FCV application, front-end dc/dc power conversion for fuel-cell inverters and ESS.

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