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Advanced DC–DC converter for power conditioning in hydrogen fuel cell systems

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ABSTRACT

The fuel cell (FC) generators can produce electric energy directly from hydrogen and oxygen. The DC voltage generated by FC is generally low amplitude and it is not constant, depending on the operating conditions. Furthermore, FC systems have dynamic response that is slower than the transient responses typically requested by the load. For this reason, in many applications the FC generators must be interfaced with other energy/power sources by means of an electronic power converter.

An advanced full-bridge (FB) DC–DC converter, which effectively achieves zero-voltage switching and zero-current switching (ZVS–ZCS), is proposed for power-conditioning (PC) in hydrogen FC applications. The operation and features of the converter are analyzed and verified by simulations results. The ZVS–ZCS operation is obtained by means of a simple auxiliary circuit. Introduction of the soft-switching operation in PC unit brings improvements not only from the converter efficiency point of view, but also in terms of increased converter power density. Quantitative analysis of hard and soft-switching operating of the proposed converter is also made, bringing in evidence the benefits of soft-switching operation mode. The proposed converter can be a suitable solution for PC in hydrogen FC systems, especially for the medium to high-power applications.

1. Introduction

In the recent past years, a great attention has been focused on energy technologies for the sustainable development, in particular to the hydrogen as the future energy carrier. The fuel cell (FC) is a DC voltage generator, whose output voltage is usually low and depends on the load current [1]. For this reason, FCs frequently need a DC–DC converter, as part of power-conditioning (PC) system, for interfacing with the loads and other possible energy/power sources. The concept of distributed generation (DG), adopts the idea of electrical energy production with large number of small scale (few kW–tenth of MW) generators situated near the load. Energy is produced where it needs. A typical block diagram of a DG system using FCs is shown in Fig. 1.

PC systems usually consist of a DC–DC converter and a DC–AC converter (inverter). Many different DC–DC converter topologies have been proposed for PC in FC systems and apparently without a single winning topology [2]. Regarding the DC–DC converter topology, the isolated type is preferred when high voltage gain is required. The galvanic insulation between the FC and the load is obtained with a high frequency (HF) transformer of reduced size and weight [3,4].

Among the proposed topologies for DC–DC converters, the full-bridge (FB) DC–DC converter (Fig. 2) can be a suitable solution for the medium and high power applications (>10 kW). The main advantage of this converter is the inherited short-circuit protection, the absence of HF transformer saturation problems and relatively low voltage and current stress [3–10]. For small power applications, the

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Nomenclature

DC	direct current
DC–AC	direct current to alternating current
DC–DC	direct current to direct current
DG	distributed generation
FC	fuel cell
HF	high frequency
PC	power conditioning
n	HF transformer turns ratio
ZCS	zero current switching
ZVS	zero voltage switching

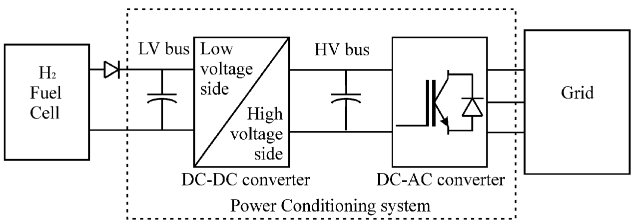

Fig. 1 – Block diagram of an FC system for distributed generation.

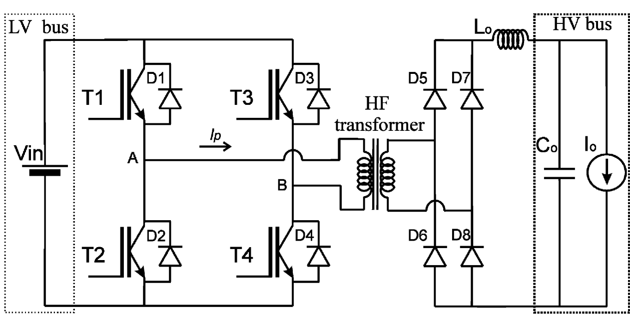

Fig. 2 – Basic scheme of full-bridge DC–DC converter.

push-pull DC–DC converter may be another competitive solution.

The switching power devices used in the converter topology can be either IGBTs or MOSFETs. For high power applications and for FC output voltage rating higher than 150 V, the IGBT can be used as power device. In spite of its lower on-state voltage drop, higher power density and lower cost respect to the MOSFET, the IGBT has higher switching losses and limited switching frequency. In particular, the turn-off switching loss is very high because of the IGBT current-tail phenomena [12].

The size and weight of DC–DC converter reactive elements (HF transformer and L–C filter) can be reduced by increasing the switching frequency, but the switching power losses will proportionally increase with the frequency. The energy dissipated during power switch turn-on or turn-off can be calculated as follows:

$$E_{sw} = \int_{t1}^{t2} v \cdot i \, dt \tag{1}$$

where t1–t2 is the time interval at which the commutation occurs, v is the voltage drop across the power switch and i is

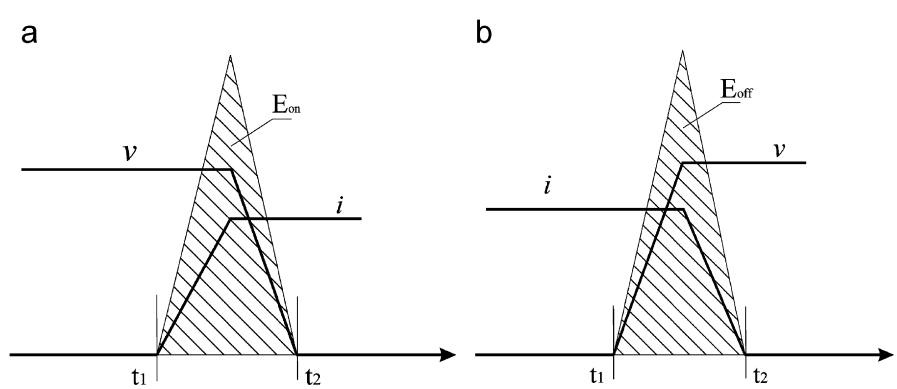

Fig. 3 – Voltage and current waveforms during commutation process in hard-switching operation. (a) Turn-on transition, hard-switching operation. (b) Turn-off transition, hard-switching operation.

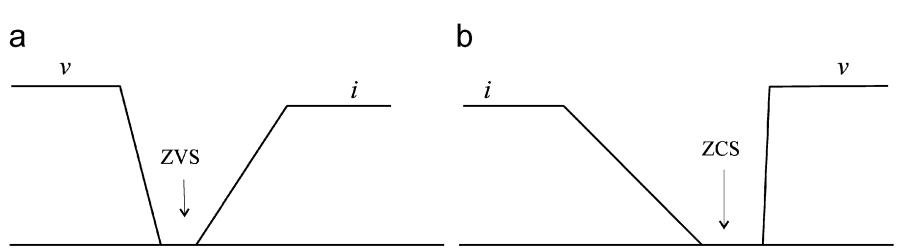

Fig. 4 – Voltage and current waveforms during commutation process in soft-switching operation. (a) Turn-on transition, soft-switching operation. (b) Turn-off transition, soft-switching operation.