Energy Conversion and Management 51 (2010) 56–63

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

New non-linear control strategy for non-isolated DC/DC converter with high voltage ratio

A. Shahin, B. Huang, J.P. Martin *, S. Pierfederici, B. Davat

Groupe de Recherche en Electronique et en Electrotechnique de Nancy – INPL – Nancy Université, 2, Avenue de la Forêt de Haye, 54516 Vandoeuvre-lès-Nancy Cedex, France

ARTICLE INFO

Article history:
Received 28 January 2009
Accepted 29 August 2009
Available online 2 October 2009

Keywords:
Cascaded converters
Interleaved boost converters
Three-level boost converters
Non-linear control
Experimental validation

ABSTRACT

In this paper, a non-isolated DC/DC converter with high voltage ratio is proposed to allow the interface between a low voltage power source like fuel cell and a high voltage DC bus. To take into account the low voltage–high density characteristics of power sources, a cascaded structure composed of two sub-converters has been chosen and allows obtaining a high voltage ratio. The choice of each sub-converter is based on the requirements of the source and its performances. Consequently, we have chosen a three-interleaved boost converter as the 1st sub-converter whereas the 2nd sub-converter is a three-level boost converter. The control of the whole system is realized thanks to energetic trajectories planning based on flatness properties of the system. The control of both the current and the balance of voltage across the output serial capacitors of the three-level boost converter is ensured by non-linear controllers based on a new non-linear model. Experimental results allow validating the proposed power architecture and its associated control.

1. Introduction

The fuel cell is currently known as a new interest so much on the industrial level than on research one. Industrialists of various sectors (electronics, cellular phones, vehicle, power generation, heating, etc.) invest in the development of this technology with high density characteristics and weak harmful gas emissions.

Because of fuel cells low output voltage characteristic, in order to connect these sources to electrical devices, a static converter has to be used to step-up the voltage magnitude of the sources to a regulated DC bus. In our case, the step-up voltage is about 10 and the converter is connected to a battery pack. In order to reach a high voltage ratio, isolated converter structures are usually applied, especially with single-phase [1,2] or three-phase [3] full bridge converter. However, the isolated structure converters are usually used for no more than several kW applications [1,3]. If we want reach a higher power with isolated structures, several isolated converters units will operate together in order to segment the input power [2].

Considering the non-isolated converter structures, classical boost converter has the highest voltage ratio. However, the highest step-up voltage ratio of boost converter is limited by parasitic elements like serial resistances [4]. Some others non-isolated converter structures are developed to increase the converter voltage ratio [5–8]. In these structures, the number of additional components used to improve the voltage ratio is important. In addition to the voltage ratio requirement, the chosen converter has to respect another constraint. In order to minimize the constraints of the fuel cell stack, a small current ripple has to be guaranteed [9,10]. So to achieve the two previous requirements, we propose, in this paper, the structure depicted in Fig. 1.

With this topology a high voltage ratio can be achieved [11]. Moreover a classical interleaved technique for the 1st sub-converter can be used to minimize the input current undulations rate [12]. To optimize the efficiency of the global structure of conversion, a three-level boost converter can be used for the 2nd sub-converter. In fact the three-level boost converter has less switching losses than the two-interleaved boost converter while the converter output voltage is a high voltage [21]. However, the two-interleaved boost converter is better for low output voltage.

Thus, the choice of the proposed cascaded converter structure allows optimizing the efficiency of the converter with high voltage ratio and small input current undulations. The intermediary voltage and the power provided to the load have to be controlled. To solve the control issues of this non-linear system, different solutions can be used. In [13], the authors proposed an input/output linearization technique to ensure the control of two stages power structure. With the power structure proposed in this paper, this control method is not suitable (unstable zeroes, difficulty to take into account losses, etc.). In this paper, a flatness based control will be used to manage energy in the system [14–16]. To ensure both the control of currents in the inductors and the balance of voltages across the output capacitors, non-linear controllers based on a new

* Corresponding author.
E-mail address: jean-philippe.martin@ensem.inpl-nancy.fr (J.P. Martin).

0196-8904/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2009.08.032

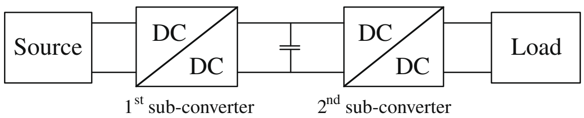

Fig. 1. Cascaded converter structure.

non-linear model of the three-level boost converter are used. In the last part of the paper, experimental results will be presented to validate the efficiency of the proposed control methods.

2. Proposed converter structure

As explained in the first paragraph, the proposed converter structure is constituted by a cascade of two sub-converters in order to obtain the desired voltage ratio and small power source current undulations. As detailed in [21], the choice of an interleaved boost converter [17] for the 1st sub-converter and a three level boost converter [18] for the second one leads to a better efficiency of the global conversion structure thanks to the use of MOSFET/Schottky diode technology rather than IGBT/ultrafast diode technology for the 2nd sub-converter. To ensure a better behaviour of the system in no load condition, the choice of reversible sub-converters has been done (note that in this case, synchronous rectification can be used to increase the global efficiency of the conversion structure). The semiconductors used to realize the test bench are given in the Table 1. The global structure of conversion is presented in Fig. 2. The fuel cell static characteristic is presented in Fig. 3.

The resistances r and r_B represents respectively the DC-link cable resistance and the parasitic resistance due to serial connection of the batteries. The resistance r_B is supposed to be known. P_{ch} represents the power delivered by the DC/DC converter. The estimation of the batteries voltage V_{B0} is realized thanks to the measures of the batteries pack voltage V_B and the load current i_{ch}.

Table 1
Semi-conductor parameters.

Structure	Switch	Diode
1st sub-converter: two-interleaved boost	MOSFET 100 V 230 A (IXFN230N10)	Schottky diode 100 V 80 A (STPS160H100TV)
2nd sub-converter: three-level boost	MOSFET 200 V 180 A (IXFN180N20)	Schottky diode 150 V 100 A (IXYS DSS2x101–15A)

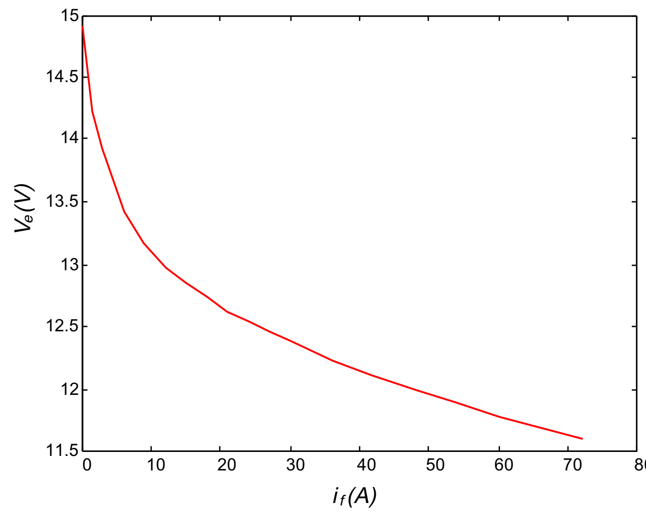

Fig. 3. Static characteristic of the fuel cell $V_e = f(i_f)$ (experimental results).

3. Global converter control

The use of a cascaded structure can lead to interactions between the controls of the two converters if they are designed separately. In this case, to study interactions between the two converters, impedance criteria are often used to study the stability of the cascaded system [19]. Nevertheless this technique allows proving the asymptotic stability only around a given operating point. The large signal stability properties or the behaviour of the system in case of large external disturbances are not foreseen by this model. In this paper, a non-linear control algorithm based on the flatness properties of the system is proposed. Design parameters are independent of the operating point, interactions between the two converters are taken into account by the controllers and high dynamic in perturbations rejection is achieved.

3.1. Introduction to flatness system

In differential algebra, a system is viewed as a differential field by a set of variables (states and inputs). The system is said to be differentially flat if one can find a variable, called the flat output, such that the system is algebraic (non-differentially) over the differential field generated by the set of flat outputs. In fact, a system is flat if an output can be found such that all states variables and the components of the input vector can be determined from this

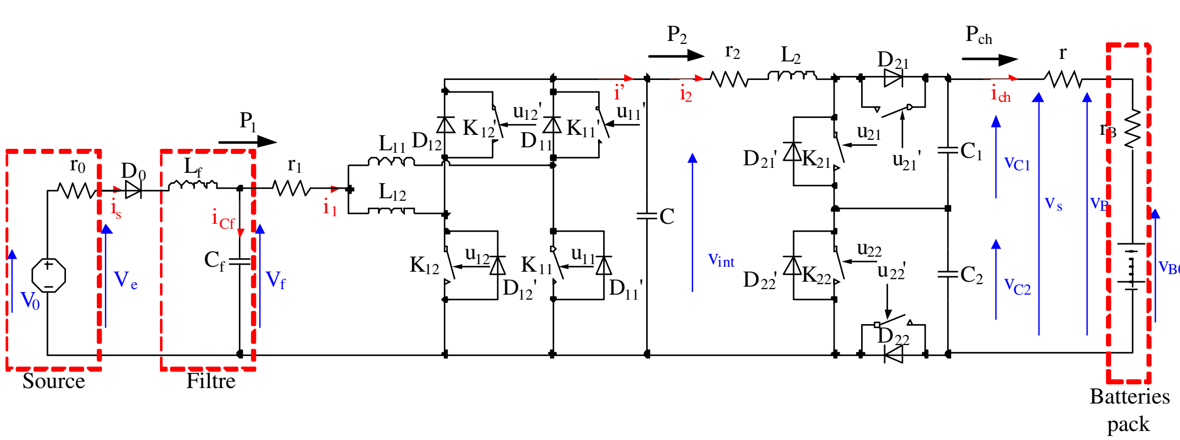

Fig. 2. Proposed converter.