Electrical Power and Energy Systems 32 (2010) 1031–1036

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

DC link voltage optimized control for efficient residential fuel cell converter

Yong Wang *, Xu Cai

School of Electronic, Information and Electrical Engineering, Shanghai Jiaotong University, Shanghai 200240, China

ARTICLE INFO

Article history:
Received 21 April 2009
Received in revised form 8 December 2009
Accepted 23 February 2010

Keywords:
Fuel cell
Converter
Efficiency
DC link

ABSTRACT

The stack of a residential fuel cell power generation system has low voltage and high current output characteristics. Therefore, a high step up DC–DC converter with high frequency transformer isolation is necessary to elevate the voltage to the DC link as inverter input. This paper deeply investigates the relationship between the DC link voltage and the converter efficiency. The calculation and simulation results reveal that the lower the DC link voltage is, the higher the converter efficiency is. Based on this conclusion, a DC link voltage optimized control scheme is proposed to improve the converter efficiency, further the power conditioning system efficiency.

1. Introduction

Efficiency is an important issue in the residential fuel cell system [1–4]. And an efficient power conditioning system (PCS) connecting between the load and the fuel cell is a key point to the whole system efficiency improvement.

Refs. [5,6] described a two stage PCS topology as shown in Fig. 1. In the first stage, the stack low voltage is elevated to the DC link high voltage by the DC–DC converter, while in the second stage, the DC link voltage is inverted to the alternative component.

It is believed that the PCS efficiency mainly depends on the high step up DC–DC converter efficiency [6]. Therefore, lots of control scheme or topologies are proposed to improve the converter efficiency. However, none of the current literature investigates the relationship between the DC link voltage with the converter efficiency. This paper first finds out by calculation and simulation that the DC link voltage influences the converter efficiency much, then a novel DC link voltage optimized control scheme is proposed to improve the converter efficiency.

The rest of the paper is organized as follows. In Section 2, some general information of fuel cell DC–DC converter and the fuel cell stack is described. Further, the widely used current fed full-bridge converter is used as example to calculate the converter power loss and efficiency. Section 3 utilizes the data acquired from Section 2 to compare the converter efficiency with different DC link voltage. Therefore, an important conclusion is summarized in Section 3 that the lower the DC link voltage is, the higher the converter efficiency is. This is the theoretical base for Section 4, in which, this paper proposes a novel DC link voltage optimized control scheme to improve the converter efficiency. And Section 5 describes the experimental results. Finally, in Section 6, this paper is summarized, and the final conclusion is given.

2. Converter power loss and efficiency analysis

Fig. 2 shows the current fed full-bridge converter topology. Where $I_{rms,SW}$ is the switch current, C_{IN}, C_{OUT} denote the input and output capacitor respectively, I_{FC} and U_{FC} are the stack current and voltage, I_{DC} and U_{DC} are the DC link current and voltage respectively, while the transformer turn ratio is denoted by n.

It should be mentioned first that the stack is always operating at nearly fixed voltage which makes the fuel cell system most efficient [7,8]. And the operating voltage point O is always near the end of ohmic region in the stack V–I curve as is shown in Fig. 3.

Where V_{SOPV} is the stack voltage at operating point, V_{SOCV} is the stack open circuit voltage, the stack allowable minimum voltage is denoted by $V_{S\min}$.

In this section, the converter efficiency is simulated and calculated at fixed stack power when V_{SOPV} is sweeping from 30 V to 60 V. The $V_{SOPV} = 39$ V simulation is used to explain the process. The main circuit parameters are:

- Stack power P_{FC}: 1500 W.
- Switching frequency: 45 kHz.
- DC-bus voltage: 360 V.
- Voltage range: 30–60 V.
- $V_{SOPV} = 39$ V.
- Transformer coupling factor: 0.9999999999.
- Inductor current ripple: 10% of the nominal current.

* Corresponding author.
E-mail address: wangziqian2006@gmail.com (Y. Wang).

0142-0615/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2010.02.001

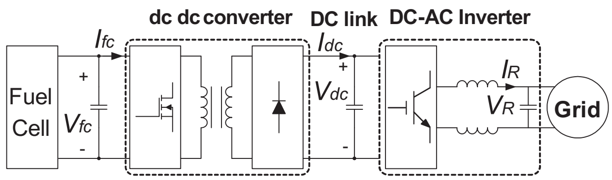

Fig. 1. Fuel cell two stage PCS topology.

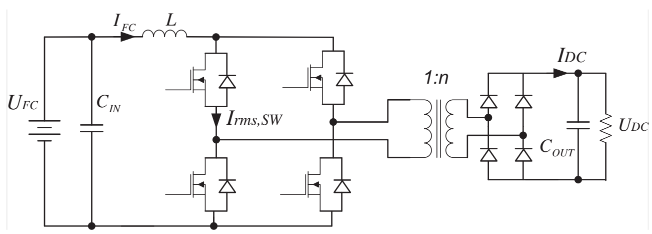

Fig. 2. Current fed full bridge for residential fuel cell converter.

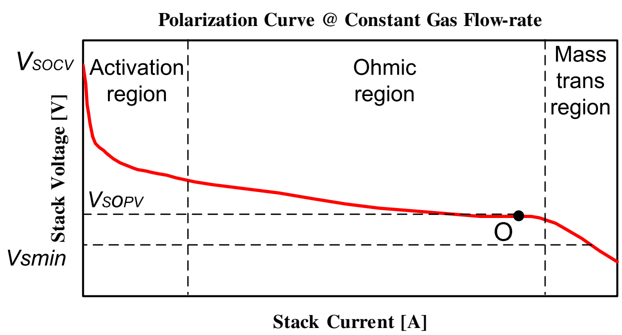

Fig. 3. Fuel cell stack *V–I* curve under constant gas flow rate.

- Output capacitance: C_{OUT} = 10 μF.
- Input capacitance: C_{IN} = 10 μF.
- Leakage inductance: 5 μH for both topologies.

And the efficiency is defined as:

$$\eta = 100 \cdot \left(1 - \frac{P_{LOSS}}{P_{FC}}\right) \tag{1}$$

$$P_{LOSS} = P_{SW} + P_{COND} + P_{DIODE} + P_{IND} + P_{TR} + P_{CT} \tag{2}$$

where P_{LOSS} is the converter total loss, P_{FC} is the fuel cell power, P_{SW}, P_{COND} are the switching loss, the switch conduction loss, respectively, P_{DIODE} denotes the rectifier diode loss, P_{IND} is the inductor loss, P_{TR} is the transformer loss, the control loss is simulated by constant P_{CT}. The other minor losses like the capacitors losses, core losses, diode recovery losses, snubber losses are not considered.

IRFB4310ZPbF is selected as the main switch, diode is selected as 600 V rating DSEI 12-06A. Therefore, the other circuit parameters can be shown in Table 1.

The simulation circuit and the waveforms are shown in Figs. 4 and 5, respectively.

By using the simulation results, variable losses can be calculated according to Fig. 5.

Table 1
Current fed converter circuit parameters.

Item	Parameter	Note
n	5	Transformer turn ratio
L	100 μH	Input inductor
R_{ON}	5 mΩ	Switch internal resistance
R_{DIODE}	12 mΩ	Diode internal resistance
V_{F0}	1.12 V	Rated diode forward voltage
t_R	100 ns	The switch rise time
t_F	100 ns	The switch fall time
R_{IND}	5 mΩ	Inductor resistance
R_{PRI}	1 mΩ	Transformer primary resistance
R_{SEC}	25 mΩ	Transformer secondary resistance

$$P_{SW} = 4 \cdot \left[\frac{1}{2} \cdot \left(\frac{I_{FC} - \frac{\Delta I_{FC}}{2}}{2}\right) \cdot \frac{U_{DC}}{n} \cdot t_R + \frac{1}{2} \cdot \left(\frac{I_{FC} + \frac{\Delta I_{FC}}{2}}{2}\right) \cdot \frac{U_{DC}}{2} \cdot t_F\right] \cdot f_{SW} \tag{3}$$

$$P_{COND} = 4 \cdot R_{ON} \cdot I^2_{RMS,SW} = 4 \cdot R^{ON} \cdot \left(I_{FC} \cdot \frac{\sqrt{2 - D}}{2}\right)^2 \tag{4}$$

$$P_{DIODE} = 4 \cdot \left(V_{F0} \cdot I_{RMS,DIODE} + R_{DIODE} \cdot I^2_{RMS,DIODE}\right) \tag{5}$$

where in Eq. (5), $I_{RMS,DIODE} = \frac{I_{FC}}{n} \cdot \sqrt{\frac{1-D}{2}}$

$$P_{IND} = \frac{1}{2} \cdot R_{IND} \cdot I^2_{FC} \tag{6}$$

$$\begin{aligned} P_{TR} &= R_{PRI} \cdot I^2_{RMS,PRI} + R_{SEC} \cdot I^2_{RMS,SEC} \\ &= R_{PRI} \cdot \left(I_{FC} \cdot \sqrt{1 - D}\right)^2 + R_{SEC} \cdot \left(\frac{I_{FC}}{n} \cdot \sqrt{1 - D}\right)^2 \end{aligned} \tag{7}$$

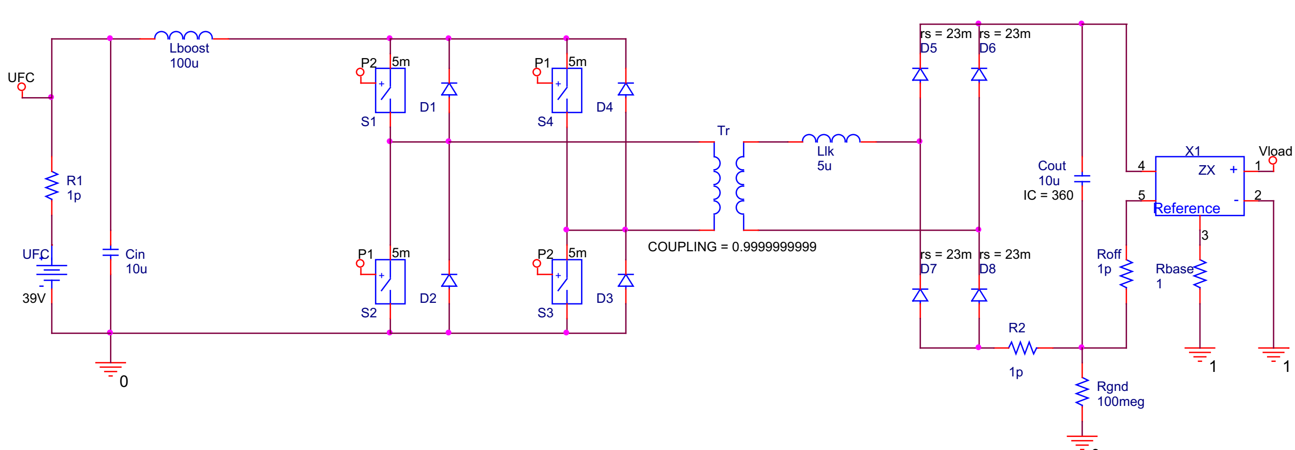

Fig. 4. Simulation schematic for the current fed full-bridge converter.