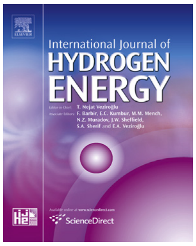
Available online at www.sciencedirect.com

ScienceDirect

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



Design of proton exchange membrane fuel cell grid-connected system based on resonant current controller

Weirong Chen, Ying Han, Qi Li, Zhixiang Liu, Fei Peng*

School of Electrical Engineering, Southwest Jiaotong University, Chengdu 610031, Sichuan Province, China

ARTICLE INFO

Article history:
Received 23 October 2013
Received in revised form
18 January 2014
Accepted 16 February 2014
Available online xxx

Keywords:
Proton exchange membrane fuel cell
Grid-connected system
Resonant current controller
Harmonic compensations

ABSTRACT

Because of its high efficiency, low pollution and good stability, proton exchange membrane fuel cell (PEMFC) is considered as one of the most promising technologies for a wide range of applications, such as distributed power generation, transportation, portable power source and automobile. In a PEMFC grid-connected system, the proportion integration (PI) regulator can achieve zero error for the dc components in the rotating frame, but cannot achieve zero error for the ac components in the rotating frame. Hence, the PEMFC grid-connected system will produce a large number of harmonics. In order to overcome this shortcoming, a proportion integration resonant (PIR) controller is utilized to realize zero magnitude error and selective disturbance rejection. Instead of the PIR controller, a vector proportion integration (VPI) controller is designed to quickly and accurately regulate current which achieve zero both amplitude and phase frequency response at the resonant frequency simultaneously. In this paper, the PEMFC grid-connected system based on PIR and VPI controllers are developed according to the operating characteristics of a PEMFC generation system, then analyze and compare the performance of compensation harmonics between them. The total harmonic distortion (THD) of grid-connected voltage and current are measured by means of the criterion of IEEE Std1547-2003. This proposed grid-connected method will provide a novel approach for the design of advanced PEMFC grid-connected control system.

1. Introduction

Future energy production and distribution networks will certainly benefit from small size (1–100 kW) Distributed Generation (DG) systems. Fuel Cells (FCs) are static energy conversion devices which convert directly the chemical energy of fuel into DG electrical energy. The main advantages of the FCs are: high efficiency, low or zero emissions when hydrogen is used as a fuel, low noise during operation and high modularity. The PEMFC is considered one of the most promising technologies for application in hybrid vehicles due to its high-power density, low operating temperature, a certain level of rather quick startup capability, and long life time [1–4].

Due to the energy crisis, economical recession and environmental issues, besides the rapid growth of the load, the penetration of DGs, especially FC DGs, are increasing rapidly around the world. Therefore, the PEMFC grid-connected

---

* *Corresponding author*. Tel.: +86 2887603332; fax: +86 2887605114.
E-mail addresses: han_ying1009@163.com, 254778440@qq.com (Y. Han).

http://dx.doi.org/10.1016/j.ijhydene.2014.02.103

Please cite this article in press as: Chen W, et al., Design of proton exchange membrane fuel cell grid-connected system based on resonant current controller, International Journal of Hydrogen Energy (2014), http://dx.doi.org/10.1016/j.ijhydene.2014.02.103

system as a hot issue is studied widely by many researches. Fuel cell current ripple reduction is a key issue for its grid-connected system [4].The IEEE Std1547-2003 standard allows a limit of 5% for the current total harmonic distortion (THD). In the general PEMFC grid-connected system, PI regulator with grid voltage feed-forward is commonly used for current controller, but this solution exhibits two well known drawbacks: inability of the PI controller to track a sinusoidal reference without steady-state error and poor disturbance rejection capability [5]. Thus, there is a large number of low-order harmonics in the PEMFC grid-connected system.

In recent years, resonant controllers have gained significant importance in harmonic compensation a due to their overall good performance. The current control scheme consisting of a PI regulator and a resonant compensator is presented in Refs. [5,6,8,9]. The PIR controller has good stable performance of PI regulator and dynamic performance of resonant controller, the dc components are regulated by the PI regulator and the ac components are controlled by the resonant regulator [9]. In fact, in order to achieve zero stationary error of the harmonic currents, the current controller should achieve zero amplitude and phase frequency response at the resonant frequency simultaneously. However, the resonant controller of the PIR is combined by a first-order molecular and a second-order denominator, it cannot achieve zero phase frequency response at the resonant frequency. A Vector-PI (VPI) controller consisting of a PI regulator and a resonant controller with a second-order molecular is proposed in Refs. [10,11]. The VPI controller can quickly and accurately regulate current and achieve zero both amplitude and phase frequency response at the resonant frequency. Thus the VPI controller has the better performance of compensation harmonics.

In this paper, a general 50 kW PEMFC grid-connected system is developed according to the operating characteristics of a PEMFC generation system. In order to improve the performance of compensating low-order harmonics, the improved current controllers with PIR controller and VPI controller are designed. The two improved current controllers are used in the PEMFC grid-connected respectively. At last, according to analysis and compare the simulation results using different current controllers, their performances of harmonic compensation can be verified.

2. PEMFC grid-connected system

2.1. *PEMFC description and modeling*

In this paper, the 50 kW PEMFC model is built with the Fuel Cell Stack provided by Matlab/Simulink. The PEMFC equivalent circuit model is shown in Fig. 1, and its function can be discretized as follows:

The stack output voltage can be described as:

$$V_{fc} = E_{oc} - V_{ohmic} - v_d \tag{1}$$

where V_{fc} is the stack output voltage, E_{oc} is the open circuit voltage, V_{ohmic} is the ohmic overvoltage, and v_d is the total polarization overvoltage.

Consideration of the effect of temperature and gas pressure open circuit potential of PEMFC is expressed as

$$E_{oc} = K_c\left[E^0 + (T-298)\frac{-44.43}{zF} + \frac{RT}{zF}\ln\left(\frac{P_{H_2}P_{O_2}^{1/2}}{P_{H_2O}}\right)\right] \tag{2}$$

where, K_c rated voltage constant, T is the working temperature, F is Faraday constant, R is the gas constant, P_{H_2} and P_{O_2} are the gas pressures, E^0 is the electromotive forces under standard pressure, z is transfer electron number.

The Ohmic overvoltage can be expressed as

$$V_{ohmic} = i_{fc}R_{ohmic} \tag{3}$$

where, R_{ohmic} is inner resistance of a stack, i_{fc} is the cell output current.

The total polarization overvoltage v_d can be represented as:

$$v_d = N \times A \times \ln(i_{fc}/i_0) \tag{4}$$

where, N is the number of cells.

The Tafel slope A and the exchange current i_0 in equation (4) can be expressed as follows

$$i_0 = \frac{zFk\left(P_{H_2} + P_{O_2}\right)}{Rh}e^{\frac{-\Delta G}{RT}} \tag{5}$$

$$A = \frac{RT}{z\alpha F} \tag{6}$$

where, k is Boltzmann's constant, h is Planck's constant.

2.2. *PEMFC grid-connected system structure*

Due to the output characteristic of PEMFC stack is "soft", its output dc voltage is obviously fluctuant while the load changes. Thus, PEMFC requires a longer response time to reach a stable output state while load changes. In order to overcome this shortcoming, a two-stage grid-connected structure is designed in this paper. Fuel cell is to provide the power with low voltage and high current to the dc–dc converter; then the dc–dc converter is to boost low voltage to proper dc link voltage, and provides stable dc voltage to the dc/ac inverter; at last, the dc/ac inverter and LC-filter convert

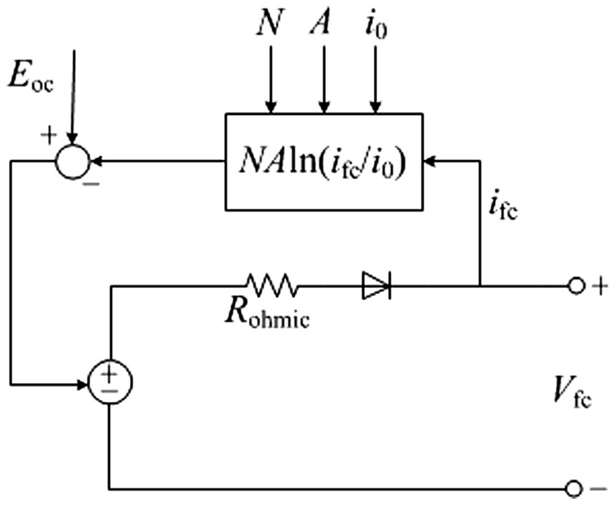


Fig. 1 – PEMFC equivalent circuit mode.

Please cite this article in press as: Chen W, et al., Design of proton exchange membrane fuel cell grid-connected system based on resonant current controller, International Journal of Hydrogen Energy (2014), http://dx.doi.org/10.1016/j.ijhydene.2014.02.103