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A new control strategy of solid oxide fuel cell based on coordination between hydrogen fuel flow rate and utilization factor

Majid Nayeripour [a,*], Mohammad Hoseintabar [b]

[a] Faculty of Electrical and Electronic Engineering, Shiraz University of Technology, Shiraz, Iran
[b] Faculty of Electrical and Electronic Engineering, Al-Taha University, Tehran, Iran

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ABSTRACT

In this paper, a new control strategy for rapid changing of output power level of solid oxide fuel cell (SOFC) power plant is proposed based on the adaptive control strategy. In the proposed control strategy, the utilization factor (UF) of solid oxide fuel cell stack is kept constant in steady state by feeding hydrogen to the stack at its rate value. In transient state, the utilization factor of the stack changes in its allowable range by controlling the current drawn and power condition unit. This coordination returns the utilization factor of fuel cell (FC) system to its optimal value. The proposed control strategy will be very useful to protect SOFC stack from internal damage during large disturbances. In order to investigate the proposed control strategy and verify dynamic modeling, the MATLAB/SIMULIK software is used. The results show the capability of the proposed control strategy under rapid changes in load demand.

Contents

1. Introduction

The ever increasing energy consumption, global warming, and oil price over the last decades, have attracted more attentions to utilize alternative energy sources instead of conventional power generation systems. FC-based power generation systems are emerging as promising alternative power generation systems because of their high efficiency, low environmental impact, modularity and high reliability. FCs are classified based on different features such as temperature or electrolyte. With respect to the electrolyte classification, the FCs systems are classified as electrolyte types such as phosphoric acids (PAFC), molten carbonate (MCFC), solid oxide (SOFC) and proton exchange membrane (PEMFC). Among them the PEMFC type is widely used in different applications such as portable or residential applications due to its low temperature, high power density and relatively short start up time. However, this type of FC system needs pure hydrogen as fuel to operate normally and have lower efficiency against high temperature SOFC [1].

SOFC produces direct current (DC) electric power through an electrochemical process. The electrolyte of the SOFC is solid and

* Corresponding author.
E-mail addresses: nayeri@sutech.ac.ir, mnayeri@yahoo.com (M. Nayeripour), mohammad.hoseintabar@gmail.com, M.hoseintabar@ut.ac.ir (M. Hoseintabar).

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Nomenclature

E_0	Ideal standard potential
F	Faraday's constant
I_{fc}	Fuel cell current
K_{an}	Anode valve constant
K_{H_2}	Valve molar constant for hydrogen
K_{H_2O}	Valve molar constant for water
K_{O_2}	Valve molar constant for oxygen
K_r	Constant $(=N_0/4F)$
M_{H_2}	Molecular mass of hydrogen
n_{H_2}	Number of hydrogen moles in the anode channel
N_0	Number of cells in series in the stack
p_i	Partial pressure
$q_{H_2}^{in}$	Input fuel flow
$q_{H_2}^{o}$	Output fuel flow
$q_{H_2}^{r}$	Fuel flow that reacts
R	Ohmic loss
R_{H-O}	Ratio of hydrogen to oxygen
R	Universal gas constant
T	Absolute temperature
U	Fuel utilization factor
V_{an}	Volume of anode
V_{fc}	Fuel cell voltage
τ_{H_2}	Response time for hydrogen flow
τ_{H_2O}	Response time for water flow
τ_{O_2}	Response time for oxygen flow

operates at high temperatures (600 °C to 1000 °C). Due to high temperature, SOFC can produce electricity from natural gases with no additional reforming catalysts needed. The output voltage of SOFC depends on fuel flow, oxidant flow, temperature, and load demand. In addition, this kind of FC system has a simple structure and internal reforming capability [2].

FCs power generation systems have slow transient (dynamic) response than the dynamic response of the power condition unit that they are connected. The FC's inability to change its current as fast as the electrical load changes has important implications on the overall power system design that should be considered [3]. Various types of modeling, control, and performance analysis of FC system in different applications have been proposed in the recent decade. A summary for SOFC system modeling and its control strategy in the recent decade is expressed in Table 1 [2,4–11].

In this paper, the simplified model of power electronics interfacing components are considered and also the effects of ripples generated due to the switching of power electronics devices are neglected to show the dynamic behavior of SOFC system for a long time.

The objective of this research is that a new control strategy based on adaptive control strategy is used to improve the dynamic response of FC systems. The proposed control strategy prevents SOFC system from overuse and underuse conditions. This control strategy is used to solve the problem of slow dynamic of SOFC system effectively and also to reduce the size of storage device which is connected to the DC link. Additionally, the effect of the proposed system on the dynamic behavior of the UF is investigated to indicate the validity of proposed system.

2. Methodology

In this section, the dynamic model of SOFC system and dynamic behavior of UF are presented. In first section, the dynamic model of SOFC system based on electrochemical equations is introduced. This model is current–voltage model of SOFC system. Voltage of SOFC system depends on amount of current drawn from SOFC system. In fact, based on current drawn from SOFC system the voltage can be calculated. With usage of these equations the

Table 1
Summary of SOFC system model.

Authors	Fuel cell model	Year	Contribution	Comments
Zhu and Tomsovic	Based on Padulles SOFC model 2	2001	Micro turbine helps load following performance	Fuel cell operates as a constant output power DG
Miao and Klein	Based on Padulles SOFC model	2002	Designed controllers to improve the oscillation damping of the whole system using linearzed model	Ignorance of incremental fuel cell output voltage. Average model of PCU
M.Y. El- Sharkh and A.K. Saha et al.	Based on Padulles SOFC model	2004 and 2007	In their proposed system PEMFC system are controlled based on traditional methods that are used for the control of active and reactive power output of a synchronous generator	It uses two proportional-integral controllers separately with FC system to control fuel flow. The two controllers are relative to each other
O.C. Onar et al.	Based on Padulles SOFC model	2006	The FC system is modified and integrated with the wind turbine generator, electrolizaer and storage model	In design of proposed model the authors did not consider the effect and behavior of FC system utilization factor under disturbance and the proposed model cannot show the exact behavior of FC system
M. Uzunoglu et al.	Based on Padulles SOFC model	2008	Hybrid power generation	In design of proposed model the authors did not consider the effect and behavior of FC system utilization factor under disturbance and the proposed model cannot show the exact behavior of FC system
M. Hoseintabar and M. Nayeripour and T. Niknam	Based on Padulles SOFC model	2010	1. The dynamic model of FC system is modified with considering the effect of utilization factor to operate in optimal value to enhance FC system performance and lifetime 2. Proposed model are investigated and are implemented with combination of SC system	
Proposed model	Based on Padulles SOFC model	2011	1. The dynamic response of FC system is improved with adaptive control strategy 2. Proposed model are investigated and are implemented with combination of SC system	