INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–15

Available online at www.sciencedirect.com

ScienceDirect

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

Power quality enhancement of grid connected fuel cell using evolutionary computing techniques

Mohamed I. Mosaad [a,b,*], H.S. Ramadan [c,d]

[a] Yanbu Industrial College (YIC), Saudi Arabia

[b] Electrical Engineering Department, Higher Technological Institute, Cairo, Egypt

[c] FCLab FR CNRS 3539, Femto-ST UMR CNRS 6174, Univ. of Bourgogne Franche-Comte/UTBM, 90010, Belfort, France

[d] Electrical Power and Machines Dept, Faculty of Engineering, Zagazig University, 44519, Zagazig, Egypt

ARTICLE INFO

Article history:
Received 15 April 2017
Received in revised form
23 January 2018
Accepted 1 February 2018
Available online xxx

Keywords:
Fuel cell (FC)
Power quality
Harmony search (HS)
Modified flower pollination algorithm (MFPA)
Electromagnetic field optimization (EFO)
Particle swarm optimization (PSO)

ABSTRACT

Fuel Cell (FC), as a type of new renewable energy sources grid-connected at Point of Common Coupling (PCC), is introduced in this study. This article presents the power quality improvement of the FC integrated to the power network through a chopper and an inverter using the conventional PI controller. Two PI controllers, tuned by three recent different evolutionary computing techniques namely Harmony Search (HS), Modified Flower Pollination Algorithm (MFPA) and Electromagnetic Field Optimization (EFO) methods are considered. The two PI controllers are used for driving the inverter connected the on-grid FC in order to govern the PCC voltage between the FC and the power network. These two controllers are exploited to drive the power and the current regulators at different voltage sag and swell conditions. The three optimization methods are compared to the Particle Swarm Optimization (PSO) with regards to voltage profile, powr quality and execution time.

Simulation results, using Matlab/Simulink™, show the significance of the three optimization techniques in regulating the voltage at PCC with reduced harmonics during the system voltage sag and swell conditions when compared to the PSO. Through the numerical analysis, the superiority of MFPA method among the different optimization metaheuristic techniques is highlighted particularly for enhanced dynamic voltage response purposes.

Introduction

The conventional fuel natural resources become unaffordable, less efficient and environmentally hazardous in comparison with other renewable resources of energy. Accordingly, different recent researches have been considered through Renewable Energy (RE) integration in Electric Vehicles (EVs) and/or Electric Grids (EGs). The energy management among the various sources of energy become of great interest. Fuel cells (FCs), as one of RE sources, have recently witnessed an increased technological advancement in both research and innovation issues particularly in EG applications. Aki et al. (2016) have studied the dynamic performance of the Energy

* *Corresponding author:* Yanbu Industrial College (YIC), Alnahdah, Yanbu Al Sinaiyah, Yanbu 46452, Saudi Arabia.
E-mail addresses: m_i_mosaad@hotmail.com, habibm@rcyci.edu.sa (M.I. Mosaad).

https://doi.org/10.1016/j.ijhydene.2018.02.001

Nomenclature

BW	Band width
CAES	Compressed air energy storage
C_{FC}	FC equivalent electric capacity
$D_i^{P_jK_j}$	Distance between positive and neutral field
$D_i^{N_jK_j}$	Distance between negative and neutral field
EMS	Energy management system
EMP	Electromagnetic particle
E_{NER}	Thermodynamic potential
EVs	Electric vehicles
ER	Energy resources
F	Faraday constant
FC	Fuel cell
GWO	Grey wolf optimizer
HS	Harmony search
IEM	intelligent energy management
i_{PEMFC}	FC current
j	Variable index of generated electromagnet
J	Cost function
k	Random index from natural field
MPFA	Modified flower pollination algorithm
MSA	Moth swarm algorithm
N	Random index from the negative field
P	Random index from the positive field
PCC	Point of common coupling
PEMFC	Proton Exchange Membrane Fuel Cell
P_{H2}	Hydrogen partial pressure
PQ	Power quality
P_{O2}	Oxygen partial pressure
PS_rate	Probability of selecting electromagnetics of generated
PSO	Particle swarm optimization
PV	Photovoltaic
r	Random value between 0,1
QSS	Quantized State Systems
R	Universal gas constant
R_a	FC equivalent resistance
RE	Renewable energy
T	Fuel cell operation temperature
TES	Thermal energy storage
T_{ref}	Reference temperature
V_{act}	Activation over potential
V_{con}	Concentration over potential
$V_{Chopper}$	Chopper output voltage
v_d	Dynamic voltage of the FC
V_{ohm}	Ohmic over potential
V_{PEMFC}	Exit voltage of a simple proton exchange membrane
ΔG	Change in Gibbs free energy
ΔS	Change in entropy
τ	Electric time constant

Management System (EMS) model considering various evaluation indices such as: energy costs, CO_2 emissions and energy consumption [1]. Valverde et al. (2016) have studied the theoretical and experimental sides of the energy management in hydrogen microgrids. The simulation results have investigated how different control approaches can greatly impact the plant performance [2]. Amrouche et al. (2016) have presented the overview of energy storage such as electrochemical/flow batteries, FCs, solar-based fuels, Thermal Energy Storage (TES), Compressed Air Energy Storage (CAES) in REs [3]. Vivas et al. (2017) have introduced the simulator H_2RES_2 for hydrogen hybridization with different RE-based systems for evaluating the energy management strategies and the corresponding optimal implementation [4]. Uyar and Besikci (2017) have presented the concept of 100% RE and the role of both hydrogen and FCs in the transportation sectors. The main objective was to attain energy self-sufficient, better managed, in harmony with nature ecological communities [5].

In addition, Migoni et al. (2016) have investigated the use of the object oriented Modelica language to build different Hybrid Renewable Energy Systems (HRES) models and to determine the relevant constraints. The Quantized State Systems (QSSs) have been proposed owing to different features that overcome discontinuities, strong non-linearities and combinations of slow and fast dynamics with reasonable time and acceptable results [6]. Trivino et al. (2016) have described the energy management model dedicated to reaching the optimized operation among the energy sources of the hybrid grid-connected RE systems: Photovoltaic (PV) and wind turbine with battery and hydrogen system (FC and electrolyzer). Formulating the multi-objective optimization considering the operating cost, efficiency and lifetime have been illustrated. Then, the Particle Swarm Optimization (PSO) is used for demonstrating the efficiency of the proposed EMS [7]. Yunez-Cano et al. have investigated the analytical model for sizing, analyzing and assessing the feasibility of hybrid PV/hydrogen (PV/H_2) systems using real weather data. The numerical analysis has shown that the hydrogen system can guarantee both supplying energy for longer periods in comparison with using only batteries and requiring less maintenance, weight and volume [8]. Mohamed et al. (2016) have discussed the possibility of generating solar hydrogen in the southern Sahara region of Algeria. The experimentation by electrolysis of water through PV energy has been studied. The simulation results have shown that FCs are suitable for use in desert areas. The output gas pressure and the relevant temperature can be dedicated to improving the FCs performance [9]. Nasri et al. (2016) have proposed accurate simulation system where both the solar and the recovery energy components are the primary load-suppliers and FCs-dependent respectively. The primary goal has been to ensure the efficient electricity generation without interruption through the proposed Intelligent Energy Management (IEM). The simulation results have verified the performance of the IEM besides its flexibility and reliability to provide adequate high-quality power to the load under uncertainties [10].

Moreover, Ramadan et al. (2016) have proposed the coupled system of both hydrogen and solar energy. The solar thermal has been considered as an energy source to supply the electrolyzer. Both parameters, the thermal efficiency and the corresponding operational time, have been considered. From the simulation results, lower mirrors number from May to August have been found due to the higher amount of generated power. However from November to January, higher

Please cite this article in press as: Mosaad MI, Ramadan HS, Power quality enhancement of grid connected fuel cell using evolutionary computing techniques, International Journal of Hydrogen Energy (2018), https://doi.org/10.1016/j.ijhydene.2018.02.001