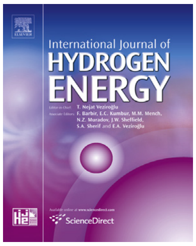
ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2016) 1–16

Available online at www.sciencedirect.com

ScienceDirect

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



Short Communication

Performances analysis of WT-DFIG with PV and fuel cell hybrid power sources system associated with hydrogen storage hybrid energy system

S. Tamalouzt [a,*], N. Benyahia [b], T. Rekioua [a], D. Rekioua [a], R. Abdessemed [c]

[a] Laboratoire LTII, Faculté de Technologie, Université de Bejaia, Algeria
[b] Laboratoire LATAGE, Université de M/Mammeri Tizi-Ouzou, Algeria
[c] Laboratoire LAB, Université Lhadj Lakhdar Batna, 05000 Batna, Algeria

ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form
17 June 2016
Accepted 18 June 2016
Available online xxx

Keywords:
AC and DC grid applications
Doubly fed induction generator
Hydrogen production
Hybrid energy storage system
Energy management system
Direct reactive power control

ABSTRACT

This paper highlights the modeling and the simulation of a micro-grid renewable power system. It comprises wind turbine (WT) doubly fed induction generators (DFIGs), photovoltaic generator (PV), a proton exchange membrane (PEM) fuel cell (FC) generator, a water electrolyzer used for long-term storage, a Hydrogen tank, and a battery bank (BB) utilized for short-term storage. Based on the given configuration and the different characteristics of the main components in the micro-grid, an overall control and a power management strategy are proposed for this system. This strategy consists in charging the BBs and producing hydrogen from the water electrolyzer in the case of excess power from the WT-DFIGs and PV generators. Therefore, the FC and the BBs will be used as a backup generator to supply the demand required power, when the WT-DFIGs and the PV energy are deficient. The effectiveness of this contribution is verified through computer simulations, where very satisfactory results are obtained.

Introduction

Nowadays, renewable energy sources (RESs) for micro-grid system applications are attracting more interest for environment considerations; non-polluting, free in their availability and continuous [1,2]. Many RESs including wind turbine (WT), photovoltaic panels (PV) and micro-turbines are reported in the literature for hybrid power source systems for micro-grid applications [2,3]. As known, the drawbacks of these structures are the seasonal and daily climatic variations (solar radiation, wind speed, temperature) and geographical conditions as well as the profiles of the required power; it is why, as solutions, other measures are needed. In this way, Energy Storage Systems (ESSs) seem to be an adequate solution to mitigate the effects of wind and/or solar fluctuations and to maintain the power and energy balance as well so as to improve the power quality. To face the fast power variations, the ESS must have a

---

* *Corresponding author*. Tel.: +213 771 801 019, +213 540 270 076.
E-mail addresses: tamalouztsalah@yahoo.fr (S. Tamalouzt), benyahia.ummto@yahoo.fr (N. Benyahia), to_reki@yahoo.fr (T. Rekioua), dja_rekioua@yahoo.fr (D. Rekioua), rachid.abdessemed@gmail.com (R. Abdessemed).

http://dx.doi.org/10.1016/j.ijhydene.2016.06.163
0360-3199/© 2016 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Please cite this article in press as: Tamalouzt S, et al., Performances analysis of WT-DFIG with PV and fuel cell hybrid power sources system associated with hydrogen storage hybrid energy system, International Journal of Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.06.163

Nomenclature

A_v	area swept by the rotor blades, m^2
C_p, C_{p-max}	power coefficient and its maximum value
P	pair pole number
e, Δe	error and its time-derivative respectively
K_{1e}, $K_{1\Delta e}$, K_{PI}	scaling factors of the fuzzy PI controller
K_{2e}, $K_{2\Delta e}$, K_{PD}	scaling factors of the fuzzy PD controller
T_t	turbine aerodynamic torque, N.m
T_{em}, T_{em-ref}	electromagnetic torque and its reference respectively, N.m
R_s, R_r	stator, rotor resistances respectively, Ω
l_s, l_r	stator, rotor leakage inductances respectively, H
M	magnetizing inductance, H
v_{sd}, v_{sq}	two-phase stator voltages respectively, V
v_{rd}, v_{rq}	two-phase rotor voltages respectively, V
i_{sd}, i_{sq}	two-phase stator currents respectively, A
i_{rd}, i_{rq}	two-phase rotor currents respectively, A
v_{rated}	rated wind speed, tr/min
$v_{cut-out}$	cut-out wind speed (limited), tr/min
$i_{r\alpha}$, $i_{r\beta}$	current components along α and β stator axes, A
V_{dc}, V_{dc-ref}	direct voltage and its reference respectively, V
E_{bat}	electromotive force corresponding to the open circuit battery voltage, V
C_{bat}	internal battery capacity, F
R_{bat}	internal battery resistance, Ω
V_{bat}	battery voltage, V
I_{bat}	battery current, A
Q_d	ampere-hours stored in the battery, A/h
n_{FC}	number of FC cells in the stack
V_{cell}	FC cell voltage, V
p_{H_2}	hydrogen partial pressure
p_{O_2}	oxygen partial pressure
E_{Nernst}	nernst voltage, thermodynamic potential of the cell, V
E_{Act}	activation voltage drop, V
E_{Con}	concentration voltage drop, V
E_{Ohm},	ohmic voltage drop, V
T_{FC}	fuel cell temperature, °C
a, b	FC constants
R_{ohm0}	part of the electrical resistance R_{ohm}, Ω
R_{ohm1}	FC internal resistance, Ω
U_{cell}	cell terminal voltage, V
U_{rev}	reversible cell voltage, V
r_1, r_2	electrolyzer parameters for the ohmic resistances
k_{Elec}, k_{T1}, k_{T2}, k_{T3}	electrolyzer parameters for the overvoltage
A_{Elect}	area of the cell electrode, m^2
I_{Elect}	electrolyzer current, A
T	electrolyzer cell temperature, °C
P_s, P_r	DFIG stator and rotor powers respectively, W
P_{L-AC}, P_{L-DC}	variable AC and DC load powers respectively, W
P_{rAC}	power transferred through DC/AC converter III respectively, W
P_{Elect}, P_{Bat}	electrolyzer and BBs powers respectively, W
P_{FC}, P_{pv}	generated FC and photovoltaic powers respectively, W
P_{AC}, P_g	exchanged powers between the proposed system and the AC grid respectively, W
P_{Net}	DC power in the DC-bus, W
P_{st}	storage power, W
P_{wind}	aerodynamic power, W
Q_{AC}, Q_{AC-ref}	reactive power exchanged between the system and the AC grid and its reference respectively, Var
Q_s	DFIG stator reactive power, Var
Q_{L-AC}	AC load reactive power, VAR
Q_{rg}	reactive power transferred through DC/AC converter III, Var

Greek letters

ρ	air density, Kg/m^3
υ	wind velocity, m/s
λ, λ_{opt}	tip speed ratio and its optimal value
β	blade pitch angle, °
Ω_t	turbine rotor speed, tr/min
Ω, Ω_{ref}	DFIG mechanical speed and its reference, tr/min
$\Phi_{r\alpha}$, $\Phi_{r\beta}$	flux components along α and β stator axes, Wb
Φ_r, Φ_{r_ref}	rotor flux and its reference, Wb
φ_{L-AC}	local load phase shift, °

Abbreviations

WT	wind turbine
DFIG	doubly fed induction generator
DFIM	doubly fed induction machine
PV	photovoltaic generator
PEM	proton exchange membrane
FC	fuel cell
BB	battery bank
RES	renewable energy source
ESS	energy storage system
HESS	hybrid energy storage system
DC	direct current
AC	alternative current
MPPT	maximum power point tracking
BBDC	buck-boost bidirectional converter
I–V	current and voltage characteristic
P–V	power and voltage characteristic
DTC	direct torque control
FLC	fuzzy logic control
DTRPC	direct torque and reactive power control
SOC, SOC_{max}, SOC_{min}	battery state of charge with its maximum and minimum value
PI	proportional and integral controller
PID	proportional, integral and derivative controller

high power density, and at the same time it must have a high energy density to give autonomy for micro-grid. For these reasons, it is necessary to associate more than one storage technology creating a Hybrid Energy Storage System (HESS) [4–6].

The ESS as BBs are very important for an efficient and economical utilization of these hybrid systems [3], but the charge and discharge cycles decrease the lifetime of batteries [6–8]. To improve the energy supply reliability of WT and PV

Please cite this article in press as: Tamalouzt S, et al., Performances analysis of WT-DFIG with PV and fuel cell hybrid power sources system associated with hydrogen storage hybrid energy system, International Journal of Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.06.163