Electrical Power and Energy Systems 62 (2014) 1–9

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Energy management optimization of a hybrid power production unit based renewable energies

Achraf Abdelkafi, Lotfi Krichen *

National Engineering School of Sfax, Control and Energy Management Laboratory (CEMLab), BP 1173, 3038 Sfax, Tunisia

ARTICLE INFO

Article history:
Received 20 May 2013
Received in revised form 24 March 2014
Accepted 5 April 2014
Available online 8 May 2014

Keywords:
Power supervision strategy
Wind generator
Fuel cell
Electrolyzer
Supercapacitor

ABSTRACT

Hybrid power production units seem to be an interesting alternative for supplying isolated sites. This study proposes a new supervision strategy in order to ensure an optimized energy management of the hybrid system. The considered hybrid unit includes a wind generator (WG), a fuel cell (FC), an electrolyzer (EL) and a supercapacitor (SC). An overall power supervision approach was designed to guarantee the power flow management between the energy sources and the storage elements. The aim of the control system is to provide a permanent supply to the isolated site by adapting production to consumption according to the storage level. A mathematical analysis of the hybrid system using models implemented in Matlab/Simulink software was developed. Simulation results illustrate the performance of the control strategy for an optimal management of the hybrid power production unit under different scenarios of power generation and load demand.

Introduction

In recent years, the energy infrastructure has undergone a great change especially for the electricity production. This event results from the growth of the energy needs in the world and also the decrease of the primary energy resources from fossil fuels i.e. coal, oil and natural gas. Actually, the integration of a conventional energy production unit will be hampered not only by the cost rising of the primary energy but also by the massive release of the pollutant gases. To ensure global energy needs, the trend converges to the use of new decentralized renewable resources [1]. Renewable energies such as wind generators (WG) and photovoltaic (PV) systems can generate electricity using clean unlimited resources. Wind energy records the fastest growth rate in the world. The technology of this energy resource has led to a great improvement in wind turbines which convert wind into electricity with a competitive installed cost. Wind power is classified into two broad categories: fixed speed and variable speed wind turbines (VSWT). The VSWT adjusts the rotational speed in order to capture the maximum power and then allows the increase of the aerodynamic efficiency compared to fixed speed [2,3].

Renewable energy sources can either be integrated in the power electrical network, or participate to resolve problems of isolated site electrification because of financial constraints for the difficult access areas. The WG is able to generate electricity in an appropriate way, technically and economically. Because of the fluctuating and unpredictable characteristic of the wind, it is necessary to include a storage system to ensure energy needs and to adapt the production to consumption in a stand-alone operating [4]. The combination of different renewable sources can reduce the availability problem of the resource, but it cannot prevent the use of a storage system. The hybrid production systems are a very interesting solution which allows optimizing the energy sources, increasing the energy efficiency and reducing the storage system capacity. These systems require a good sizing to increase energy efficiency and to ensure working continuity. Indeed, the study of various renewable potentials, the knowledge of load profiles and the power production management ensure a correct sizing of the hybrid system.

The use of a hybrid system to supply an isolated site allows meeting the energy needs during all the year. A hybrid system is mainly made up of renewable sources, a long-term storage unit and a short-term storage unit used for fast dynamic energy needs. The possible structures of multi-sources power station differ according to the organization of these three elements [5]. The hydrogen storage system, based on a hydrogen fuel cell (FC) and an electrolyzer (EL), is considered as a good means of long-term storage. Indeed, it facilitates the integration of a WG to ensure a permanent supplying of an isolated site in spite of production fluctuations and load variations [6,7]. When the WG produces more power than consumption needs, the EL must absorb the power

* Corresponding author. Tel.: +216 74 274 418; fax: +216 74 275 595.
E-mail address: lotfi.krichen@enis.rnu.tn (L. Krichen).

http://dx.doi.org/10.1016/j.ijepes.2014.04.012
0142-0615/

Nomenclature

V_w	wind speed (m s^{-1})	U_{rev}	reversible cell voltage (V)
ρ	air density (1.22 Kg m^{-3})	r_1, r_2	parameters for ohmic resistance of electrolyte
R_w	blade radius (m)	s_i, t_i	parameters for overvoltage across electrodes
ω	rotational speed (rad s^{-1})	A_{el}	electrode area (cm^2)
R_s	stator winding resistance (Ω)	T_{el}	electrolyzer temperature (°C)
L_s	stator winding inductance (H)	N_{el}	number of electrolyzer cells
ϕ_m	permanent magnetic rotor flux (Wb)	$I_{t1}, I_{t2}I_{t3}$	inverter output current (A)
p	number of pole pairs	$I_{L1}, I_{L2}I_{L3}$	load currents (A)
V_{sd}, V_{sq}	d–q components of the stator voltages (V)	U_{c1}, U_{c2}	line-to-line voltages (V)
I_{sd}, I_{sq}	d–q components of the stator currents (A)	ξ	damping ratio
T_{em}	electromagnetic torque (N m)	ω_n	undamped natural frequency

excess by producing hydrogen which can be stored in a tank. When the WG produces less power than consumption, the FC generates the power difference by using the stored hydrogen. The slow dynamics of hydrogen system requires the use of a storage system that allows a fast dynamics in order to provide the missed power and to circumvent the delay due to the response time of the FC and the EL [8–10].

Many hybrid power production structures were studied in Refs. [6,11–13]. Ref. [6] presents an investigation on a stand-alone hybrid system based on an FC and an EL. This work analyses the performance of integrating the hybrid system for supplying an isolated site without taking into consideration the slow dynamics of the hydrogen system. Refs. [11–13] propose a stand-alone WG/PV/FC/EL hybrid energy system with a battery bank used for short-time backup and storage system. This structure presents a good performance, but requires a high installation cost and imposes the availability of two main sources: the wind and the sunlight.

In this study, we suggest a stand-alone hybrid power production unit made up of a WG and an FC as energy sources, an EL as a hydrogen storage system and a supercapacitor (SC) as a fast dynamics storage system. The main contribution of this work is to propose an energy management algorithm according to the following constraints: (i) wind speed fluctuations, (ii) load demand, (iii) storage level of hydrogen system and SC, (iv) hydrogen slow dynamics and (v) optimal operation of each element. The considered approach offers many power flow possibilities according to six operating modes of the hybrid system in order to meet the energy constraints. Therefore, the proposed control strategy ensures an optimal energy management and increases the overall system reliability.

The remainder of this paper is organized as follows. The structure of the considered hybrid system is detailed in section 'Hybrid system structure'. Sections 'Modeling of the hybrid system' and 'Control of the hybrid system' are devoted to the modeling of each component and the control design are detailed, respectively. Section 'Proposed power supervision strategy' gives a description of the proposed power supervision strategy for the coordination of the hybrid system elements. The simulation results are provided in section 'Results and discussion'. Finally, in the last section a conclusion of this work is presented.

Hybrid system structure

The structure of the hybrid system is shown in Fig. 1. The WG consists of a VSWT with a rated power of 3.85 kW, based on a permanent magnet synchronous generator (PMSG). The hydrogen system is made up of a proton exchange membrane fuel cell (PEMFC) with a rated power of 1 kW and an EL as a hydrogen storage system rated at 1 kW. The considered hybrid unit is equipped with a SC type BMOD0094 rated at 2 kW used as a fast dynamic storage system in order to circumvent the slow dynamics of the hydrogen system.

The different elements of the production unit are connected to a common DC bus through four power converters. These converters are considered as adaptation modules placed between the multi-source unit and the DC bus. The AC/DC converter (1) ensures the maximum power extraction from the PMSG and so the operating at variable speed. The boost DC/DC converter, (2) adjusts the PEMFC voltage to the DC bus voltage. The buck DC/DC converter, (3) adapts the DC bus voltage to the EL voltage. The reversible DC/DC converter, (4) controls the SC current to adapt production to consumption. A DC/AC converter is used to transfer the generated power by the hybrid system to a three-phase load through an LC filter. This filter ensures a three-phase voltage source reducing the harmonics generated by the inverter.

Modeling of the hybrid system

Wind generation system

The aerodynamic power captured by the wind turbine is defined by the following expression:

$$P_{aer} = \frac{1}{2}\rho\pi R_w^2 V_w^3 C_p \tag{1}$$

The power coefficient C_p expresses the wind turbine efficiency for converting energy from kinetic to mechanical. This coefficient is related to the tip speed ratio (TSR) λ and the pitch angle β. The TSR is the ratio of the tangential velocity $R\omega$ to the wind speed.

$$\lambda = \frac{R\omega}{V_w} \tag{2}$$

The main advantage of the VSWT is the rotation speed adjustment to extract the maximum power at each wind speed. As a matter of fact, the TSR should be fixed at its optimum value λ_{opt}, therefore, the ratio ω/V_w should be constant.

This wind turbine is coupled directly to a smooth pole PMSG to convert mechanical energy into electrical energy. The PMSG equations in the Park reference frame are expressed as follows:

$$\begin{aligned} V_{sd} &= R_s I_{sd} + L_s\frac{dI_{sd}}{dt} - p\omega L_s I_{sq} \\ V_{sq} &= R_s I_{sq} + L_s\frac{dI_{sq}}{dt} + p\omega L_s I_{sd} + p\omega\phi_m \end{aligned} \tag{3}$$

$$T_{em} = p\phi_m I_{sq} \tag{4}$$

The WG and the PMSG parameters are given in Table 1.