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Control, energy management and performance evaluation of desalination unit based renewable energies using a graphical user interface

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ABSTRACT

Renewable energy sources coupled to desalination unit offers a promising prospect for covering the fundamental needs of power and water in isolated regions. In this context, this study aims to control a reverse osmosis desalination unit powered by renewable energy sources and hydrogen storage situated in the Kerkennah islands (Tunisia). The hybrid system is made up of two wind turbines, a photovoltaic generator, a fuel cell and an electrolyzer. In order to ensure an optimum exploitation of the produced energy, a novel power management algorithm is developed to control the different energy flows exchanged among the system components. This algorithm determines the reference powers of the fuel cell, the electrolyzer and the desalination unit in seven operation modes, and supervises the fill levels of fresh water and hydrogen tanks. The daily simulation of the desalination system with the proposed algorithm for any month of the year and the annual simulation of the energy supervision algorithm are carried out by new graphical interfaces. These interfaces facilitate the simulation and display the different curves describing the hybrid system behavior. The simulation results show that the proposed control strategies provide good installation autonomy and improve the system stability under varying load power demand.

1. Introduction

Freshwater and energy are two crucial commodities for well being of mankind. Owing to increasing population growth, the world is facing a great challenge for meeting the current needs for these two commodities as well as ensuring the needs of future generations. In the last few years, the implementation of reverse osmosis desalination plants powered by renewable energy sources (RES) have been going through an upwards trend especially in remote and arid regions [1–4]. Renewable energies, especially wind and solar, are the fastest growing and the most promising alternative sources [5,6]. However, considering the sun irradiance and the wind speed as uncontrollable parameters, an energy storage system is quite necessary. The battery represents the most widely-used technology as storage system. This system involves low capital investment, yet it is unsuitable and unsustainable for long runtimes [7,8]. Recent researches have focused towards the use of the hydrogen storage system composed of fuel cell (FC), electrolyzer (EL) and hydrogen tank [9]. Their strengths are high specific energy and reliability, and no pollution. The storage system is considered among the best alternatives due to their low operating temperature and relatively fast response time [10,11].

To ensure a better autonomy of the hybrid system and guaranty the optimal use of the energy production, control and regulation strategies are needed. These proposed methodologies allow to stabilize the DC bus voltage, frequency and amplitude of the load voltage whatever the load variations, to control the storage system and to supply the load with the required current. These command systems and control loops are very efficient, but a suitable energy management is needed in the desalination system to limit the reference powers sent to the EL, the FC and the desalination unit and to continuously control the fresh water tank fill level as well as the hydrogen tank. References [12–14] showed some examples of energy management system, whose objective was to check the performance of the hybrid systems hourly and during long periods. D. Zejli et al. [15] developed an optimization model to control the energy flows exchanged among the system components in order to satisfy the domestic water demand. To evaluate the performance of

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the desalination system powered by a hybrid renewable energy system, simulation software can be used. HYBRID2 is a software for simulation hybrid system. It was developed by the Renewable Energy Research Laboratory (REEL) University of Massachusetts [16].

In our study, a suitable power management algorithm is developed to control and manage the different energy flows between the various system components. Taking into account the different energetic constraints of the hybrid system, the proposed algorithm generates the reference powers of the FC, the EL and the desalination unit and continuously controls the fill levels of the fresh water tank and the hydrogen reservoir in seven operation modes. These powers are sent to the regulation systems. To simulate the desalination unit powered by renewable energy sources and controlled by regulation strategies equipped with an energy management algorithm, a graphical user interface is developed. This software is mainly characterized by a simple user interface. The users can simulate the desalination system with the power management algorithm for one day during any month of the year. In addition, it can also make the annual simulation of the energy supervision algorithm. Moreover, these interfaces allow to present the different simulation results. These latter have shown the efficacy and the robustness of the developed control strategies and energy management algorithm.

The paper is organized as follows; After the Introduction, Section 2 describes the desalination unit powered by renewable energy sources. Section 3 presents the models of the hybrid system components. The control and regulation strategies of the hybrid system are detailed in Section 4. Section 5 is devoted to present the energy management algorithm. The proposed graphical interface is detailed in Section 6. The simulation results are discussed in Section 7, and finally, the conclusion is presented in the last section of this study.

2. Installation description

The hybrid system proposed in this paper (Fig. 1) powers an autonomous seawater desalination unit situated on the Kerkennah islands located in the south of Tunisia. The reverse-osmosis desalination unit is designed to treat a feed water with a total dissolved solid (TDS) level set at 39000 mg/l at permeate TDS of less than 50 mg/l. The power generation system combines two renewable energy sources such as solar with wind. The wind generator (WG) is composed of two identical wind turbines of a rated power 900 kW each. Every wind turbine (WT) drives a permanent magnet synchronous generator coupled to a rectifier that transfers the maximum power to a DC bus. The photovoltaic generator (PVG) represents the second source of energy in this system. It consists of 4700 panels. This generator is connected to a boost converter equipped with a tracker Maximum Power Point Tracking (MPPT) in order to extract the maximum power. To make the balance between consumption and production and to guarantee the good performance of the installation, an electrolyzer of rated power 600 kW equipped with a fuel cell of 750 kW are used as a storage system. This storage system is connected to the DC bus via two DC/DC converters. This installation includes a fresh water tank to provide autonomy to the area for two days in July. The transfer of the generated power to the DC bus towards the load is achieved by means of an inverter and an RLC filter.

3. Modeling of hybrid system

3.1. Modeling of wind generator

Wind turbines extract the kinetic energy of the wind by transferring the momentum of the air passing through the wind turbine rotor blades. The relation between power production and instant wind speed is given by the equation [17,18]:

$$P_{WT} = \frac{1}{2}\rho S V_v^3 C_p \tag{1}$$

"ρ" is the air density, "V_v" is the wind speed, "S" is the wind turbine swept area and "C_p" is the efficiency of the wind turbine. In the literature, the expression of the power coefficient is given by the following relationship:

$$C_p(\lambda,\beta) = 0.53\left[\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 10\right]\exp\left(\frac{-18.4}{\lambda_i}\right) \tag{2}$$

with:

$$\lambda_i = \frac{1}{\frac{1}{\lambda-0.02\beta} - \frac{0.003}{\beta^3+1}} \tag{3}$$

The tip speed ratio "λ" is defined as the ratio between blade tip speed and wind speed; it is expressed as:

$$\lambda = \frac{R\Omega}{V_v} \tag{4}$$

A permanent magnet synchronous machine with smooth poles is adopted in this study. This machine is modeled in the Park reference frame by the following equations [19]:

$$V_{sd} = R_s I_{sd} + L_s\frac{dI_{sd}}{dt} - p\Omega L_s I_{sq} \tag{5a}$$

$$V_{sq} = R_s I_{sq} + L_s\frac{dI_{sq}}{dt} + p\Omega L_s I_{sd} + p\Omega\phi_m \tag{5b}$$

$$C_{em} = p\phi_m I_{sq} \tag{6}$$

3.2. Modeling of PV generator

The PV generator is used to obtain electric energy from the available solar energy. The electrical equivalent circuit used in the PV cell model development is shown in Fig. 2. The output current can be expressed as [20,21]:

$$I_c = I_{ph} - I_d - I_{sh} \tag{7}$$

There are four parameters (I_{ph}, I_d, I_{sh} and I_s) that need to be determined before the I-V relationship can be obtained. The photo current "I_{ph}" can be calculated as:

$$I_{ph} = P_1\cdot E_G\cdot\left[1 + P_2\cdot\left(E_G - E_{ref}\right) + P_3\cdot\left(T_j - T_{ref}\right)\right] \tag{8}$$

with:

$$T_j = T_a + E_G\cdot\left(\frac{N_{oct}-20}{800}\right) \tag{9}$$

Besides, the current through anti-parallel diode "I_d" can be expressed as: