Energy 145 (2018) 195–205

Contents lists available at ScienceDirect

Energy

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

# Assisted power management of a stand-alone renewable multi-source system

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ARTICLE INFO

*Article history:*
Available online 28 December 2017

*Keywords:*
Assisted control
Multi-source system
Renewable energy
State of charge
Power balance

ABSTRACT

The work presented in this paper deals with an assisted management of a standalone multi-source power system. The proposed structure consists of a wind turbine (WT) and a photovoltaic generator (PV) used as renewable sources, a super-capacitor (SC) as an energy storage system and a diesel generator (DG) as an emergency power supply. The aim of this work was to develop an assisted management strategy in order to control the power flow in the system operation with the highest reliability. Four limits of the SC state of charge (SOC) were defined states for the power control strategy. The main advantage of the used strategy was to protect the storage system from the deep charge and discharge and then increase its lifespan. The proposed energy management concept was tested in simulation by applying all possible cases. The obtained results confirm its efficiency and harmony between production and consumption was guaranteed.



## 1. Introduction

The renewable energy potential has an emerging growth. Special attention was devoted to the energy production by the wind turbines (WT) and by the photovoltaic generators (PV). However, the primary resource of this type of energy is very fluctuating and unpredictable. This uncontrollable randomness influences both the quality and quantity of the produced energy and makes it difficult to control the production of these renewable sources [1,2]. The combination of renewable energy sources can reduce random nature, but does not produce stable production over time. The autonomous operation of the renewable energy system must be equipped with an energy storage device to guarantee the electricity production at the desired time [3,4]. For the long-term operation of the stand-alone system, adding a DG as a back-up power system can cover the demand for electricity and then solve the power balancing problems [5].

The combination of renewable energies with a storage system and a back-up power system constitutes a stand-alone multi-source system. This multi-source system makes it possible to improve the operation of the various energy sources from the technical and economic point of view, so as to fully benefit from renewable energy, to minimize fuel consumption and to increase the autonomy of the storage system. The role of the storage device and the DG is to compensate for the intermittence of renewable energy production in the short and long term [6].

Several researches have been studied in the framework of a stand-alone multi-source system. The common thread between these works is the level of the power distribution of the various elements that constitute each multi-source system. Ref. [2] presents a comparative study of several energy production systems used in an isolated site. The results of this work showed better technical and economic performance with a solar-wind-diesel-battery system. The work carried out in the Refs. [6–10] focused on the development of optimal dimensioning algorithms for the size of the autonomous multi-source system, with the aim of reducing the cost of installation and improving the efficiency of the system. In Refs. [11,12] the authors have worked on the energy management of autonomous hybrid systems. These two studies limit the supply of loads to the DC bus. Ref. [13] established a power management law to manage energy exchanges in a system composed of Diesel-wind-biomass-ESS designed to supply three-phase loads. The dynamics of each element in this system has not been taken into consideration in this work.

In this general context, the multi-source system adopted in this work includes two renewable energy sources based on WT and PV generator, an SC as a storage system and a DG. The approach considered in this study focuses on the development of an assisted

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https://doi.org/10.1016/j.energy.2017.12.133
0360-5442/

management strategy in order to ensure the appropriate power distribution between the various elements of the stand-alone multi-source system. The control strategy gives priority to photovoltaic and wind generation, controls the charge or discharge cycles of the SC and triggers the start of the generator. The developed management algorithm aims to determine the reference powers of each element according to a main criterion: the control of the SC SOC. This specification directly affects the energy efficiency of the SC and subsequently the efficiency of the overall system. The idea of subdividing the SOC over four limits ($SOC_{Low\_Low}$, $SOC_{Low}$, $SOC_{High}$, $SOC_{High\_High}$) increases both the autonomy and the lifetime of the SC. Depending on the SOC, the storage system operates in normal or assisted mode. The assisted operating mode makes it possible to partially or totally limit the amount of energy stored or restored by the SC. When the SOC reaches one of the two maximum levels ($SOC_{High}$, $SOC_{High\_High}$), the management algorithm intervenes on the production of the wind energy: transition from the Maximum Power Point Tracking (MPPT) operation to the operation without MPPT. Otherwise, when the SOC reaches one of the two minimum levels ($SOC_{Low}$, $SOC_{Low\_Low}$), the power deficit will be compensated by intervening on the request: disconnection of the least priority loads. This assisted control strategy solves the power balancing problem and improves the overall operation of the stand-alone multi-source system.

This paper is organized into seven sections. After the general presentation of this work in the introduction, Section 2 and Section 3 respectively present a description and a characterization of the studied multi-source system. The modeling and control of this system is the objective of Section 4. Section 5 focuses on the development of a management algorithm to ensure efficient energy distribution between the elements that make up the multi-source system. The discussion of the simulation results and the conclusion of this work are detailed in Section 6 and Section 7, respectively.

## 2. Description of a stand-alone multi-source system

The autonomous multi-source system, which is the subject of our work, is shown in Fig. 1. This system consists mainly of a WT based on a Permanent Magnetic Synchronous Generator (PMSG), a PV generator and an SC storage system. These three elements are interconnected via a DC bus through three static converters. An AC/DC converter placed at the PMSG terminals controls the variable speed operation of the WT and the MPPT for each wind speed. A DC/DC converter placed at the PV generator terminals controls the tracking of the maximum power point. A bidirectional DC/DC converter is used to manage the power flow of the SC in the event of a power lack or excess of the overall system. A fourth DC/AC converter is used to transfer the energy produced by the three WT/PV/SC equipments from the DC bus to the AC bus. A DG used as a standby power system is interconnected to the main power system through the AC bus to supply the loads when necessary. This configuration of the multi-source system offers more flexibility for the control of each source.

## 3. Characterization of a stand-alone multi-source system

The dimensioning of the stand-alone multi-source system is based on the power demanded by the loads, in order to guarantee an energy coverage of the site [6,8,11–13]. The consumption profile of our site varies between the minimum power demanded by the permanent priority loads ″$P_{L\_\min} = 2kW$″ and the maximum power demanded by all the loads that exist on the site ″$P_{L\_\max} = 6kW$″. The multi-source system studied consists of a WT with a rated power of ″$3.85kW$″ and a PV generator with a rated power of ″$2.25kW$″. The PV generator comprises three parallel groups of six photovoltaic modules connected in series. The nominal renewable power ensures supplying the site with a full load. An SC of ″$293Wh$″ is integrated with renewable energy sources to solve the problem of power balancing. A DG able to generate ″$2kW$″ supplies the permanent loads when the renewable energy is interrupted and when the storage device is completely discharged.

## 4. Modeling and control of a stand-alone multi-source system

### 4.1. Wind turbine generator

The WT is directly coupled to the PMSG to convert the wind into electricity. Variable speed operation of the VSWT is performed through the control of the AC/DC converter. This control consists in adjusting the speed of the PMSG to fix the electromagnetic torque to a reference value, calculated to maximize the extracted power [14–16].

The aerodynamic power appearing at the rotor of the turbine is written as follows:

$$P_{aer} = 0.5\rho\pi R^2 V^3 C_p \tag{1}$$

The PMSG is represented by its Park model whose equations are established in the following matrix form:

$$\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \begin{bmatrix} R_s & -p\Omega_m L_s \\ p\Omega_m L_s & R_s \end{bmatrix} \begin{bmatrix} I_{sd} \\ I_{sq} \end{bmatrix} + L_s \frac{d}{dt} \begin{bmatrix} I_{sd} \\ I_{sq} \end{bmatrix} + \begin{bmatrix} 0 \\ p\Omega_m \phi_m \end{bmatrix} \tag{2}$$

The development of the dynamic models and the control of the WTG subsets are detailed in the work presented in the Refs. [14–16].

### 4.2. Photovoltaic generator

Photovoltaic energy comes from the direct transformation of solar irradiation into electrical energy. The behavior of a photovoltaic cell is equivalent to a generator of electric current shunted by a diode. To take account of physical phenomena at the cell level, the model is supplemented by two series and shunt resistors ($R_{s-cell}$, $R_{sh-cell}$) as shown in the equivalent electrical diagram of Fig. 2. The parameters that influence this model are illumination and temperature.

The output current of the photovoltaic cell is expressed by the following relationship [17–19]:

$$I_{cell-PV} = I_{ph} - I_s\left(\exp\left(\frac{V_{cell-PV} + R_{s-cell} I_{cell-PV}}{V_T}\right) - 1\right) - \frac{V_{cell-PV} + R_{s-cell} I_{cell-PV}}{R_{sh-cell}} \tag{3}$$

A group of 36 cells in series form a PV module. Fig. 3 shows the variation effect of the illumination on the characteristic of a PV module "I–V" and "P–V". The PV generator used in this work consists of three parallel groups of six PV modules connected in series.

Since the power delivered by the PV generator varies as a function of irradiation and temperature, control of the DC/DC converter can position the operating point to draw the maximum power. An iterative method such as Perturbation & Observation (P & O) is used to find the maximum power of the PV generator