Renewable and Sustainable Energy Reviews 60 (2016) 144–154

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Design methodologies for sizing a battery bank devoted to a stand-alone and electronically passive wind turbine system

Malek Belouda [a,*], Amine Jaafar [b], Bruno Sareni [b], Xavier Roboam [b], Jamel Belhadj [a]

[a] Université de Tunis, E1 Manar, ENIT – LSE, BP 37, 1002 Tunis le Belvédère, Tunisie
[b] Université de Toulouse, LAPLACE, UMR CNRS INP-UPS, ENSEEIHT, 2 rue Camichel, BP 71 22, 31071 Toulouse Cedex 07, France

ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form
27 August 2015
Accepted 19 January 2016

Keywords:
Passive wind turbine
Storage
Batteries
Inverse problem
Evolutionary algorithms
Hybrid system

ABSTRACT

In this paper, the authors investigate four original methodologies for sizing a battery bank inside a passive wind turbine system. This device interacts with wind and load cycles, especially for a stand-alone application. Generally, actual wind speed measurements are of long duration which leads to extensive processing time in a global optimization context requiring a wide number of system simulations. The first part of this article outlines two sizing methodologies based on a statistical approach for the sizing of the electrochemical storage device of a stand-alone passive wind turbine system. Two other efficient methodologies based on the synthesis of compact wind speed profiles by means of evolutionary algorithms are described in the second part of this paper. The results are finally discussed with regard to the relevance of the battery bank sizing and in terms of computation cost, this later issue being crucial to an Integrated Optimal Design (IOD) process.

Contents

Abbreviations: WT, Wind Turbine; IOD, Integrated Optimal Design; SOC, State Of Charge; DOD, Depth Of Discharge; PMSG, Permanent Magnet Synchronous Generator

* Corresponding author. Tel.: +216 71 874 700; fax: +216 71 872 729.
E-mail addresses: malek.belouda@gmail.com (M. Belouda), Jaafar@laplace.univ-tlse.fr (A. Jaafar), sareni@laplace.univ-tlse.fr (B. Sareni), xavier.roboam@laplace.univ-tlse.fr (X. Roboam), jamel.belhadj@esstt.rnu.tn (J. Belhadj).

http://dx.doi.org/10.1016/j.rser.2016.01.111
1364-0321/

1. Introduction

Continuity and reliability of electricity supply from wind energy are the two basic criteria for feeding isolated sites. These two criteria can be satisfied by including several types of storage (accumulators, H_2 storage, etc.), but this solution is hampered by high ownership costs [1–5]. Thus, providing consumers in remote areas with reliable and cheap electricity depends upon optimal combination and sizing design of the wind generation system coupled with the storage bank. Recently, most optimal configurations are obtained by performing a global optimization process, where a high number of simulations is required [6–14]. However, the unpredictable character of the wind speed presents a significant drawback since the system simulations are carried out over a long period of time. In numerous publications, Bagul, Borowy and Salameh [15–17] have developed several methodologies for optimally sizing a Wind/PV system associated with a battery bank for a given load. These methods are based on the use of long term data for both irradiance and wind speed. Several studies have used the average hourly wind speed data over a few years simulation period. Other researchers [18–20] have developed probabilistic methods to determine the annual energy output of a wind system. In particular in [21], a probabilistic approach was developed to calculate a long term system performance with respect to the average monthly fraction of a load fed by generation systems. In this context, the present study deals with the optimal design of a battery bank for a passive Wind Turbine (WT) system ensuring the continuous supply of an isolated typical farm (see Fig. 1). The design of this system requires taking account of the wind potential and the load demand.

However, the "time phasing" of wind data, generating WT energy/power with the load profile (here a cycle time of 24 h), sets a specific problem when sizing the storage device: indeed, the difference between power production and power consumption profiles is not sufficient to characterize the battery sizing. Finding the most critical phasing between WT production and load consumption must be considered. This worst case for the battery sizing will be identified by varying the phase shift between production and consumption profiles. This will be specifically shown in Section 4.3.

In this study, four battery sizing methodologies for a 8 kW stand-alone passive WT system are investigated. The first two methodologies are based on statistical approaches and consist in determining the constraints (in terms of power and energy needs) associated with the storage system from temporal Monte-Carlo-based simulations including wind and load profile variations. The evolution of the wind speed was considered as stochastic while the load profile was deterministically repeated from day to day (Fig. 2). In order to take account of the wind potential features, only slow dynamics related to seasonality have been integrated in the wind profile, i.e. fast dynamics related to turbulence are neglected. Wind features are then represented with a Weibull statistic distribution. Finding the most critical constraints in the storage system requires simulating the system over a long period of time in order to include all correlations between power production and consumption (e.g. time windows with low wind power and high load power and inversely). Such a process is rather expensive in terms of computation cost. It can locally be used to size the battery when the other components of the system (i.e. the passive WT) are known. However, if a global integrated design process is concerned, where all components have to be simultaneously optimized the computation cost of these latter approaches may be problematic. In order to solve this issue, we have investigated two other methodologies for reducing wind profile duration while keeping a trace of wind features in terms of intensity, variability and statistics. This original approach suggested in [22] is adapted for compacting wind speed profiles: it consists in generating compact wind profiles by aggregating elementary parameterized segments in order to fulfill target indicators representing the features of a reference wind profile of longer duration [23]. This inverse problem involving the determination of the segment parameters is solved using an evolutionary algorithm.

The remaining of the paper is organized as follows. The passive wind system and the battery characteristics are described in Section 2. In Section 3, statistical battery bank sizing methodologies are presented. Section 4 is dedicated to the sizing process based on the synthesis approach of a representative and compact wind speed profile. The results obtained from these sizing approaches are summarized and compared in Section 5 in terms of performance (sizing accuracy) and computation cost.

2. Description of the hybrid system

The considered system is a 8 kW full passive WT battery charger without active control and with a minimum number of sensors as studied in [8,9]. The deterministic load profile is set for 24 h and repeated from day to day as indicated in Fig. 2.

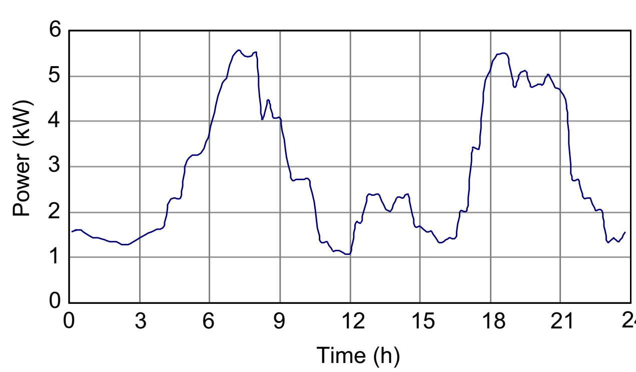

Fig. 2. Typical farm load profile for one day.

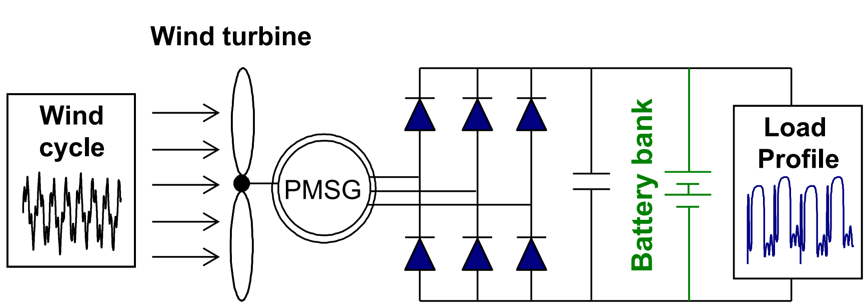

Fig. 1. WT system with battery for stand-alone application (rural site electrification).