Energy and Buildings 75 (2014) 419–429

Contents lists available at ScienceDirect

Energy and Buildings

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

Real-time performance analysis of an optimally sized hybrid renewable energy conversion unit

O. Erdinc*, O. Elma, M. Uzunoglu, U.S. Selamogullari

Department of Electrical Engineering, Faculty of Electric-Electronics, Yildiz Technical University Davutpasa Campus, Esenler, Istanbul, 34220, Turkey

ARTICLE INFO

Article history:
Received 15 August 2013
Received in revised form 24 January 2014
Accepted 29 January 2014

Keywords:
Fuel cell
Fuzzy logic
Hybrid system
Optimum sizing
Solar energy
Wind energy.

ABSTRACT

Lately, interest in renewable sources, especially for wind and solar energy, has gained a significant momentum with an increasing share of installed power production facilities of these sources together with the incentives of many developed/developing country governments. However, the intermittent structure of the wind and solar energy systems directly related with the dependence on meteorological conditions lowers the reliability of such sources especially for sole use in a stand-alone small scale system. Thus, utilizing these sources with energy storage units in a proper hybrid combination is the most accepted solution today to overcome the mentioned drawbacks of solar and wind systems. In order to make the mentioned hybrid system investment as economic as possible together with considering technical limitations, optimum sizing algorithms have been widely utilized. In this paper, a real-time performance analysis of an optimally sized hybrid energy system is conducted to examine the effectiveness of the optimum sizing approach proposed in a recent study of the authors. The experimental tests have been realized in Davutpasa Campus of Yildiz Technical University, Istanbul considering different case studies and worst case scenarios.

1. Introduction

Recently, the concerns on energy issue have increasingly grown in terms of many subtopics: Environmental sustainability, energy independence, political imbalance between developed/developing countries, etc. Among these hot topics, environmental sustainability is a major research area as the conventional fossil fuel consumption based energy production results in a significant increase in global greenhouse gas (GHG) emissions, which in turn may cause global warming [1,2]. Many developed countries have set future targets for reduction in GHG emissions for meeting the targets provided by Kyoto Protocol as well as European Union 2020 perspective [3]. Thus, due to the existing drawbacks of conventional energy sources utilization, interest in alternative and especially renewable sources of energy is soaring upwards both in academic research and industrial application areas.

Nowadays, renewable energy systems such as wind, solar, etc. are becoming a regular part of our daily lives with a day-by-day increasing penetration ratio both in small and large scales of application [4,5]. Such renewable sources of energy provide nearly zero GHG emissions during operation and utilize local available sources to promote energy independence. There are many issues to be solved for such new kind of energy production methodologies such as the improvement of operational efficiency and cost reduction, etc. Such developments are under consideration of many research and development (R&D) activities in all around the world and are likely to be obtained step-by-step in a foreseen future. However, there is a major drawback of leading renewable sources such as wind (via wind turbines) and solar (via photovoltaics—PVs) coming from the nature of these systems that cannot be solved with such R&D activities: Intermittent and stochastic varying power production profile directly related with the instantaneous meteorological conditions in the local construction area [6]. Thus, utilizing a sole solar or wind energy system cannot perfectly match the variation of the load demand [7,8]. A simple example can be given as follows: As most people work in day time, people usually consume more energy at evening or early night times through the use appliances and lightning. However, the peak power production value for solar energy system is generally obtained at noon times neglecting abnormal cloudy-sunny varying transient conditions. Thus, utilizing a sole solar energy system for supplying such a residential load demand will be far away from being sufficient. In this regard, utilization of these intermittent energy sources in a proper hybrid structure combining them with grid connection or an energy storage/back-up power production unit (battery, fuel cell—FC, diesel generator, etc.) is the most accepted solution

* Corresponding author. Tel.: +90 212 383 58 00; fax: +90 212 383 58 58.
E-mail addresses: oerdinc@yildiz.edu.tr, ozanerdinc@gmail.com (O. Erdinc).

http://dx.doi.org/10.1016/j.enbuild.2014.01.052
0378-7788/© 2014 Elsevier B.V. All rights reserved.

Nomenclature

FC	Fuel cell
FLC	Fuzzy logic controller
GHG	Greenhouse gas
MPPT	Maximum power point tracking
PEMFC	Proton exchange membrane fuel cell
PV	Photovoltaic
$P_{difference}$	Net load demand
P_{load}	Load power
P_{PV}	Photovoltaic power
P_{WT}	Wind turbine power power
VRLA	Valve-regulated lead-acid
WT	Wind turbine

to overcome the mentioned drawbacks of these new generation power production systems especially for electrification of rural areas [9,10].

A broad literature is dedicated to the evaluation of such hybrid combinations from different perspectives. Efficiency improvements of each system component is a widely investigated issue with the development of new materials especially for use in hybrid system components like PVs, batteries, FCs, etc. with a chemical structure. On the other hand, optimum sizing of these hybrid system components is the leading academic research area in the literature considering the whole energy production structure. Many different techniques have been employed for this target and a broad survey of the relevant literature was provided in a former study of the authors in Ref. [11]. On the other hand, experimental evaluation of such hybrid systems has also been the topic of several literature studies especially for the observation and discussion of an energy management strategy performance in real-time systems [3,12–14]. However, none of these studies have combined the results of an optimum sizing with further experimental applications for verifying the acceptability of the optimum sizing results. In this concept, the normalized scale prototype based experimental application of a pre-optimized hybrid renewable energy system in a recent study of the authors (Ref. [13]) is considered in this study. The mentioned optimum sizing of the stand-alone hybrid alternative energy system was realized with a new perspective considering the performance degradations of hybrid system components in the worst case scenario. An “area based observe and focus (AOF)” methodology was employed in the sizing procedure. The performance of this optimally pre-sized hybrid system is tested under different conditions of a typical day. Besides, slope angle determination of PV systems is also realized in this study. All of the mentioned experimental tests have been conducted for different demand-supply conditions in Davutpasa Campus of Yildiz Technical University, Istanbul.

This paper is organized as follows: Section 2 describes the specifications of the hybrid system components, while Section 3 presents the experimental results derived from the constructed hybrid system under different scenarios. Finally, the overall study is discussed and conclusions are presented in Section 4.

2. System description and methodology

The system considered here is constructed with normalized values of the results presented in the above mentioned recent study of the authors on optimum sizing [13]. The load demand given in Ref. [13] is considered as the load demand profile. The maximum level of the load demand as 71 kW is normalized to 1.2 kW considering the maximum power rating of available load bank in the lab and the sizes of other system components are normalized considering this ratio. In this regard, nearly 1 kW PV system, 1 kW WT unit, 680 W FC system obtained with the limitation of the maximum output power of a 1.2 kW FC system and a battery group are employed in the test system The hybrid system including renewable sources as well as back-up and energy storage units are collaboratively supplying the load demand from a common DC bus within the constructed test system. The block diagram of the mentioned test system is shown in Fig. 1. In the following subsections, each component of the system is presented and discussed.

Table 1
The utilized PV panel specifications.

Open circuit voltage (V_{OC}) (V)	21
Short circuit current (I_{sc}) (A)	8.25
Maximum voltage (V_{mp}) (V)	17
Maximum current (I_{mp}) (A)	7.65
Module power (W)	130
Number of cells	36

2.1. PV and WT systems

For solar energy utilization, 8 roof-top PV panels available in the authors’ lab are utilized. Each panel provides a rated power of 130 W. The mentioned polycrystalline PV panels are constructed by Solen Company and equipped with a commercially available TriStar maximum power point tracking (MPPT) unit. It is to be noted that there are two groups of PV panels each including four individual PV panels and the slope angle of the each group can be adjusted from 10° to 60° with a mechanical system. The technical specifications of the utilized Solen PV modules are presented in Table 1.

The WT utilized in this study is Zephyr AirDolphin 1000 that generates 1 kW rated power. A permanent magnet synchronous generator is employed in the WT structure. The power curve of the utilized WT is given in Ref. [12]. The cut-in wind speed is 2.5 m/s. The turbine can provide up to 2.3 kW. A stall control system is activated after 20 m/s which enables electromagnetic regenerative braking and provides power generation under brake control. The WT is installed on a foldable pole from the ground and then the electrical output of WT system is connected to the provided DC bus.

2.2. PEMFC system with necessary hydrogen storage and battery banks

In this study, a proton exchange membrane FC (PEMFC) system is selected among the different FC alternatives due to its relatively simple structure, high power density and operation at lower temperatures. The FC used in this paper is Ballard Nexa PEMFC system (1.2 kW, 46 A). The nominal output voltage of the mentioned FC stack varies between 22–50 V. The system is designed as air cooled. The purification of the input hydrogen for the mentioned FC stack should be 99.99% or better. The technical parameters of the utilized 1.2 kW PEMFC are listed in Table 2.

Hydrogen gas needed for the operation of FC system can be stored in high pressure, liquid hydrogen, or metal hydride, but for

Table 2
Ballard Nexa 1.2 kW PEMFC system specifications.

Nominal output power	1,2 kW
DC voltage interval	22–50 V
Maximum output current	46 A DC
Fuel input	Hydrogen gas with 99.99% purity
Maximum stack temperature	70 °C
Weight	13 kg