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A new perspective in optimum sizing of hybrid renewable energy systems: Consideration of component performance degradation issue

*O. Erdinc**, *M. Uzunoglu*

Department of Electrical Engineering, Yildiz Technical University Davutpasa Campus, Esenler, 34220 Istanbul, Turkey

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ABSTRACT

The ever increasing demand for energy and the concerns on the environmental sustainability issue all around the world lead to more interest in alternative sources for energy production. However, as the current costs of the alternative sources such as solar, wind energy conversion systems etc. are relatively higher as compared to the conventional means of energy production, an optimum sizing approach is quite necessary in order to avoid over-sizing of such systems without lowering the reliability of load demand supply in all possible conditions including the variability of meteorological conditions or the changing power demand of load. There are many research papers available in the literature dealing with this optimum sizing issue. Even the mentioned papers significantly contribute to the wider penetration of such sources, none of them consider the power output degradation of alternative energy sources due to aging during their pre-defined operating life time. Besides, there are a few studies utilizing detailed dynamic models of energy sources apart from first-degree linear equations based models that may fall short in presenting the exact dynamics of the related system. Thus, an "observe and focus" algorithm based optimization of a hybrid alternative energy system considering the power output degradation and detailed models of each hybrid system component is performed in this study. Related details presented within the paper can provide a new perspective in optimum sizing of such hybrid systems and may further be considered in future updates of famous sizing software programs commercially or freely available in websites of several laboratories or universities.

1. Introduction

Energy is one of the main requirements in human life and the continuous development of technology has raised this need of energy. Today, a great portion of energy requirements is supplied by direct or indirect utilization of conventional fossil fuels such as oil, natural gas, coal [1]. However, due to the political, technical, economical and environmental negative impacts of conventional means of energy production, there is a significant effort to decrease the need for conventional fossil fuels and several legal promotions for this issue are supplied by the governments of both developed and developing countries.

Several alternative as well as renewable sources for replacement of fossil fuels have been investigated or are still

* *Corresponding author*. Tel.: +90 212 383 5800; fax: +90 212 383 5858.
E-mail addresses: oerdinc@yildiz.edu.tr, ozan.erdinc3@gmail.com (O. Erdinc).
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under investigation for employing in many kinds of applications. Among the stated alternatives, wind and solar energy technologies have drawn a significant attention, recently [2]. However, there is a main common drawback of the solar and wind energy technologies: the dependence on meteorological conditions. This dependence lowers the reliability of these sources for ensuring the energy demand/production balance at each instant as the power production of wind turbines (WTs) for wind energy and photovoltaic (PV) units for solar energy directly changes with the variation of wind speed, solar irradiation and temperature in the constructed area [3,4]. Thus, a back-up as well as an energy storage unit is an indispensable requisite for the reliable operation of such technologies. A system composed of such alternative energy technologies and back-up as well as energy storage units is called a “hybrid alternative energy system”.

The fuel cell (FC) technology has recently been employed as a back-up unit in such systems as presented in many studies in the literature [5–8]. An electrolyzer unit is also considered in these studies as an energy storage device for generating hydrogen from excess power productions of main renewable sources like WT and/or PV for future use by FC system. This kind of FC and electrolyzer combination can also be called as a “regenerative hydrogen energy system”. A relatively small scaled battery or ultra-capacitor (UC) unit is also considered as a buffer of fast variations in load demand that can be risky to be supplied by FC system considering the relatively slow response time characteristics of FC technology to transient demand changes [9–11].

One of the main issues related with the application of such hybrid alternative energy systems is the sizing of the hybrid system components that ensures the load demand supply in all conditions with the lowest total cost. Thus, the economic disadvantages of the alternative energy systems compared to conventional energy sources can partially be overcome. The sizing procedure is a complex multi-dimensional problem especially when the number of hybrid system components increases. The requirement of a maximum power point tracking (MPPT) action of hybrid system components (such as well-known MPPT controller strategies for PV and WT systems, a pre-evaluated MPPT operation of FC system, etc.) together with an overall supervisory controller design that can adapt to the different configurations also contributes to this stated complexity. Besides, the varying load demand in different time intervals of the day that may not match with the power productions of non-dispatchable energy sources as stated before further promotes the complex structure of the sizing procedure. Thus a detailed analysis is required for the sizing of hybrid systems and the studies presented in Refs. [12–15] have well-analyzed such complexities of the hybrid system sizing process.

As a basic sizing approach, the base level of the load demand can be considered to be supplied by some of the hybrid system components while the other components are employed for tracking the rest of the load demand by load following concept. This type of mathematical calculation based approach was formerly proposed by Wang and Nehrir [16] that includes the sizing of PV and WT for supplying the base load while FC ensures the load following action together with a battery group. However, this type of sizing procedure ensures just the reliability of load demand supply without the consideration of economic aspects. Thus, in order to provide the fact of load demand supply reliability especially in an economic way, an optimization algorithm is required to provide the “optimum” sizing and many optimization approaches such as genetic algorithm (GA), particle swarm optimization (PSO), etc. have been employed in this regard. There are also famous simulation software programs like Hybrid Optimization Model for Electric Renewables (HOMER) that can be freely downloaded from the websites of different research laboratories and universities. A great number of studies are dedicated to this optimum sizing issue in the literature and a related broad literature survey has been provided in a recent study of the authors given in Ref. [17]. A brief presentation of the details and results of some similar studies [2,18–21] is given in Table 1. Even the above given studies make significant contributions to the wider consideration of hybrid alternative systems, none of them has taken the performance degradation of hybrid system components during the lifetime of the project into account. The renewable sources and back-up units have been considered to provide the same performance until their replacement even the declared lifetime of each component is related with the measurement of a specific performance degradation criterion. As an example, battery systems are considered to be replaced after the initial usable capacity of battery degrades to %80 [22,23]. However, above given literature studies consider the battery to provide a performance with its full initial capacity until the replacement time. This issue is valid for each hybrid system component and provides a risk for the load supply near the end of the project lifetime as each component is considered to provide an output power with its initial performance until its operating lifetime. Thus, an optimum sizing of a stand-alone hybrid alternative energy system is realized in this study 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 is employed in the sizing procedure. Different hybrid system options including regenerative hydrogen system back-up, gas reformation based FC back-up, only battery system based back-up are discussed in terms of economy together with considering the above stated performance degradation issue. It is again to be noted that the main focus and novelty of the proposed study is dedicated to showing the importance of this mentioned performance degradation issue on the results of the sizing process for a target hybrid system structure. It should also be stated that the further conducted case studies that will be discussed below and the employment of the proposed algorithm are just subsidiary contributions of the study provided to enrich the content of the paper.

This paper is organized as follows. Section 2 describes the simulation model of the hybrid system, economic aspects of the sizing study and the approach employed in the sizing procedure. Section 3 presents the obtained results and the relevant discussions. Lastly, the overall study is concluded in Section 4.