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Original article

Techno-economic-environmental study of hybrid power supply system: A case study in Iran

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ABSTRACT

This paper presents an optimal planning model of a hybrid renewable energy system to meet a real load with a combination of photovoltaic panels (PV), diesel generators and batteries. Also, replacing the conventional energy storage system with a fuel cell is investigated. Energy Modelling and Energy Resources Assessment Lab (EMERAL), at University of Tehran, in Tehran, Iran has selected as a case study. A technical, economic and environmental assessment was conducted for optimal planning of the hybrid energy system. Finally, the impact of diesel fuel price fluctuation on the economic competitiveness of proposed hybrid renewable energy systems in providing off-grid electrical load demand is investigated. In this study simulation, optimization and modeling procedures are done by HOMER software.

Introduction

Obviously, world energy consumption has rapidly increased in recent years. Depletion of fossil fuel resources and low efficiency of current energy systems are caused many concerns about providing energy in the future [1]. Furthermore, conventional energy resources, which are mainly fossil fuels, have environmental issues and their carbon emission lead to concerns about global warming problem [2,3]. These issues have led to the use of alternative energy sources such as renewable energies that have little environmental impact and have the ability to produce clean and sustainable energy [4,5]. However, these resources have periodic nature and their production capacity is not precisely predictable and is always uncertain. In order to solve this problem, it is possible to use these resources as hybrid systems with other energy sources, along with the use of energy storage systems. The hybrid energy systems have become more common due to uncertainty and the high investment cost of renewable systems. Therefore, renewable energy sources can be combined with other traditional energy sources and that will lead to the creation of hybrid renewable energy systems (HRES) [6]. A comprehensive overview of planning models, as well as operational optimization and control of HRES in remote areas, can be found in [7]. The models presented for PV-base HRES in off-grid mode have been investigated in [8] from the planning, modeling, control, and optimization aspects. Also, related information about optimization technique for optimal sizing of PV/diesel hybrid power generation systems can be found in [9]. An overview of hybrid energy systems consisting of photovoltaics, wind turbines and batteries from optimal planning, suitable converter design, and operational optimization aspects can be found in [10]. Also, reviews of the models presented for HRES in the micro-network content, taking into account the role of energy storage systems, can be found in [11,12]. Examples of modeling, optimization, and application of HRES can be found in [13]. In this regards, other work has been done which includes integration of the tidal power into a hybrid PV/wind/battery renewable energy system [14].

Due to the existence of various energy technologies and systems in HRES, the problem of planning and optimizing these systems is very important. Therefore, considering the problem conditions and the application of the power supply system, the choice of appropriate method and tool for optimizing the HRES should be carefully performed. An overview of existing simulation tools for evaluating, optimizing and planning the HRES has been done by Sinha and Chandel [6]. The results of this study showed that among all the available software, HOMER has been most used and applied for planning and optimization of hybrid energy systems. This has been due to the prominent features of this software. HOMER has the capability to assess the technical, economic, and environmental aspects of the energy systems, and reliability indicators can also be used for optimal scheduling of the system. HOMER also has the ability to handle a large number of system components and related variables in a reasonable time and also evaluate the system in different scenarios. On the other hand, sensitivity analysis on input data is another feature of this software [6]. In this study HOMER software

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has been selected to design and evaluate hybrid energy systems.

Solar energy is a clean energy [15] and due to its various advantages, such as no greenhouse gas (GHG) emission and low maintenance costs is applied in many studies [16–19]. In Off-grid applications, battery units can be used as a storage system with PV panels to reduce the uncertainty related to renewable energy resources production and increasing the system reliability. However, due to environmental concerns of the battery units, finding an alternative option for these storage systems is necessary. Energy systems that convert electricity to hydrogen can be a practical solution to this issue [20–23]. Other studies on solar and hydrogen hybrid energy systems for use in remote areas and off-grid mode can be found in [24].

In this study, four different hybrid energy systems including different combination of diesel generators, PV, battery, and hydrogen storage system for providing the electrical load of EMERAL at the University of Tehran in Tehran is investigated and analyzed. This paper also provides an evaluation of the technical, economic, and environmental aspects of replacing conventional hybrid energy systems with an HRES based on the conversion and storage of hydrogen. Due to the low price of diesel fuel in Iran, sensitivity analysis is done with respect to the future price of diesel fuel based on the average price of diesel fuel in Europe. The effects of rising diesel prices on hybrid energy system performance and costs are discussed. The proposed energy systems are simulated by HOMER software [25].

System description

Load demand

The electrical load is the electricity consumption of a renewable energies laboratory in Faculty of New Science and Technology of the University of Tehran. The average electrical energy consumption in the laboratory is 60 kWh/d and the peak load is estimated 8.61 kW. Fig. 1, shows daily load profile during a year. As can be seen, the main part of energy consumption occurs between 8 am and 8 pm. Also, the hourly AC primary load is shown in Fig. 2.

Solar energy

The information of solar energy is obtained from Solar Energy and Surface Meteorology NASA [26]. Hourly and average monthly solar radiation data for the studied area are shown in Figs. 3 and 4, respectively. Average daily radiation in this area is 4.89 kWh/m^2/d.

System components

The hybrid system studied includes various combinations of a diesel generator, PV, battery, and hydrogen storage and conversion system. The generator modeled in this study is a sample generator with the general specification of HOMER models. This model of the generator has an investment cost of 420 euros per kilowatt, yearly operation & maintenance (O & M) and replacement costs of 0.1 and 420 €/kW respectively. The cost of the generator's fuel is separate from its (O & M) costs. The investment cost for PV panels is 3000 €/kW, replacement cost and O & M costs are 0 and 64 €/kW, respectively. Amount of derating factor set to 80%, this factor reduces the production of PV by 20% in order to make an approximation to various influences such as temperature and dust and slope of the PV panels set to 35.5 degrees toward a south direction. In this study Trojan IND17-6V type of battery has been used with the following configuration: The price of each battery is 800 €/kWh. The replacement cost and O & M costs are set 800 €/kWh and 16 €/yr, respectively. The parameters of the other components of the system are presented in Table 1.

By considering 20 years as the lifetime of the project, the real annual interest rate is assumed 6%. The real interest rate equals the nominal interest rate minus the inflation rate [27]. System shortage factor (CSF)

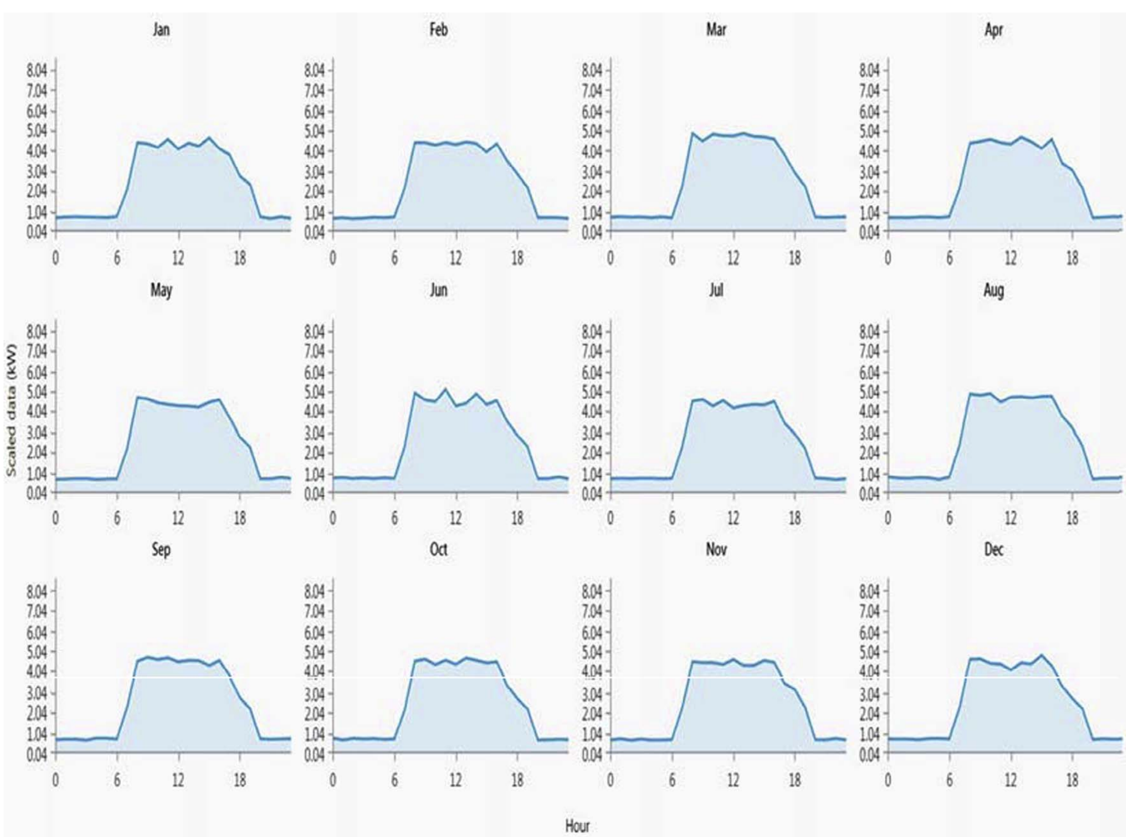

Fig. 1. Daily load profiles within a year.

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