Energy Conversion and Management 106 (2015) 1318–1326

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Optimization of operating parameters in a hybrid wind–hydrogen system using energy and exergy analysis: Modeling and case study

Amir Hossein Fakehi [a], Somayeh Ahmadi [a,*], Mohammad Rezaie Mirghaed [b]

[a] Institute of International Energy Studies (IIES), 65, Sayeh St., Vali-e-asr Ave., Tehran 1967743711, Islamic Republic of Iran
[b] Energy Engineering Department, Sharif University of Technology, Azadi St., Tehran, Islamic Republic of Iran

ARTICLE INFO

Article history:
Received 25 July 2015
Accepted 3 October 2015

Keywords:
Exergy analysis
Hybrid renewable system
Efficiency
Wind turbine
Fuel cell
Electrolyzer

ABSTRACT

In this study, hybrid renewable energy system based on wind/electrolyzer/PEM fuel cell are conceptually modeled, and also, exergy and energy analysis are performed. The energy and exergy flows are investigated by the proposed model for Khaf region-Iran with high average wind speed and monsoon. Exergy and energy analysis framework is made based on thermodynamic, electro-chemical and mechanical model of the different component of hybrid system. Also, the effects of various operating parameters in exergy efficiency are calculated. The results show an optimum wind speed where the exergy efficiency and power coefficient is at maximum level, and also, when the ambient temperature start to be increased in wind turbine, the efficiencies decrease by a great deal for constant wind speeds. Also, the optimum temperature is calculated by exergy analysis in electrolyzer and fuel cell as 353 and the exergy efficiency of electrolyzer decreases by increasing the membrane thickness. Furthermore, pressure changes affect exergy and energy efficiency in PEM fuel cell. Finally, the electrolyzer and fuel cell efficiencies are calculated as 68.5% and 47% respectively.

1. Introduction

Availability and environmental hazard of fossil fuel has caused to use resource energy and develop the new technology by human in recent years. Hydrogen is a new environment-friendly energy carrier which is capable of substituting fossil fuels in different applications [1–4]. On the other hand, it can be used in combination with other renewable energy resources, such as wind turbine, to increase reliability [5–7]. As a stand-alone power system, hybrid wind/hydrogen systems have great potentials for contribution in energy markets especially in remote areas [8,9].

In a typical wind/hydrogen hybrid system, hydrogen can be produced by wind power in an electrolyzer and then be consumed by the fuel cells. Among various types of fuel cells, Proton Exchange Membrane (PEM) fuel cells have high efficiency and demonstration level [10]. Since small PEM fuel cell units have been commercially available recently, new opportunities have been created to design hybrid energy systems for remote applications with energy storage in the hydrogen form [11–14]. Thus, hydrogen production can lead to a pathway for electricity generated by wind turbine to store energy for a long time [15,16], and the stored hydrogen can be used by PEM fuel cell power plants under the low wind speed conditions.

Some studies have been reported in the literature that model energy and exergy flow of hybrid systems using wind energy as the energy source. Nfaoui et al. [17] described a model which investigated the feasibility of using a hybrid energy system to provide electricity for an isolated village. They also quantified the optimum wind turbine size and the benefits of a storage system on fuel saving. Ozgnar and Ozgnar [18] studied an exergy and reliability analysis of wind turbine systems. They described if failure rate can be decreased, real availability, capacity factor and exergy efficiency will be improved in the system. Yang and Aydin [19] also carried out theoretical investigations about a hybrid power generation system which utilized wind energy and hydrogen storage. They used a revised wind turbine model to determine the wind power density and the electric output power for hydrogen production. Ni et al. [20] perform energy and exergy analysis to investigate the thermodynamic–electrochemical characteristics of hydrogen production by a PEM electrolyzer plant. They also offered better understanding of the PEM electrolyzer plant characteristics for hydrogen production by renewable energy. In recent years, there have been some studies on fuel cell-wind hybrid systems. Onar et al. [21] described a dynamic model of a wind–fuel cell-ultra capacitor hybrid system. Their proposed system could tolerate the rapid changes in wind speed and suppress the effects of

* Corresponding author. Tel.: +98 21 27644278; fax: +98 2122047188.
E-mail address: sepide.ahmadi2006@gmail.com (S. Ahmadi).

http://dx.doi.org/10.1016/j.enconman.2015.10.003
0196-8904/

these fluctuations on the equipment side power demand. In the same vein, Kasseris et al. [22] optimized a wind-power fuel-cell hybrid system in an autonomous electrical network environment and concluded that hybridization of wind turbine can increase the plant factor. Kazim presented a comprehensive exergy analysis of a 10 kW PEM fuel cell at variable operating temperatures, pressures, cell voltages and air stoichiometric conditions [23]. Obara et al. investigated the exergy flow and efficiency of a 3 kW proton-exchange-membrane fuel cell and considered the regional characteristic of the distributed energy system [24]. Xydisa et al. analyze exergy concept of wind farms for a case study in Greece, and calculate capacity factor and exergy efficiency [25]. Calderon et al. consider a hybrid wind–solar system with hydrogen storage and simulate the hybrid system for one day, and evaluate performance and exergy efficiency of the whole system [26]. Koroneos and Katopodi assess and maximize wind energy penetration by using hydrogen production. The survey was done using exergy approach and Sankey diagrams [27]. Zafar and Dincer consider energy, exergy and exergoeconomic analysis of electric wind–solar and fuel cell hybrid system. Hydrogen flow rate and the efficiencies were calculated for a constant specification of the system [28]. Baskuta and Ozgener assess exergoeconomic of the wind power plant in the case of Izmir region and calculate exergy loss and costs of the studied plant [29]. Rahimi et al. considered a techno-economic evaluation of wind–hydrogen hybrid system (wind turbine, electrolysis, and PEM fuel cell) in household size [30]. Ludwig et al. utilized the exergy efficiency and cost analyses to compare pathways of hydrogen generation, storage, transportation and utilization [31].

In this paper, the exergy analysis and modeling of a wind turbine and fuel-cell hybrid system is performed. The main objective of this study is to design and develop a model for exergy and energy analysis of a wind hybrid system that uses fuel cell system. The energy and exergy flows are investigated by the proposed model for Khaf region-Iran with high average wind speed and monsoon. Also, this study differs from the previously conducted ones as follows: (i) exergy and energy analysis in a hybrid wind turbine/electrolyzer/fuel cell system and in each component of system, (ii) investigation of the effects of various operating parameters in exergy efficiency, (iii) comparison of exergy and energy efficiency in each of hybrid system's components.

2. System configuration

The various components used in the developed system include the wind turbines, electrolyzer, hydrogen storage tank, PEM fuel cell. The block diagram of the integrated overall system is shown in Fig. 1.

Wind energy is converted to electricity by the wind turbine. The generated electricity may be transmitted to desired places to supply the energy demand. However, continuous power flow to stand-alone loads cannot be guaranteed due to the lack of energy capacity of storage systems especially under worst climatic conditions. It is possible though to overcome the fluctuations in the output power with an efficient storage technology. Generally, batteries could be used in such systems to eliminate the power fluctuations and improve the operation of the hybrid system. As a promising alternative, the fuel cell can be used as the efficient energy conversion device for the hybrid generation system. In this case, the excess power is transmitted to the electrolyzer and the generated hydrogen is stored in a hydrogen storage tank (Fig. 1a). The fuel cell converts the hydrogen in order to produce electricity and meet the load demand (Fig. 1b).

3. Modeling

3.1. Exergy modeling of system

One of the main parameters to achieve in exergy analysis of a system is exergy efficiency. The exergy efficiency of a complicated system can be obtained by dividing useful exergy streams to

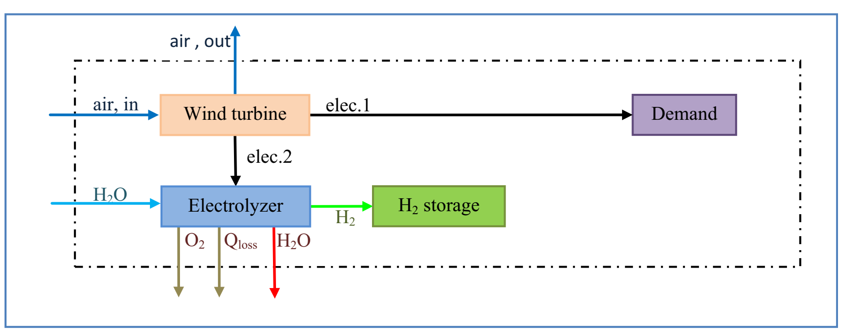

Fig. 1a. The block diagram of wind turbine–electrolyzer system.

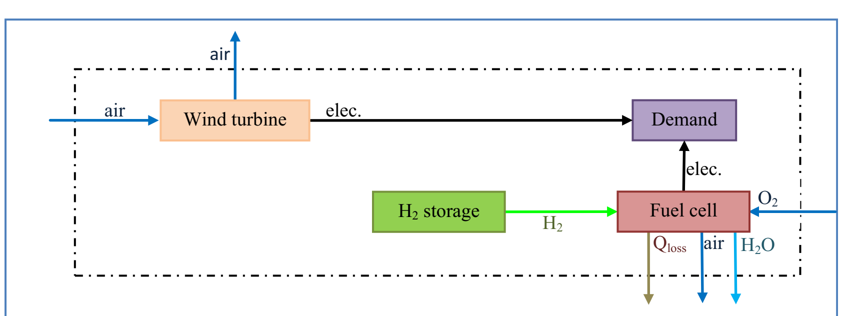

Fig. 1b. The block diagram of wind turbine–fuel cell system.