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An efficient auxiliary power generation system for exploiting hydrogen boil-off gas (BOG) cold exergy based on PEM fuel cell and two-stage ORC: Thermodynamic and exergoeconomic viewpoints

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ABSTRACT

A heat recovery system is employed for power generation from a PEM fuel cell's waste heat. The proposed system involves the parallel organic Rankine cycle for utilizing the provided heat and hydrogen boil-off gas (BOG) stream as a heat sink for the cycle. Also, this stream generates power by using an expander and prepares some chilled water that enhances system performance. The PEM fuel cell as the major component of the system is modeled and then the parallel two-stage ORC (PTORC) and BOG streams are analyzed in points of the energy and exergy view. Exergoeconomic concept is applied to evaluate the economic view of the system besides energy and exergy analyses. Also, a sensitivity analysis is performed by system key parameters which provided some valuable information to comprehend the performance of the overall system. The results show that the proposed system can generate 1353 kW power. Exergoeconomic factor, energy efficiency and exergy efficiency of the overall system are computed to be 26.21%, 58.15%, and 36.64%, respectively. Also, it is concluded that the higher current density and lower operating temperature, will raise the total cost rate.

1. Introduction

The Commission of the European Communities planed in 2007 to get three objects including decrement 20% of greenhouse gas emission from the 1990 levels, utilizing 20% additional renewable energy sources, and promotion of energy efficiencies [1]. So, finding new energy sources that result in minimum greenhouse effects has been required in order to increase energy consumptions, limited non-renewable fuel sources, and global warming issues. These demands are nominated the fuel cells as remarkable and effective energy conversion systems that adopt with environmental issues especially exploiting fuels such as hydrogen which revealed to be a clean energy carrier cause of producing only water as its product [2,3]. Hydrogen as a fuel has been used in a wide range of applications like hydrogen engines and various industries have been alluded to its positive features. Hydrogen and fuel cells will play a key role in future albeit current relevant technology costs should be reduced and government's preference may mostly focus on reduction of carbon dioxide emissions to persuade researchers to investigate and upgrade economical aspect of related technologies. Among different kinds of fuel cells, Proton Exchange Membrane (PEM) has been considered due to features of better durability, rapid startup time, high efficiency and power density, safety, low temperature and suitable for portable, mobile, and stationary applications. Therefore, many studies have been done on it [4].

Peighambardoust et al. [5] reviewed a variety of applications for PEM fuel cells and their modifications. Some information of PEM's membrane features such as proton conductivity, water uptake, the capacity of ion exchange, gas permeability, durability, and thermal stability were provided in their paper. Santarelli and Torchio [6] and Ozen et al. [7] investigated the effects of operating parameters such as pressure, current density, and temperature on a PEM fuel cell and analyzed them in the aspect of the energy and exergy view to enhance fuel cell's operation. They also compared their results with other studies for various current density to identify the optimum amount of fuel cell's voltage and concluded that by increment in the operation temperature, the conductivity of the membrane ion increases. Ozgur and Yakaryilmaz [8] analyzed a 1 kW PEM fuel cell and compared parametric with experimental results. Effects of operating temperature, pressure and output power on energy and exergy efficiencies were investigated and it was found that increasing output power will decrease energy efficiency and increment in operating temperature and pressure will rise the exergy efficiency. Penkuhn et al. [9] investigated an actual lab

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