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Analysis and assessment of an integrated hydrogen energy system

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ABSTRACT

A renewable energy based integrated system with wind turbines and solar photovoltaic arrays to supply power for residential applications is analyzed and assessed energetically and exergetically. In addition, the excess electricity generated by the system is used to produce hydrogen through water electrolysis which is utilized during peak demand periods via a proton exchange membrane fuel cell. Energy is thereby stored as hydrogen. The proposed system is designed for a building in Oshawa and evaluated by considering energy and exergy efficiencies. The effects of various parameters on energy and exergy efficiencies of the system are also investigated. In addition, the levelized cost of electricity and net present cost are determined, and the proposed system is optimised based on these parameters. The overall energy and exergy efficiencies of the proposed system are found to be as 26.0% and 26.8%, respectively. The present simulation results show that the electrolyser produces 1523 kg/yr hydrogen and fuel cell consumes 1492 kg/yr hydrogen. The levelized cost of electricity from the optimised system is $0.862/kWh.

Introduction

Extreme use of fossil fuels in the residential sector and their related destructive environmental impacts bring a substantial challenge to engineers within research and industrial communities throughout the world to develop more environmentally benign methods of meeting energy needs of residential sector in particular. About 40% of the total energy produced in the world is consumed in the residential sectors of the developed countries [1]. Fig. 1 shows the primary energy consumption share by sector wise in the year 2008. It is clearly seen from the Fig. 1 that energy supply for the building is about 20% of the total energy consumption in the world which indicates the high energy requirements for buildings. This leads us to believe that the development of sustainable energy systems for buildings by using the renewable energy sources is crucial so that these buildings would have minimal impact on the environment.

The drawbacks associated with these renewable energy sources are that the availability of a specific source depends upon the season and varies throughout the day. In order to overcome this problem, the integration of two or more renewable energy sources in energy systems can be advantageous. These integrated systems are sometimes found to be cost effective and reliable for the generation of energy. An important advantage with these systems is that they reduce the energy storage requirements for providing stable

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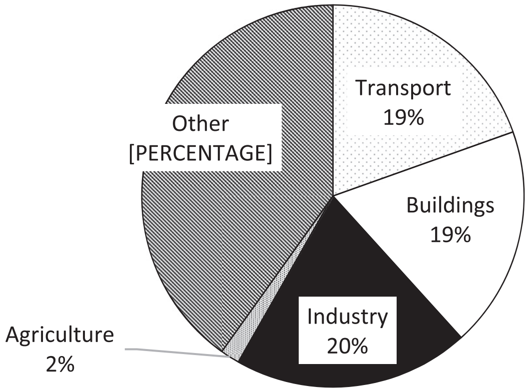

Fig. 1 – Breakdown of primary energy consumption by sector in 2008 (Data from IEA, 2014 [1]).

operation. Still with the integration of the renewable sources there is a need to store excess energy when available from these energy sources so that it can be utilised during peak periods. There are many ways of storing electric energy like batteries, flywheels, supercapacitors, pumps, and hydrogen. Of these, from Fig. 2 it is clear that hydrogen storage is the technique with highest specific energy. The other benefit of the use of hydrogen is that it is sustainable if it is obtained from renewable energy sources.

Much research has been reported on use of renewable energy in buildings in general and on the use of hydrogen in residential applications in particular. Recently, Kalinci et al. [3] have conduct the techno-economic analysis of the standalone hydrogen energy system using hydrogen as a storage option. They conclude that use of production of hydrogen from renewable energy sources is a solution for energy storage in an environmentally benign manner. Khalid et al. [4] analyzed the use of renewable energy sources in HVAC systems for buildings. Zafar and Dincer [5] thermodynamically analyzed a fuel cell and photovoltaic thermal collector for the generation of power, heat, fresh water and hydrogen for a residential building. Hosseini et al. [6] proposed a system for a residential building that uses solar PV and a fuel cell to meet the heating and power demands. An analysis of the system was performed based on energy and exergy. Hassoun and Dincer [7] study an integrated energy system for a net zero energy house using organic Rankine cycle. They conduct the energy and exergy analyses of the proposed system with the cost assessment. Lacko et al [8] study various hydrogen based energy systems for the isolated household application and find that these systems are capable of meeting the electricity demand of the house. Several mathematical models have been developed to study the performance of the electrolyser and fuel cell [9–12]. For instance, An et al. [13] have developed a mathematical model for the performance of anion-exchange membrane water electrolyser, however in this study the model developed by Zafar and Dincer [5] is used to predict the performance of fuel cell and electrolyser.

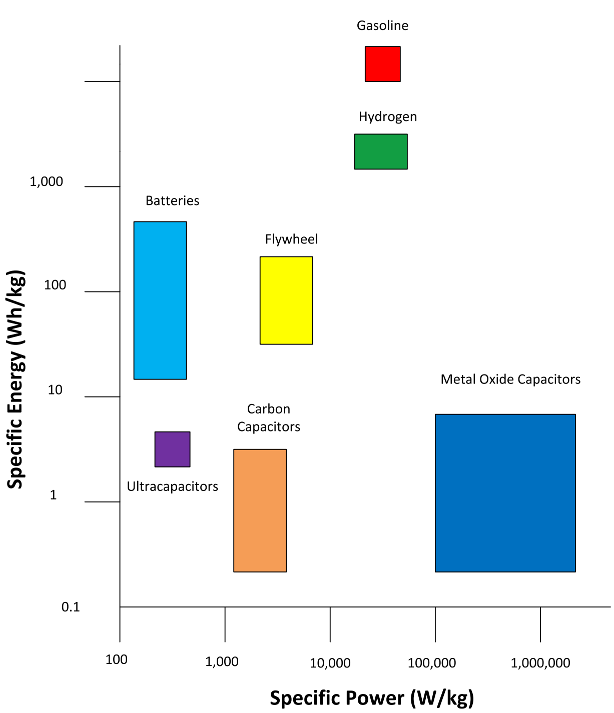

Fig. 2 – Comparison of specific power and specific energy storage potential for various energy storage technologies (adapted from NREL, 2014 [2]).

In this study, an energy system for buildings using renewable energy sources with hydrogen, as a storage option to offset the mismatch between demand and supply by using the excess electricity which will be used peak hours, is proposed and assessed thermodynamically. Both energy and exergy analyses are used in the analyses and assessments, including determination of energy and exergy efficiencies of the overall system. The parametric studies are carried out to determine the effects of various parameters on the energy and exergy efficiencies of the overall system. An economic assessment of the present system is carried out by employing HOMER [14] software, in terms of levelized cost of electricity and net present cost.

System description

The system presented in Fig. 3 is designed for a building located in the Oshawa, Canada. The system consists of wind turbine, PV solar collector, electrolyser and fuel cell. The solar radiation falls on the PV collector which produces the electricity. A portion of electricity generated by the PV collector is sent to the electrolyser to produce the hydrogen and the rest of the electricity goes to meet the electricity demand of the building. The electricity produced by the wind turbines is used to meet the electricity requirement of the building. The excess electricity produced by the wind turbines is used to produce hydrogen with an electrolyser. A proton exchange membrane (PEM) electrolyser is consider in this study to produce the hydrogen through electrolysis. The water enters the electrolyser where it is converted to hydrogen with the help of the electricity generated by the photovoltaic collector and the wind turbine. The produced hydrogen is stored in the hydrogen tank and is subsequently

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