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Renewable Energy 30 (2005) 421–439

RENEWABLE ENERGY

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Technical note

Dynamic modeling and simulation of a small wind–fuel cell hybrid energy system

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Received 30 November 2003; accepted 31 May 2004

Abstract

This paper describes dynamic modeling and simulation results of a small wind–fuel cell hybrid energy system. The system consists of a 400 W wind turbine, a proton exchange membrane fuel cell (PEMFC), ultracapacitors, an electrolyzer, and a power converter. The output fluctuation of the wind turbine due to wind speed variation is reduced using a fuel cell stack. The load is supplied from the wind turbine with a fuel cell working in parallel. Excess wind energy when available is converted to hydrogen using an electrolyzer for later use in the fuel cell. Ultracapacitors and a power converter unit are proposed to minimize voltage fluctuations in the system and generate AC voltage. Dynamic modeling of various components of this small isolated system is presented. Dynamic aspects of temperature variation and double layer capacitance of the fuel cell are also included. PID type controllers are used to control the fuel cell system. SIMULINK™ is used for the simulation of this highly nonlinear hybrid energy system. System dynamics are studied to determine the voltage variation throughout the system. Transient responses of the system to step changes in the load current and wind speed in a number of possible situations are presented. Analysis of simulation results and limitations of the wind–fuel cell hybrid energy system are discussed. The voltage variation at the output was found to be within the acceptable range. The proposed system does not need conventional battery storage. It may be used for off-grid power generation in remote communities.

Keywords: Hybrid energy systems; Wind energy; Fuel cells; Dynamic modeling of energy systems; Control and simulation; Distributed power generation

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0960-1481/$ - see front matter
doi:10.1016/j.renene.2004.05.013

1. Introduction

Long-term storage of power generated by wind turbines in remote locations has always been a problem. Lead–acid batteries can be used to store a limited amount of power for a few days. For long-term storage, electrical energy can be converted into hydrogen using an electrolyzer for later use in fuel cells. After many technological advances, proton exchange membrane fuel cell (PEMFC) technology has now reached the test and demonstration phase [1]. The recent commercial availability of small PEMFC units has created many new opportunities to design hybrid energy systems for remote applications with energy storage in hydrogen form. Production of hydrogen using energy from wind turbines for later use in fuel cells is being studied at the Hydrogen Research Institute [2]. A detailed study [3] performed for the US Department of Energy indicates that a wind–fuel cell based integrated system will produce power at a much lower cost and will emit a much lower amount of CO_2 to the environment. Many aspects of such a hybrid energy system need to be investigated, e.g. cost, efficiency, reliability, and dynamic response to sudden changes. One important aspect of a wind–fuel cell hybrid energy system that needs further investigation is design and simulation of the control system. A block diagram of a wind–fuel cell hybrid energy system is shown in Fig. 1.

The load can be supplied from the wind turbine and/or fuel cell. If the wind turbine produces enough power, the load will be supplied entirely from wind energy. In the case of low wind, a share of power can be supplied from the fuel cell. If the output power from the wind turbine exceeds demand, the excess power may be used to produce hydrogen for later use in the fuel cell. Most of the time, in such a system, the fuel cell stack is to be operated in the variable current output mode, while in most applications, fuel cells are operated at a constant current output mode. A wind–fuel cell hybrid energy system may be based on reversible fuel cell system [4,5]. Reversible fuel cells are still commercially not available. Therefore, in this study, a more practical fuel cell and electrolyzer based system is considered. The system description, dynamic modeling, simulation using Matlab-SIMULINK™, and an analysis of system dynamics are presented below.

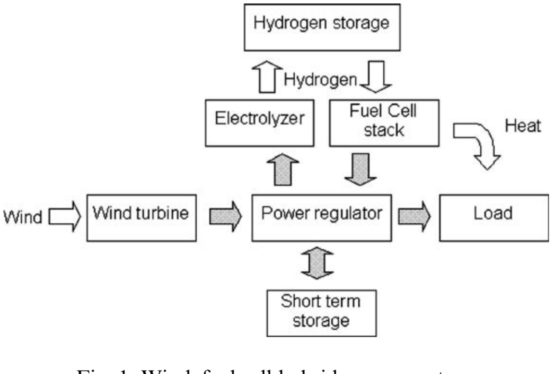

Fig. 1. Wind–fuel cell hybrid energy system.