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ScienceDirect
Renewable Energy 33 (2008) 839–845
RENEWABLE ENERGY
www.elsevier.com/locate/renene

Review

Economic and technical analysis of a hybrid wind fuel cell energy system

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Received 30 October 2006; accepted 21 September 2007
Available online 5 November 2007

Abstract

This paper presents the simulation and analysis of a system created by the combination of a wind turbine, an electrolyser and a fuel cell working together in order to provide constant electric energy supply over 1 year. The entire system is simulated according to two different operation strategies focused mainly on the operation of the electrolyser at either constant nominal operating power or varying from 20% to nominal operation. The different configurations and dimensions of every component of the system are tested. The entire system has been created using TRNSYS 15 software which permits global simulation and behaviour analysis. Using this tool, it is possible to specify the viability based on technical and economic aspects.

Keywords: Electrolyser; Energy storage; Fuel cell; Hydrogen; Wind energy

Contents

1. Introduction . . . 839
2. System description . . . 840
   2.1. Model 1: electrolyser working at non-constant point of operation . . . 840
   2.2. Model 2: electrolyser at nominal constant operation mode . . . 840
3. Simulation results . . . 841
4. Conclusions . . . 845
   Acknowledgements . . . 845
   References . . . 845

1. Introduction

Electric energy supply using wind turbines is already a quite mature technology. Over the last few years, it has spread all over the world and has proven its profitability. It does present, however, one important handicap: the variability of the power generated at any moment by such systems due to the variability of the wind, its primary power source. This adversely affects the inclusion of this renewable energy source into the grid, as it is difficult to ensure the quality and continuity of the energy provision [1]. In addition, the proliferation of this energy, and the absence in many cases of the necessary improvement of the transport and distribution grid lines, reduces the possibilities of new wind farms being installed due to the saturation of the existing lines [2]. It is therefore necessary to look for solutions to these problems in order to permit the unrestricted deployment of wind energy. To do so, new control and management methods

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0960-1481/$ - see front matter
doi:10.1016/j.renene.2007.09.023

are needed, as well as alternative applications for this kind of energy.

One of the main options for overcoming these problems is the storage and later use of the energy generated by the wind farm, enabling the control of the energy supplied at any moment independently of the strength of the wind. Due to the current difficulties for storing electrical energy, it is necessary to look for new methods of electrical energy storage.

An interesting process to achieve this goal is hydrogen production through an electrolysis process using the electrical energy from the wind turbine, storing the hydrogen at high pressure and then re-converting it to electrical energy using a fuel cell [3–9]. By means of this process, continuous electrical energy generation would be possible over long periods of time, something which is impossible when using the energy produced by the wind turbines directly on demand. Taking this issue into account, many authors link the expansion of the energy system to wind energy generation and hydrogen production from cheap and clean electricity obtained from the wind [1,3–5]. Nevertheless, such systems are still undergoing research and development, which means it is necessary to study adequate strategies of operation in order to achieve an efficient management of the energy generated [8,10].

Based on these concepts, this work develops and analyses a system made up of a wind turbine to extract the energy from the wind, and a subsystem oriented to hydrogen production, storage and reutilisation in order to provide a constant electrical power supply over long periods of time. The subsystem consists of a set of electrolysers to exploit the energy from the wind turbine during periods of over-production, converting it to hydrogen, which is stored at high pressure and later reconverted into electrical energy by a fuel cell when extra power is needed, over and above that provided directly by the wind power, in order to maintain the power constant alongside the demand.

2. System description

Two models of the hybrid wind–hydrogen system have been developed based on HYDROGEMS, a library made up of technical hydrogen energy models developed at the Institute for Energy Technology [11], compatible with TRNSYS, a transient system simulation program [12]. Both systems have the same global strategy which is to supply a constant electrical power over a whole year, while one of them operates the electrolyser at constant nominal operating power and the other within a range varying from 20% to nominal. Both models of the system permit an in-depth analysis of their performance and technical viability associated with economic aspects.

The first step for both models is the choice of the electrical power to be supplied over the year. This depends on forecasting the wind present in the place to be simulated and the type of wind turbines to be used at this place, which are both inputs to the model. The operation strategy of the whole system is based on the best exploitation of the excess energy produced by the wind farm over and above the constant amount to be supplied on demand, storing it in hydrogen form. This treatment of the extra energy is conditioned by several control criteria based mainly on the limited capacity of the hydrogen vessels and the excess of power generated by the wind turbine at any particular moment.

2.1. *Model 1: electrolyser working at non-constant point of operation*

In this operation mode, the electrolyser starts working when the power generated by the wind turbine exceeds the power demand by 20% of the electrolyser nominal power plus the power needed to run the hydrogen compressor. The main aspect of this operation mode is that the excess energy from the wind turbine in its entirety is used to produce hydrogen, as long as none of the controls or technical characteristics of the electrolyser prevent its operation. On the other hand, its main disadvantage is that there are many interruptions in the operation of the electrolyser, thus lowering its performance, reducing its useful life and decreasing the purity of the hydrogen produced. This disadvantage appears when using an alkaline electrolyser, which is the case for the present system, because it shows a better performance in constant operation [13]. On the other hand, this is not a big problem when using a PEM electrolyser, although this is much more expensive, which limits its use when high power handling is required, as is our case.

There are several states and variables to be managed during the operation of the system. One is the electrical power generated by the wind turbine, which determines the excess energy to be used in the electrolyser. The other is the necessary power generated by the fuel cell to fulfil the demand. In order to control the start/stop of the electrolyser, its nominal operating power and the level in the hydrogen vessels are taken into account. The operation of the fuel cell is managed according to the extra power needed to cover the demand while the amount of stored hydrogen is sufficient to ensure the safe operation of the fuel cell and, when the hydrogen level is too low, that the fuel cell must be stopped according to a standard procedure.

This model, despite its disadvantages regarding the operation and performance of the electrolyser, provides a good basis for the analysis of the behaviour of its components and their sizing according to the prime objectives (Fig. 1).

2.2. *Model 2: electrolyser at nominal constant operation mode*

This system tries to overcome the inconvenience of the continuous start/stop of the electrolyser presented previously by ensuring the constant operation of the