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Stochastic Energy Source Access Management: Infrastructure-integrative modular plant for sustainable hydrogen-electric co-generation

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Abstract

The proposed Stochastic Energy Source Access Management (SESAM) comprises renewable energy sources coupled via a direct current bus with storage modules of complementary characteristics to achieve co-generation of hydrogen and electric power on a continuous duty basis. As complementary solutions, hydrogen energy storage to provide a large capacity and access-oriented storage based on magnetic, electric or kinetic energy with less capacity but a faster response time are considered. These are arranged to form a multi-level storage that can compensate stochastic fluctuations of power over diverse time scales. The developed energy management coordinates the operation of the diverse storage modules. In this context, the access-oriented storage acts as a shock absorber in order to shield fuel cells and electrolysers from fast fluctuations of wind power and load. The functions of the plant are validated through simulation using meteorological information obtained from the National Wind Technology Center in the USA. The plant is shown to provide the scheduled output of hydrogen and electric power. Since seen from its terminals SESAM behaves in the same way as a power plant with controlled fuel input, it can be readily integrated with given infrastructures.

Keywords: Co-generation; Distributed generation; Energy storage; Flywheels; Fuel cells; Hybrid plant; Hydrogen; Multi-level storage; Power electronics; Power system simulation; Renewable energy; Solar energy; Supercapacitor; Superconducting magnetic energy storage; Wind energy

1. Introduction

According to news from the American Wind Energy Association (AWEA), globally installed capacity has grown 500% since 1997, from 7636 to 39 294 MW in 2003 [1]. No fuel is required for wind energy conversion, no pollutants occur, and prices for wind power have dropped significantly over the past years. However, the widespread exploitation of wind energy conversion is complicated by the fact that the maximum possible power output is a function of the given wind speed. Similar observations apply to other renewable energy sources with stochastic output.

In the development of renewable power plants for continuous duty, the value of hydrogen as both a storage medium and as a fuel to be delivered for other purposes was already recognized in [2]. In most presented concepts, however, the focus was either on hydrogen delivery or its use as a storage medium to provide controllable output for renewable power conversion. For

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example, hydrogen production and delivery using stand-alone systems was studied in [3,4]. In [5,6], hydrogen serves as a storage medium to provide controllable electric power in a stand-alone configuration. In [7], hydrogen serves the same purpose in a plant that is connected to the electricity infrastructure. In [8], the concept of Stochastic Energy Source Access Management (SESAM) is introduced. On a direct current (DC) bus, the stochastic renewable energy source is connected in parallel with storage modules of diverse but complementary characteristics to provide a high level of controllability. This distinguishes SESAM from the concept in [2]. A DC–AC power electronic converter is used to connect the DC bus with the alternating current (AC) grid of the electricity infrastructure.

The solution presented in this paper is centered on the SESAM concept. In addition to the integration of renewable sources in the electricity infrastructure, the proposed solution is aimed at supporting the development of the hydrogen economy. It is shown that the concept can provide continuous duty of both electric power and hydrogen flows.

To provide the reader with the relevant background information, basics and prior work are reviewed in Section 2. In Section 3, the proposed plant is described. In Section 4, the plant is modeled and tested in simulations. Conclusions are drawn in Section 5.

2. Background

Stochastic renewable energy sources and storage are key to the proposed plant. In order to provide the reader with the relevant background, selected characteristics of stochastic energy sources and storage are discussed in the following.

2.1. Stochastic renewable energy sources

An example of measurements of the wind speed in the form of a time series over one month is shown in Fig. 1. As the power in the wind varies with the cube of the wind speed, the stochastic nature of wind power conversion is obvious [9]. In Fig. 2, an example of solar radiation measured in the form of a time series over one month is shown. Since the output of a photovoltaic cell is a function of the intensity of sunlight striking its surface, the electric power generation through solar energy conversion is stochastic, too.

The expectation or average of the stochastic power can be described as a function of the rated power P_{st}^{max} of the stochastic source and its capacity factor C_{Fst} [10]:

$$E\{P_{st}\} = P_{st}^{max} C_{Fst}. \quad (1)$$

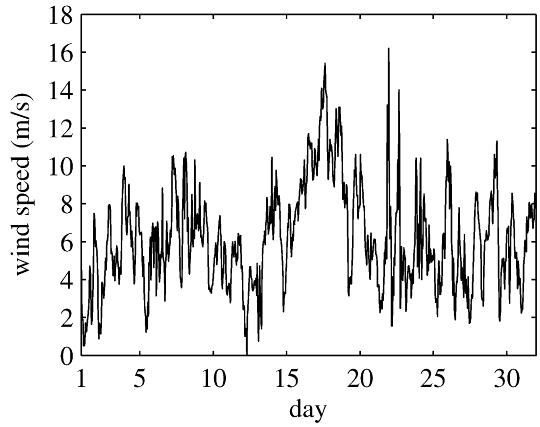

Fig. 1. Example wind speed measurements over one month.

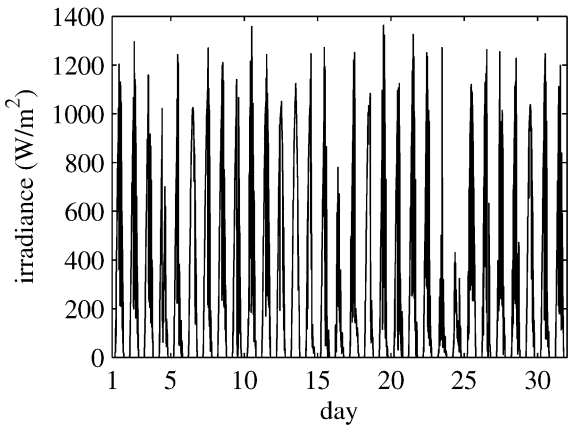

Fig. 2. Example solar radiation measurements over one month.

If the lines of the electricity infrastructure are subject to congestion, however, it may not always be possible to transmit the harvested power to the loads. This can have a detrimental impact on the capacity factor of the stochastic source.

Despite the intermittent availability, renewable energy sources are attractive and receive attention increasingly. They are clean sources that have a much lower environmental impact than those based on the combustion of fossil fuels. They are sustainable and so reduce the reliance on fossil fuels. Key to a sustained and widespread use of renewable sources, however, is affordability. Over the past years, the cost of electricity generation using renewable energy technology has dropped significantly. As an example, the cost of generating one kilowatthour