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Performance optimization of the BIPV powered electrolyser and fuel cells installation

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ABSTRACT

A practical multipurpose implementation of hybrid renewable energy system completely located within the building and including building integrated photovoltaic (BIPV) solar power energy source is presented. The system uses solar photovoltaic electricity generated by the building skin to produce hydrogen for fuel-cells, which in turn, when converted to energy in fuel cells, may be used to supply additional power to the building (or fuel cell vehicles) when solar power is not sufficient, for example at night or in periods of low insolation. Electricity generated from 8.2 kW_p BIPV array optimally supplies the electrolyser near the maximum power point level of the BIPV array. To further optimize hydrogen production, the electrolyser is connected to the local electrical utility, and DC power is provided to the electrolyser through a custom on-board DC power supply that supplements the BIPV array. Performance of the complete installation is optimized to provide continual production at the optimal efficiency level of hydrogen production at constant power. The results obtained from the system operation have shown excellent voltage and current regulation during operation of the electrolyser. The project shows the potential for development of similar building integrated hybrid systems elsewhere with possibilities for inclusion of additional renewable energy sources and added functionality.

1. Introduction

The use of renewable energy sources attracted much interest in the scientific community, among policy makers and general public in recent years due to an energy demand that surpasses the available energy on the market, increased awareness about depletion of available energy resources, global warming and environmental issues related to consumption of fossil fuels. Combination and integration of building construction elements and renewable energy sources has shown a great potential due to excellent performance results collected at a large number of experimental facilities around the world [1]. Of particular interest is the replacement of conventional building materials in parts of the building envelope, such as the roof and facades, by BIPV constructed from new photovoltaic materials. The advantage of BIPV over conventional non-integrated systems is the reduced cost of building materials and labor as well as the saved construction time that overbalances the somewhat high initial investment into the integrated solar systems. However the advantages of building integrated systems place the BIPV as the fastest growing part of the photovoltaic industry which also induces important impetus to the research and development of new materials and technologies employed in the uses of solar energy. Hydrogen, another source of energy, can be produced from abundant sources like water through the process of electrolysis, which is efficient on both small and large scales [2,3]. The hydrogen produced in the electrolyser is compressed and stored in tanks and provides the source of energy for fuel cells which in turn, may be used for various purposes. A combination of BIPV and hydrogen produced from electrolysis assumes that the photovoltaic energy is used to power electrolyser for production of hydrogen which, when converted to energy in fuel cells (FCs), may be used to supply additional power to the building when solar power is not sufficient, for example at night or in periods of low insolation. Any excess energy stored in fuel cells may be used for other purposes such as to power vehicles whose use, for example, may be related to the activities taking place in the building. Hence, a hybrid system combining BIPV and hydrogen energy may be constructed as a stand-alone system whose functionality, reliability and energy saving may be of great use in urban and rural areas. In general, different renewable energy resources may be used to complement each other to the extent that depends on the available supply, so that hybrid systems may offer a higher quality and more reliable power than a single renewable energy source.

Here we describe the performance of the optimization process for the "closed loop" installation (Fig. 1) that consists of a building integrated photovoltaic (BIPV) powered electrolyser and fuel

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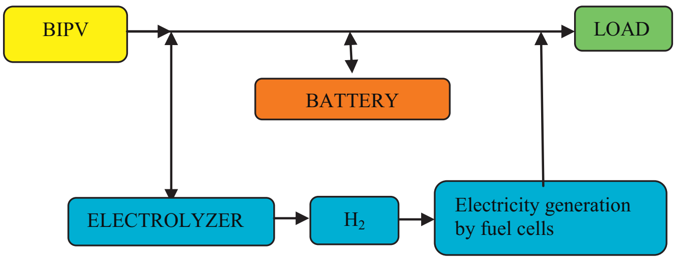

Fig. 1. Hybrid energy project combining building integrated solar photovoltaics, fuel cells and hydrogen production.

cells for providing supplemental energy for the building and for powering fuel cell/electric cars, constructed and mounted at the NRC building in Vancouver, B.C. Since the entire system is located within the building the project has been an important experimental implementation towards zero energy sustainable buildings and cities development in Canada. It also provides the ground for the research into the interaction of distributed renewable energy generation and utility power, while it has also been the subject of the smart grid development efforts.

The goal of the project was construction of a hydrogen generation system that uses BIPV array to produce hydrogen, and to optimize complete system operation, so that maximum BIPV system input is utilized [4–6], while at the same time hydrogen production is performed at constant power. In this project a proton exchange membrane (PEM) electrolyser manufactured by Hydrogenics [7] and powered by optimized electrical energy generated by the BIPV array is deployed to efficiently produce hydrogen for fuel cells. The complete system consists of: a BIPV array including Maximum Power Point Tracking (MPPT) unit to optimize exploitation of solar irradiance, boost (step-up) voltage DC–DC converter, buck (step-down) DC–DC voltage converter, inverter, battery (Pb-accumulator), electrolyser, hydrogen compressor, hydrogen storage vessels, de-ionized (DI) water supply, Fuzzy Logic controllers, environmental monitoring sensors and data acquisition system. The BIPV is used as the primary power sources and the FC–electrolyser combination is used as a backup and long-term storage system providing either supplemental energy for the building or for the electric vehicles. All major controllers in the system are of fuzzy logic type for the reason of offering several important advantageous properties in comparison with other controller types. They may operate using several input variables thus enabling easy adaptation to changes in system configuration, if necessary, without increasing the controller's complexity. The operation of the whole system based on the entire set of input variables may be controlled using only a small number of rules. Nonlinearity and imprecise inputs are efficiently handled and implementation in the microcontroller software is relatively easy. Also control easily adapts to situations which are difficult to explain in mathematical terms but easily expressed in words. Finally, unlike neural networks and genetic algorithms, fuzzy control does not require learning process based on the large historical data sets. Although there have been several model studies of the renewable hybrid energy system similar to the one presented here, such as the models of Refs. [8–10] for example, no experimental verification of the feasibility of such a system has been fully explored and certainly not in the building equipped with BIPV.

The paper is organized as follows. Following introductory section the system configuration and general characteristics of the system are discussed in Section 2. In Section 3 each major component of the system is discussed, while in Section 4 we discuss the major power management strategy and optimization issues. Finally, conclusions and potentials for future work are presented in Section 5.

Table 1
System components characteristics.

BIPV Array	
Module unit	91 W
Module number	90
Power rating	8.2 kW$_p$
Fuel cells	
Number of PEMFC	15
PEMFC power rating	
Electrolyzer	
Rated power	4.2 kW
Number of cells	15
Operating voltage	28 V
Production rate	2 kg/day at 860 kPa

2. System configuration

The system configuration of the hybrid renewable energy system combining solar power and hydrogen energy stored in fuel cells is presented in Fig. 2.

The energy generated from the solar PV array is controlled and adjusted to its optimal output value by means of the maximum power point tracking (MPPT) unit which traces the power point in the BIPV system which yields the maximum power output. The MPPT system is usually part of the boost (step-up) DC–DC converter, however in order to stress the importance of this unit in the overall optimization of the whole system it is displayed as a separate piece in Fig. 2, assuming that the boost converter is also part of it. When there is a surplus production of solar energy the electrolyser produces hydrogen which is stored in storage vessels, and through pressure regulators passed through to fuel cell stacks (FC stack 1 and FC stack 2 in Fig. 2). When there is a deficit in solar power generation the power is compensated by the energy stored in the fuel cells (FC stack 1). The fuel cells from stack 2 are used solely to provide the fuel for the hybrid electric vehicles. The battery serves several important purposes. First and the more important one would be to provide the information on the state of the whole system through its state-of-charge (SOC). It also acts as an energy buffer maintaining constant DC bus voltage at 48 V and also providing short-term storage. Several other experimental configurations with different control mechanisms have been tested and the operational characteristics of these altered systems will be presented elsewhere. Controllers for both the MPPT and the state of the whole system are of fuzzy logic type.

3. Component characteristics

Characteristics of the system's components are presented in tabular form in Table 1.

3.1. BIPV array and MPPT

In Fig. 3 the data collected in Vancouver on solar energy reaching the vertical surface is presented as a function of monthly periods. The data clearly indicate favorable conditions for solar energy exploitation throughout most of the year.

The BIPV system consists of an 8.2 kW$_p$ building integrated photovoltaic array consisting of ninety custom glass-on-glass PV modules. The fully building integrated PV elements manufactured by Schüco seamlessly blend into the curtain wall facade of the NRC building and deliver power to the electrolyser unit, while simultaneously reducing solar gain in the building. The array is mounted vertically on the south side of the building along the top of the curtain wall as shown in Fig. 4.

The BIPV system is designed to supply the electrolyser with the maximum power available from the BIPV array by means of the MPPT digital control unit, which controls the voltage and current