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Regulated hydrogen production using solar powered electrolyser

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ABSTRACT

A solar PV powered electrolyser with a DC-DC buck converter interface to help regulate hydrogen generation is presented. The converter serving as a current regulator maintains a constant direct current through the electrolyser. Field and laboratory based experimental studies are used to obtain the characteristics of both PV panel and electrolyser. Flow rate characteristics and electrical equivalent circuit of the electrolyser besides I-V characteristics of the solar panel yielded the parameters required for the current regulator design. The regulator when tested in the closed loop control mode, with a 68 Wp rooftop installed PV panel and a laboratory scale 30 W electrolyser, maintained a constant current in turn producing hydrogen at a constant rate over a range of solar irradiance from 440 to 975 W/m^2.

Introduction

Renewable energy sources like solar radiation and wind being intermittent in nature demand energy storage, when used for electric power generation. Use of hydrogen as a means of energy storage is a viable option [1]. Compressed hydrogen having about ten times higher energy density than lead acid battery, is an effective energy storage medium that can either complement the electric power grid or be a stand-alone power supply fuel [2].

There are several means of hydrogen generation [3,4] that are currently employed: (i) Oxidation of hydrocarbons to form carbon monoxide and then making it react with water, (ii) Steam Reforming of natural gases (most widely used method) (iii) Coal gasification by oxidizing coal and then treating it with water, (iv) Electrolysis of water, and (v) Thermochemical process of superheating water to 2500 °C. Of these, electrolysis has the maximum appeal being environment-friendly and water has easier access than hydrocarbons. Besides, electrolysis can be combined with renewable energy (RE) sources and together they create a more stable hybrid system. Steam reforming cannot be integrated with solar or wind energy; as such it causes carbon dioxide emission. Electrolysis has a lower initial investment when compared to steam reforming.

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Techno-economic feasibility of PV-Wind based generation schemes supported by fuel cell has been active area of study by researchers in the recent past [5,6]. The state of the art of RE based hydrogen production was reviewed and published in 2011 [7]. A direct coupling between PV and electrolyser makes the system cost effective inviting early commercialization; but it demands proper sizing of components [8,9]. Power supply parameters also influence the process of electrolysis and its efficiency [10]. A DC-DC converter is proposed for matching the PV with the electrolyser in Refs. [3,11].

There has been a growing interest in treating hydrogen as one of the fuels [12]. However, there are management issues related to variations in RE based hydrogen production [13]. Control of hydrogen and energy flows in a network of hydrogen refueling stations powered by mixed renewable energy systems is discussed in Ref. [14].

Solar PV powered electrolysers cited above, notwithstanding the nature of interconnection as direct coupling or DC-DC converter interface, did not intend to maintain hydrogen flow constant. Mostly in hydrogen refueling stations storage cylinders have valves to be operated at a certain pressure and this demands a uniform hydrogen flow rate. This requirement of regulated generation of hydrogen using solar PV is addressed in this paper and a suitable method is suggested to meet it. A DC-DC converter interfaced between the solar PV panel and the electrolyser is used as a current regulator here to maintain a constant current through the electrolyser thus regulating the generation.

The electrolysis process and the performance of a laboratory scale electrolyser powered by rooftop mounted solar PV panel are studied in detail in Sections Production of hydrogen and Investigation on solar-powered electrolyser. The design of the current regulator is based on the electrical equivalent circuit parameters of the electrolyte and these vary with concentration of the latter. Therefore the optimum electrolyte concentration is confirmed and the respective equivalent circuit parameters are obtained aided by Electrochemical Impedance Spectroscopy (EIS). The EIS results are given in Section Electrochemical impedance spectroscopy (EIS). The current regulator has been developed in hardware as per the design presented in Section Design of current regulator and tested with the PV panel and electrolyser. The results are presented and discussed in Section Test results. Section Conclusion provides the conclusion.

Production of hydrogen

The chemical reactions involved in the process of water electrolysis are [15].

At the anode:

$$2H_2O_{(l)} \rightarrow O_2\,(g) + 4H^+_{(aq)} + 4e^- \quad E_{oox} = -1.23\ \text{V} \ldots \tag{1}$$

At the cathode:

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)} \quad E_{ored} = -0.83\ \text{V} \ldots \tag{2}$$

Overall cell reaction:

$$2H_2O_{(l)} \rightarrow 2H_{2(g)} + O_{2(g)} \quad E_{ocell} = -2.06\ \text{V} \ldots \tag{3}$$

where E_{oox} refers to oxidation potential for the reaction, E_{ored} refers to reduction potential for the reaction, and E_{ocell} refers to overall cell potential.

It infers that at a potential above such value the cell reaction occurs. The factor that determines the rate of the reaction is the current supplied to the cell.

There are several factors that contribute to the electrical efficiency of an electrolyser, of which the electrolyte concentration is an important one [16]. It has been reported that the same volume of hydrogen can be obtained at lesser power input by increasing the concentration of the electrolyte [17].

Investigation on solar-powered electrolyser

The solar PV panel chosen for the study has cells made of amorphous silicon, rated at 68 Wp with open circuit voltage of 23.1 V and short circuit current of 5.1 A at standard solar irradiance, S of 1000 W/m^2 and temperature of 25 °C. The panel is installed on the rooftop of the renewable energy laboratory of Amrita University Coimbatore campus where the study is carried out.

Fig. 1 shows the PV panel characteristics experimentally obtained. It shows that the PV panel has the maximum power output of 40 W when the solar irradiance is about 950 W/m^2. The electrolyser selected for the study has a current rating of 3A and power rating of 30 W, so that the chosen solar PV panel is capable to supply this.

Hydrogen flow rate test was carried out first to determine the electrolyser efficiency and then to decide the right operating point of the electrolyser. The experimental setup to measure the flow rate was assembled by connecting the electrolyser filled with NaOH electrolyte in series with the solar panel and a rheostat to vary the current through the electrolyser. The hydrogen pipe from the electrolyser was laid

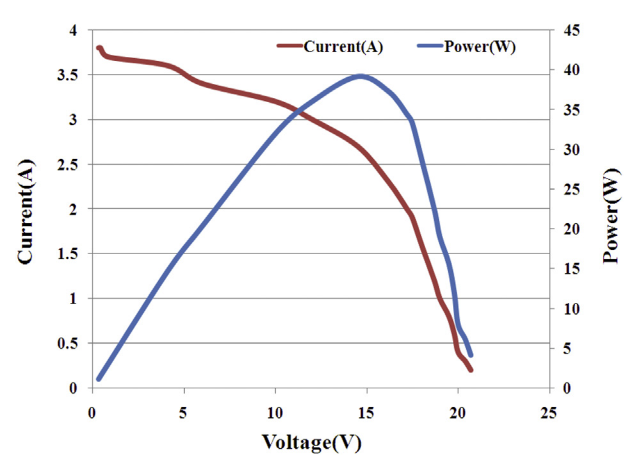

Fig. 1 – I-V and P-V characteristics of the solar PV panel at S = 950 W/m^2.