CONCEPT OF THE HYDROGEN REDOX HIGH ELECTRIC POWER GENERATION SYSTEM

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Abstract

The purpose of this paper is to introduce the hydrogen redox electric power (HREG) and hydrogen generation systems (HRG). The HREG offers considerable conceptual advantage such that it functions with zero energy input, zero matter input and zero emission without violating the laws of thermodynamics. Its application ranges from the large scale central-station power generation down to the small scale on-board power generation system for electric vehicles with infinite cruising range. This generator utilizes a combined energy cycle consisting of a fuel cell that produces power and an electrostatic-induction potential-superposed water electrolytic cell (ESI-PSE) for the synthesis of a pure stoichiometric H₂/O₂ fuel for the fuel cell. According to the calculations using the data of operational conditions for the commercial electrolyzers and fuel cells, more than 70% of the power delivered from the fuel cell can be extracted outside the cycle as net power output. Because of the simplicity, effectiveness, cleanliness and self-exciting, this novel generator may offer a potential route for its practical application to the electricity and hydrogen production systems of the future.

Keywords: electric power generation, hydrogen, energy cycle, fuel cell, water electrolytic cell.

1. Introduction

This energy cycle can be viewed as a two-stage generator that consists of two different energy conversion devices. The hydrogen generation device is an electrostatic-induction potential-superposed electrolytic cell (ESI-PSE) that enables the H₂O→H₂+1/2O₂ reduction reaction based on electrical-to-chemical energy conversion. The power producing device is a fuel cell (FC) in which the reverse reaction occurs, i.e., the H₂+1/2O₂→H₂O oxidation reaction, based on chemical-to-electrical energy conversion. Part of the power generated by the fuel cell is returned to the ESI-PSE water electrolytic cell and the remainder represents the net power output. In addition to cycling the generated power, H₂O, which contains heat from the exothermic reaction in the fuel cell, is transferred to the electrolytic cell to be utilized for the endothermic reaction. The problem is how to achieve a highly positive power balance for this cycle, such that more than 70% of the power delivered from the fuel cell can be extracted outside the cycle as net power output. If a process is thermodynamically reversible, then the amount of electrical energy delivered by the fuel cell must equal the amount of electrical energy required by the electrolytic cell for a given H₂.
circulation rate. However, this electrical power generation system is based on a thermodynamic cycle where the electrical energy delivered by the fuel cell is the total power, whereas the electrical energy required by the ESI-PSE electrolyzer specifically for electrolytic decomposition of a chemically stable compound such as H₂O is mainly electrostatic energy free of power; theoretically, 82% of the total energy, i.e., the standard enthalpy change required for the reduction of H₂O, is the electrostatic energy for which the outside voltage source is not required to provide power, only a time-invariable static voltage. To carry out the direct electrostatic-to-chemical energy conversion free of power in water electrolysis, and thus achieve a highly positive power balance of the energy cycle, attempts have been made to connect an external energy supply circuit based on the ESI-PSE mode to the electrodes of water electrolytic cells [1-3]. The experimental verification of the ESI-PSE has been performed and previously reported [3].

2. Outline of the power generator

This energy cycle can be viewed as a two-stage generator that consists of two different energy conversion devices (Figure 1). The hydrogen generation device is an electrostatic-induction potential-superposed electrolytic cell that enables the H₂O → H₂ + 1/2O₂ reduction reaction, based on electrical-to-chemical energy conversion. The power producing device is a fuel cell in which the reverse reaction occurs, i.e., the H₂ + 1/2O₂ → H₂O oxidation reaction, based on chemical-to-electrical energy conversion. Part of the power generated by the fuel cell is returned to the ESI-PSE water electrolytic cell and the remainder represents the net power output. In addition to cycling the generated power, H₂O, which contains heat from the exothermic reaction in the fuel cell, is transferred to the electrolytic cell to be utilized for the endothermic reaction.

3. Principle of the ESI-PSE and HREG systems

The main point of this power generation system is the principle of “zero power input” electrostatic field based on the electrodynamics. If there is a voltage difference between electrodes, then there is an electrostatic field present in the system, and this electrostatic field can arise spontaneously. The power supply located outside the cell can only provide power to the areas in the conductive leads and electrodes where free electrons can exist. The free electrons cannot enter the electrolyte between the electrodes. Most extreme areas to generate power is the electrode-electrolyte interface where the electrons can react with the ions from the electrolyte. It must be noted that the energy source is the electrostatic field established by a constant voltage applied by the power supply located outside the cell. The ions in the electrolyte are transferred to the electrode under the electrostatic field spontaneously created between the electrodes and exerting Coulomb’s force. For this process, the power supply located outside the cell does not need to provide power, but merely a static voltage to the electrodes. Therefore, the electrostatic energy is free of power.
Figure 1. Schematic representation of the hydrogen redox electric power generator and the hydrogen redox hydrogen generator. ESI-PSE: Electrostatic-induction potential-superposed water electrolysis; FC: Fuel cell

The electrolytic cell can be regarded as an electrical circuit element, of which the V-I characteristics are represented in Figure 2b. The electronic behavior of this device may be approximated by a forward-biased diode. Once the external bias voltage reaches the decomposition voltage $E_d$, the current then increases significantly. Thus, the decomposition voltage, $E_d$, refers to the barrier potential [4-8]. The electrostatic field exerted by the constant static voltage applied across the electrodes by a voltage source typically produces the energy, $E_{\text{ion}}$. The cell does not begin to conduct until the applied voltage exceeds $E_d$, which creates the effect of the barrier potential. The energy of electrons in the external circuit must overcome the effect of the barrier potential before the cell conducts. For a cell undergoing electrolysis, the voltage source external to the cell must supply a voltage $E_e$, given by:

$$E_e = E_d + \Delta E.$$  

(1)

When the current $I$ flows, by the application of $E_e$, the product $E_e I$ represents the total power that the
power supply is required to provide. The value of this power is dependent on the value of $E_d$, as expressed by:

$$P_{el} = I_e (E_d + \Delta E).$$

The first term $I_e E_d$ represents the power provided by the source to the electrons to overcome the barrier potential $E_d$ before the cell conducts. The current $I_e$ flows due to the emf of $\Delta E$, not $E_d + \Delta E$, so that the second term $I_e \Delta E$ is the electrical power that is useful specifically for the electrolytic reactions at the electrode/solution interface. Thus, the electrical energy required by typical standard single voltage source electrolysis is the total power.

The method termed the electrostatic-induction potential-superposed electrolysis (ESI-PSE) supplies potentials to the electrodes in a dual mode as shown in Figure 2a, i.e., the superposition of two voltages on the electrodes with two independent voltage sources; one is a bias-voltage source, which induces $E_d$ at the cell electrodes and the other is a power supply, which provides power to the cell. Figure 2d is a closed circuit with two voltage sources connected in opposing directions. These sources can act in parallel independently, and supply the cell electrodes with individual potentials, which yields a superposition such that the resulting voltage between the cell electrodes equals the magnitude of the algebraic sum of the individual potential, i.e., $E_d + \Delta E$. The performance of the cell can be explained by a series of steps. First, when the PS2 output voltage $V_{PS2} = E_d$, $I = 0$ (null point) because of the usual condition of uniformity of the electrochemical potential throughout the electrolyte solution [9]. Second, if $V_{PS2}$ is increased from the null point, then an electrolytic current $I = I_e$ flows due to the total source voltage of $\Delta E = V_{PS2} - E_d$ (Figure 2c). Hence, the two sources can be replaced by a single source (PS2) that delivers $\Delta E$. The bias-voltage-source does not need to produce electrical current, but only a static voltage because of the null-current condition at $E_d$. The cell voltage $E_e$, is the superposition of $\Delta E$ on $E_d$, and the entire corresponding electrolytic process is the superposition of the charge-transfer process where $\Delta E$ is applied (i.e., where power is used) to the electrostatic process where $E_d$ is applied (i.e., where power is not used). If the current $2F$ flows to produce 1 mole of $H_2$ and half a mole of $O_2$, and the current efficiency is almost unity, as in a commercial electrolyzer, then the total power requirement reduces to the generalized form for any given cell, regardless of the decomposition voltage $E_d$, temperature, pressure, composition of electrolyte solution and cell dimensions:

$$P' = 2F\Delta E.$$  \hspace{1cm} (3)

Figure 3 shows the HREG closed combined energy cycle. In the ESI-PSE cell, the zero power input electrostatic energy plus the power recycled from the fuel cell converts directly into the thermodynamic energy of $H_2$-$O_2$ fuel, and subsequently it converts directly into the electrical power by the fuel cell. Part of the power is recycled to the ESI-PSE electrolytic cell. Because the energy delivered by the fuel cell equals the energy required...
by the electrolytic cell, this internally created energy must be equal to the net power output to the outside of the generator. Then, we can recognize that the internal energy created originally by the Coulomb' force is responsible to the power which can be extracted from the generator. Thus, the overall energy balance of HREG does not violate the energy conservation law. This power generation system HREG works within the laws of thermodynamics. It has no relation to the perpetual motion machine.

Figure 2. Principle of the ESI-PSE. a, A single cell unit: FG: Field generator. b, V-I curve for water electrolysis. $E_d$: Decomposition voltage; $E_e$: Electrolytic voltage; $\Delta E$: Extra-applied voltage over $E_d$. c, ESI-PSE in operation. d, Equivalent circuit for ESI-PSE. $R_{cell}$: Cell resistance
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Figure 3. Thermodynamic cycle of the HREG

Figure 4. Schematic diagram showing the electrostatic-induction potential-superposed bipolar water electrolyzer.

FG: Field generator; AWE: Alkaline water electrolyte
1. Predicted facility design

Figure 4 shows the basic construction of the bipolar ESI-PSE water-electrolyzer.

Because the electrode potential of any individual cell in the stack is given by the electrostatic induction, the external power supply circuit should be connected in such a way that the outermost pair of electrodes is used as a field generator and should be connected to the bias voltage source PS1. The power supply PS2 for providing power to the stack should be connected to the electrodes next to the field generator with the polarity opposing the induced voltage. In principle, there is no current in Loop 1.

Figure 5 shows the schematic diagram of a predicted facility for the HREG system. Continuous and direct circulation of gases, water and heat between the fuel cell and electrolyzer is achieved by placing them side by side with the shortest possible distance, therefore the operational temperature, pressure and electrolyte are required to be the same for the two devices. In this sense, the combination of alkaline-water electrolytic cell and alkaline electrolyte fuel cell is desirable.

![Diagram of the HREG system](image)
There are two routes for the FC stack to supply power. One is the ESI-PSE EC stack inside the generation system and the other is the load outside the generation system. The fuel cell stack then consists of two sections responsible to provide power to the respective routes (Figure 6). For this purpose, the FC stack section must be designed such that it can deliver the voltage and current that its own route requires. To supply the load with power, dc current is converted to ac current by the inverter. To provide the ESI-PSE with power, the dc current from the FC stack is first converted to ac current by the inverter and second converted to dc current by means of the converter like the rectifier.

![Figure 6. Schematic flow diagram for the HREB system](image)

**FC**: Fuel cell stack; **EC**: Electrolytic cell stack; **I**: Inverter; **R**: Rectifier; **a, c, d**: dc current; **b**: ac current.

### 2. Cycle power efficiency assessment

In this combined energy cycle, the main device is the alkaline fuel cell (AFC) to produce electricity. The alkaline water electrolytic cell (AWEC) in this system is a backup reactor to synthesize fuel for the fuel cell. Part of the power generated by the fuel cell is returned to the electrolyzer, and the remainder represents the net power output. To represent the productive capacity, the cycle power efficiency is defined as the ratio $\xi_p$ of the net power extracted from the cycle, $P_{net}$, to the power produced by the pure stoichiometric $\text{H}_2$-$\text{O}_2$ fuel, $P_t$:

$$\xi_p = \frac{P_{net}}{P_t}$$

If the voltage efficiency is taken into account, then for 1 mole $\text{H}_2$,

$$P_t = 2F\eta E^0.$$  \hspace{1cm} (5)

Mass balance in the cycle requires equality of the electrolytic and galvanic currents. If the current efficiency is assumed to be unity, then Equation (3) is subtracted from Equation (5) to yield the theoretical net power output of the cycle, $P_{net}$. Hence, the cycle power efficiency is rearranged in the form:

$$\xi_p = \frac{P_{net}}{P_t} = 1 - \frac{\Delta E}{\eta E^0}.$$  \hspace{1cm} (6)

Assessments have been made on the achievable
cycle power efficiencies for the hydrogen redox power generation system when a commercially available AFC is combined with an existing AWE that is connected to the ESI-PSE mode. Assessments of the cycle power efficiency require the V-I characteristics for the AWEC and the voltage efficiency of the AFC. The V-I characteristics shown in Figure 7 were determined using data for the operating conditions of typical electrolyzers, with \( j = 1000, 3000, \) and 4500 A/m\(^2\) at \( E_e = 1.9, 2.2 \) and 2.4 V, respectively, and also with reference to the literature [10,11]. Commercially available AFCs operate with a voltage efficiency of \( \eta = 0.8 \) on average [12, 13]. In view of Equation (7), points on the V-I curve are related to the corresponding cycle power efficiencies. The three calculated points shown in Figure 7 indicate that highly positive power balance like \( \xi_p = 70\% \) may be achievable for the hydrogen redox power generator using commercially available devices.

Figure 7. V-I characteristics for the commercial bipolar water electrolyzer

3. Conclusion

We have thus investigated the role of the electrostatic energy in the electrolytic cell. As a result, we could suggest the electric power generation systems, namely hydrogen redox electric power generators that work on a mechanism of no energy
input, no matter input and zero emission, without violating the laws of thermodynamics. Because of the simplicity, effectiveness, cleanliness and self-exciting, this novel generator may offer a potential route for its practical application to the central-station power generation in the regions where the primary energy source is unavailable.

References


