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PERFORMANCE CHARACTERITICS OF HYDROGEN GENERATOR USING SODIUM BOROHYDRIDE STORAGE FOR UNINTERRUPTED POWER SYSTEM

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ABSTRACT

Performance characteristics of hydrogen generator using sodium borohydride storage for uninterrupted power system was evaluated in the present study. For fuel cell-based uninterrupted power system, compressed and liquefied hydrogen have been mainly used as a hydrogen storage, but safety for long-term storage is still problematic due to its storage characteristics. In this paper, the reaction of sodium borohydride with an acidic solution was employed to generate hydrogen in order to compensate the storage problem. Using this mechanism, a hydrogen generator for 1 kW fuel cell was developed and the performance evaluation was carried out in the various operation conditions.

Keywords: Fuel cell, Chemical hydride, Uninterrupted power system, Energy conversion, Hydrogen.

1. INTRODUCTION

Recently, fuel cell-based UPS (Uninterrupted power system) has been widely developed. Previously, the fossil fuels such as coal, petroleum, and LNG (Liquefied natural gas) have been used as a energy source of UPS. However, as the depletion of fossil fuel and air pollution problem were issued, electric power should be generated using an eco-friendly fuel. There are two promising solutions for electric power generation including secondary battery and fuel cell. However, the secondary battery itself has a low energy density so that it is impossible to provide sufficient operation time in case of blackout. Thus, the fuel cell comes into the spotlight because of its high energy density.

There are many examples of using the fuel cell for the power generation of UPS [1]. However, the hydrogen storage was hard to handle because of the gaseous state in room condition that makes the hydrogen easy to diffuse and explode. Hence, the alternative methods for the hydrogen storage and generation have been widely studied. The compressed and liquefied hydrogen could be used for hydrogen storage. However, the compressed hydrogen is not appropriate for the UPS because of the low storage density, heavy weight of the storage tank, and filling method [2]. The liquefied hydrogen requires high costs for hydrogen storage and maintenance [3].

Recently, chemical hydride has been applied as an alternative hydrogen storage [4]. Among chemical hydrides, $LiBH_4$, and $AlBH_4$ have a high gravimetric density in comparison with the other chemical hydrides such as $NaBH_4$. However, Li and Al contained in the hydride have a low ignition point, which means it can be explosive and be ignited at the low temperature. In terms of cost, they are not competitive compared to the other chemical hydride. Whereas, $NaBH_4$ as a chemical hydride has a higher ignition point and low cost.

The notable feature of $NaBH_4$ is to be possible to control its half-life by changing the pH value. Lee et al. suggested the hydrogen generation method from the $NaBH_4$ in the solid state by injecting the hydrochloric acid (HCl) solution [5]. Kwon et al. developed and evaluated a $NaBH_4$-based hydrogen generator using this hydrogen generation method [6]. However, the performance evaluation of hydrogen generator was carried out at the constant hydrogen consumption rate. Therefore, it is necessary to evaluate the performance of hydrogen generator in the various operation conditions.

Therefore, the performance of hydrogen generator using the sodium borohydride ($NaBH_4$) storage was evaluated under the dynamic hydrogen consumption rate.

2. DEVELOPMENT OF HYDROGEN GENERATOR

2.1 Hydrogen generation method from $NaBH_4$

The hydrogen generation from $NaBH_4$ consists of two main chemical reactions. The first is a $NaBH_4$ hydrolysis as shown in Eq. 1. However, the reaction rate was too slow to rapidly generate hydrogen, which make it low the efficiency and responsiveness. Thus, HCl solution was used to accelerate the reaction of $NaBH_4$ hydrolysis as shown in Eq. 2 [5].

$$\mathrm{NaB}H_4 + (2+\alpha)H_2O \rightarrow \mathrm{NaB}O_2 + 4H_2 \quad (1)$$

$$\mathrm{NaB}H_4 + (\mathrm{HCl} + 3H_2O) \rightarrow \mathrm{NaCl} + 3H_3BO_3 + 4H_2 \quad (2)$$

2.2 System mechanism

The 1 kW-class hydrogen generator using $NaBH_4$ as a hydrogen storage is shown in Fig. 1. The schematic of the system mechanism is illustrated in Fig. 2. The hydrogen generator consists of agent tank, reactor, and control module. The agent tank is used for storing the acid solution which is injected into the reactor. The reactor stores the $NaBH_4$ and hydrogen generated by the chemical reaction between the $NaBH_4$ and acid solution in the certain pressure. At this time, the temperature is increased up to 100°C.

Figure 1 $NaBH_4$-based 1 kW-class hydrogen generator

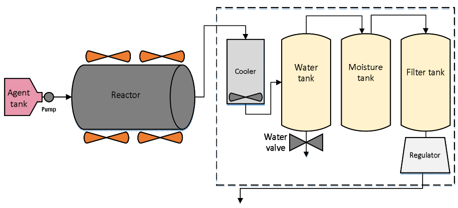

Figure 2 Layout of $NaBH_4$-based hydrogen generator

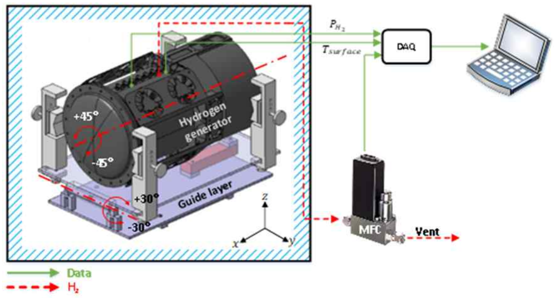

Figure 3 Configuration of experiment setup

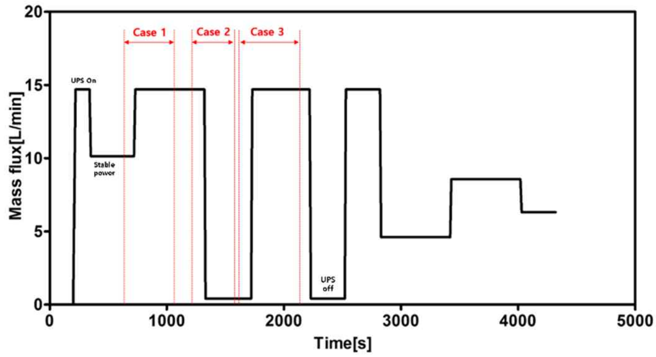

Figure 4 Mission profile to evaluate the dynamic hydrogen consumption rate

The hydrogen with a high temperature can damage the membrane of fuel cell. Thus, first of all, the fans attached around the reactor cool down the reactor, and the hydrogen passes through the cooling-coil to cool down the temperature. As a result, the hydrogen passing through the fan around the reactor and cooling coil was cooled down to room temperature. However, byproduct of the reaction was produced containing not only the hydrogen but also water vapor or acid. As both hydrogen and vapor was cooled down to room temperature, the water was formed by the condensation of the vapor.

If the condensed water goes into the stack, it would be damaged by the impurities that may be dissolved in the water and would make it lower the purity of the hydrogen so that a fuel cell cannot meet the required power. Thus, to eliminate the vapor and water, water trap and filter tank were installed in the control module. The water trap was storing and discharging the water according to the signal of the level sensor.

However, eliminating the acidic gas, vapor and water was hard because the gas passes the cooling coil for the short time. To prevent entering the acidic gas, vapor, and water into the fuel cell, the moisture filter was installed containing the silica-gel which absorbs the vapor and water, and the acid absorbent which absorbs the acidic gas. Through this mechanism, the hydrogen generator could have high reliability.

3. EXPERIMENT SET UP

3.1 Performance evaluation setup

The configuration of performance evaluation setup for the inclination (pitch & roll) change, and high and dynamic hydrogen consumption rate. The pressure and temperature were measured at the upper and side surface of reactor, respectively. The mass flow, 20L/min, was controlled through the mass flow controller (MFC). All the data was collected at the DAQ, and the pump, valve and fan were controlled using Lab-View, National Instrument (NI).

3.2 Pitch and roll change experiment

Normally, the fuel cell uses the compressed and liquefied hydrogen as a hydrogen storage. There method are not limited to the inclination of system. However, the compressed and liquefied hydrogen tank are too heavy and bulky so that the hydrogen storage density is very low. For this reason, the chemical hydride was used, but when using the chemical hydride, the inclination can be limited such as leaning one side because the $NaBH_4$ hydrolysis reaction is phase changing reaction. Thus, the pitch and roll change experiment were focused on hydrogen generation rate with the inclined angle.

3.3 Response characteristics of hydrogen generation in dynamic hydrogen consumption rate

The dynamic hydrogen consumption rate for the performance evaluation is shown in Fig. 4. The power consumption can be varied suddenly depending on the electric load of UPS in case of blackout. Accordingly, the hydrogen generator must be able to supply the amount of hydrogen sufficient to operate the fuel cell for each condition. Thus, the response characteristics of hydrogen generation in dynamic hydrogen consumption rate was evaluated based on Fig. 4.

4. RESLUT AND DISCCUSION

4.1 Performance stability under pitch and roll change

The performance stability under the pitch -30/+30, and roll -45/45 is shown in Fig. 5.

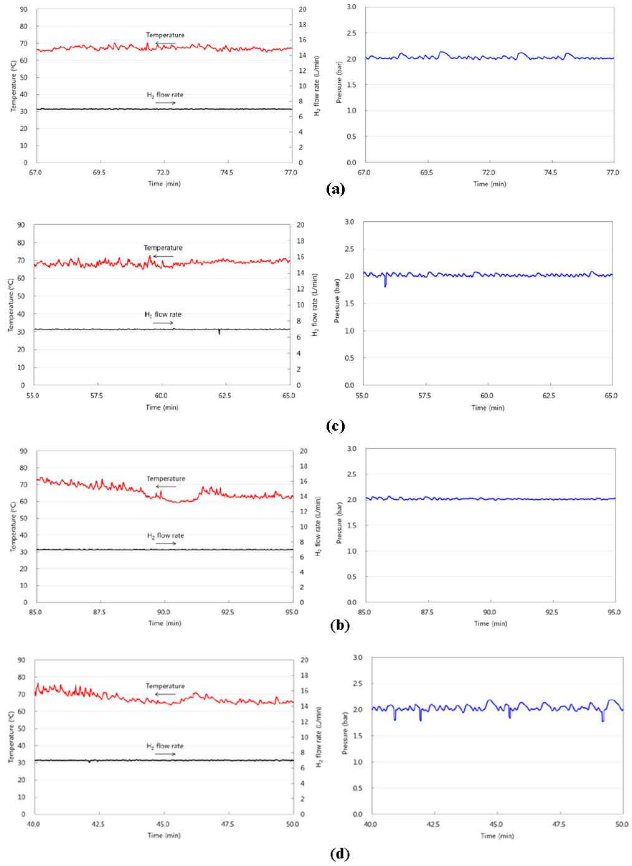

Figure 5 Performance stability of hydrogen generation under the pitch +30°(a), pitch -30° (b) Roll +45° (c) and Roll -45° (d)

At the pitch angle +30, the pressure, temperature, and mass flow were almost stable. Although the initial temperature was slightly higher with both the pitch +30 and roll +45 compared to the pith -30 and roll -45 due to the power cut while changing the pitch angle, the temperature was cooled down and the terminal temperature was almost same. However, in the previous study [6], the system was operated ordinarily though the power supply was discontinued. In this part, the system was proven that the hydrogen was generated stably though the fuel was cornered one side.

4.2 Performance stability of hydrogen generation in dynamic hydrogen consumption rate

The performance stability of hydrogen generation in the dynamic hydrogen consumption rate is shown in Fig. 6. In the Case 1, which is the operation mode transition from the rate power mode to the maximum power mode, the hydrogen generation rate followed the set point that was varied from 10.1 to 14.7 L/min without considerable response delay time. The reactor pressure was maintained constant into the set pressure of 2.0 bar

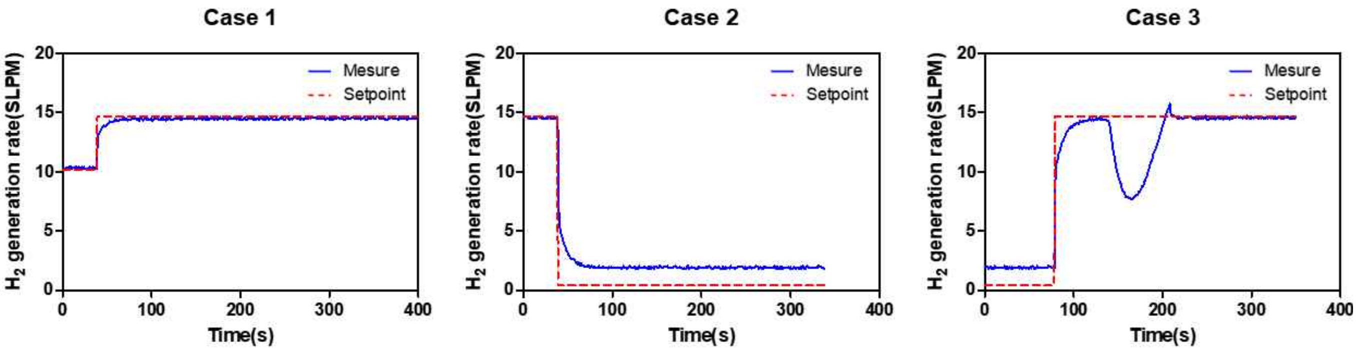

Figure 6 Performance stability of hydrogen generation in the dynamic hydrogen consumption rate

that was predetermined considering the buffer amount for the stable hydrogen supply to the fuel cell. The Case 2 had the profile of the hydrogen generation rate dropping sharply from 14.7 L/min to 0.4 L/min, which corresponds to the operation mode transition from the maximum power to the idle mode.

In the Case 3, the hydrogen generation rate was raised rapidly from 0.4 to 14.7 L/min, which corresponds to the operation mode transition from the idle to the maximum power mode. At the beginning of the Case 3, the hydrogen generation rate followed the profile of the sudden rise from 0.4 to 14.7 L/min. However, the hydrogen generation rate was not maintained, being dropped down to 8.7 L/min immediately after reaching 14.7 L/min.

5. CONCLUSION

In the previous study, the performance of hydrogen generator was simply evaluated. However, it is difficult to guarantee the reliability of mounting on an actual uninterrupted power system only by simple hydrogen generation performance tests. Therefore, in this paper, the performance test of the hydrogen generator was performed under various environments. First, when the system was inclined, the fuel could be leaned to one side. As a result, it was confirmed that hydrogen was generated smoothly even at a pitch angle of ±45° and a roll angle of ±30°. Finally, the hydrogen generator was evaluated based on the dynamic hydrogen consumption rate. In Case 3, when the operation mode was changed from the idle mode to the maximum power mode, in which the hydrogen consumption rate raised from 0.4 L/min to 14.7 L/min, the hydrogen generation rate was not maintained. However, the hydrogen generation rate was recovered to 14.7 L/min. Based on the result of the performance evaluation, the performance for applying the hydrogen generator to the uninterrupted power system was confirmed.

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