ENERGY MANAGEMENT FOR HYDROGEN ENERGY STORAGE SYSTEM

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ABSTRACT

While the amount of renewable energy sources is rapidly increasing, a hydrogen energy storage system which can store energy for long term without loss is promising technology for supply-and-demand balancing of electric power and for absorption of surplus power.
Furthermore, the hydrogen energy storage system is capable of storing a large amount of energy which will meet weekly or monthly energy demand by expanding the volume of hydrogen tank. Therefore, the hydrogen energy storage system can be applied to disaster application such as a Business Continuity Plan (BCP).
In this paper, the operation and function of the hydrogen energy storage system combined with renewable energy is described using a BCP model and an island model. For the BCP model, a mini-model of photovoltaic (PV) and hydrogen energy storage combination system has been introduced to Hydrogen Energy Research & Development Center in Toshiba. In the island model which is regarded as a small community, power complement between two hydrogen energy storage systems that minimizes fuel consumption of the generator is proposed.

INTRODUCTION

Sustainable low-carbon society would be realized by power generation system using renewable energy such as PV system or wind power system. However, as it is well known, renewable energy systems are susceptible to weather fluctuations, and cannot generate stable power or power to match with the demand. While area with a stable power grid can increase amount of renewable energy sources on a large scale, area where the power grid is vulnerable has difficulty in increase of renewables. Although lithium-ion batteries or sodium-sulphur batteries can be solutions for suppression of short-term fluctuations, these batteries are not suitable for long-term control of supply and demand because they merely have capacity that last for 20 minutes to 6 hours.
The hydrogen energy storage system that is described in this paper can easily store large amount of energy by increasing the volume of the tank. We have proposed combination system of hydrogen storage, a small power generator, a renewable energy source, and a small battery system which can be applied to small communities. The logic of energy management for this system enables maximum utilization of the renewable energy and can be used for BCP as well. In this paper, experimental results at the Hydrogen Energy Research & Development Center (HRDC) in Toshiba and simulation results are reported.

SYSTEM CONFIGRATION OF HRDC

Figure 1 shows overview of HRDC. Table 1 shows specification of components at HRDC, and Figure 2 shows system configuration. In the HRDC, mini-model of the hydrogen energy storage system is installed and various operation scenarios are assumed to verify functions of hydrogen energy management system, including prediction of renewable energy output and prediction of demand.
Brief summary of these components are described below.

(a) Overview of HRDC

(b) Components of HRDC

Figure 1 Photo of HRDC

Table 1 Specification of HRDC components

Items	Spec
PV system	Nominal generated power 96kW
Battery system	100kW-22kWh
Hydrogen storage tank	150Nm^3
Electrolysis cell (EC)	PEM(Polymer Electrolyte Membrane):10Nm^3/h
Fuel cell (FC)	8.4kW
Efficiency of hydrogen energy storage system	95% (electric:55% + heat 40%)

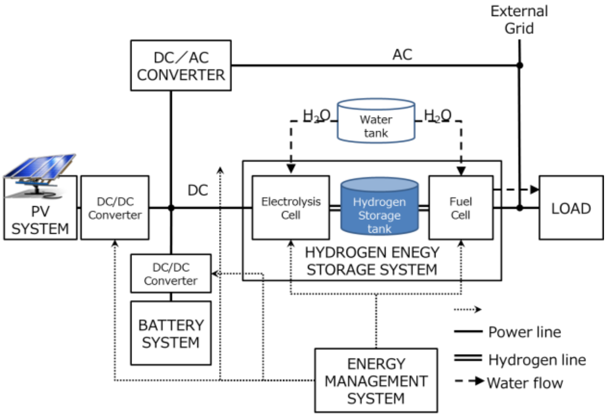

Figure 2 System configuration of HRDC

ENERGY MANAGEMENT SYSTEM

As a short-term control, the energy management system (EMS) suppresses the voltage fluctuation by controlling the DC/AC controller, the electrolysis cell (EC) and the fuel cell (FC). As a long-term control, the EMS controls these apparatuses so that the amount of battery energy and amount of hydrogen are kept at appropriate level.

PV SYSTEM

PV panels are placed on the roof of HRDC. The DC converter controls PV output by MTTP method.

BATTERY SYSTEM

The battery system is composed of lithium-ion batteries. The battery system is capable of quick charge and discharge in response to its reference signal. As described below, the EC and the FC have response delay to their power reference. Therefore, battery system mainly compensates the response delay of EC and FC.

HYDROGEN ENERGY STORAGE SYSTEM

As noted in Table 1, overall system efficiency of the hydrogen energy storage system is 95%. This is a round-trip efficiency which includes energy conversion efficiency of both EC and FC. When only electric power output is considered, round-trip efficiency of the system is 55%. The remaining 40% efficiency is achieved by utilizing heat output from the FC.

Hydrogen storage tank

The volume of hydrogen is measured in Nm^3 (Normal cubic m). 1Nm^3 represents amount of hydrogen with volume of 1m^3 under pressure of 1 atmosphere and temperature of 0 degrees Celsius .

Electrolysis Cell (EC)

The EC generates hydrogen by water electrolysis. Two types of electrolysis method are used in HRDC such as PEM (Polymer Electrolyte Membrane), SOEC (Solid Oxide Electrolysis Cell). Figure 3 and Figure 4 show examples of response characteristics of hydrogen generation regarding to EC power reference using PEM. When the EC starts generating hydrogen, there is about 16secons delay in start-up. When the EC stops generating hydrogen, there is about 5seconds delay which is shorter than start-up.

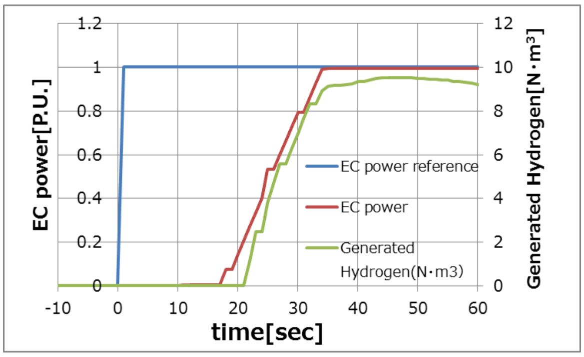

Figure 3 Response characteristic of the EC
EC output from 0% to 100%

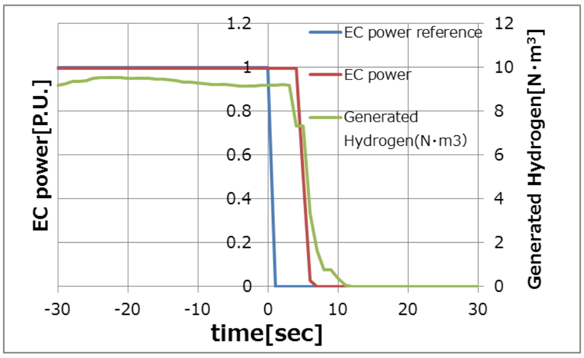

Figure 4 Response characteristic of the EC
EC output from 100% to 0%

Fuel Cell (FC)

The FC generates electric power by the chemical reaction between hydrogen and oxygen. Therefore, FC has response delay to its power reference. Figure 5 and Figure 6 show response characteristics of the FC to its power generation reference signal. The response delay of the FC from low-output to high-output is shown in

Figure 6. The length of the delay in Figure 6 is shorter than that of Figure 5, which shows the response of the FC from zero-output to high-output. Figure 5 indicates that the FC requires 94sec for start-up. Figure 6 indicates that the FC requires only about 40sec to change its output from 36% to 90%.

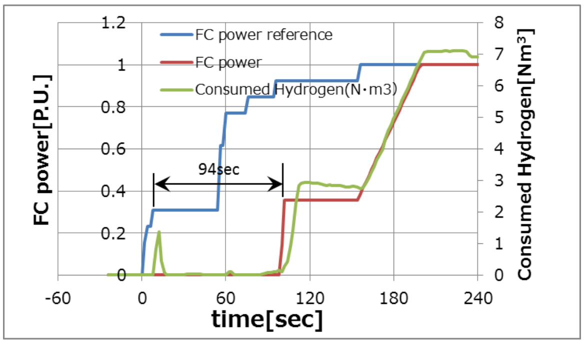

Figure 5 Response to electric power generated FC output from 0% to 100% at start-up

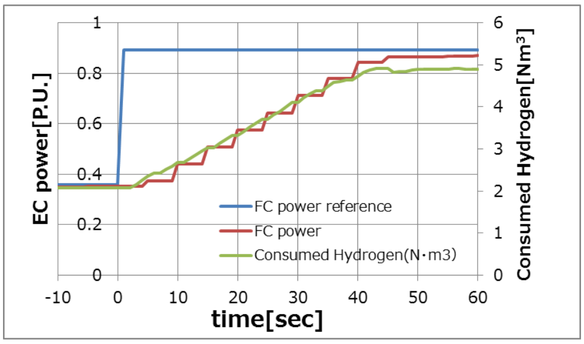

Figure 6 Response to electric power generated FC output from 36% to 90%

BCP MODEL

The BCP model enables continuous supply of energy even at a time of power outage. The outline of the BCP equipment is shown in Figure 7. A PV system is used as power source of the BCP equipment to enable its standing alone operation.

Figure 7 Outline of BCP equipment

While the hydrogen energy storage system is connected to the distribution grid, the EMS controls the amount of hydrogen by estimating the demand of outage power. When power outage is detected by drop of distribution grid voltage, the EMS disconnects the system from the distribution grid and starts supplying power to load from hydrogen energy storage system. Figure 9 shows the supply power waveform during 7days of power outage.

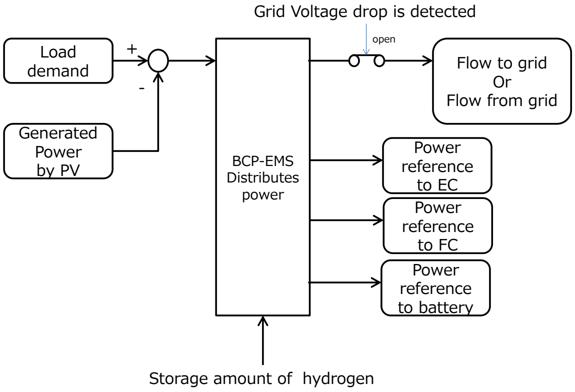

Figure 8 Block diagram of BCP EMS

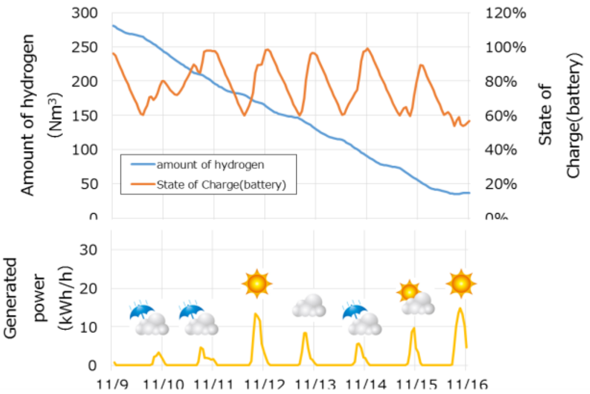

Figure 9 Test result of BCP model Stand-alone mode

ISLAND MODEL

In a remote island, high fuel transport costs will encourage introduction of renewable energy systems. The island model of the hydrogen energy storage system has PV system and wind power system as power sources. The Energy Management System (EMS) controls the electric power output of hydrogen energy storage system. Electric power is exchanged between two hydrogen energy storage systems, and fuel consumption of the generator is minimized.

Figure 10 shows the configuration of the island model. Two sets of hydrogen energy storage systems are assumed and one of them is connected to a wind power system while the other is connected to a PV system.

The effectiveness of the EMS has been verified by simulations. Table 2 shows specification of components used in the simulation.

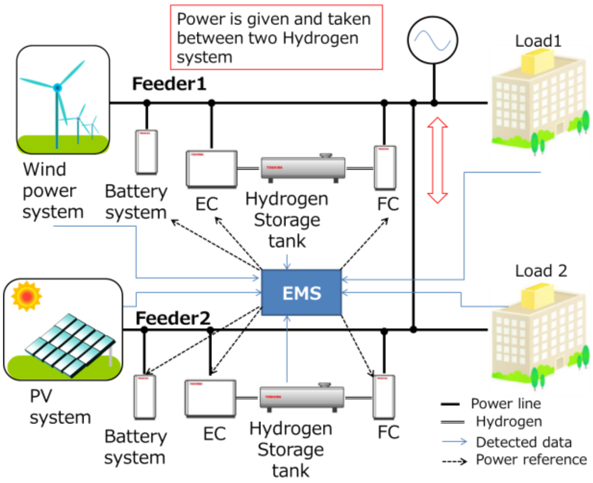

Figure 10 System configuration of island model

Figure 11 and figure 12 show simulation results of the island model. Output data of PV and wind turbine are annual data obtained from a real system. The graphs show results during July and they indicate that power output from the wind turbine is relatively low. Without power complement from another hydrogen energy storage system, the stored amount of hydrogen drops to zero. However, power complement between two systems enables continuous operation of each load.

Table 2 Specification of components

Items	Specification	
	Feeder 1	Feeder 2
Rated power output of PV system	-	200kW
Rated power output of wind turbine	750kW	-
Hydrogen storage tank capacity	$35*10^3$Nm^3	400N m^3
Electrolysis cell PEM	400kW 65Nm^3/h	80kW 13Nm^3/h
Fuel cell	100kW	20kW
Maximum power demand of load	100kW	20kW

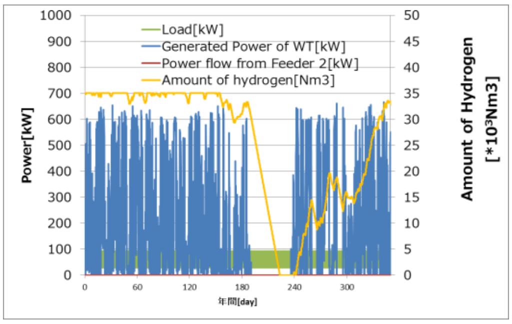

Figure 11 Simulation result of the island model without power complement between two systems

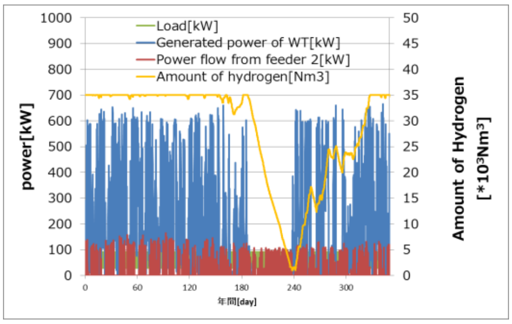

Figure 12 Simulation result of the island model with power complement between two systems

In this model, the method of system capacity determination is an important issue. If annual output power curves of PV and wind turbine are given, these systems' capacity can be calculated according to following block diagram in Figure 13.

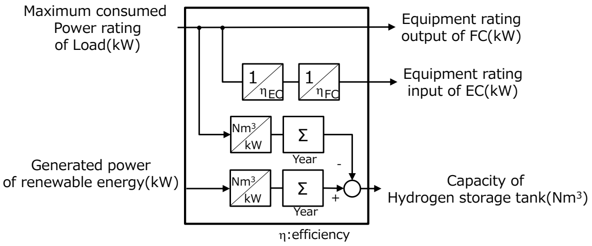

Figure 13 Block diagram of system capacity calculation

CONCLUSION

In this paper, two models of hydrogen storage and EMS application -the BCP model and the island model- have been studied. In the BCP model, the 7days continuous BCP operation has been described. Response delays of the EC and the FC are compensated by the battery system. Furthermore, continuous power supply using PV and hydrogen energy storage system has been described. In the island model, power complement between two hydrogen energy storage systems has been proposed for minimization of generators' fuel consumption. A block diagram to calculate system capacity has been proposed as well.

For future work, the cost effect of the hydrogen energy storage system will be studied.

REFERENCE

[1] Masato Yoshino, Kentaro Matsunga, Ryo Nakajima, 2015, "High-Efficiency Hydrogen-Based Electric Power Storage System", *Toshiba Review*, vol.70, No.5 p8-11