Demonstration of Hydrogen Refueling Station Using Renewable Energy for Fuel Cell Vehicles

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Abstract

To significantly reduce CO_2 emissions during the production of hydrogen for hydrogen refueling stations, it is effective to use water-electrolysis hydrogen generated with renewable electricity. Kobe Steel has devised a configuration to add a hydrogen generator using a solid-polymer-electrolyte water electrolyzer (20 Nm^3/h) and equipment for storing generated hydrogen at a high pressure (45 MPa) to a standard hydrogen refueling station (hydrogen supply capacity 300 Nm^3/h) and has designed and built a demonstration plant. The demonstration included the operation of the water-electrolysis hydrogen generator for about 780 hours with the variable power source without any problems with followability and durability. In addition, the function of the entire system designed was verified by the operation linked with the hydrogen refueling station. In the future, further cost reduction and efficiency improvement will be considered. It is necessary to set a social value for hydrogen, which emits less CO_2.

Introduction

Japan's Fifth Strategic Energy Plan was formulated in 2018 by the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry (METI).[1] This Strategic Energy Plan positions hydrogen as the secondary energy, and hydrogen infrastructure is becoming an energy infrastructure that Japan should develop as a measure against global warming. In December 2017, the Ministerial Council on Renewable Energy, Hydrogen and Related Issues enacted the Basic Hydrogen Strategy.[2] With a view to 2050, this basic strategy has been established as an action plan covering the period up to 2030 to realize a hydrogen society, as well as the direction and vision that the public and private sectors should share as concepts and goals to aim at in the future. In addition, this Basic Hydrogen Strategy is directed at "establishing a fully CO_2-free hydrogen supply system by combining hydrogen production with CCS [Note 1] or by utilizing hydrogen based on renewable energy" around 2040 as a CO_2 reduction measure during hydrogen production.

Furthermore, the New Energy and Industrial Technology Development Organization (NEDO) is developing a hydrogen production technology based on alkaline water electrolysis using renewable energy generated by wind power, for example, in the "Advancement of Hydrogen Technologies and Utilization Project, (FY2014-FY2017); Research and development of low-cost hydrogen production system."

On the other hand, against the backdrop of the fact that fuel cell vehicles (hereinafter referred to as "FCVs"), using hydrogen as fuel, are attracting attention as Zero Emission Vehicles in the mobility field, the development and network construction of hydrogen refueling stations for FCVs are in progress. The hydrogen sources for hydrogen refueling stations employ off-site supply, including the transport and supply of by-product hydrogen from large-scale natural gas reforming and refinery plants, as well as on-site hydrogen supply that locally manufactures hydrogen using natural gas or liquefied petroleum gas (LPG) as raw material.

In Japan, the construction of a hydrogen supply network is being prioritized; however, since the hydrogen is based on fossil fuels, CO_2 is currently emitted during the production process. Hence, it is expected that there will be a greater increase in the social demand for the use of hydrogen based on renewable energy, which can significantly reduce the amount of CO_2 emissions.

The hydrogen supplied to the hydrogen refueling station is required to be high-purity hydrogen of 4N (99.99%) or higher. Also, it is required to be easy to use and handle in urban areas without any problems such as waste liquid emissions and corrosiveness. Hence, the method using a solid-polymer-type water-electrolysis hydrogen generator, which has already been commercialized and can produce high-purity hydrogen, is considered to be advantageous for producing hydrogen based on renewable energy for this application. Meanwhile, regarding its application to hydrogen refueling stations, there are challenges, including the reduction of hydrogen

[Note 1] CCS stands for Carbon Dioxide Capture and Storage.

production cost and improvement of hydrogen production efficiency.

Hence, in collaboration with Kobelco Eco-Solutions Co.,Ltd. and Shinko Engineering & Maintenance Co.,Ltd, Kobe Steel has jointly developed technologies related to refueling stations using hydrogen based on renewable energy and conducted a demonstration testing (hereinafter referred to as "the present development"). This paper gives an outline of these activities.

1. Configuration of facility for demonstrating refueling station to supply hydrogen based on renewable energy

The present development aims to supply water-electrolysis hydrogen based on renewable energy to a hydrogen refueling station. Hence, it was planned to install a water-electrolysis hydrogen generator and hydrogen storage facility (**Fig. 1**) with a capacity of 20 Nm^3/h adjacent to a standard-scale hydrogen refueling station (rated 300 Nm^3/h). This is because a 300 Nm^3/h water-electrolysis hydrogen generator at the current cost will not be acceptable for a hydrogen refueling station and not be easily adapted to large-scale renewable energy power of MW-class. The process capacity of 20 Nm^3/h corresponds to approximately 6% of the 300 Nm^3/h rating, and the CO_2 reduction effect is limited. However, it can be replaced with a larger-scale one as the demand increases.

The demonstration facility used in the present development was designed to comply with the regulations applicable to hydrogen refueling stations. The facility was annexed to the hydrogen refueling station installed in Kobe Steel's Takasago Works to verify its own equipment. **Fig. 2** shows the layout and installation of this facility. The following outlines its main components.

(1) Water-electrolysis hydrogen generator

A 20 Nm^3/h water-electrolysis hydrogen generator [3)] manufactured by Kobelco Eco-Solutions, Co., Ltd. was used (**Fig. 3**). This generator is a development product with an electrical current density 1.4 times greater than that of the conventional model and has been designed with the aim of reducing initial cost and downsizing. It has also been configured as a package type that can be installed outdoors, assuming installation in a hydrogen refueling station.

(2) Hydrogen storage unit

When hydrogen is made using power based on

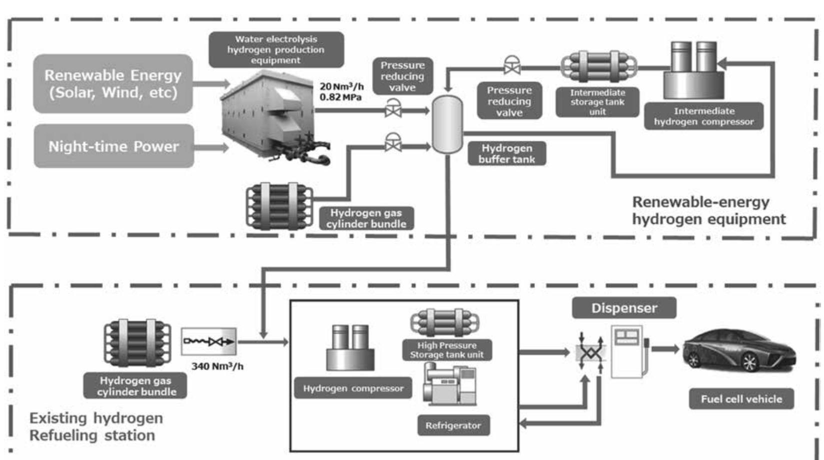

Fig. 1 Conceptual diagram of refueling station of hydrogen based on renewable energy

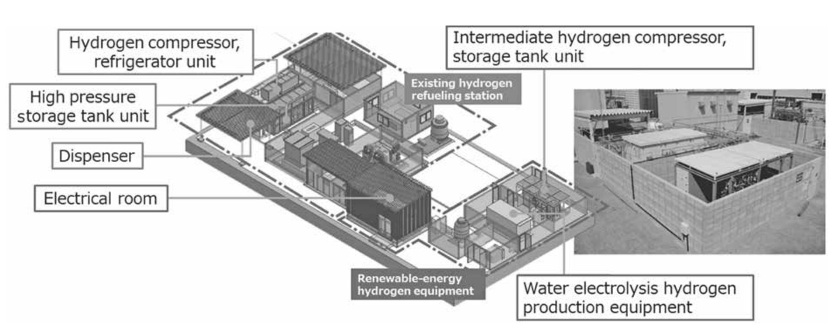

Fig. 2 Demonstration facility for refueling station of hydrogen based on renewable energy

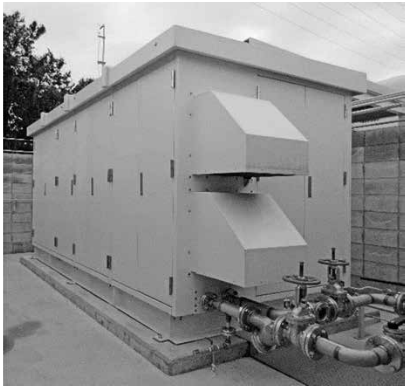

Fig. 3 Water-electrolysis hydrogen generator

renewable energy, a fluctuating power source, the hydrogen flow rate fluctuates in accordance with the power. In addition, the hydrogen demand at the hydrogen refueling station is unsteady, due to the filling demand for FCVs. Therefore, it is necessary to temporarily store the generated hydrogen in the case where the demand is low. Hence, the present development has adapted a system comprising an intermediate compressor and an intermediate accumulator, wherein hydrogen is stored as compressed gas.

Since the hydrogen storage capacity depends on the pressure and capacity settings of the intermediate accumulator, it is necessary to design in accordance with the hydrogen production capacity and the demand on the side of the hydrogen refueling station. The hydrogen storage capacity for the present development was set to approximately 90 Nm^3, which enables hydrogen supply to about two FCVs and can operate the water-electrolysis hydrogen generator for approximately 4 hours.

The pressure of the intermediate accumulator was set to a normal operation pressure of 45 MPa, which is equivalent to that of the accumulator used for unloading from the hydrogen curdle at an off-site hydrogen refueling station. In addition, two intermediate accumulators were installed to deal with such problems as valve troubles, for example. The accumulator capacity that meets the above requirements was studied, and an accumulator with 150-liter capacity was adopted.

In addition, a low-pressure hydrogen buffer tank was installed to suppress the pressure fluctuation of the hydrogen supplied to the hydrogen refueling station. Connected to this were the inlet piping of the intermediate compressor, the outlet piping of the intermediate accumulator, the outlet piping of the water-electrolysis hydrogen generator, and the hydrogen supply piping to the hydrogen refueling station. This construction aims at minimizing the equipment configuration so as to respond to each operational pattern of hydrogen production, storage, and supply.

2. Demonstration operation

2.1 Verification of water-electrolysis hydrogen generator

The applications of conventional water-electrolysis hydrogen generators have been predominantly for industrial hydrogen supply and mainly focused on hydrogen production using a stable power source. On the other hand, the refueling station of hydrogen based on renewable energy produces hydrogen by using renewable energy power, which is generally regarded as an unstable power source. Hence, in the present development, a hydrogen production test was conducted using a solar-cell simulating power source to verify the followability and durability of the water-electrolysis hydrogen generator with respect to the photovoltaic power source, whose power generation fluctuates particularly steeply among the power sources based on renewable energy.

The amount of photovoltaic power generation varies depending on the season and the weather. Hence, in the present development, "summer", "intermediate period", and "winter" were set as the seasons, and "sunny", "cloudy" and "rainy" were set for the weather. The water-electrolysis hydrogen generator was operated on the premise of the amount of power generated based on the solar radiation data in each season and weather (integrated operation time, 780 hours). Also, as for the solar radiation data, reference was made to the Solar Radiation Database Browsing System[4)] published by NEDO to set the solar radiation data that is regarded as the standard in Tsukuba City from June 2011 to December 2012.

As a typical example, **Fig. 4** shows the changes over time in the amount of power generated and the

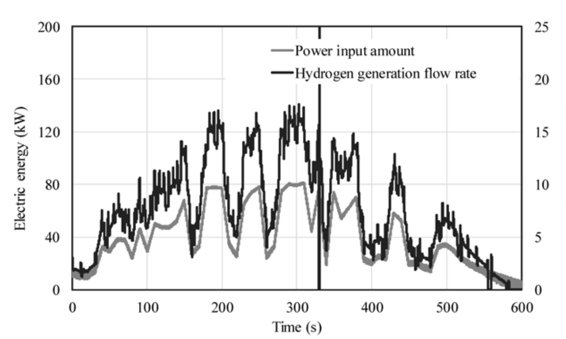

Fig. 4 Changes in electric energy and amount of hydrogen production over time (by pattern of cloudy weather in summer)

amount of hydrogen produced in the solar radiation pattern assuming cloudy weather in summer. It has been confirmed that hydrogen production that follows the power fluctuation is feasible, although the load fluctuation is great, and the conditions are severe for a water-electrolysis hydrogen generator. In addition, the operation was completed without any particular problems during the demonstration period. The change rate of the electrolytic cell voltage, which affects the efficiency, is 1% or less before and after the demonstration period, which is a sufficiently acceptable value from the viewpoint of durability. Also, regarding hydrogen purity, it was confirmed that the concentration of impurities is lower than the allowable impurity concentration, specified by ISO, in the hydrogen fuel for FCV and is suppliable to FCVs.

From the above, it has been confirmed that the newly developed water-electrolysis hydrogen generator has no problem with the fluctuating power source.

2.2 Demonstration operation of hydrogen production and hydrogen refueling to FCVs

The demonstration facility has the following 3 processes assuming actual operation:

(1) Hydrogen production process: The process in which the water-electrolysis hydrogen generator produces hydrogen.

(2) Hydrogen storage process: The process of storing the produced hydrogen in the intermediate accumulator using the intermediate compressor.

(3) Hydrogen supply process: The process of dispensing hydrogen from the intermediate accumulator and supplying it to the hydrogen refueling station in association with hydrogen refueling an FCV with hydrogen.

The hydrogen supply process has been designed so that the water-electrolysis hydrogen and hydrogen supplied from the intermediate accumulator are supplied to the hydrogen refueling station with stable pressure via the low-pressure hydrogen buffer tank.

To confirm the operation as a refueling station of hydrogen based on renewable energy, in which the station is linked with a hydrogen generator, demonstrations have been conducted for the hydrogen production and hydrogen refueling to FCVs. **Fig. 5** shows the test results. It should be noted that, in Fig. 5, the start time of refueling an FCV with hydrogen is set to 0.

Since water-electrolysis hydrogen is introduced into the intermediate accumulator before the start of filling, the pressure of the intermediate accumulator

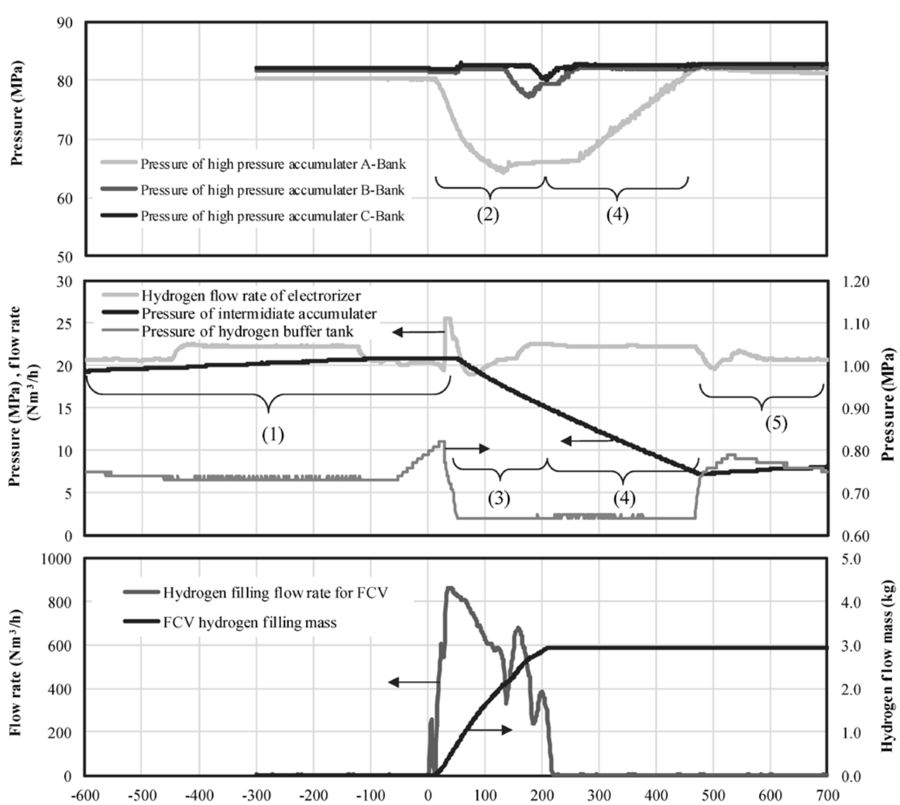

Fig. 5 Demonstration operation of hydrogen production/hydrogen refueling of FCV

increases (Part (1) of Fig. 5). After the filling begins, hydrogen is first supplied from the high-pressure accumulator to the FCV, so the pressure of the high-pressure accumulator decreases (Part (2) of Fig. 5). Next, a start command is sent to the compressor on the side of the hydrogen refueling station, and hydrogen is introduced to the high-pressure accumulator. At the same time, the hydrogen supply process begins, and as a result, the pressure of the intermediate accumulator decreases (Part (3) of Fig. 5). The hydrogen filling completes in 219 seconds, but the compressor continues to operate until the high-pressure accumulator returns to the initial pressure. Thus, the hydrogen supply process goes on. (Part (4) of Fig. 5). As soon as the pressure returns to the initial, the hydrogen supply process is completed, and the hydrogen accumulation process is restarted (Part (5) in Fig. 5).

The following has been confirmed by this demonstration:

- The FCV was filled with 2.9 kg of hydrogen, and approximately the same amount of water-electrolysis hydrogen was supplied from this demonstration facility during that period.
- During the operation, the pressure in the low-pressure hydrogen buffer tank was controlled within the set pressure range.
- The water-electrolysis hydrogen generator was stably producing hydrogen during the series of processes.

As described above, the operation linked with the hydrogen refueling station has been demonstrated.

Conclusions

As a form of refueling stations of hydrogen based on renewable energy, a demonstration facility was designed and built to supply hydrogen produced by a water-electrolysis hydrogen generator with a capacity of 20 Nm^3/h to a hydrogen refueling station. This demonstration facility was used to demonstrate hydrogen production & storage, supply to hydrogen refueling station and filling to an FCV under fluctuating power source.

This demonstration assumed a production and storage facility of hydrogen based on renewable energy, the facility being annex to an existing hydrogen refueling station, i.e., on-site hydrogen production. The application, however, is not limited to this, but possibly includes producing hydrogen by utilizing renewable energy power and/or surplus power, supplying the hydrogen to a trailer or a hydrogen curdle, etc., on a transportation network and thus introducing hydrogen based on renewable energy to the supply network of off-site hydrogen refueling stations.

In the meantime, in order to disseminate hydrogen based on renewable energy, it is necessary to reduce the cost and improve the efficiency of various facilities including water-electrolysis hydrogen generators. In addition, it will be necessary to define hydrogen containing a small amount of CO_2 emissions and to establish the certification system for it.

Kobe Steel will strive to study optimization and cost reduction to contribute to the future of the hydrogen energy society.

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