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A Renewable Energy Based Hydrogen Demonstration Park in Turkey – HYDEPARK

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Abstract

The main goal of this national project is to research hydrogen technologies and renewable energy applications. Solar and wind energy are utilized to obtain hydrogen via electrolysis, which can either be used in the fuel cell or stored in cylinders for further use. The management of all project work packages was carried by TÜBİTAK Marmara Research Center (MRC) Energy Institute (EI) with the support of the collaborators. The aim of this paper is to present the units of the renewable energy based hydrogen demonstration park, which is in the demonstration phase now and share the experimental results.

Keywords: Hydrogen, electrolysis, renewable energy, decentralized power production

1 Introduction

The world's increasing energy demand is mainly provided by the fossil fuels, whose amount decreases strictly; therefore researchers have focused on alternative clean energy sources and how to set them for practical usage economically. One of the methods to produce hydrogen which is one of the most favourable alternative energy carriers is water electrolysis, which can be feasible when integrated with the renewable energy sources [1]. Also hydrogen production by renewable energy can be realized as a decentralized power generation application, which becomes popular nowadays [2–6].

Hydrogen, in many respects, is a better fuel than the existing transportation fuels. In the long term, hydrogen could play a key role in adapting energy supply to energy demand as hydrogen has the potential for large-scale, even seasonal, energy storage [3]. For both transport and stationary applications, widespread production and a reliable hydrogen distribution system should be in place. The outlook for future markets for hydrogen as a fuel can be governed by two economic scenarios:

1. Hydrogen produced from fossil sources
2. Hydrogen produced from nonfossil sources.

While not currently practical, it appears that nonfossil energy sources will become dominant in the future. A long-sought goal of energy research has been a method to produce hydrogen fuel economically by using nonfossil fuels such as sunlight, wind and hydropower as the primary energy source [7]. Although production of hydrogen via the use of solar cells or wind turbines has been regarded as the cleanest and most desirable method, these processes do not supply enough hydrogen at the present stage.

2 General Description of Project

"Development of Hydrogen Production, Conversion and Storage Technologies – HYDEPARK" project, which was supported by the State Planning Organization of Turkey (DPT), started on June 1st, 2005 and completed by the end of 2007. The main goal of this national project was to research hydrogen technologies and renewable energy applications. The project had two segments of the laboratory studies such as indoor and outdoor applications. Indoor applications included the design and construction of reactor systems with the required sub-units for hydrogen production from methane and purification of syngas. On the other hand, hydrogen production via electrolysis by using renewable energy sources was investigated within the outdoor applications. Hydrogen could either be stored for further use or directly utilized by a fuel cell to obtain energy. The design, purchase and integration of all the units and sub-units were carried out by TÜBİTAK MRC EI. Finally a renewable energy based hydrogen production and storage system was established and now it is in the demonstration phase (Figure 1a).

Figure 1a: HYDEPARK demonstration park.

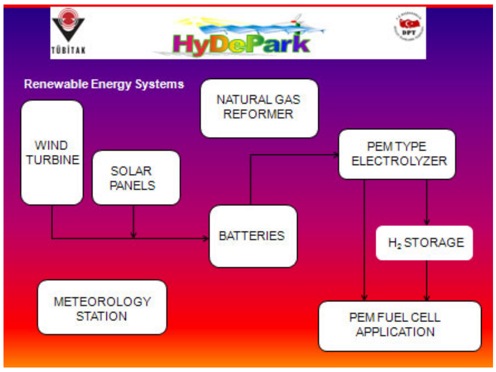

Figure 1b: System components.

3 Description of Components

As seen from Figure 1b, the main units of HYDEPARK demonstration park are solar panels, a wind turbine, batteries, an electrolyser, a hydrogen compressor, hydrogen storage cylinders, fuel cells and a meteorology station. Except the solar panels, the wind turbine and the meteorology station, all units are placed in two containers. There is also a natural gas reformer test unit in EI laboratory, which was designed and constructed in the scope of the indoor laboratory activities.

3.1 Photovoltaic (PV) panels

The photovoltaic system (Figure 2a) includes totally 145 PV panels and the total installed power is ~12 kW_p in the standard conditions (values correspond to 1000 W/m^2, 25°C and 1.5 air mass). 120 PV panels are CIS type thin film, which have 9.6 kW_p total with ~ 10.5% efficiency. 10 PV panels are multicrystalline type and they were produced by Ege University Solar Energy Institute which was one of the collaborator organizations. The multicrystalline solar power capacity is 1.2 kW_p total with ~ 13% efficiency. The rest 15 PV panels are monocrystalline type, which have ~ 1.1 kW_p installed capacity with ~ 14% efficiency.

3.2 Wind turbine

The wind turbine peak power is 5 kW_p which was produced by a national company (Figure 2b). The wind generator is a permanent magnet and a three-phase synchronous machine. The nominal power of the generator is 5 kVA and the rated rpm is 375 (the wind speed is 13 m/s). The DC output voltage is 45-60 V DC. This voltage can be easily used for 48 V batteries charging. There is also 220 VAC output voltage from the PWM inverter. The height of the pole is 15 m and the blade radius is 1.65 m. The wind turbine produces electricity in the range of 3–13 m/s wind speed.

Figure 2a: PV panels.

Figure2b: Wind turbine.

3.3 Batteries

All the generated renewable energy is stored in conventional stationary type lead acid batteries which were produced by a national company (Figure 3a). The designed DC busbar voltage is set to be 48V. Therefore 2V DC cells are connected serially in number of 24 in order to achieve this voltage. The capacity of the desired battery is calculated to be 1500Ah. The batteries are Low Maintenance Tubular Stationary (OPzS) which are a new version of common lead-acid batteries. The batteries have a long life of 10-15 years or more. The dimension of each battery (W x L x H) is 275 x 210 x 848 (mm). The weight with acid is 114.3 kg for each battery.

Figure 3a: Lead acid batteries.

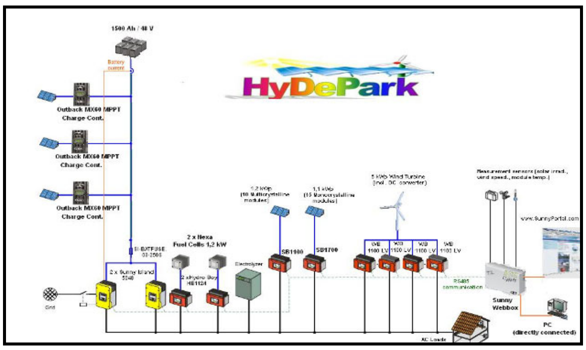

Figure 3b: Power conditioning layout of HYDEPARK.

3.4 Control units / converters / inverters

The system was designed to operate the electrolyser by the renewable energy source, so an AC bus was created since the electrolyser operates in 220 V and 50 Hz AC line (Figure 3b). The main important component of the system is a bidirectional inverter, which acts as a battery charger and an inverter. This unit supplies loads on the standalone grid side and charges battery banks with power that is provided by feeding electricity into the grid on the AC side. The bidirectional inverter unit achieves a maximum efficiency of more than 95%. The parallel operation of two bidirectional inverters on a single phase of a battery bank which has 48 V and 1500 Ah capacity enables to stand up a power supply for electrolyser load. The bidirectional inverter can also automatically deactivate loads if the battery does not have sufficient electrical energy available.

3.5 Proton exchange membrane (PEM) type electrolyser

The electrolyser is used to produce hydrogen by utilizing the electricity generated by the wind turbine and the PV panels (Figure 4a). The net hydrogen production rate of the electrolyser is 1.05 Nm^3/h with a delivery pressure of maximum 13.8 barg. The purity of the product hydrogen is 99.9995% and the power consumed is 6.7 kWh/Nm^3 H_2 (for optimal conditions). The electrolyser uses deionized water that should meet minimum of ASTM Type II requirements, to produce hydrogen and to actively cool the cell stack. A deionized water feeding system was purchased from a national company, since deionized water can be supplied from an already established system in TUBITAK MRC Campus. The electrolyser produces also oxygen in electrolysis process, which can be directly vented inside the container with small amounts of water condensate since the required ventilation was established. The electrolyser has a hydrogen vent port, which should be vented outside the container for safety. The product hydrogen port is separated into three lines, one of which goes to the hydrogen compressor to be pressurized, one goes to the vent, and the other one directly goes to the PEM fuel cell. Although electrolysis reaction needs DC current, the electrolyser is designed to be connected to the grid so it requires AC current. In this project, the electrolyser supplies the power from the batteries after converting/adjusting the current to AC, which also serves to buffer the electrolyser from power spikes. If a problem occurs with this system, electrolyser can be directly connected to the grid.

Figure 4a: PEM type electrolyser.

Figure4b: Hydrogen compressor.

3.6 Hydrogen compressor

The single-stage hydrogen compressor has a triple diaphragm construction, which isolates hydrogen from hydraulic oil (Figure 4b). All piping, tubing and wetted compressor parts are type 316 stainless steel which is corrosion-resistant. It has a 4 kW motor with a flameproof enclosure. It has a flow capacity of 4 Nm^3/h at maximum suction and it can compress hydrogen gas to provide a discharge pressure up to 103 bar (1450 psi). No water cooling is required. Hydrogen is fed to the compressor through a buffer tank with an inlet pressure of 7–10 bar. The pressurised hydrogen leaving the compressor is cooled through a heat exchanger before sent to the cylinders for storage.

3.7 Hydrogen storage cylinders

Hydrogen produced by the electrolysis is stored in high pressure cylinders in gas phase after pressurized by the compressor up to 103 bar. There are 12 cylinders placed in a stationary bundle and 4 individual cylinders which are ready to be carried to the laboratory in case of need (Figure 5a). Stored hydrogen in the cylinders can also be utilized in the fuel cell after the pressure is regulated. The stored hydrogen in the cylinders can be directly fed to the PEM fuel cells after regulating the pressure.

3.8 PEM fuel cell

PEM Fuel Cell is air-cooled and comprises all necessary fuel, electrical and control interfaces (Figure 5b). There are two power modules in this demonstration park. Each fuel cell module works at atmospheric pressure and generates up to 1200 Watt of unregulated DC electrical power from hydrogen and oxygen (air). All necessary auxiliary components including an air compressor, cooling fan, humidity exchanger, purge valve, pressure regulator and microprocessor controller are built into the system.

Figure 5a: Hydrogen cylinders.

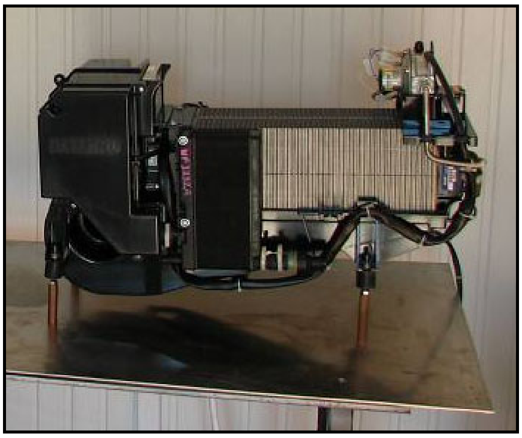

Figure 5b: PEM fuel cell.

4 Operational Experience and Performance

Since the main goal of HYDEPARK project was to obtain the electrolyser load from the renewable energy sources, the energy consumed by the electrolyser was considered to define the required renewable energy capacity. The energy consumption of the electrolyser is 6.7 kWh/Nm^3 H_2 and its net production rate is 1.05 Nm^3 H_2/h. This means that the electrolyser needs 7.04 kWh energy per hour. For 3 hours operation per day, the energy consumption is 21.12 kWh/day. When the electrolyser is operated 3 hours per day and 5 days per week, the daily hydrogen production is 3.15 Nm^3 and the yearly hydrogen production is 819 Nm^3.

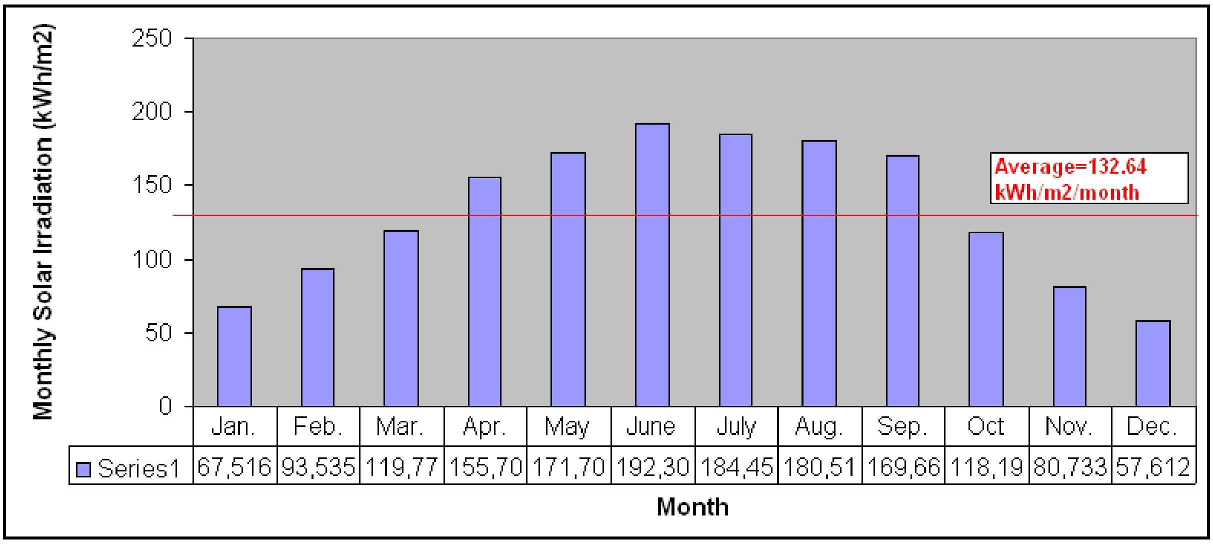

Figure 6: The monthly solar irradiation values in Gebze.

The location of the installation area is so important to define the energy potential on solar and wind energy sources. The solar irradiation and the wind speed are important factors for photovoltaic and wind power systems, respectively. At the beginning of the project, measurements of the reliable sources (the solar irradiation, module temperature and wind speed values) were used to calculate the system requirements. The capacity of the PV system was calculated to be sufficient for the operation of the electrolyser load. When the PV power capacity was not enough, the wind power would compensate the lack of it. The average daily solar radiation energy and the load consumption energies were taken as the essential parameters for solar system sizing (The yearly total solar irradiation is ~ 1.6 MWh/m^2 in Gebze).

Assuming that the PV rated efficiency was 13.5%, the battery efficiency was 70%, the mean inverter efficiency was 90%, the mean charge controller efficiency was 90%, the other components (wires, temperature losses in PV etc.) efficiency was 80% and then the total solar system efficiency was calculated to be ~ 6% (Other efficiencies such as wind turbine, fuel cell, and hydrogen storage etc. are not included in it). By using these values, the peak power of the PV generator was calculated to be approximately 12 kW_p.

Considering that the battery efficiency was 70%, 2 days in autonomy duration and the daily load consumption was 21.12 kWh, the essential battery capacity was calculated to be ~ 61 kWh. Therefore the battery capacity in Ah at 48 V battery voltage was ~ 1270 Ah. By regarding the additional energy supplies (wind turbine, fuel cell etc.), the storage battery bank was set up to be 48 V 1500 Ah.

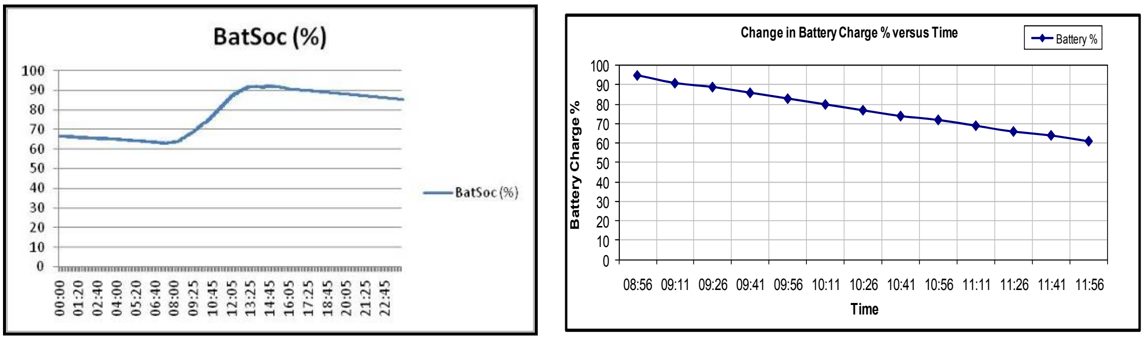

Figure 7: Battery charge and discharge versus time.

The operational parameters of the electrolyser can be monitored and stored by using its original PC program. Also it is possible to measure other system parameters and a PC system is set to view and save them. So efficiency of the individual systems and total system efficiency can be calculated and the system efficiency is found to be 9% according to the formula given below:

$$\eta_{system} = \eta_{PV} * \eta_{PCU} * \eta_B * \eta_o$$

where η_{system} is the system efficiency, η_{PV} is the PV efficiency (12.5%), η_{PCU} is the power conditioning unit efficiency (96%), η_B is the battery efficiency (75%) and η_o is the efficiency of others (98%).

5 Safety

Hydrogen is odourless, tasteless, colourless, and highly flammable. It is very combustible in the presence of oxygen and burns with a colourless flame. The lower explosive limit of hydrogen is 4% by volume [8]. Within the safety considerations of the electrolyser, a combustible gas sensor is located at the exit of the air purge stream to detect hydrogen. The sensor will cause an alarm and an automatic shutdown of the electrolyser when it detects the concentration of hydrogen within the purge air stream is in excess of 1.2%. If hydrogen leakage occurs due to any internal equipment failure, the indoor hydrogen detector safety circuit of the electrolyser will stop any further generation of hydrogen by automatically shutting down the electrolyser. A ventilation system was established to avoid the accumulation of hydrogen in the container in any case of leakage. Climatization of the container was realized due to the operational conditions of the electrolyser (5°C–40°C). Also the electrolyser shutdown circuits should not be bypassed. Hydrogen storage cylinders are placed outside the containers in a fixed position for safety reasons.

All inverters which are used in the project are compatible with all communication products and impressive with a high degree of protection (IP65). The robust enclosure design and high protection degree IP65 ensure secure operation even in extreme climatic conditions, both indoors and outdoors. The design also ensures over voltage protection on DC and AC sides.

Acknowledgements

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