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Energy Accumulation by Means of Hydrogen Technologies

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Abstract— *Energy accumulation is an important part of the issue of alternative energy sources. In the near future, energy accumulation systems based on hydrogen technologies have a great potential to achieve broader application in connection with alternative sources though having unstable and unreliable power supplies, but their installed output is steadily increasing. Energy accumulation systems in the form of hydrogen are based on the use of alternative energy sources (solar, wind, hydro, etc.) as a primary source for the hydrogen production process by means of water electrolysis, for its subsequent storage. Such accumulated energy can later be converted by hydrogen oxidation to another kind of energy, e.g. electrical, mechanical or thermal. Oxidation can occur either by direct combustion in a combustion engine or by controlled electro-chemical process in the fuel cell.*

Keywords— *Energy accumulation, hydrogen, renewable energy sources, storage capacity.*

I. INTRODUCTION

Energy accumulation in the form of hydrogen is a very important component of the hydrogen economy. Very light weight, significant diffusion capability and a wide range of hydrogen explosion represent negative factors, resulting in the demanding storage and distribution of this fuel. Although hydrogen has higher calorific value than other fuels, its storage systems are larger, heavier and more susceptible to mechanical damage compared to energy adequate systems for storage of fossil fuels [1-3].

While water electrolysis is the key to the functionality of the entire system, effective hydrogen storage is the key to its implementation in practical applications. If hydrogen were to become a competitive energy medium, it would be necessary for the storage method to combine the costs, lifespan, assembly and other factors to the extent acceptable for the given application. The storage material should be stable enough to meet and solve the issue in the field of:

- accumulation of the necessary amount of hydrogen;
- release of the accumulated amount of hydrogen;
- the release of hydrogen must be performed by delivering a certain amount of energy that will not pose unreasonable secondary demands on the entire system;
- the release of hydrogen must be technically linkable to other parts of the system (suitable pressure, required hydrogen purity, fuel feed rate in the fuel cell, etc.);
- the material must be capable of regeneration;
- regeneration must be stable for a specified number of cycles [4], [5].

It follows from the above that the entire process for the use of the materials for the hydrogen accumulation is affected by the capacity options (volume and mass) of the given material to accumulate hydrogen in connection with the thermodynamics and kinetics of the whole process [6], [7].

II. THE SOLAR ENERGY ACCUMULATION SYSTEM IN THE FORM OF HYDROGEN

The energy accumulation system in the form of hydrogen is based on the use of solar radiation as a primary source for the hydrogen production process by means of water electrolysis. Solar radiation depends on many factors, such as geographical location, season, cloudiness and the angle of the incident radiation.

A laboratory accumulation system based on hydrogen technologies (the “Hydrogen Technologies Laboratory”) was commissioned in the research workplace of the Department of Energy Technology, the Faculty of Mechanical Engineering, Technical University of Košice, Slovakia, in April 2014.

A solar energy accumulation system in the form of hydrogen is considered to be a comprehensive device used for electricity production based on a combination of solar energy and hydrogen, which can be operated without the involvement of conventional energy sources based on fossil and nuclear fuels (Fig. 1).

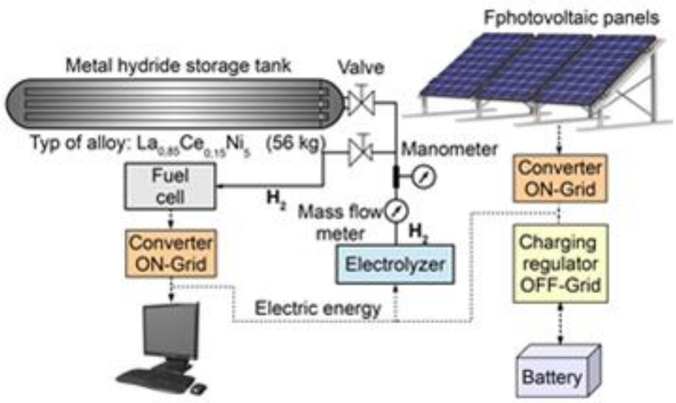

Fig. 1. The solar energy accumulation system using hydrogen technology.

Solar radiation energy is transformed into electric energy by means of photovoltaic panels, which are placed on the steel structure over the roof of the “Hydrogen Technologies Laboratory” structure with a surface vector oriented to the

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southwest side (Figure 2). The photovoltaic system consists of 12 SanyoHIT250 panels.

This is a hybrid photovoltaic (PV) panel in which monocrystalline silicon is coated with amorphous silicon. The combination of monocrystal with amorphous silicon allows a more effective transformation of the sun's radiation, especially its diffusion component, and is characterized by a favorable temperature coefficient, i.e. there is no reduction in efficiency by heating the panel during the summer months at higher temperatures. The amorphous panels show sufficient efficiency even in worsened light conditions.

Fig. 2. Photovoltaic panels system.

PV panels are connected in two strings of six panels, each with 250 W_p output (total output of 3000 W_p). The interconnection of PV panels is serial-parallel in order to ensure sufficient battery charging voltage and also to reduce voltage losses.

Electric energy is accumulated into the batteries, or it is further used in electrolysis for hydrogen production. The batteries are maintenance-free with electrolyte fixed in the AGM glass fiber of a Hopecke 12V135 type. Two batteries are connected in series with a total nominal capacity of 135 Ah and an electric capacity of 3.24 kWh. However, in real operation, this capacity is unattainable because, with the increasing current load of the battery when discharging, its usable energy decreases. The decrease is dependent on the internal electrical resistance. In case of continuous discharging for 10 hours, the battery capacity decreases to 2.76 kWh. In the threshold case, when solar energy is not available and the electricity consumption is performed only from batteries, the usable energy decreases even more.

The batteries are charged only from PV panels, excluding the possibility of charging them from fuel cells. The batteries are able to cover the need of an electrolyzer for approximately one hour of operation at full load during a temporary restriction of the electric energy production from the PV panels due to meteorological conditions.

Battery charging is provided by SunnyIsland 2224 converters (Fig. 3) that maintain the stable frequency of an island network. The converters can redirect surplus energy into batteries, but also supply electric energy from batteries into an island network.

Direct electric current passes through the SunnyBoy5000 converter, which connects to the island network whose voltage is maintained using OFF-Grid Battery Inverter 2224 type (Fig. 4), allowing synchronization (*the process of connecting the alternator to the electrical network) of the transformed energy into an island network. Its maximum output is 5 kW.

The main task of the panels and converters is to transform solar energy into electric energy, which is used to power the electrolyzer. It is necessary to ensure a continuous supply of deionized water, which is prepared in the SolPure 7 deionizer (Fig. 5) for the proper operation of the generator.

Fig. 3. Connecting the Hopecke batteries to the SunnyIsland converters.

Fig. 4. SunnyBoy converter.

Fig. 5. SolPure water deionizer.

All the equipment necessary for the hydrogen production along with the auxiliary device needed for autonomous operation is powered from the island network.

The Nitidor H_2 high pressure alkaline electrolyzer is the primary energy consumer. The laboratory is equipped with two electrolyzers (Fig. 6). The production of one electrolyzer is 0.5 $Nm^3 \cdot h^{-1}$ at a pressure of 2 MPa. The electrolyzer efficiency is 58.5%, and its power input is 3 kW.

The hydrogen produced during electrolysis has a purity of 99 vol. %. Subsequently, it passes through a drying unit, catalytic combustion of residual oxygen, and again through a second drying unit using water vapor adsorption. The hydrogen coming out of the device has a purity of 99.85 vol.

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% and is subsequently transported by a pipeline for further processing.

Fig. 6. SolPure water deionizer.

The produced hydrogen is divided into the majority part supplied to the HBond © 9000 MH vessel (Fig. 7), and a small amount passes to the analyzer (the ratio is set by the dosing valve). It has a built-in sensor for measuring the oxygen content while if its limit value is exceeded, a total system shutdown will occur. A backup power source is also part of the device allowing emergency shutdown in case of an unexpected power failure in the network. A major part of the hydrogen passes through a mass flow meter of the Bronkhorst F-111B-10K-AGD-33-V type into the filled with 56 kg of alloy $La_{0.85}Ce_{0.15}Ni_5$ into which hydrogen is absorbed. The pressure measurement is performed by the DMP-331 sensor. The vessel capacity is 9 m^3 of hydrogen, which represents a weight of 0.80892 kg of H_2 at a very low density.

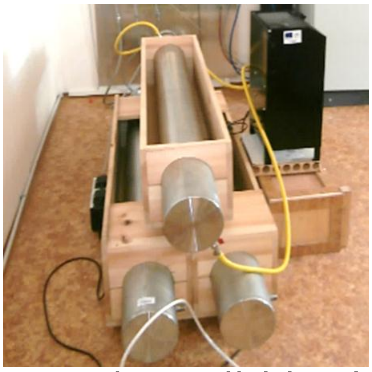
Fig. 7. HBond©9000 metal hydride vessels.


Fig. 8. The distribution system.

When the hydrogen is absorbed into the alloy, heat is released, which is necessary to be discharged by the cooler during the process. In the event that there is no cooling of the vessel, the gas pressure rapidly increases and exceeds the permitted value of 1.5 MPa given by manufacturer even with a small quantity stored. Conversely, in the event of hydrogen desorption, it is necessary to supply the same measurable heat in order to avoid a significant pressure drop, which would also lead to a decrease in the hydrogen release kinetics.

Produced and stored hydrogen, depending on the need of island operation (based on the control system), is possible to be used as a fuel for the PEM low temperature DEA0.5 fuel cell (Fig. 9).

Fig. 8. Fuel cell.

The nominal power of the fuel cell is 500 W at a voltage of 14 V. For the production of electric energy, this module also needs oxygen, which is supplied from the ambient air..

The operation of fuel cells is determined by the lack of lighting of the PV panels at the current capacity of the backup batteries. In such a situation, the supply of the island network is ensured from the fuel cells.

A continuous supply of electric energy to the load of the island network is ensured by the PV panels, batteries or fuel cells module according to need.

Laboratory safety is ensured by an air-conditioning device for suction and air circulation to prevent the formation of an explosive mixture. The laboratory is equipped with a powerful suction device along with several hydrogen leak detectors already from a concentration of 20 ppm. In the event of detection, the alarm system turns on, and suction starts at full power. Within the framework of the control system, we work on a concept of fully automatic operation with remote control capability.

III. THE MEASUREMENT AND CONTROL SYSTEM

The measurement system converts the measurement of electrical and non-electrical quantities in the individual components of the accumulation system through PC visualization and their archiving (Fig. 10 and 11). The measurement system consists of the measuring sensors connected to the software application in the LabView environment (Fig. 13).

Fig. 10. Hydrogen accumulation system control room.

The system records the following parameters:

- electrical quantities and flow rates of electrolyzer along with error messages and warnings;
- operational quantities of fuel cells, which are separately recorded using FUEL CELL SUPERVISOR software due to copyright;
- flow rates, pressures and temperatures of hydrogen distribution system;
- reports of the hydrogen leak detector;
- electrical quantities of individual wiring branches (PV panels, batteries, own consumption, distribution network, island network, fuel cells).

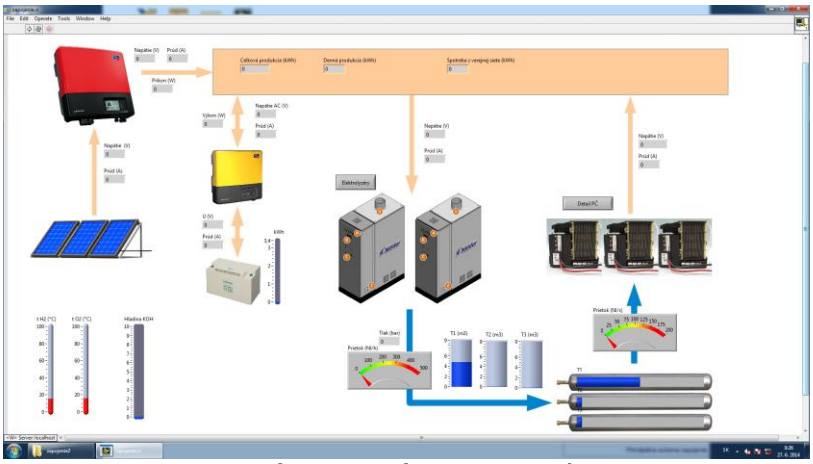

Fig. 11. Hydrogen accumulation system visualization.

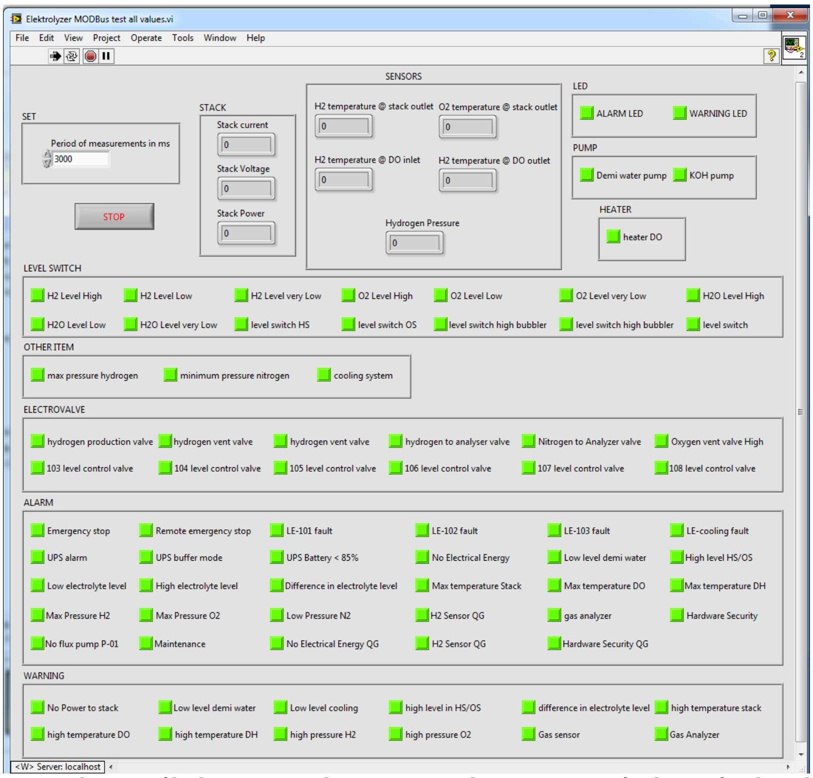

Fig. 12. Visualization of hydrogen accumulation system in the environment of LabView for electrolyzer.

Within the framework of the control system, we work on a concept of fully automatic operation with remote control capability.

IV. The Principle and Function of Accumulation System

An accumulation system may work from the beginning of the day, when the output power of the PV panels progressively increases and the batteries are recharging. The load can be supplied from the fuel cells module, which uses hydrogen stored in metal hydride vessels. As soon as the output power of PV panels reaches the required output (evaluation is performed by the control system), the fuel cells module will shut down, and the power of the load is fully covered by the PV system.

Potential fluctuations of supplied electric energy are covered by the batteries. At the time of their full recharge, the control system will switch on the electrolyzer, and hydrogen will start to produce. In this case, PV panels are distributing electric energy both to the load and the electrolyzer. This operation works until the intensity of the solar radiation falls below a specified limit.

Significant variability is also allowed by the possibility of an electrolyzer operation in the range of 20 to 100 % of nominal power. This ensures the required flexibility of operation even at low output power of the PV panels. The load can be charged first from the batteries during the night, and a fuel cell module is connected to the system at the moment when the battery voltage drops below the limit value. The module again produces electric energy from the stored hydrogen and delivers it through converters to the load.

V. Conclusion

The matter of energy accumulation is important particularly in the context of its use in practical applications. Alternative or renewable energy sources (RES) have a positive impact on the environment around us. The use of RES (e.g. solar, water, wind, geothermal energy, etc.) is limited by the geographical conditions of the given site and by the limitations of the RES balance in relation to the theoretically and possibly usable potential of these resources. The limiting factor is the output power density of the RES. Under Slovakia’s conditions, the theoretically usable potential is in solar and wind power, but their output power densities are generally very low, which is related to the increased dimensions of the facilities used for the concentration of the dispersed energy flow and its subsequent use for conversion to electric energy.

The electric energy production from renewable energy sources is marked by inequalities caused by unstable natural conditions that represent a burden for the power transmission and distribution system. It is possible to store the produced electric energy in order to increase the variability of the output power of renewable sources. Electric energy can be stored only if converted into another form of energy. Hydrogen technologies are used to accumulate the energy produced from alternative sources in their volatile performance directly at the place of consumption. Systems using alternative energy sources connected with electrolyzers provide some flexibility since the output can be electric energy or hydrogen itself. Hydrogen, as a medium for storing energy, can play a significant role with the increased use of renewable energy sources.

Hydrogen production from alternative sources of energy and its accumulation require continuous development, leading to an effort to reduce energy consumption and the costs of technological devices. It is expected that in the coming decades, the hydrogen produced from RES will enter as a competitive energy medium, both in the transport, industrial and communal spheres, especially in the context of reducing emissions and increasing the diversification of energy sources to ensure the required demand, especially for electric energy at the point of its consumption.

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