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Research of the hydrogen storage system with photovoltaic panels

***Abstract**. The fuel cells laboratory at the VSB-Technical University of Ostrava have recently finished the realisation of the laboratory energetic system for storage of electric power from renewable energy source (RES). This system comprises of two parts. The first part of the system consists of hydrogen production using the electric power from photovoltaic panels and its storage in vessels. The other part of the system uses hydrogen fuel cells to transform the energy from hydrogen into electric power. The researched storage system should works especially in synergy with unreliable renewable energy sources, such as photovoltaic and wind power plants. Those use the renewable source that gains ground quickly not only in the Czech Republic.*

Streszczenie.** Laboratorium ogniw paliwowych na VSB-Technical University of Ostrava niedawno zakończyło realizację projektu systemu energetycznego do magazynowania energii elektrycznej z odnawialnych źródeł energii (OZE). System ten składa się z dwóch części. Pierwsza część systemu dotyczy produkcji wodoru z energii elektrycznej pozyskanej z ogniw fotowoltaicznych i przechowywanie jej w zbiornikach. Druga część systemu wykorzystuje wodorowe ogniwa paliwowe do przekształcenia energii z wodoru w energię elektryczną. Badany system pamięci masowej działa w specjalnej synergii pomiędzy niepewnymi źródłami odnawialnymi, takimi jak systemy fotowoltaiczne i elektrownie wiatrowe. Korzystanie z odnawialnych źródeł, jest coraz bardziej popularne nie tylko w Czechach.**(Badania systemu magazynowania wodoru z paneli fotowoltaicznych)

Keywords: energy storage, renewable source, storage system.
Słowa kluczowe: magazynowanie energii, źródła odnawialne, system pamięci masowej.

Introduction

Systems for storage of electric power based on hydrogen technologies are forecasted extensive scope of application in the near future, especially in association with renewable energy resources with unstable and unreliable supply of electric power, whose installed capacity is still increasing. The research of utilisation of hydrogen technologies in connection with RES is of concern at numerous laboratories all over the World. The most recent decade saw the start-up of several pilot projects of hydrogen storage systems. The research laboratory at VSB - Technical University of Ostrava has recently implemented the laboratory storage system built on hydrogen technology basis. The data obtained during realisation of the system has been included in this paper. It was used to verify some of the currently available information and especially to define problems associated with realisation of this power system and other similar projects.

The fuel cells laboratory

The fuel cells laboratory at the VŠB - Technical University of Ostrava started its operation in 2007. The laboratory was built as the outcome of joint efforts of two work units at this university, i.e. the Faculty of Electrical Engineering and Computer Science and Faculty of Mechanical Engineering. This laboratory is run with the research activities focused in the two main directions:

- research on mobile devices using hydrogen as an energetic carrier (vehicle with low fuel consumption for urban operation). [1]
- research on stationary units based on fuel cells for production and supply of electric power into the distribution network (on-grid systems) as well as to supply energetically subsistent isolated systems (off-grid systems). [2]

The laboratory is currently concerned with the research on storage of electric power into hydrogen, once gained from a renewable source - photovoltaic panels. That is an off-grid system using a hydrogen technology unit. For a simplified block diagram of this hydrogen storage system see the Fig. 1.

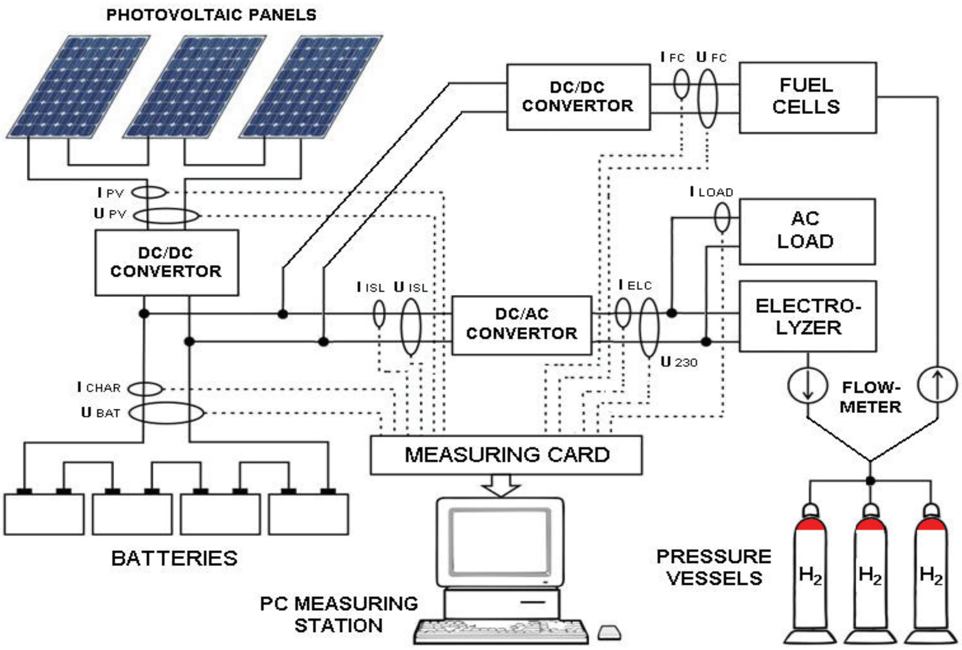

Fig.1 Diagram of the system with highlighted measurement points

Storage System Description

Our newly realized storage system uses solar radiation as the primary source of renewable energy. That is transformed into electric power via photovoltaic (PV) panels located on the fuel cell laboratory building roof. There are 12 poly-crystalline panels of Schott Poly 165 type installed, with the output of 165 Wp each. The total installed capacity of PV panels is 1980 Wp. [3] The PV panels are interconnected in series-parallel pattern in order to ensure sufficient operation voltage of the battery charger as well as to control the current (reduction of output losses). The most vital parameters of PV panels can be found in the Table 1.

Table 1. The parameters of PV panels (for 1000 W.m^{-2}, 25 °C) [4]

Nominal power (total)	1980 Wp
Voltage at nominal power	105,3 V
Current at nominal power	18,8 A
Open - circuit voltage	130,8 V
Short - circuit current	21,08 A
Module efficiency level	12,6 %
Number of PV panels	12

The energy produced by PV panels is stored into batteries and consumed by the electrolyzer to produce hydrogen. The batteries are made from lead, four units connected in series, with the nominal capacity of 75 Ah. The batteries are charged solely using energy from PV panels, whereas the option of their charging from the fuel cell module is avoided. That is determined by the control system. [5] The batteries with total energy capacity equal to 3600 Wh determine the operation voltage on the direct current bus (48 V, the maximum voltage when charging the batteries equals to 57,6 V and the minimum voltage during when discharging the batteries equal to 47 V). The batteries in hydrogen storage system shall serve to storage the energy produced by PV panels that is not directly consumed by the load (an AC appliance or electrolyzer connected). When the production of electric power from PV panels is temporarily reduced due to weather conditions, the batteries are able to cover full amount of electric power consumed by the electrolyzer. Charging the batteries is ensured by means of the charger (DC/DC converter).

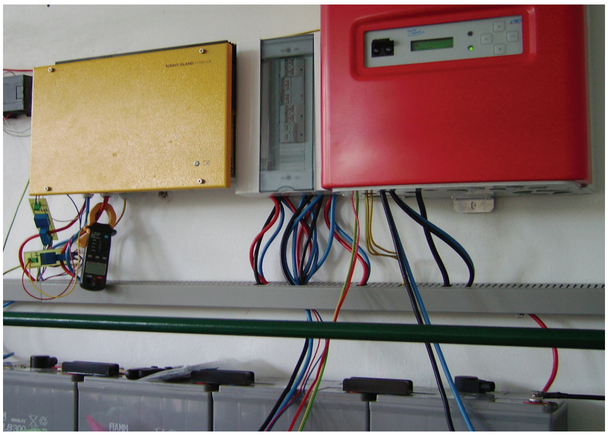

Fig.2 DC/DC converter (left), DC/AC converter and four batteries

Fig.3 Pressure vessels to store hydrogen produced by the electrolyzer (right)

The storage system includes three converters: Sunny Island Charger 40, Sunny Island 4282 and SD-1000L-48. There is another AC/DC converter integrated within the electrolyzer. DC converters control the receipt of energy into the DC bus, which further supplies the output to the terminals of DC/AC converter (see Figure 2). One of the DC/DC converters transforms the electric power from PV panels to a convenient level and also serves as the voltage controller (charger) for the batteries. The second DC/DC converter operates towards stabilisation of the input voltage from the fuel cells module. The input terminal of DC/AC is connected to batteries or the fuel cells module (depending on the storage system operation mode). Hydrogen pressurised at 13,8 bar is produced by the electrolyzer, and that is always at the time of surplus of electric power generated by PV panels. The Hogen GC600 electrolyzer of PEM type (Proton Exchange Membrane) and it is supplied from the DC/AC converter.

The hydrogen produced (0,6 Nl/min, 99,9999 % pure) is stored in three pressure vessels with the total volume of 2 Nm^3 of gaseous hydrogen (see Figure 3). The electrolyzer needs de-mineralised water that is produced by the Demiwa osmotic filtering unit. [6] Once produced and stored, the hydrogen is used as needed (depending on the control system operation) to fuel the low-temperature module of NEXA type fuel cells (see Figure 4). Production of electric power by this module also requires oxygen drawn from the atmosphere. The nominal output is 1200 W and the nominal voltage is 26 V. During operation of the NEXA module, the batteries will be disconnected from the DC bus. The load connected to output from the DC/AC converter is then supplied from the NEXA module only. Continuous supply of electric power into the load is then assured depending on specific circumstances, either from PV panels, batteries or the fuel cells module.

Measurement and Control System

The measurement system performs measurements on electric and non-electric values of particular components within the storage system, their evaluation and visualisation using a PC and their storage. The measurement system comprises numerous measurement sensors (voltage and current LEM sensors), two measurement cards type NI USB-6218 and two PC´s to host the virtual measurement SW applications (within the LabView environment). [7] One of these applications also allows for assessment of temporary events within the storage system, and that is ensured by means of defined level changes over time (triggers). The control system, provided by the programmable PLC automatic unit type Simatic (Siemens), ensures the control of the entire hydrogen storage system. The system can be operated using the touch LCD control display. The control of storage system is then conducted pursuant to evaluation of selected voltage levels. Those are set depending on the operation characteristics of individual components of the storage system. [5] For function diagram of the storage system with highlighted measurement points see Figure 1.

Storage System Functioning Principle

The storage system operates as follows: From the beginning of the day, the output of PV panels shows conti nuous increase and charging of batteries occurs. The AC load is supplied from the fuel cells module (NEXA), which consumes the hydrogen previously produced. As soon as the output from PV panels has reached a sufficient level (assessed by the control system), the NEXA module will be switched off and the AC load will be supplied from PV panels. Any potential deviations in the electric power supply will be catered for by batteries. Once those have been fully charged, the control system activates the electrolyzer and starts with production of hydrogen. Under such circumstances, the PV panels supply energy into both the AC load and electrolyzer. The latter is then operated until the drop of solar radiation intensity (output of PV panels) below the defined threshold. The AC load is supplied from the batteries during night time and in times when the voltage in batteries has dropped below defined threshold the system is connected to the fuel cells module. The system produces electric power using the stored hydrogen to supply the AC load.

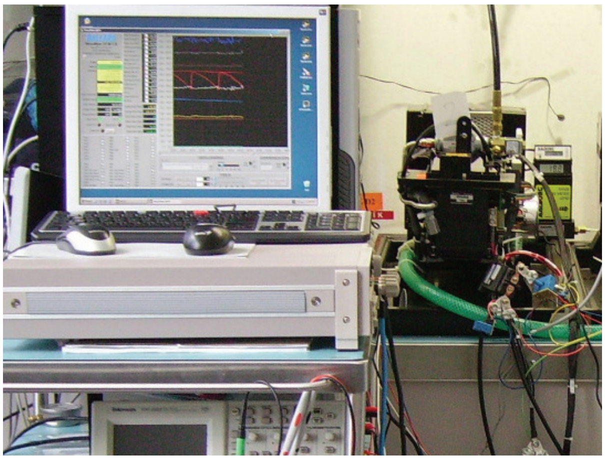

Fig.4 PC measuring station and NEXA fuel cells module

Measurements on hydrogen storage system

The measurement was conducted within the almost four-day period at the end of March (24th - 27th March 2011) under favourable weather conditions (higher intensity of solar radiation). The data obtained from measurement was used to process time characteristics of selected values related to the storage system, as stated in the figures below. The Figure 5 shows that the days of 26th and 27th March were associated with more rapid drop of PV panels output after 1 p.m., compared to the situation on 25th March. That was caused by a quicker decrease of solar radiation intensity during afternoon hours due to overcast skies. The course of electrical power at the output from DC/DC converter (charger) illustrated by Figure 6 copies the course of electrical power of PV panels. The course of electrical power at the output from DC/AC converter (Figure 7) shows that the entire period of measurement was associated with assurance of continuous supply into the load with the total installed capacity of 200 W. During noon (between 11:30 a.m. and 02:00 p.m. every day), the electrolyzer was also operated to produce hydrogen. The course of the electrolyzer input is shown in Figure 8.

Figure 9 and Figure 10 then show time characteristics of voltage and current on PV panels. The time characteristics of voltage on batteries (Figure 11) indicate that, from the beginning of measurement (05:30 p.m., 24th March), the load was supplied solely from the batteries, which then resulted in gradual decrease of their voltage to the level of 47 V. Later on (01:30 a.m.), these were disburdened as the supply into the load was then fully switched to the fuel cells module (NEXA), consuming the previously stored hydrogen. The NEXA module was in operation till morning hours (08:00 a.m., 25th March, see Figure 12), when the control system conducted the assessment of performance of PV panels to rate it sufficient for supplying the load. The same moment also brought the start of re-charging of the batteries used to supply the load at the end of the day only (from 04:30 p.m., on 25th March to 00:00 a.m. on 26th March). The electrolyzer was in operation around noon (see Figure 13 and Figure 14). The hydrogen produced by the latter was then consumed by the NEXA module, always commissioned during morning hours each day.

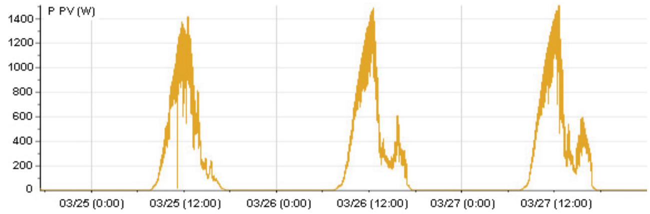

Fig.5. Time characteristics of electrical power of PV panels (P PV)

Fig.6. Time characteristics of electrical power at the DC/DC inverter output (P CHAR)

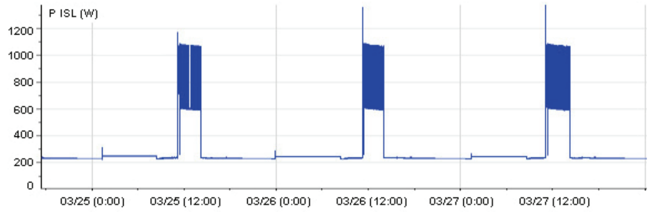

Fig.7. Time characteristics of electrical power at the DC/AC inverter input (P ISL)

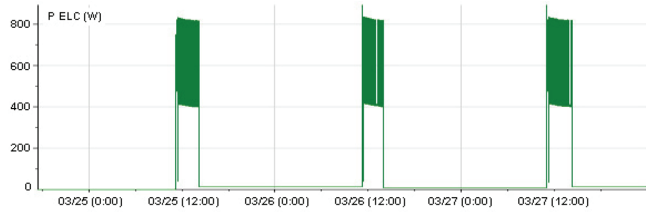

Fig.8. Time characteristics of the electrolyzer input (P ELC)

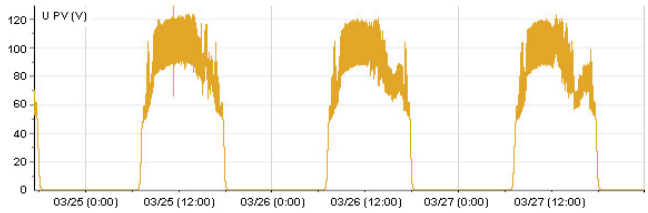

Fig.9. Time characteristics of voltage on PV panels (U PV)

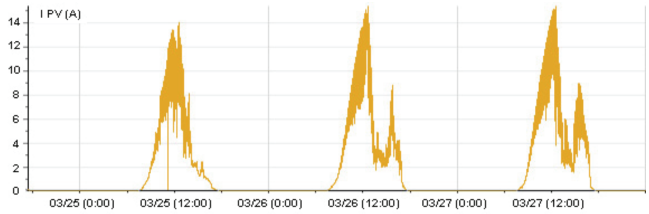

Fig.10. Time characteristics of PV panels current (I PV)

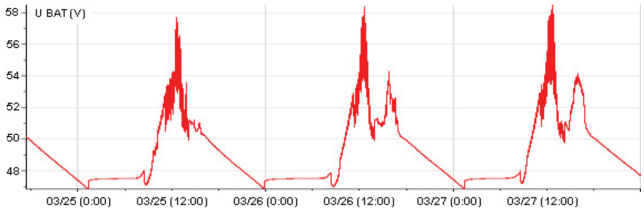

Fig.11. Time characteristics of voltage on batteries (U BAT)

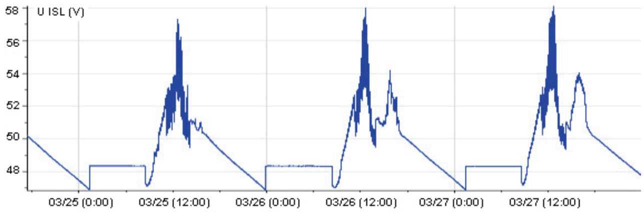

Fig.12. Time characteristics of voltage at the DC/AC inverter input (U ISL)

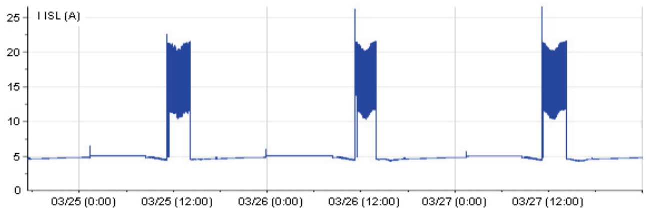

Fig.13. Time characteristics of current at the DC/AC inverter input (I ISL)

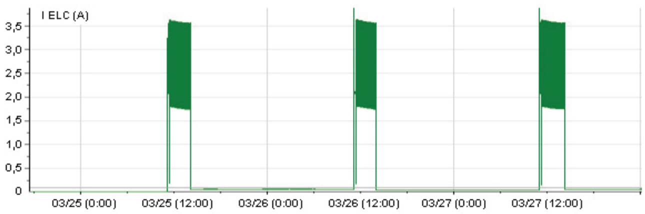

Fig.14. Time characteristics of electrolyzer current (I ELC)

Efficiency Evaluation

The efficiency parameters of individual components of our hydrogen storage system were evaluated using the data obtained from measurement. The following values have been established:

- Despite the efficiency level stated by the manufacturer (12,6 %), the poly-crystalline PV panels worked at the efficiency level of 8,5 % only.
- The efficiency of DC/DC converter - battery charger (Sunny Island Charger 40) connected to outputs from PV panels: 97,8 %.
- The efficiency of fuel cells module (NEXA) that produces electric power from hydrogen: 41,3 %.
- The efficiency of DC/AC converter (Sunny Island 4282) that transforms the energy from DC bus into a single-phase alternating voltage: 87,1 %.
- The efficiency of DC/DC converter type SD-1000L-48 that stabilises the output voltage from the fuel cells module (NEXA): 89,9 %.

The efficiency of electrolyzer (Hogen GC600) that produces hydrogen using de-mineralised water and electric power supplied from PV panels: 24,4 %.

The low efficiency of electrolyzer is mainly due to the energy losses incurred during the electrolyzer operation without hydrogen supply. That is to say that once started up, the electrolyzer needs to pass the commissioning sequence associated with its pressurising and warm-up to the operation temperature (approx. 10 min). [8]

Conclusion

Our hydrogen storage system provide for uninterrupted supply to the selected load - AC appliance. This is an off-grid system that is capable of compensating for the immediate surplus or lack of electric power produced by the renewable energy resource - photovoltaic panels. Pursuant to the measurements completed and described in this paper, there were assessments conducted to address the efficiency parameters of individual components within this system. The total efficiency of our laboratory hydrogen system for storage of electric power from photovoltaic panels has achieved the value of 8 % (excluding the value of PV panels´ efficiency). The value of hydrogen system level achievable shall be up to 30 %, if we consider the theoretical efficiency of electrolyzer within the range of 70-90 %. [9] Despite the low efficiency level we discovered, the importance of storage of renewable energy into hydrogen will be rising in the future. That is actually the toe of storage to solve operation problems both at systems based on RES and connected to the grid (on-grid systems) as well as the off-grid systems (island). The hydrogen system can be also used as a solution for storage of electric power within a broad range of output.

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