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Integrated Wind-Hydrogen Systems for Wind Parks

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SUMMARY

Hydrogen is presented as a product from wind parks, complementary to electricity. An innovative wind-hydrogen system has been designed and constructed at the wind park of the Centre for Renewable Energy Sources (CRES), near Athens, Greece. A 500 kW gearless, synchronous, multipole Enercon E40 wind turbine supplies power to a water electrolyser of 25 kW, a hydrogen compressor of 7.5 kW, and other electrical utilities. The individual components and the system as a whole have been commissioned with success, and the operation of the plant has already supplied very interesting results regarding the performance of such a wind-hydrogen system. The preliminary results show that the overall efficiency of the system, from the AC power supplied by the wind turbine to the high heating value of the hydrogen produced and compressed at 220 bar, is approximately 50%.

INTRODUCTION

The simultaneous production of an environmentally clean fuel and electrical energy is an interesting challenge for wind park developers. Wind-hydrogen systems may be optimised for different situations such as off-shore wind parks, where produced hydrogen may be transported to the user site by sea, and weak electricity grids or stand-alone systems, where hydrogen as chemical or energy carrier may be fed to the market through the road network. An innovative wind-hydrogen system has been designed, erected and tested at the wind park of the Centre for Renewable Energy Sources (CRES), near Athens, Greece in the context of the RES2H2 project that is co-funded by the EC under the 5th Framework Programme.

The 3 MW demonstration wind farm is situated in Lavrion, SE Attica, in a complex terrain site including hills up to 120 m high above sea level and coastal regions, with an average annual wind speed of 6.7 m/s. The energy produced from the wind turbines is fed into the interconnected 20kV electricity grid. There are five wind turbines of various sizes and power control strategies:

- An Enercon E40-500 kW gearless, synchronous, multipole, variable speed wind turbine.
- A NEG Micon 750kW stall regulated, constant speed with 2 asynchronous generators wind turbine.
- A Vestas V47-660 kW pitch regulated, constant speed, with one asynchronous generator wind turbine.
- An OA-500 kW stall regulated wind turbine, using an advanced variable speed technique and an active line inverter, developed in Greece and manufactered by PYRKAL SA.
- An OA-600 kW, identical to the above turbine.

DESCRIPTION OF THE WIND HYDROGEN PLANT

The hydrogen plant is composed of a water electrolysis unit of 25 kW with a nominal capacity of 0.45 kg/h hydrogen, metal hydride tanks for long term storage at high efficiency and a hydrogen compressor for filling high pressure cylinders. Utilities include a nitrogen cylinder for inertisation, a water chiller with closed circuit for cooling water and an instrument air compressor. All electricity users are supplied by the central power board, which is connected to the low voltage side of the transformer of a 500 kW gearless, synchronous, multipole Enercon E40 wind turbine. The system is controlled by a Programmable Logic Controller (PLC) and monitored on a personal computer, with data acquisition. A block diagram of the hydrogen plant is shown in Figure 1.

The 25 kW water electrolyser has a nominal production rate of 0.45 kg/h (5 Nm^3/h) hydrogen and has been supplied by Casale Chemicals SA, Lugano, Switzerland. It operates under 20 bar pressure and can withstand rapid variations of input power (20-100% of nominal capacity in 1 second). The electrolyser is of the alkaline type, with a 30%w. KOH solution as electrolyte. Tap water for electrolysis passes through a column with an ion-exchange resin, to reduce water conductivity down to 5 μS/cm. The demineralised water consumption is 4.1 l/h at nominal capacity. Electrolytic hydrogen is purified up to 99.98%v. by passing through a deoxidiser to reduce the oxygen content down to 10 ppm and through driers, to reduce the humidity level down to an atmospheric dew point of -40°C. The electrolyser is composed of the process part, the control panel and the power supply panel with an AC/DC converter for the conditioning of the direct current applied to the electrode-stack, in the range 0 – 300 A, 0 – 120 V.

The hydrogen compressor is a single-stage, triple metal diaphragm compressor by PDC Machines Inc., USA. It is designed for an inlet pressure varying in the range 10 – 18 bar, an inlet temperature around 30 – 40°C and an outlet pressure of 220 bar. The nominal rate of compression is 0.45 kg/h (5 Nm^3/h) hydrogen for an inlet pressure of 14 bar and inlet temperature of 40°C. A small conventional tank, of 0.36 m^3 volume, acts as hydrogen buffer to smooth the pressure and flow variations at the compressor inlet. The hydrogen filling station is actually composed of two high pressure cylinders and one 12-cylinder stack of 0.6 m^3 volume, with a total hydrogen capacity of 10.7 kg (120 Nm^3).

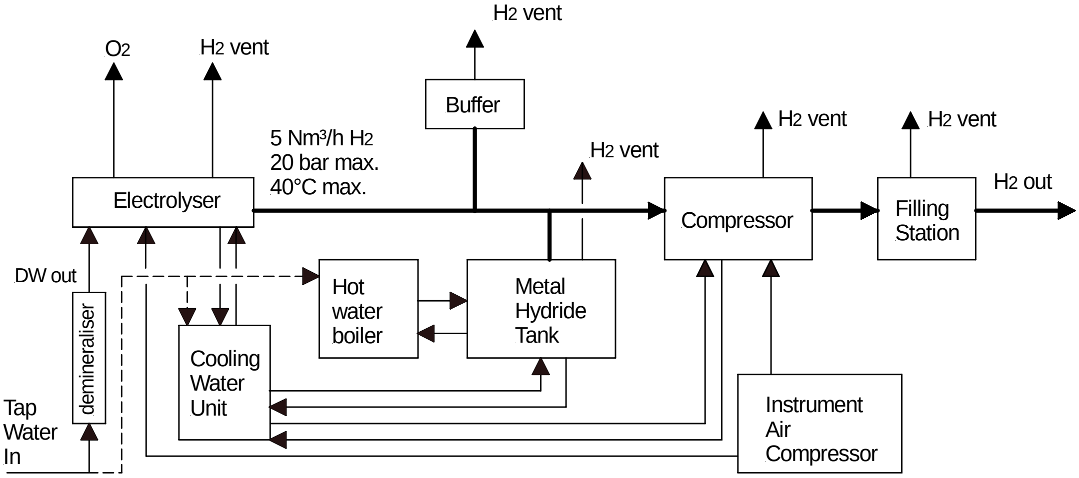

Figure 1. Block diagram of the wind-hydrogen process at the experimental wind park of CRES

The metal hydride tanks have been designed by the Frederick Institute of Technology (FIT), Cyprus, and manufactured by Labtech SA, Bulgaria. There are six tanks, with a total rated storage capacity of 3.78 kg hydrogen (42 Nm^3), filled with the metal alloy $La_{0.75}Ce_{0.25}Ni_5$. The mass specific hydrogen capacity is 1.28%w for the alloy and 0.66%w for the complete metal hydride tanks. The metal hydride tanks are water-cooled during the absorption of hydrogen from the electrolyser, and heated with the help of a 4 kW water boiler for hydrogen desorption.

The system also comprises an air compressor and drier to supply instrument air to the pneumatic valves, a nitrogen cylinder for the inertisation of the electrolyser and the process lines whenever required, and a closed circuit for cooling water with water chiller, in order to reduce water consumption to a minimum. The mean electrical power requirement for the instrument air compressor has been estimated at 0.2 kW and for the water chiller at 1.5 kW. The whole system is centrally controlled through a Programmable Logic Controller (PLC) and connected to a data monitoring and acquisition unit. A PLC-based control system has been preferred over a PC-based one, for safety and reliability reasons, although it is less flexible for the implementation of modifications.

The different items have been commissioned individually, and the operation of the integrated system started in October 2005.

RESULTS

The system may be operated manually, in semi-automatic and in automatic mode. Until now, the system has run in the semi-automatic mode, in order to assess the performance of each component in the system. The characterisation of the electrolyser's performance is particularly important, because the automatic mode is based on a simplified model of the direct current-voltage relation for electrolysis.

Typical operating data of the electrolyser are shown in Figure 2. Electrolysis current was kept stable during most of the time of the experiment at 200 A, 250 A and 270 A (nominal value), but intermittent operation was applied at different intervals. The corresponding voltage values vary in the range 85 – 100 V. The wind turbine output power, as well as the AC power consumed by the electrolyser are also shown on Figure 2.

Typical data of the electrolyser operation under variable power input are shown in Figure 3. Direct current values were manually varied, according to the reading of the power turbine output. The data acquisition frequency is one measurement per second, which is similar to the response time of the electrolyser. The delay between the power and current values is of the order of a few seconds, due to the manual introduction of the values.

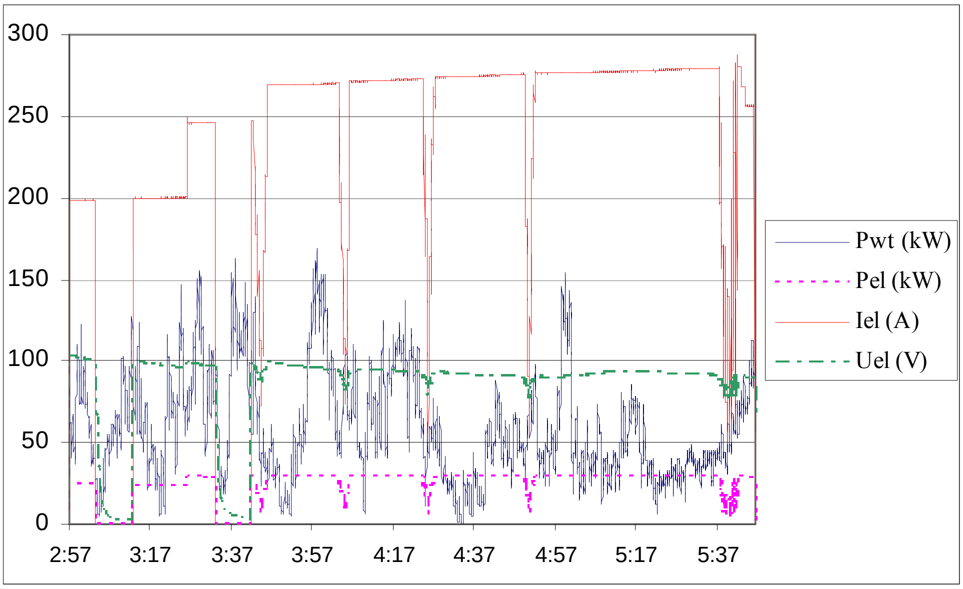

Figure 2. Typical operating data of the electrolyser

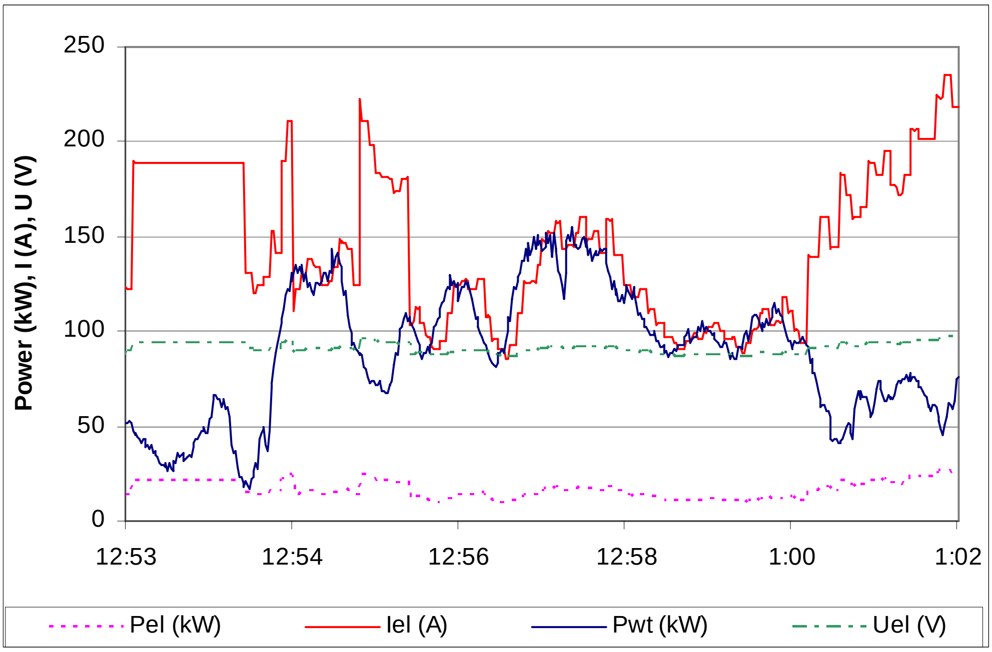

Figure 3. Electrolyser operation under variable power input

Generally, when an electrolyser is not in operation, a protective polarisation current should be applied, in order to protect the electrodes from corrosion. The polarisation current is very small, and the corresponding power requirement is not significant, when the electrolyser operates continuously through the year. In the case of intermittent operation however, the energy loss due to the application of such a “protective” current cannot be neglected. The current, voltage and AC power of the electrolyser during “protective polarisation” are shown in Figure 4. A DC current of 2.5 A is applied, with a corresponding DC voltage of 61V, consuming 0.15 kW of DC power and 0.35 kW of AC power. The protective polarisation current was applied after the start-up of the plant for some tests, but has never been applied since. The non-application of a protective current to the electrolyser is a major innovation in the operation of such hydrogen plants. Assuming an optimistic capacity factor of 0.5 through the year, which means that protective polarisation would have been applied for approximately 27 weeks, the amount of energy saved is approximately 1.6 MWh. This is possible thanks to the use of corrosion-resistant activated electrodes in the stack.

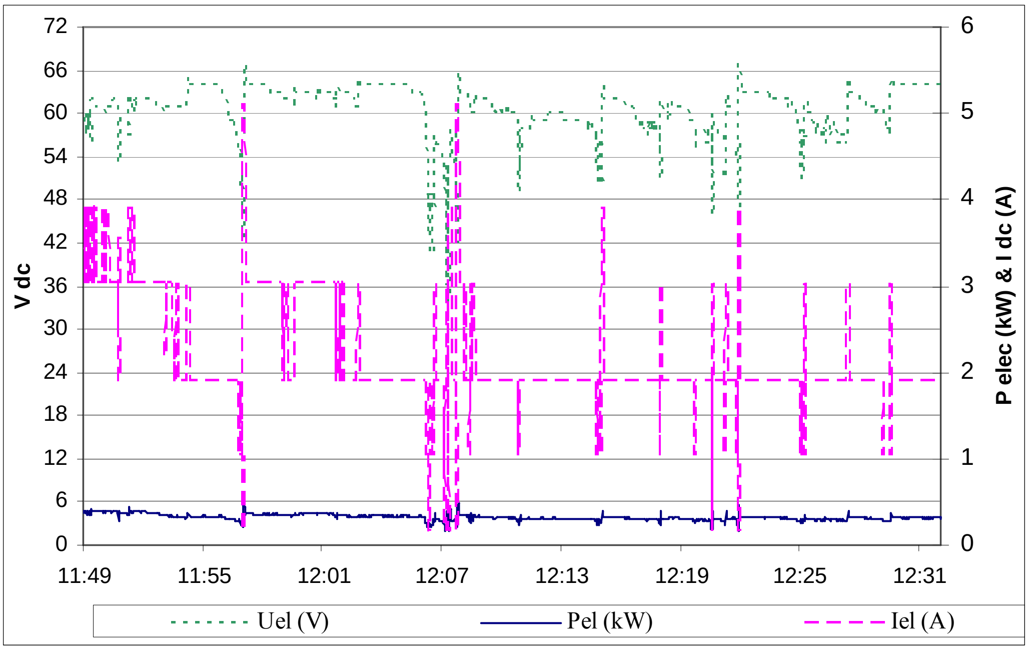

Figure 4. Data during the application of protective polarisation applied to the electrolyser

Some typical current-voltage relations of the electrolyser operation are shown in Figure 5, for two different temperatures, namely 45°C and 70°C. The AC power requirement of the electrolyser as a function of applied current, for the same temperatures, is also reported on Figure 5. The DC efficiency of the electrolyser increases with temperature, thanks to a reduction of the voltage with increasing temperature at the same current. Note, that the DC efficiency increase with temperature is not reproduced for the AC power requirement. This is due to the fact that an important part of AC power losses are due to the AC/DC conversion, which is independent of the electrolyser temperature.

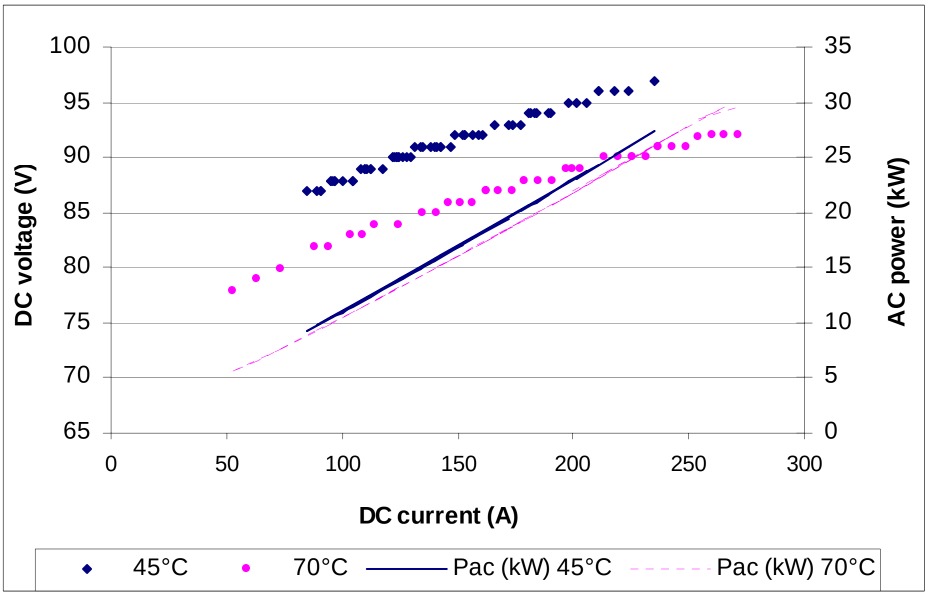

Figure 5. Current-Voltage relations of the electrolyser at 45°C and 70°C.

According to the results obtained until now, the stack efficiency, defined as the ratio of the theoretical amount of energy content of the produced hydrogen, divided by the DC power consumed for the production of hydrogen lies in the range 70-80%, with respect to the high heating value of hydrogen. The DC efficiency depends both on temperature and on the applied current. The AC power efficiency, defined as the ratio of the theoretical amount of energy content of the produced hydrogen, divided by the AC power consumed for the production of hydrogen lies in the range 55-65%, with respect to the high heating value of hydrogen. At present, the energy loss during the AC/DC conversion and conditioning of the electrolysis current is very high. The power electronics of the electrolyser are actually under investigation, in order to find the reasons of this excessive inefficiency.

Typical operating data during the compression of electrolytic hydrogen in a high pressure cylinder are shown in Figure 6. In the beginning, only the electrolyser operates and fills the hydrogen buffer, with an electrolysis current of 143A followed by intermittent operation and finally 200A. The buffer pressure increases from circa 10 bar to 18 bar during the first hour. The compressor then starts operation, and the pressure in one high pressure hydrogen cylinder increases from circa 35 bar to 220 bar in one hour. The hydrogen rate of compression is higher than the production rate of the electrolyser when the cylinder pressure is still low, so the buffer pressure decreases and stabilises around 11 bar, when the rate of compression decreases due to the higher pressure in the cylinder.

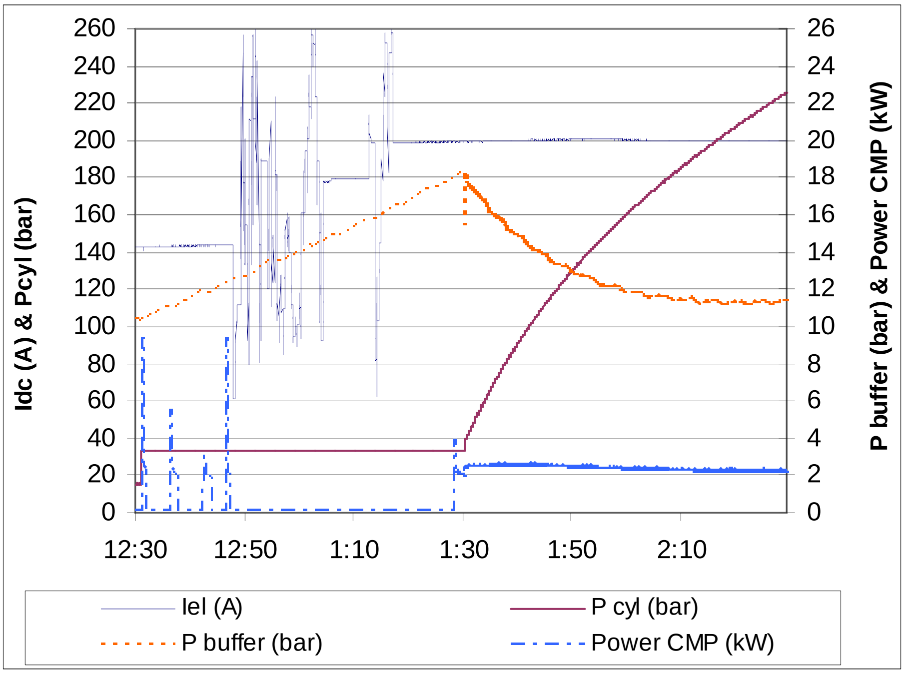

Figure 6. Operating data of the hydrogen plant during the filling of high pressure cylinders.

The system has been constructed with commercial components, to the extent possible. The interfacing of the components with respect to hydrogen and information flow is crucial for the smooth operation of the plant. The buffer volume has been minimised, in order to reduce the cost of the plant, and it proved sufficient for the operation of the wind-hydrogen plant. The integration of the auxiliaries, vital for the safe operation of the hydrogen plant has also been treated with special care. Several lessons were also learned from the design and construction phase of the plant, regarding transportation and installation issues and the protection of the equipment from nature's elements, theft and even wild animals, in remote areas with poor access.

Except for the hydrogen storage in high pressure cylinders, the electrolytic hydrogen can also be stored in the metal hydride tanks, in order to compare the two methods of hydrogen storage. The performance of the metal hydride tanks has not been studied in detail yet. They are actually filled with hydrogen, and a preheating phase is necessary, in order to increase the pressure inside the tanks at the desired level and sustain the desired hydrogen delivery rate. Some preliminary results, regarding the non-optimised preheating phase of the metal hydride tanks during winter conditions, are shown in Figure 7. The 4 kW boiler was in operation during the first 2 hours of the experiment, and the pressure of the metal hydride tanks increased from circa 8 bar to 18 bar. The temperature of the water supplied to heat up the tanks is measured at the inlet and outlet of the metal hydride tanks. Note that equilibrium conditions have not been reached during the experiment. According to these preliminary results, it seems that the electrical energy consumed by the metal hydride tanks for the release of the stored hydrogen is higher than the energy consumption by the compressor for the filling of high pressure cylinders.

The overall efficiency of the wind-hydrogen plant, defined as the ratio of the theoretical amount of energy content of the produced hydrogen, divided by the total AC power consumed for the production and compression of hydrogen is approximately 50%, taking into account the energy consumption of both the main components and the auxiliaries. The electrolyser is by far the most inefficient component of the system.

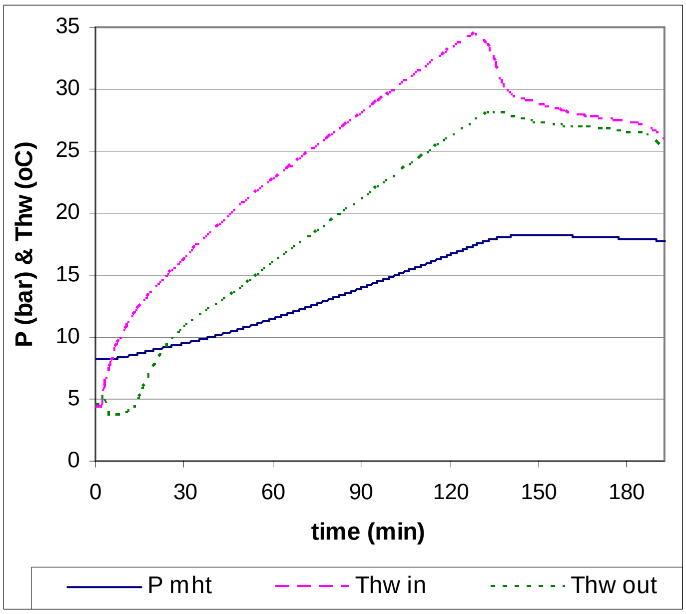

Figure 7. Operating data during the preheating phase of the metal hydride tanks

CONCLUSIONS

The wind-hydrogen system designed and erected at the experimental wind park of CRES has started operation with success and supplies very interesting results concerning the performance of the individual items and the plant as a whole. According to the preliminary results, without optimisation of the operating parameters, the overall system efficiency is approximately 50% with respect to the high heating value of hydrogen. However, there are important margins for an efficiency increase, especially concerning the power electronics of the electrolyser and the wind turbine – electrolyser electrical interface.