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Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 3: Hydrogen Production Technologies - Part 2
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-3
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-653-8

Flexible Production of Hydrogen from Sun and Wind: Challenges and Experiences

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1 Introduction

With the looming threat of global climate change and progressing depletion of fossil fuels, renewable power sources, especially wind and solar, experienced an economic boom in the past decade [1, 2]. Both wind and sun supply significant amount of electrical power without generating any pollution during the operation. Unfortunately, both sources generate power of intermittent nature, regardless of the demand, which consequently stresses the existing electrical grid.

To mitigate this drawback, renewable energy needs to be converted into a storable intermediate, which could be used in the times of electricity peaks or alternatively used as a fuel for vehicles. The energy carrier of choice is hydrogen produced by water electrolysis [3, 4].

Water electrolysis is a well-established method of producing hydrogen and an ideal candidate due to the general availability of water, scalability of the electrolysis plant and zero-emission production of hydrogen. Traditionally, in industrial applications electrolysers are connected to the grid and operated under stable conditions. Renewable energy sources by contrast, supply intermittent power leading to new requirements to the electrolysers [5-8]. Conventional electrolysers tend to utilize only a fraction of the available renewable power due to a number of reasons: long start-up times, inability to follow rapidly changing power input and last but not least limited operating range in terms of capacity. The latter can be attributed to a reduced hydrogen gas quality at low power input.

We have demonstrated previously the feasibility of running a 1 Nm^3/h PEM electrolyser on emulated intermittent wind power [9]. Pursuing this route the research on the coupling of renewable energies to water electrolysis has now been taken a step further. In this study, performed by Statoils Research Centre in Porsgrunn, we have tested a prototype of a new pressurized alkaline electrolyser from Hydrogen Technologies operating under emulated power profiles from renewable energy sources. The electrolyser has shown excellent load-following capabilities opening for new possibilities in using excess renewable energy efficiently.

2 Experimental

The Energy Park with a hydrogen refuelling station at Statoils Research Center in Porsgrunn, Norway is a laboratory for testing and qualifying technologies and components for renewable energy production and energy storage (Figure 1). The Energy Park consists of two 6 kW wind turbines from Proven Energy and two 2.5 kW mono-crystalline silicon solar panels with sun tracking from SolarWorld. A 70 kWh lead-acid battery bank from Suntek has been installed for energy storage means. The Energy Park can be run as a stand-alone system using a 48 V DC grid, or it can deliver excess energy to the mains 230 V AC grid. A simplified layout of the Energy Park and hydrogen refuelling station is presented in Figure 2. The latest addition to the Energy Park is a pressurized alkaline electrolyser from Hydrogen Technologies, which has been coupled to the wind turbines and solar panels and can be operated under intermittent power conditions. The produced hydrogen serves fuelling purposes at the hydrogen station supplying the local hydrogen vehicle fleet of 9 Toyota Prius H2-ICE. The hydrogen refuelling station is an integral part of the Norwegian hydrogen highway system, HyNor [10].

With the electrolyser connected to the grid any power input profile can be emulated with a time resolution of 1 second. The system can be run on three different emulated operation modes, either on wind power, on wind and photovoltaic (PV) or on PV solely.

In this study we have chosen to operate the electrolyser firstly on a wind power profile and secondly on a photovoltaic power input. The power input was capped by scaling to about 45% of the name plate capacity in order to test the electrolyser in the most demanding regime i.e., at low power input yielding a low hydrogen production.

Figure 1: Energy Park and hydrogen refuelling station with the solar panels and wind turbines.

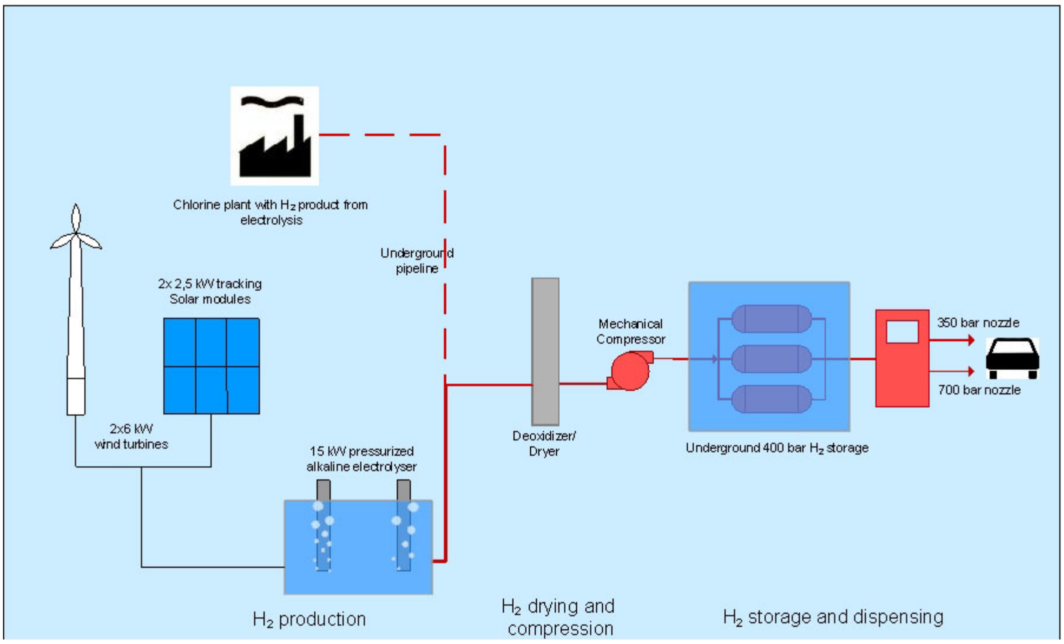

Figure 2: Schematic of Energy Park in Porsgrunn, Norway.

The technical specifications for the pressurized alkaline electrolyser are given in Table 1.

Table 1: Technical specifications for the alkaline electrolyser.

System	Alkaline, 30% KOH
Capacity	3.4 Nm^3/h
Pressure (max)	12 bar
Number of cells	10
Operation range, % of total capacity	12 %– 100%
Response time	< 1s
Operation temperature	60 °C

3 Results and Discussion

Figure 3 shows a short period of electrolyser operation under intermittent power. The green line shows the emulated power produced by the wind turbine with a resolution of 1 s. This power is converted to a current according to the specifications of the electrolyser stack. The converted current is used as a set-point in the power supply (blue line in Figure 3). The measured current is given as the red line. As seen in the Figure 3, a very fast response to the applied set point is observed proving the excellent load-following abilities of the unit. The control system is set to force a set point of 0 A as soon as the power supplied by the wind turbines becomes lower than a critical value. This value corresponds to an electrolyser current of 80 A, and is used to assure that the gas quality remains within the specified safe boundaries. Below 80 A the electrolyser enters a standby mode, maintaining operational pressure. As soon as the power production reaches acceptable levels again, hydrogen production resumes at once. Such a forced pause in production can be seen between ~120 and 190 s in the figure.

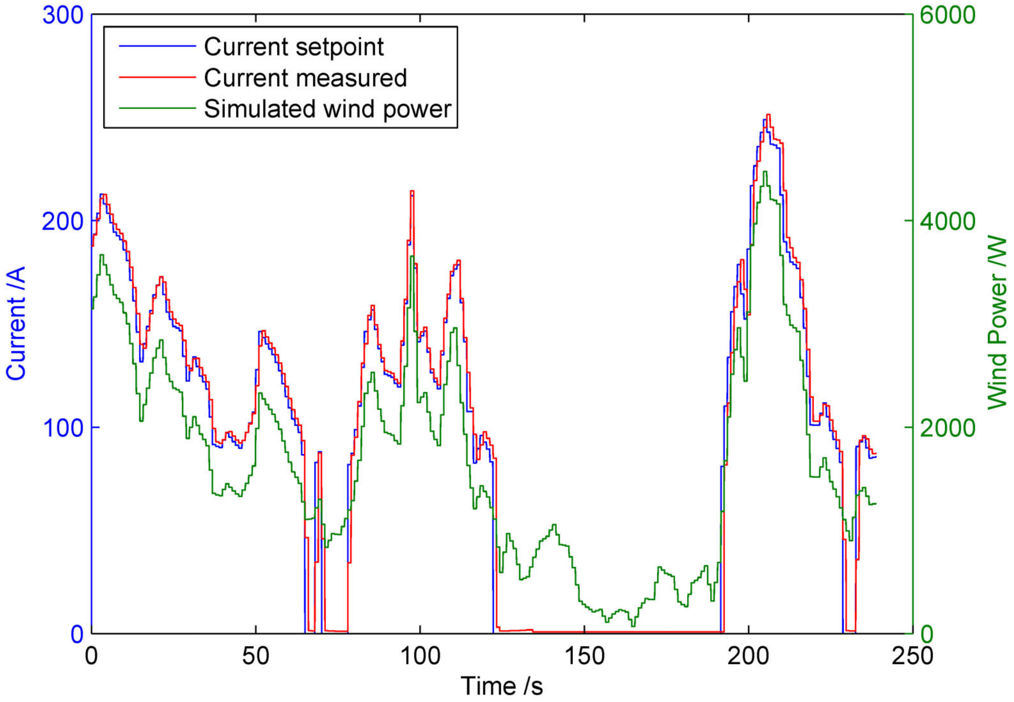

Figure 3: Operation characteristics of electrolyser under intermittent operation on emulated wind profile. The wind data has a resolution of 1 s^{-1}.

The ability of the system to resume hydrogen production even after long stand-by periods is shown in Figure 4. After a longer period with poor wind conditions and no hydrogen production, the electrolyser is responding immediately when the power produced by the wind turbine exceeds the critical limit. Before the system is started up at t~ 0.4 h, the hydrogen content in oxygen exceeds 1.5 %, Further deterioration of gas quality is experienced, due to a low initial power input. After ~0.6 h the wind conditions stabilize, the electrolyser is operated continuously between 20 and 40 % of maximum load and consequently the gas quality improves to a level well below 1 % H_2 in O_2. In general, the purity of the produced gases decreases with decreasing production rate. The gas quality is compromised by secondary electrolysis, gas crossover through the diaphragm and gas mixing due to mixing of anolyte and catholyte in the lye circuit. The operating conditions for the electrolyser in this regime are very demanding with power input ranging from 10% to 45% of the nameplate capacity. However, it is noteworthy, that even in this regime, the electrolysers performs very well and the hydrogen content in oxygen remains far below the LEL of 4%. Equipping the electrolyser with completely separate lye handling systems would improve the gas quality and thus broadening the operational range even further.

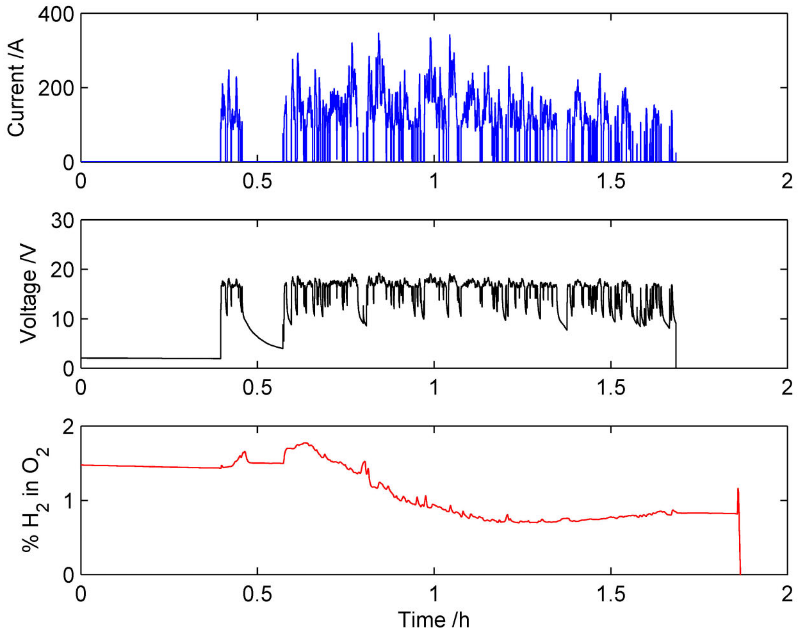

Figure 4: **Start-up and operation after prolonged stand-by.**

Figure 5 shows the difference in operation on PV and emulated wind power. During the first 0.4 hours the electrolyser is operated on the emulated wind profile. The operation is of intermittent nature switching the operational mode of the electrolysers between hydrogen production and stand-by. At t ~0.4 h the operation is switched to PV mode. As can be clearly seen, the production profile exhibits a far less transient behaviour illustrating the differences in requirements for an electrolyser running on wind versus solar energy.

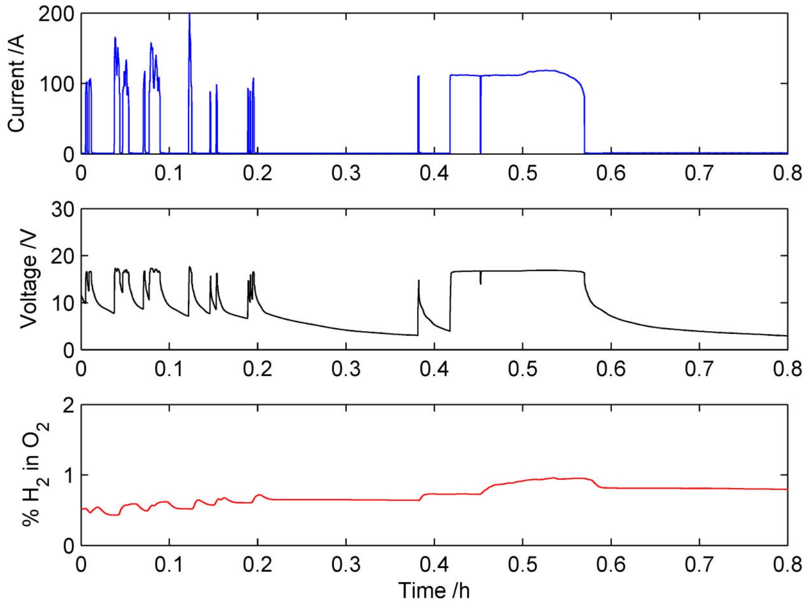

Figure 5: **Operational characteristics of electrolyser running on emulated wind power. At t~0.42 h power is supplied from the PV panels in the Energy Park.**

4 Conclusion

We have demonstrated a pressurized alkaline electrolyser that has crossed the traditional technology boundaries associated with the coupling of renewable energy and water electrolysis. With a quick response time (<1s) and a broad operational range (10-100%), the system has proven its ability to capture the fast variations in energy production associated with wind energy. Compared to earlier generations of alkaline electrolysers [11], this technology marks a technological breakthrough in the coupling of renewable energy and hydrogen generation. In the near future the electrolyser will be connected directly to the wind turbines and solar panels and its performance will be verified by long-term testing.

Acknowledgements

This work has been performed by staff at Statoils Research Center in Porsgrunn, Norway and was initiated by Torgeir Nakken. Audun Furumo and Stein Solum are acknowledged for their excellent work completing the experimental setup.

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