Utsira - demonstrating the renewable hydrogen society

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ABSTRACT:

The Norwegian energy company Hydro together with the German wind turbine manufacturer Enercon, and with financial support from the Norwegian government, has built the world's first wind/hydrogen plant in the municipality of Utsira, Norway. The plant produce hydrogen through an electrolyser when there is excess wind energy available, and then provide electricity to domestic customers via a fuel cell and a hydrogen combustion engine when the wind turbine slows or stops. Utsira is the first large-scale demonstration of a Stand-Alone renewable energy system where the energy balance is provided by stored hydrogen.
Utsira has been in operation since winter 2004/2005, and the paper presents results and experience from this first year in operation. Focus will, besides on operational results, be on key lessons learned from planning, building, and operation of the plant.

KEYWORDS : *hydrogen, wind, electrolysis, autonomous systems.*

Introduction

Hydrogen is predicted to play an important role in future sustainable energy markets. The term hydrogen society is often used to describe a society where hydrogen and electricity both produced from renewable primary energy sources are major energy carriers [1-2]. The most promising market applications for hydrogen are as fuel in the transportation sector, and as storage medium for renewable electricity. Hydrogen offers these opportunities for a number of reasons, but primarily because it can be made and used without polluting emissions, and because of its flexibility. Hydrogen is applicable in both transport and stationary applications, and can be produced from almost all other energy carriers.

One of the most promising early markets for stationary "renewable hydrogen solutions" is autonomous energy systems on islands or in remote locations where the traditional power supply often is based on diesel and may be both costly and polluting. In such places hydrogen and electricity from local renewable energy sources may be a competitive alternative [3-5].

Norwegian energy company Hydro and its partner German wind turbine manufacturer Enercon GmbH, are now at the remote island Utsira 20 km off the west coast of Norway, demonstrating the hydrogen society [6-7]. The plant at Utsira is the worlds first full-scale combined wind power and hydrogen plant. The project's main goal is to answer whether wind power in combination with hydrogen can offer a reliable energy solution for such remote areas.

It's the large local wind resource that makes Utsira a natural choice for wind power production, and the wind turbine installed will on a yearly average produce significantly more energy than the islanders need. However, wind power production is intermittent. For instance, when there is too little wind the turbine will stop. To compensate for this, at Utsira, excess wind power is stored in the form of hydrogen. When it is windy, an electrolyse use the surplus power to produce hydrogen for storage, and when it is calm, a hydrogen engine and a fuel cell convert the hydrogen back to electricity. By doing this, ten households on the island will regardless of wind speed receive wind power all along. It may also be envisaged that stored hydrogen in the future can also be used as fuel for the islands vehicles and boats.

The technology employed at Utsira will be especially useful in areas with insufficient power production or insufficient electricity infrastructure. Other more high cost niche applications may also emerge, mainly based on the possibilities hydrogen represents as a medium for storing electricity [4]. For instance, stored hydrogen can be used to provide back-up/emergency power or to secure a more reliable and higher quality power supply.

The Utsira project

The Utsira project is primarily an R&D project. The main purpose is to better understand how an intermittent energy source like wind can be more rationally and effectively utilised using hydrogen as energy storage medium. The knowledge gained from the project shall give us a better fundament for identifying the best commercial solutions.

We are in the demonstration period:

1. Gaining experience from a renewable energy supply system for isolated areas based on hydrogen production and storage, and fuel cell/H_2-ICE operation.
2. Demonstrating safe, reliable and robust operation.
3. Demonstrating high quality power supply.
4. Providing a basis for evaluation of new market opportunities.

The most innovative aspect of this project is the way we put all the different components together into a functioning system. The major challenges are the high number of interfaces we have in the system, controlling a grid with a large wind turbine serving a relatively small load, and operation of the fuel cell and hydrogen engine. Hydro's subsidiary company Norsk Hydro Electrolysers is the manufacturer of the hydrogen production equipment, and for Hydro, besides the overall operation, the performance of the electrolyser and the H_2 genset/fuel cell has been particularly important to optimise. The goal is to develop an electrolyser that is well suited for operation in combination with renewable energy sources.

The main components of the system and their capacities are (Table 1): i) a 600 kW wind turbine utilising the good wind conditions on the island; ii) a 48 kW (10 Nm^3/hr) electrolyser converting excess wind energy to hydrogen; iii) a 5 kW compressor increasing the pressure of the hydrogen to maximum 200 bar; iv) a 12 m^3 H_2-storage tank having enough capacity to cover the customer's demand for 2-3 days without wind; v) a 10 kW fuel cell and a 55 kW hydrogen combustion engine/generator (a converted MAN diesel engine) providing the power when power from the wind turbine is not sufficient to cover the demand; vi) a 5 kWh flywheel and a 100 kVA synchronous machine stabilising the local grid; vii) and a 35 kWh battery providing emergency back-up power. The domestic customers connected to the plant have a peak demand of approximately 50 kW.

The main design criteria for the plant were:
- Energy balance in the autonomous system.
- Peak power capability in relation to maximum expected customer load.
- Power quality requirements.
- Redundancy and emergency mode requirements.
- Technology robustness.

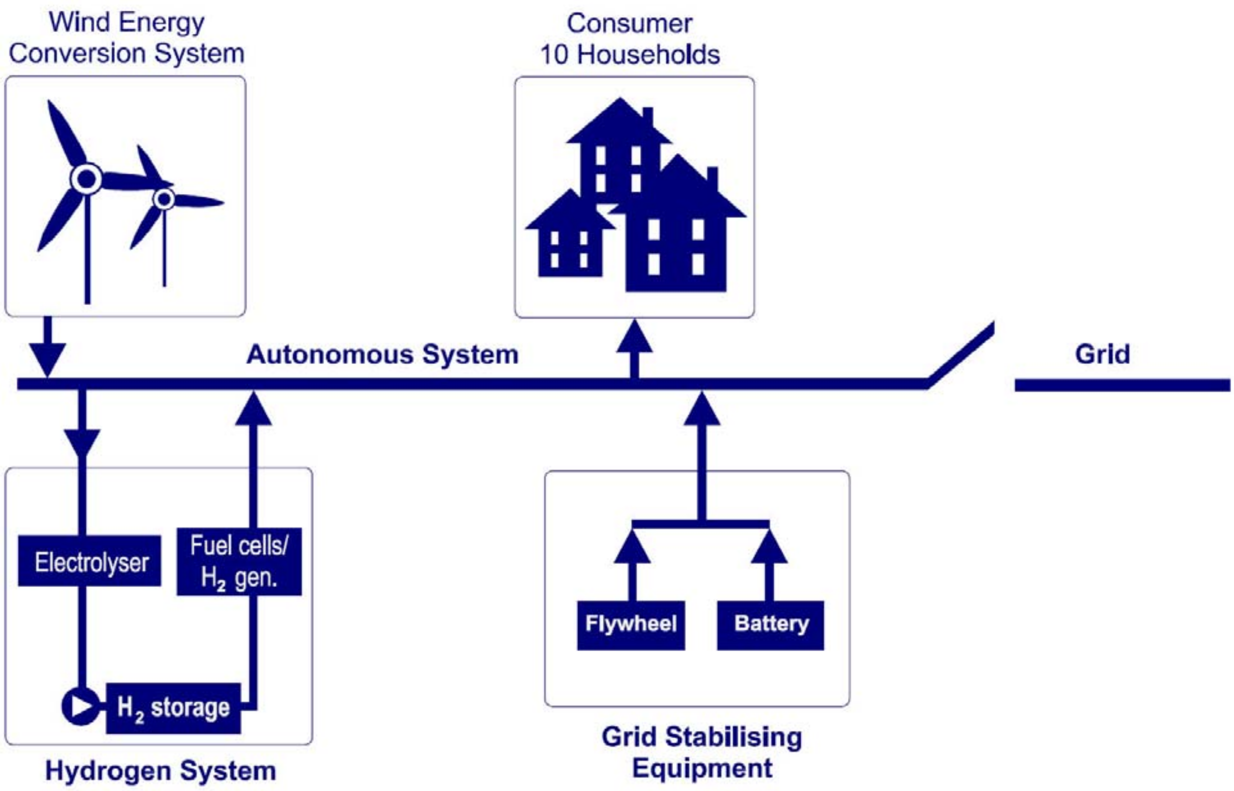

Figure 1: Illustration of the Utsira stand-alone wind-hydrogen energy system.

At Utsira the average wind speed is measured to more than 10 m/s. Energy consumption for the 10 households is measured to approximately 200 MWh/year. Simulations [8-12] using the component characteristics in Table 1 and measured wind and power demand profiles suggest that the total operation time of the electrolyser and hydrogen genset is approx. 2000 and 1000 hours per year, respectively. The number of starts and stops of the electrolyser and H2-engine are for both estimated to approx. 100. Operations so far also suggest that this could be close to the real behaviour. However it is too early to conclude since the time in continuous regular operation is too short. Operation so far shows that the total yearly operational hours will be around 1500 and 500 for the electrolyser and H2-engine, respectively. The number of starts and stops seems to be around 2-300 for both the electrolyser and H2-engine.

Table 1: Utsira wind-hydrogen system – component characteristics

Key Components	**Key data**	**Manufacturer**
Wind turbine	600 kW	Enercon
Battery	35 kWh	Enercon
Flywheel	5 kWh, 200kW$_{max}$	Enercon
Synchronous Machine	100 kVA	Enercon
Electrolyser	10 Nm^3/h, 48 kW	Hydro Electrolyser
Compressor	11 Nm^3/h, 5.5 kW	Andreas Hofer
Hydrogen storage unit	12 m^3 @ 200 bar = 2400 Nm^3	Martin Larsson
Hydrogen genset	55 kW	Continental
Fuel cell	10 kW	IRD

Figure 2: Photograph of the wind-hydrogen power plant at Utsira. To the left: the wind turbine tower. Below the tower: the electrolyser and compressor container. In the front: the H2-storage tank. To the right: the fuel cell and H2-ICE container. In the background: the grid stabilizing equipment.

Operational results

Our main focus during the first part of the demonstration has been to make the installed components in the autonomous system function together and deliver power with the expected quality and reliability to the customers. We now have just over one year of operation of the plant. Here we present the major results and experiences from this first year. The results will show that these first two points are fulfilled.

All the individual components were delivered, installed, and tested at Utsira during the summer of 2004. During the remaining time of 2004 the components were interconnected and the autonomous energy system was established. The system was ready for full scale testing in February 2005. After that, we have had a very steep learning curve. Since this is the first, and so far only project of this type and scale, we did not fully know what to expect. We have during these first months of operation met many problems that we could not foresee. Even though there are still things to be improved we have solved most problems and this has given us valuable experience and knowledge on how to build and operate the next wind-hydrogen plant. The most important lessons learned we would like to share with others that are now planning such installations [13-14].

The main achievements so far are:

- More than 8 months in Stand-Alone mode

- Functionality – very good (Figure 3, 4, and 5)
- Availability – close to 100% (Figure 6)
- Power quality – very good (Figure 7)
- Customers satisfied – no complaints
- Good media coverage, several publications, several presentations in conferences and at fairs
- Contribution to local activity
- Many visitors
- No accidents

Remote operation is implemented and is working as expected. So far there have been no complaints of any kind about the power supply. Power quality is continuously measured using grid analysers and is excellent and well within the required norm (Figure 7). The biggest challenge has been to control and regulate the autonomous grid especially at times with large power production and low demand. It has also been a challenge to learn how to more rationally and efficiently operate the hydrogen part of the plant. This general work is part of the learning process, and will continue for at least two more years before we conclude. As shown in Figure 3, 4, and 5 the functionality of the plant is also working as expected. In low wind mode the hydrogen engine starts to compensate for the insufficient wind power production, while in the high wind mode with sufficient excess energy available the electrolyser start to produce hydrogen.

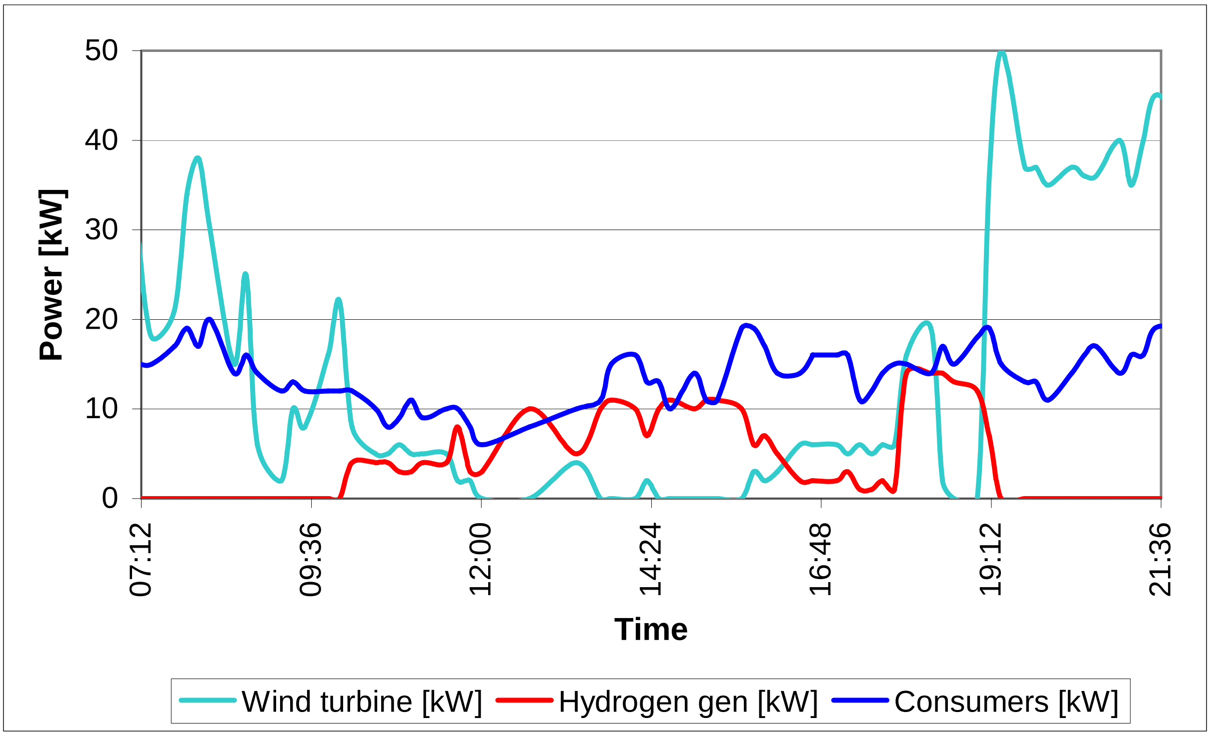

Figure 3: Example of operation. During the period one can see that the wind power decreases and cannot supply the demand. In this period the H_2-engine is started and is balancing the load.

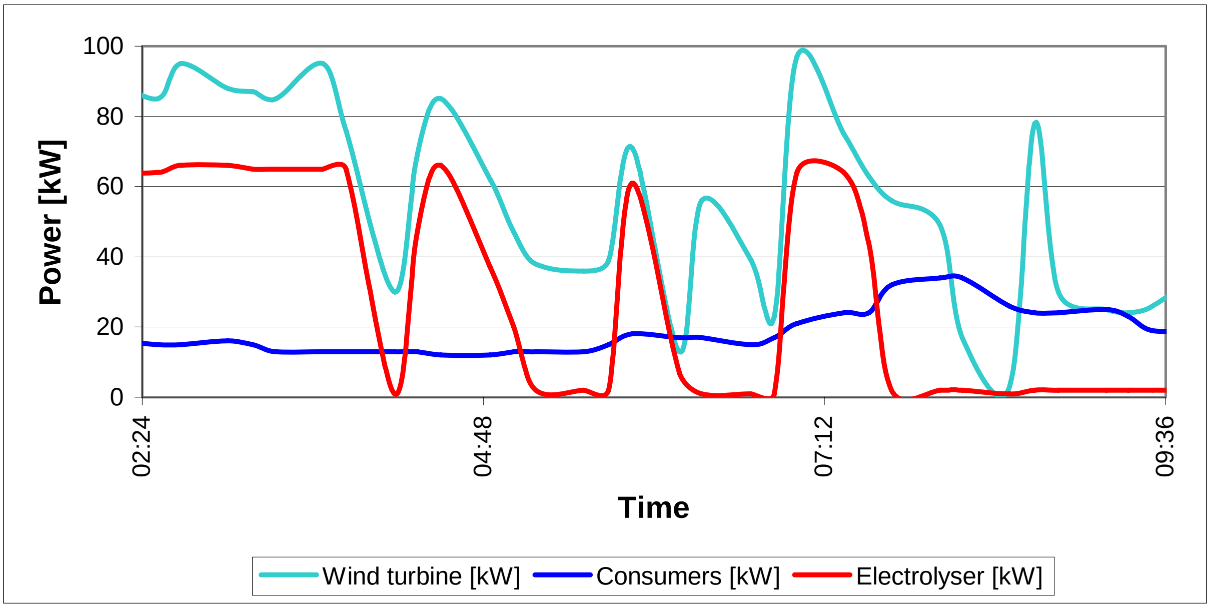

Figure 4: Example of operation. During the period one can see high wind modes with H_2-production in the electrolyser.

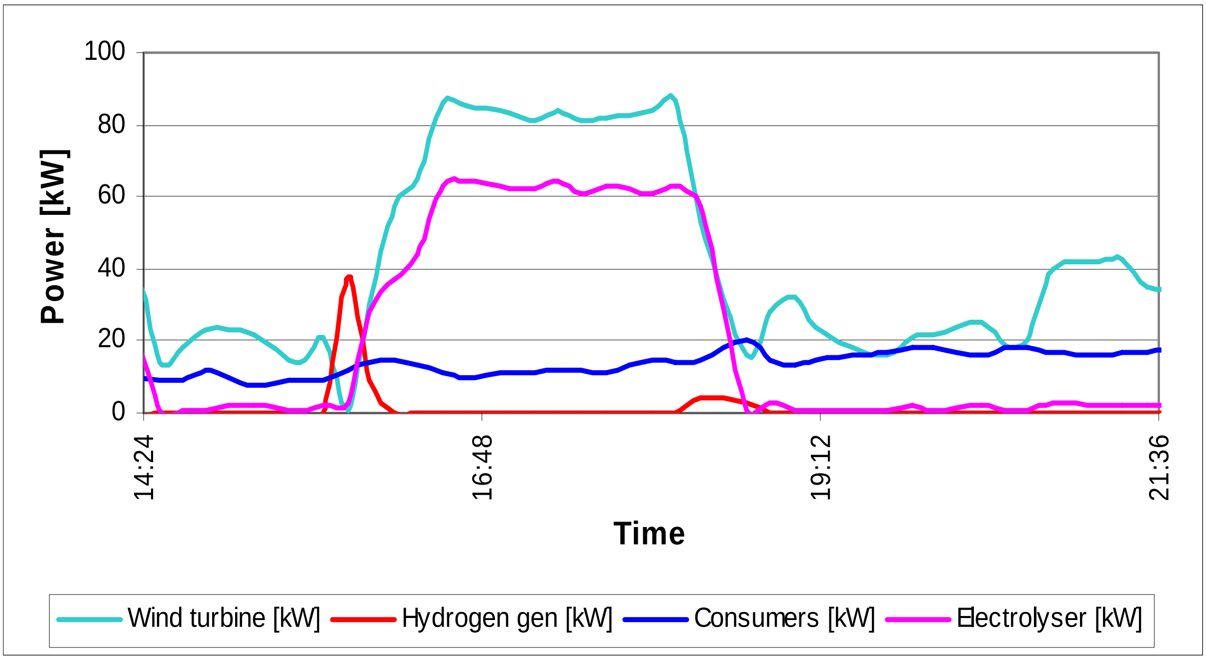

Figure 5: Example of operation. During the period one can see both the high wind mode with H_2-production in the electrolyser and the low wind mode with the H2-engine balancing the consumers demand.

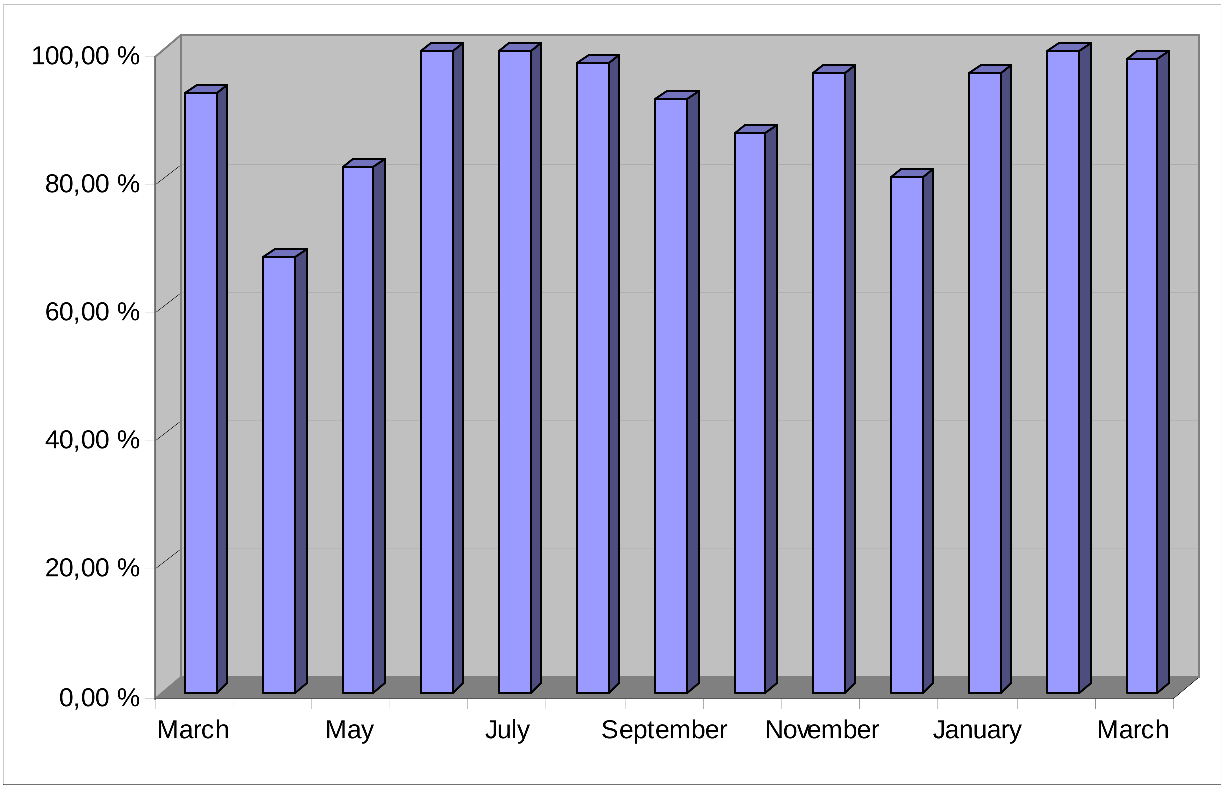

Figure 6: Availability of the Utsira wind-hydrogen system measured from March 2005 until March 2006. Deviation from 100% is due to errors in the system, and the customers are in these situations connected to the mainland grid.

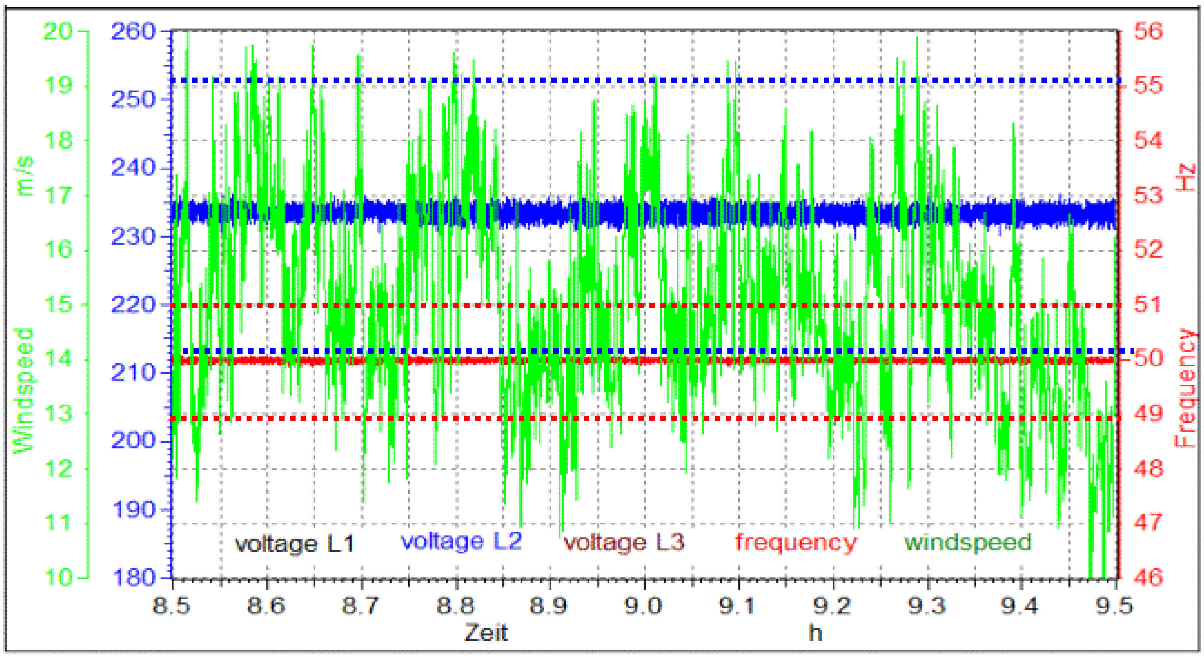

Figure 7: Grid quality measured (1 hour) in the Stand-Alone system. Both frequency (red) and voltage (three phases –blue, brown and black) is well within the required norm EN 50160 (limits – dotted lines). Wind speed measured during this period shown in green.

Lessons learned

The following points are identified as the most important experiences made from the planning, building, and operation of the plant so far:

- Have a well-defined design basis and operational philosophy - focusing on:
    - Climate
    - Signal quality
    - Communication (control and regulation)
    - Interfaces
- This is not plug and play but an R&D project
- Have focus on safety, health, and environment
- Select the right partners
- Select an appropriate location
    - Good wind conditions
    - Small but representative load
    - Back-up system in place
    - Not too remote
    - Supporting community
    - Access to service personnel

Some of these points are discussed in more detail below.

Climate here means offshore climate, i.e. wind, waves, temperatures below zero, and salt must be considered. Waves, because during the winter period the largest components can be difficult to transport. Some of these are also long lead items and therefore it is important to plan the installation with the weather conditions in mind. Electronic equipment and housings must be prepared for a saline environment. Especially, the fuel cell and the electrolyser must not be exposed to temperatures below 0 °C.

Variations in signal quality (voltage and frequency) were inevitable at least in the start up phase of the project. Reactive power, resonance, over-harmonics can occur and must be considered. Especially, the power supply of the electrolyser could be a source for such problems. All equipment should be designed to handle this. The equipment should generally be kept as simple and robust as possible and redundancy should also be considered. Because of the uncertainty in future wind power production and customer demand one should also consider over-dimensioning the plant. This is off course, as for redundancy, a trade off that must be made between plant availability and cost. The power system is normally operated with inverters based on IGBT technology, but some conventional inverters are also installed. The influence these inverters have on the (weak) gird must be carefully considered.

The plant is meant to be remotely operated, and therefore self-testing and automatic remote resetting of components after shutdowns should be possible. Remote resetting was not possible for all components from the start of the project. We had to choose from available technology, and this equipment was not designed for remote operation. However, this is now partly implemented. It is important to specify or choose equipment with high degree of fail-safe and remote operation. Remote operation is a necessity for safe operation.

Even though different suppliers often have proprietary control systems, communication and interfaces between components should be described and standardized. This applies especially for the hydrogen part of the plant.

It is also very important for these first demonstrations that the back-up system for the households is working without problems. At Utsira the customers can in case of failures or testing in the Stand-Alone grid be connected back to the ordinary grid (1 MW sub sea cable to the mainland). This system is working well. We have also installed a “dummy load” which has proven useful. This load bank can be used to simulate the households in test periods before the real households are connected. To keep the customers satisfied and positive is also important for the public acceptance of hydrogen.

Safety is very important. It would be detrimental to the development of hydrogen as an energy carrier if a serious accident should occur in highly profiled projects like this. The Utsira plant is both compact and complex and it contains explosive zones, advanced equipment and regularly has many unskilled visitors. Safety has therefore the highest priority, and so far we have had no accidents. The key for achieving this is proper training of operator personnel, good working instructions for the whole system, and clear distribution of responsibility at site.

Partners with the right equipment and competence are off course important, but having a partner that is fully determined and dedicated to pull this through is equally important.

Conclusion

We believe that, if successful, large-scale demonstration projects like Utsira can prepare the way for a future hydrogen marketplace and we will therefore continue to initiate and participate in demonstrations of sustainable energy solutions using hydrogen as an energy carrier. We trust that these demonstrations will help improve public awareness and acceptance, improve cost competitiveness of renewable energy, and reduce market barriers for new energy and technology solutions in general and hydrogen technology in particular.

The Utsira project has so far shown that it is possible to supply remote areas with wind power alone using hydrogen as storage medium. Still there are several things to improve in order to make the system competitive, both technically and economically, to alternative systems like wind-diesel. However, we have identified several elements that together with the ongoing day-to-day improvement of the plant, will help close the gap we see today. This includes

- Consider utilisation of more of the surplus energy (for instance for pumping or heating water)
- Consider utilisation of H_2 (possibly also O_2) for other purposes like fuel for transportation
- More effective re-electrification (smaller H_2-storage)
- Hybrid solutions (diesel, PV, biofuel,…)
- Load control and production forecasting
- Heat utilisation

Other more general development trends that will also work in favor of the Utsira concept are:

- Introduction of “green” incentives (RECS/CO_2-tax)
- Increase in oil and gas price
- Valuation of green image and security of supply and independence

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