The Utsira wind-hydrogen system - operational experience

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Summary

During 2003 and 2004, the Norwegian energy company Norsk Hydro together with the German wind turbine manufacturer Enercon, built a 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 world's first large-scale test 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. After approximately one year of operation an average availability of approximately 90% have been achieved. The high availability have been achieved without having designed the system with redundancy in key components e.g. two hydrogen generators or two wind turbines. The design and operation of the system have given invaluable insight for further development of wind-hydrogen systems. A extension of the Utsira project have been decided to test a new type of electrolyser based on PEM technology with a higher operational flexibility as well as greatly reduced footprint.

Keywords: hydrogen, wind, electrolysis, distributed generation, renewable energy, autonomous systems

Introduction

Hydrogen is predicted to play an important role in future sustainable energy markets. The term hydrogen economy is often used to describe an energy infrastructure 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:

- Environmentally friendly - can be made and used without polluting emissions.
- Flexible - applicable in both transport and stationary applications, and can be produced from almost all other energy carriers.
- Energy storage medium - contribute to increased incorporation of renewable energy

One of the most promising early markets for stationary "renewable hydrogen solutions" is autonomous energy systems 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 and wind-swept 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 remote areas.

The ample wind resource makes Utsira a natural choice for wind power production. However, as is also the case with other renewable energy sources, power production will vary. At Utsira, excess wind power will be stored in the form of hydrogen. When it is windy, an electrolyser will use the surplus energy to produce hydrogen for storage, and when it is calm, a hydrogen engine and a fuel cell will 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. Other possibilities, which are currently being investigated, are for grid-reinforcement in areas with weak grids or with a high share of intermittent power, as a means to perform peak shaving, or as a way of increasing the utilisation factor of intermittent energy sources.

The Utsira project

The Utsira project is primarily an R&D project. The main purpose is aimed at better understanding how an intermittent energy source like wind can be more effectively utilised using hydrogen as energy storage medium. The knowledge gained from the project shall give us a better foundation for identifying commercial stand-alone system solutions.

Key focus areas for the demonstration period are:

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

The most innovative aspect of this project is the way all the different components are put together into a functioning system. The major challenges are the high number of interfaces 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 in parallel. Hydro's subsidiary company Norsk Hydro Electrolysers (NHEL) is the manufacturer of the hydrogen production equipment, the electrolyser, 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 next phase of the Utsira project will test a PEM electrolyser developed by NHEL that have higher efficiency, much smaller footprint, and higher operational flexibility.

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 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 including H2 storage optimisation.
- Peak power capability in relation to maximum expected customer load.
- Power quality requirements.
- Redundancy and emergency mode requirements.
- Technology robustness.

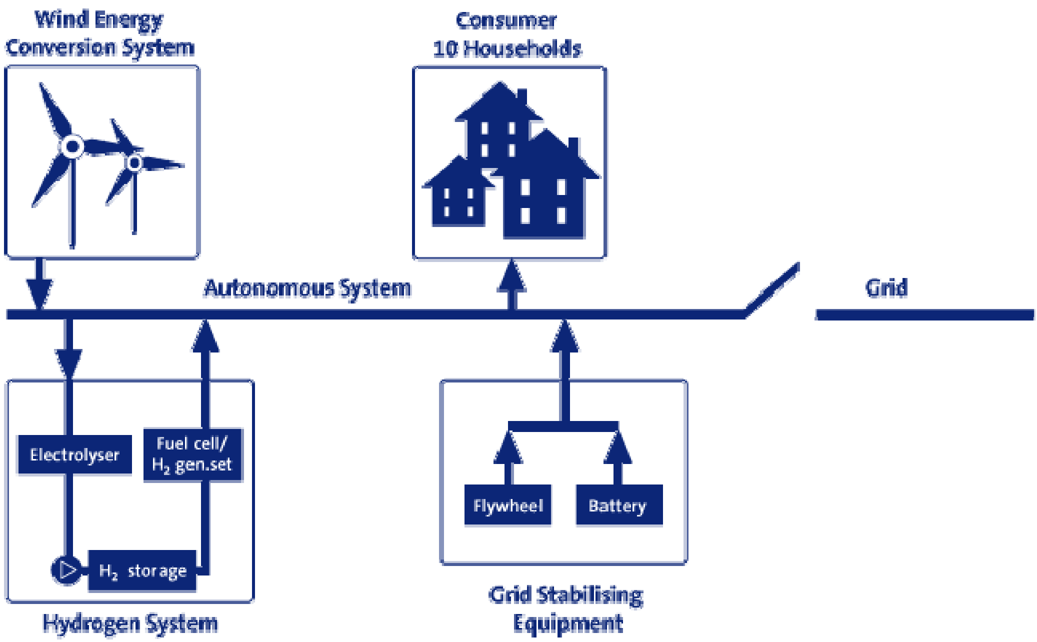

Figure 1 Illustration of the Utsira stand-alone wind-hydrogen energy system.

At Utsira the annual 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 indicate a total operation time of the electrolyser and hydrogen genset of 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. 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. This indicates that the wind resource was underestimated in the pre-studies.

Key Components	**Key data**
Wind turbine	600 kW
Battery	35 kWh
Flywheel	5 kWh, $200kW_{max}$
Synchronous Machine	100 kVA
Electrolyser	10 Nm^3/h, 48 kW
Hydrogen storage unit	12 m^3 @ 200 bar = 2400 Nm^3
Hydrogen genset	55 kW
Fuel cell	10 kW

Table 1 Utsira wind-hydrogen system – component characteristics

Figure 2 Photograph of the wind-hydrogen power plant at Utsira. 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

As pointed out above 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. The plant have now operated for one year. Here we present the major results and experiences from this first year. The results will show that these first two points are fulfilled. The operational data and experience gathered will provide a good basis for further development and commercialisation of Stand-Alone systems based on hydrogen storage.

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]. We think that more large scale demonstration projects like Utsira, and the dissemination of key lessons learned from them, is important in order to

- Prove the technology
- Improve public awareness and acceptance
- Improve cost competitiveness
- Reduce market barriers

The main achievements so far are:

- More than 6 months in Stand-Alone mode
- Availability – 90% (Figure 6)
- Power quality – very good
- 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 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.

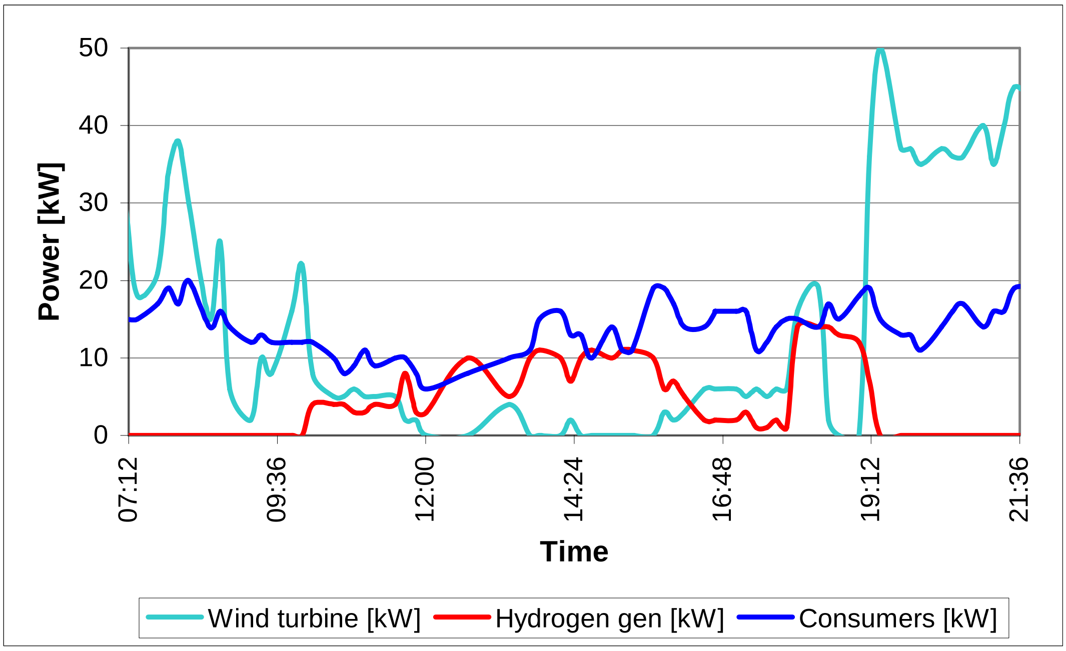

Figure 3 Example of operation. During the period one can see that the wind power decreases and cannot supply the demand. In this period the H_2-engine is started and is balancing the load.

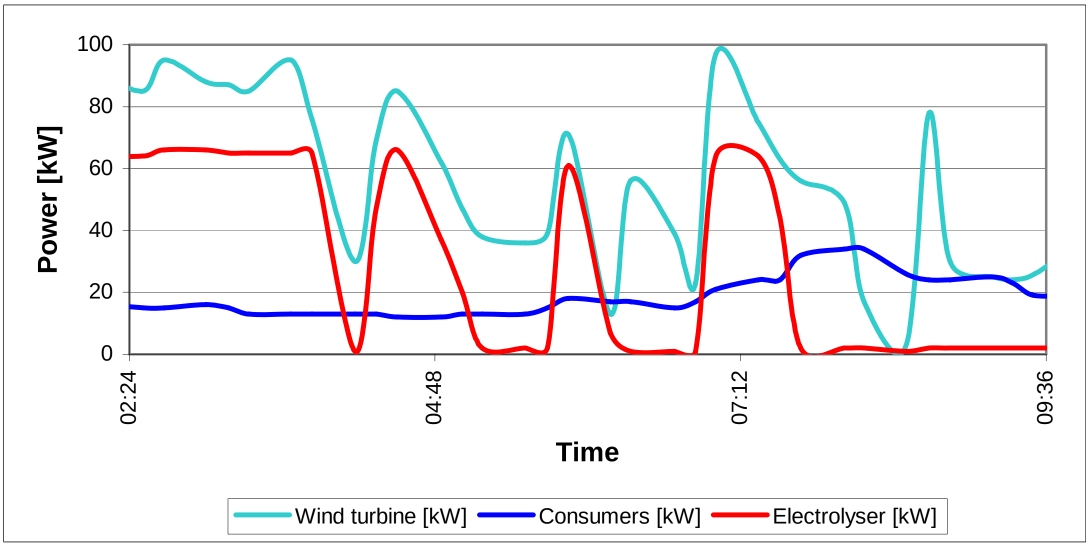

Figure 4: Example of operation. During the period one can see high wind modes with H_2-production in the electrolyser.

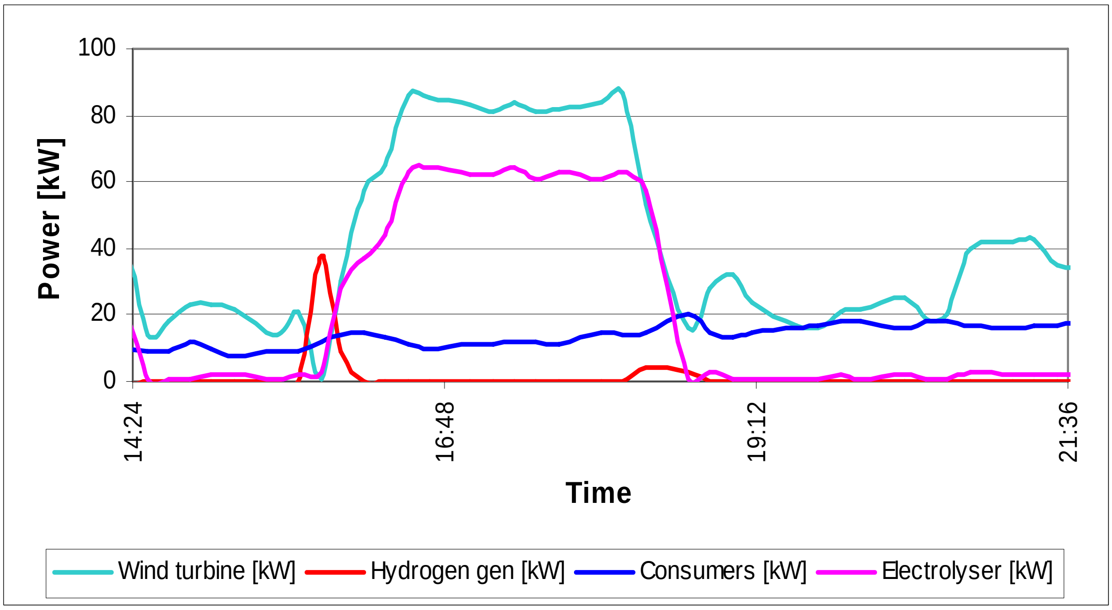

Figure 5: Example of operation. During the period one can see both the high wind mode with H_2-production in the electrolyser and the low wind mode with the H2-engine balancing the consumers demand.

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

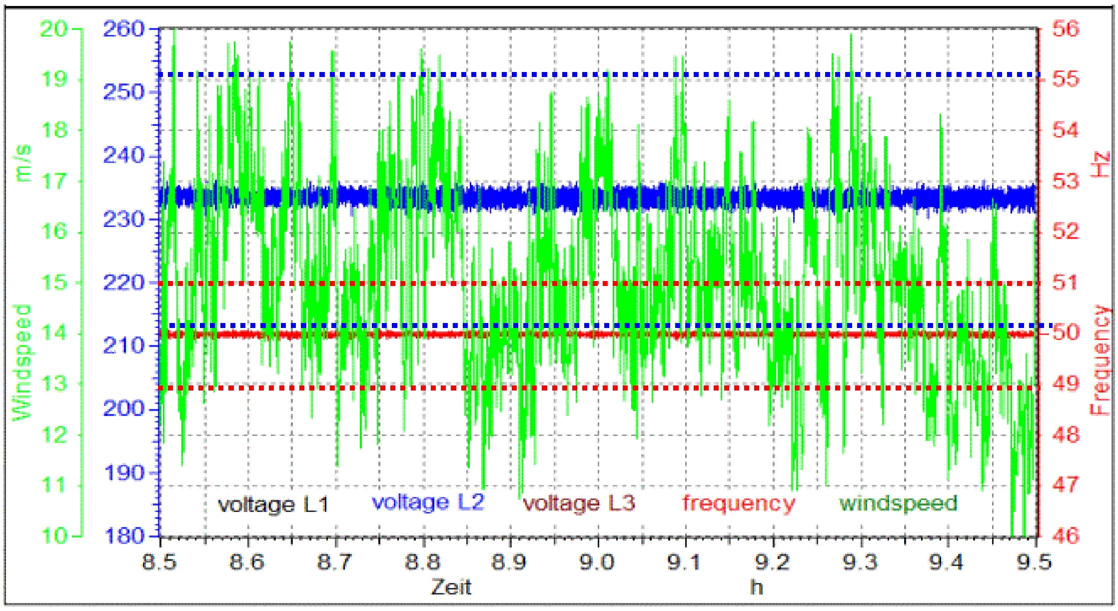

Figure 7: Grid quality measured (1 hour) in the stand alone system. Both frequency (red) and voltage (three phases – blue, brown and black) is well within the required norm EN 50160 (limits – dotted lines). Wind speed measured during this period shown in green.

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:
  - Climatic conditions
  - Signal quality
  - Communication (control and regulation)
  - Key component interfaces
- Have focus on safety, health, and environment
- 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.

At Utsira climatic conditions are close to offshore conditions, i.e. wind, waves, temperatures below zero, and salt must be considered. Wave height must be considered, as transport of the largest components during the winter period can be difficult. Some of these are also long lead items and therefore it is important to plan 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 of 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 (thyristor) 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 standardised. This applies especially to 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. A load bank serving as "dummy load" was proven valuable during commissioning simulating the households in test periods before the real households where connected. To keep the customers satisfied and positive is also important for the public acceptance of hydrogen.

Safety is very important. 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

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 surplus energy (today 80% not used)
- Consider utilisation of H_2 (possibly also O_2) for other purposes
- More effective re-electrification (smaller H_2-storage)
- Hybrid solutions (diesel, PV, biofuel,…)
- Load control and production forecasting
- Heat utilisation

Some of the points we will implement in the next project phase starting in 2006. Other more general development trends that will also work in favor of the Utsira concept are:

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

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.

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