HYDROGEN AS A MEANS TO CONTROL AND INTEGRATE WIND POWER INTO ELECTRICITY GRIDS

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ABSTRACT

The integration of wind energy into electricity grids will pose future challenges as the levels of production rise, power fluctuations have to be balanced and especially coastal grids are overloaded. Ways of controlling and storing wind electricity have to be developed in order to better integrate the wind resource into the electricity supply system and overcome limitations of grid development. Hydrogen storage offers some advantages towards these goals.

The *HyWindBalance* project, which is described here, looks into the possibilities of using

- a hydrogen production and storage system to store wind electricity,
- a fuel cell system to re-electrify the hydrogen.

INTRODUCTION

The power produced by wind farms varies due to the natural fluctuations in wind speed. Although the short term variations (including turbulence) generally obey random patterns (1), the mid-term and geographical variations in wind speed show some correlation. This results in a levelling out of high frequency (short term) contributions, when large wind energy systems are considered that are necessarily spread of considerable areas (2). Furthermore, the energy contained in the wind flow is predictable to a certain degree. This has given rise to the development of wind energy prediction tools (3) (also see below).

With increasing contributions of wind energy in the power supply system, as seen in many parts of Europe today, problems regarding the wind resource integration are expected, regarding

- the management of wind energy production, in making maximum use of the natural resources;
- the necessary enhancement of grid capacity, creating additional transport lines connecting the up-to-now little developed coastal regions to the centres of electricity demand;
- the additional provision of balancing power, in order to compensate the fluctuating input.

It is generally expected that an increasing need for balancing power will result from the advent of large offshore wind parks in the North Sea. To neutralise this effect, it is necessary to adjust the operation of the grid as a whole to the requirements of a modern mix of energy sources. Critics claim that the additional supply of balancing power will induce increased use of fossil fuelled power stations at low capacity factors and thus low efficiencies (4). As a consequence, this would cause additional emissions and fossil fuel consumption which contradicts the basic idea of environmentally benign energy production from wind.

THE *HyWindBalance* CONCEPT

Today's electricity grids will have to adapt to the new challenge of high renewable energy penetration and will not be able to proceed with 'business as usual' regarding the integration of fluctuating power generation. A closer analysis reveals that even today many tools are available in balancing power generation and demand – weather forecasts have been a standard tool in grid management for decades, as have knowledge-based approaches to predicting electricity demand and balancing the short term, statistical fluctuations of the electrical load. Therefore the problem of integrating renewable, fluctuating power is reduced to an optimised network management obeying novel constraints.

The *HyWindBalance* concept addresses this issue by attempting to describe solutions to renewable power management (concentrating on wind energy) by making use of electricity storage via hydrogen. The overall economic efficiency of renewable energy supply is increased by the possibility of feeding wind energy into the grid in a controlled manner ("dispatching"). This

- enables scheduling of wind electricity production (bringing increased reliability of wind energy generation and allowing for intermediate storage of excess energy); and
- minimises the use of traditional balancing power (minimising the consumption of fossil fuels).

The project couples hydrogen production, storage and re-conversion to electricity with an intelligent control unit that incorporates wind as well as load prediction routines. Fig. 1 gives an overview of the system modules and their interaction. The main aim of the project is to develop a wind hydrogen system that, in its function as a "virtual power plant", establishes the following options for wind energy

- scheduled generation, thus making the wind resource 'controllable';
- reduction of need for balancing power from conventional power plants (secondary balancing power);
- active (scheduled) sale of wind-based electricity as (amongst others) balancing or peak power on the spot market.

It should be noted that wind-hydrogen-systems of the type described here can provide balancing power free of carbon dioxide. In the medium term, it will also be possible to sell hydrogen from excess wind energy to other markets than the energy sector, for example as fuel for road vehicles. Such diversification of wind energy can relieve the energy market from excess production, stabilise market prices and supply hydrogen gas at marginal (input energy) cost.

Companies and organisations with a variety of backgrounds are cooperating in the R&D project *HyWindBalance.* The Carl von Ossietzky University of Oldenburg, several engineering companies and consultancies in the fields of wind energy, hydrogen technology and information technology, as well as financial service providers and utilities have teamed up in this project. It is co-financed by the federal state of Lower Saxony, the European Regional Development Fund, and the EWE AG, and the companies involved,

HARDWARE DESCRIPTION

Besides developing the concept and tools necessary to realise the concept described in Fig. 1, the consortium has also set up a laboratory-size system which is to be used in practically verifying the concept. It combines a (virtual) wind power input with a real hydrogen production and storage system and a fuel cell. This 'brass board' unit is also being used to optimise essential system components, especially with regard to the software algorithms connecting wind power and load prediction with the system control and hydrogen resource management. The main elements are an electrolyser, hydrogen storage, a fuel cell, and the control unit.

HyWindBalance has been installed at the scale of few Kilowatts at the renown 'Energy Laboratory' of the Carl von Ossietzky University, Oldenburg. The layout of the system considers the following aspects

- limitation of the financial risk by keeping the system small,
- generation of meaningful experimental results by exploiting the modular properties of electrolysis and fuel cells – it is expected that the dynamic responses of small and large scale equipment are similar in nature, and
- simulation of a large scale system using ‘hardware in the loop’, i.e. a software system controlling hardware equipment and thus allowing the evaluation of the control unit under realistic conditions.

The hardware was chosen at ratings between 1 and 5 kW_{el}, which also reflects the lower end of equipment available on the market. In this way the supply of meaningful experimental data was combined with the limited budget possibilities. As a further aspect, only commercially available products (excluding prototypes) were acquisitioned thus obtaining insight into the state-of-the-art of hydrogen and fuel cells technology and at the same time receiving standard guarantees for the component function.

The system now comprises of an AccaGen alkaline electrolyser of 5 kW rating and 30 bar operating pressure, supplying high-purity hydrogen (99.999%). Considering the operation with fluctuating input and the requirements for safety equipment in the university laboratory this was the only equipment suitable for the application. Due to the elevated pressure standard storage bottles were chosen with no further compression step. This simplifies the laboratory setup but also might introduce a systematic difference to later large-scale systems using a compressor to store hydrogen at high pressures, thus reducing storage volume.

The fuel cell is a Nexa unit available from Ballard of Canada, rated at 1.2 kW_{el}. At an efficiency of 35 to 40% this corresponds to a hydrogen consumption of approx. 1 Ncbm/h, which is more or less in agreement with the production rate of the electrolyser.

Fig. 2 shows the setup in the laboratory in Oldenburg.

INTEGRATING WIND POWER PREDICTION

Wind power predictions are required for the efficient operation of the wind-hydrogen system, especially with regard to an optimal management of the storage. The predictions provide the information how much wind power will be available in the near future, i.e. over a time horizon from 0 to 48 hours. Hence, the fluctuations of wind power due to meteorological conditions are known within the uncertainty of the prediction. The storage system can either be used to eliminate the prediction error, or supply scheduled or balancing power as described above.

Depending on the type of application the wind-hydrogen system is required to follow a given production schedule for the next day or eliminate fluctuations. In the former case the system has to compensate for the differences between wind power output and the scheduled values and the wind power predictions are needed to estimate the anticipated share of wind power. The layout of the storage system can then be adapted to the typical forecast errors of the predictions which are much smaller than the full fluctuations of the power output of the wind farm. In the latter case the storage content has to be managed thus that the statistically expected fluctuations can always be compensated for.

The Previento *wind power prediction system*

Based on the various numerical weather prediction (NWP) data the wind power predictions are calculated with the established forecasting system *Previento*. The prediction system delivers forecasts of the anticipated power output of single wind farms or the aggregated output of many wind farms in a region up to five days ahead. In addition to the forecast value Previento can provide the individual uncertainty depending on the prevailing weather situation.

Previento is a so-called physical system (3) and is based on a meteorological description of the atmosphere. The coarse resolution of the NWP is spatially refined to obtain the wind speed for given sites. However, the systems differ significantly in their refinement methods and the physical parameterisation to obtain the wind speed in hub height. The wind speed is then plugged into the power curve of the wind turbines to calculate the power output. The advantage of physical models is their deterministic parameterisation based on meteorological parameters and the fact that no measured data is needed to produce a prediction. Of course, measured data can optionally be used to improve the forecast accuracy.

Fig. 3 shows the principal scheme of the forecast system. The main ingredients are the NWP input, site-specific data of the wind farm, and, for aggregated predictions, a database of all wind farms in a given region.

SYSTEM AND OPERATING COSTS

During the first six months of 2006, transmission capacity shortages within the high voltage grid caused operators of wind farms in Schleswig-Holstein (North Germany) to suffer from shut-downs worth 7% of energy production amounting to revenue losses of about 10,000 € per MW with an already visible upwards trend (5). In Lower Saxony regional utilities have now taken to the practice of placing power purchase contracts only on condition that the power output of the wind turbines is reduced by up to 20% in case of exess of wind power (6).

On this background, calculation models for the profitability analysis of wind-hydrogen-systems are being developed within the project *HyWindBalance*.

Looking at and comparing today's costs for hydrogen / power producing systems (electrolyser, fuel cell) with other technologies for renewable power production, we see a significant difference between investment costs on one side and output on the other side. This can easily be traced back to the lack of readiness for series production of any components to produce power from hydrogen.

Wind power projects can be realised onshore with an investment cost index of about 1,100 €/kW (7). For realised photo-voltaic installations, the investment cost index is currently about 5,000 €/kW (8). A comparison of the actual investment cost index of a hydrogen fuel cell laboratory installation of about 26,000 €/kW (9) clarifies the large current gap with respect to the marketability of the systems at the time being. It also has to be noted, though, that a kW-scale laboratory installation does not compare to full-scale MW-class installations. Reliable data for hydrogen equipment is still lacking at that scale.

In the area of wind power, subsidies and market incentive programs have achieved a reduction in the installation costs of wind turbine generators in the MW-class by about 60% within one decade in Germany (7; 8). For a wide market penetration of a system to store power by means of hydrogen, the comparison of the investment cost index already shows that the production costs for each component will have to be reduced drastically.

AN ENERGY UTILITIES' PERSPECTIVE

As described in the introduction, the increasing amount of wind converters in Northern Germany and also the projected offshore wind farms in the North Sea impose high requirements on the electricity grids especially in the costal regions. Because of this, the local grid operators have to deal with the fluctuating power feed-in to prevent grid overloading and ensure grid stability. Furthermore, electric utilities have to provide energy to balance the fluctuating demand on one hand, and the energy produced by conventional power plants and fluctuating wind power, on the other hand.

These challenges require new power plants to balance the grid load. The electricity utilities are currently analysing and evaluating different energy storage systems. Hydroelectric power plants, for example, offer good solutions for the balancing problem. Due to the local geographical factors it is not possible to install large plants of this type in Northern Germany, though, near to the main German wind resources. Another possibility to handle the described challenge is to operate compressed air energy storage systems (CAES). The disadvantages of CAES-systems systems are high costs and the discharge of carbon dioxide.

Underlined by the actual climate discussion, energy storage systems should not be evaluated exclusively by the current energy costs. The environmental compatibility also plays a relevant role. To produce and store hydrogen from wind electricity offers a big opportunity to handle the fluctuating wind power in an efficient and ecological way. *HyWindBlance* will determine if hydrogen systems can be operated economically in the future.

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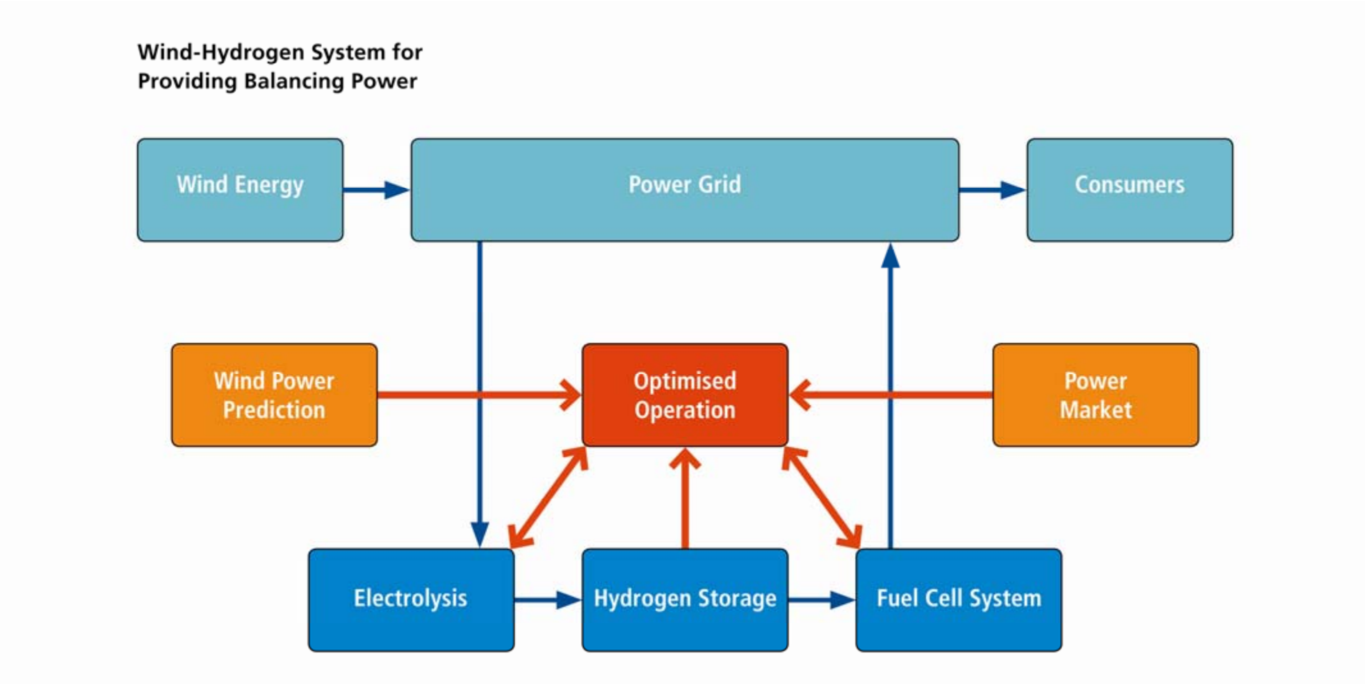

Figure 1: Principal structure of the *HyWindBalance* wind-hydrogen storage system.

Figure 2: View of the laboratory setup of the *HyWindBalance* experimental system during the official inauguration. From left to right: fuel cell unit, electrolyser, electrical control unit.

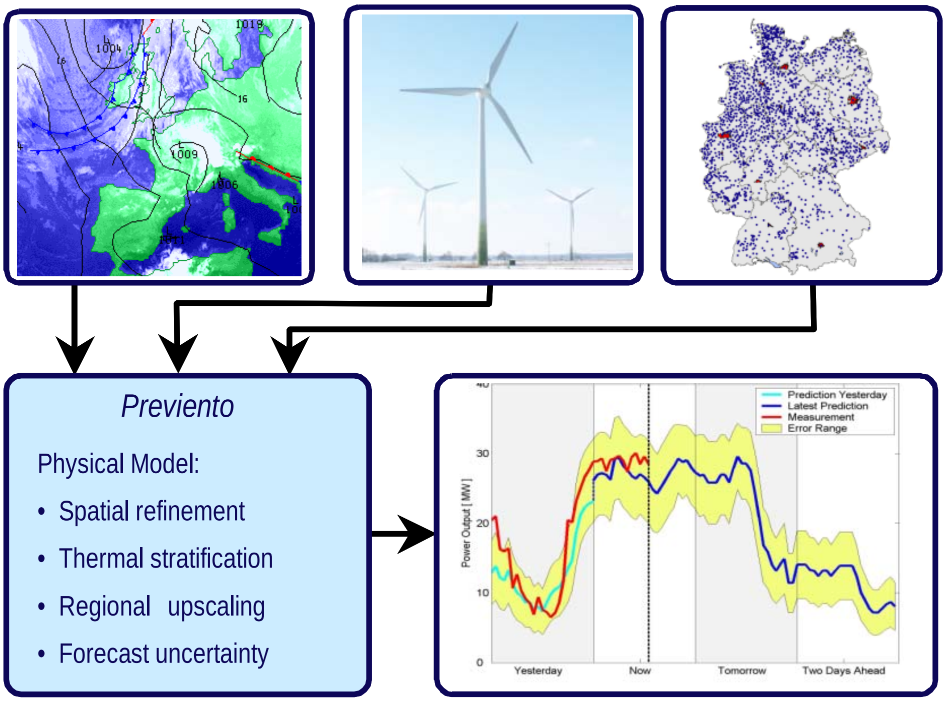

Figure 3: Basic scheme of the physical prediction system *Previento*. Based on weather data from several meteorological services and information on all German wind farms the system uses physical methods to provide a wind power forecast.