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D. Krieg, Th. Grube, D. Stolten

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Analysis of the Impact of Hydrogen on Wind Power

Dennis Krieg, **Thomas Grube**, **Detlef Stolten**, Forschungszentrum Jülich GmbH, Germany

1 Motivation for Wind Power and Hydrogen

Due to environmental circumstances (climate change, security of energy supplies, etc.) a rethinking is needed in both energy and environmental policy.

There is a general consensus that the share of renewable energy sources will increase massively in the future.

Renewable energy sources can be divided into two groups. The first group can be used almost continuously, e.g. hydro, geothermal, biomass. The second group is characterized by intermittent energy supply, such as solar power and wind.

Due to the fact that the potential of the first group is too low, energy policy must focus on the second group, whose potential exceeds energy demand by far. Unfortunately, supply and demand for energy differ enormously, which consequently leads to the fact that the power supply needs to be adjusted [1].

Wind power is the most promising alternative due to its mature stage of development and the fact that it also tends to be economically attractive. It has almost achieved a level comparable to normal coal-fired power plants. At an average wind velocity of 25 km/h, the cost of electricity ranges between 4 and 6 ct/kWh [2, 3, 4].

The target of the policy is to increase the share of renewable energies up to 2020 by as much as 30% or even 40% [5, 6]. Wind is the most successful form with average growth rates of 30 to 40% (2005) per year [7].

The wind power capacity installed worldwide increased from 1.9 GW in 1990 to almost 60 GW in 2005. Hence wind power plants delivered roughly 125 TWh of electrical power (2005), which is around 0.7% of the global electrical output [7, 8].

Estimations of the general potential of wind power plants differ enormously depending on the assumptions made. The theoretical potential is estimated to be roughly 480,000 TWh whereas only 20,000 TWh seems to be technically available [7, 9]. This technical potential ranges up to 64,000 TWh [7, 10] or even 96,000 TWh [7, 11].

Surveys of 100 wind power plants have shown that the average capacity factor is roughly 24% (2003) [12, 13]. Due to the high degree of intermittency it is usually assumed that a penetration of 20 to 30% will affect the grids, even those that are very stable at the moment [5, 14].

With increasing wind penetration the share of curtailment, i.e. the share of power that cannot be applied to the grid, rises dramatically. Calculations have shown that more than 30% cannot be used in the case of 50% wind penetration on the market (=installed wind power capacity/total installed power capacity). Hence CO_2 savings will not be as high as expected [12].

Besides selling the electricity instantaneously on the market it can be converted into hydrogen via water electrolysis.

This hydrogen can be used to stabilize the grid (e.g. lack of current wind power) or it can be used as fuel within the transportation sector.

Water electrolysis is the most effective method to generate hydrogen by electricity and generally also one of the simplest methods. Several other advantages are listed in the following [2, 12, 15]:

- Mature and commercially available technology
- Reasonable efficiency (more than 70% based on HHV) with a power demand of about 4.3 kWh/Nm^3
- Both small and large applications feasible
- High degree of purity
- Small footprint and maintenance cost
- Application of off-peak power is possible in order to reduce electricity costs.
- Fast reaction: from 16% to 100% power input within 40 seconds.
- Possibility of producing CO_2-free hydrogen: conventional steam reforming: 6 – 11 kg CO_2/kg H_2

2 Stationary Storage

Hydrogen can be used to store excess electricity. This may be done in the case of low demand or abundant wind power. This hydrogen may then be re-converted into electricity if needed [15]. The efficiency of the energy chain is roughly 33% [1].

A recent survey calculated that one kWh would cost between € 0.43 and € 1.7 , assuming the same profit as if the power had been fed into the grid [16]. This is due to the high investment costs and the tremendous energy losses.

The authors assumed an electrolysis efficiency of 65% (based on HHV, comprising all losses) and a fuel cell efficiency of 36.4%. Internal combustion engines are cheaper to purchase (200 to 500 €/kW) in comparison to fuel cells (1000 to 2500 €/kW), but also less efficient (≤ 30%) [16].

More optimistic assumptions for an electrolyzer are investment costs of 1300 €/kW [17] and an efficiency of roughly 70%. For stationary fuel cells 50% seem to be adequate [1].

As mentioned above, wind power is a power source that fluctuates greatly. Hence storage is needed in order to [1]:

- compensate for temporary blackouts which might cause contractual penalties ,
- make the input more predictable

Due to the amount of energy losses (caused by every conversion step) as well as the enormous investment costs, hydrogen is seen as a technically feasible alternative to store excess electricity but not as an economically attractive option [1].

Depending on the size of the system, different alternatives are preferred. Lead or lithium batteries are preferable for small and medium-size systems (up to a few 100 kWh). Large systems (from a few MWh upwards) in contrast prefer compressed air storage etc., which leads to a decisive advantage in procurement costs [1].

3 Application in the Transport Sector

All renewable energy sources, except biomass, have in common that they cannot be used directly as fuel.

Nonetheless, via water electrolysis it is possible to produce a clean energy carrier which can be used as fuel [12].

Other methods, such as those mentioned above, are only able to provide “electricity in – electricity out” options [12, 18, 19].

The markets for hydrogen and its related technologies are potentially huge and hydrogen could, in the long term, replace most other fossil fuels [12].

Positive is also the high well-to-wheel-efficiency that can be achieved of 22 up to 33% At present, gasoline vehicles normally have an efficiency of 15% [20, 21].

It is estimated that after market introduction it will take 15 years before the first million fuel-cell vehicles are sold in the EU. After a further 10 years up to 12 million fuel-cell-driven cars might be in operation [22]. This is in keeping with the recently published EU strategy of achieving one to five million fuel-cell cars in 2020 [22, 23].

Hydrogen may be produced on site or at centralized facilities. Centralized production needs an appropriate distribution infrastructure. Hence trucks or pipelines should be taken into account.

Hydrogen is expected to be produced via steam reforming with natural gas and on-site electrolysis with wind power in the early stages. At this stage, all transport will be realized by trucks [24].

None of the needed technologies is expected to be technically very challenging. The only exception may be pipelines due to the fact that a large new infrastructure has to be constructed, which might cause some difficulties. Therefore pipelines are not expected before 2025 [24].

Examples of a well-performing application of hydrogen are the fuel-cell buses from ISE Corporation. They need 50 kg hydrogen, which is stored at 345 bar, for a range of 400 to 480 km [5].

4 Optimizing Hydrogen Production

Water electrolysis is a well-known process. It has been established for years, but the hydrogen produced is almost exclusively used for chemical applications (e.g. margarine production) or as a coolant. No appreciable quantity is used for energetic purposes in the sense of fuel (e.g. space industry).

Due to the fact that hydrogen has completely different properties (cost, purity, efficiency, etc.) as a chemical product and as a fuel, new efforts are needed to implement hydrogen on the market.

Therefore it is very important to calculate the appropriate capacity of the electrolyzer as well as the storage system.

Besides the well-known parameters, such as investment cost, operation and maintenance, etc., three parameters have a decisive influence on how electrolyzers should be used.

The first is the electricity price (which is time-variable), the second is the fuel price and the third one is the penalty to be paid if the agreed amount of electricity is not supplied to the grid.

Today it is obvious that operators of wind power plants will supply their electricity to the grid at any time. There are no incentives, such as greatly varying prices within one day, that could induce the operator to store the electricity in order to supply it to the grid when needed.

All other suppliers suffer from this situation because they have to adjust their electricity production according to the electricity input of wind power plants. The additional losses (due to partial load and overcapacities) will ultimately be paid by the consumers.

Hence some countries, e.g. Spain, have chosen to punish wind power plant operators if they supply less electricity than agreed and if they supply more electricity to the grid.

The amount of electricity is agreed upon roughly one day in advance.

Operators adjust their behavior depending on the three above-mentioned parameters. The promised amount of electricity will be slightly less than expected on the basis of the weather forecast in order to avoid penalties. Very high penalties will make operators supply very little electricity, so that they will (under all circumstances) be able to supply as much electricity to the grid as agreed. This extreme would lead to a permanent under-utilization, which would increase the attractiveness of storage capacity. The indirect energy losses, such as wasted electricity, could outweigh the loss due to the conversion chain.

The same might occur with respect to economic attractiveness. Investment costs for electrolyzers and fuel cells may be less than those due to the wasted electricity from the wind power plant, which is never used at full load.

Therefore hydrogen might be used to store excess electricity.

Calculations by Norwegian scientists have shown that hydrogen production costs are extremely dependent on the system. Grid-connected hydrogen production costs were estimated to be roughly 2.8 €/kg while hydrogen in an isolated system will cost twice as much (6.2 €/kg). Therefore the grid-connected system is assumed to be far more economically attractive [17].

The price difference is mainly due to the components that need to be much larger in an isolated system in order to prevent too much electricity from being wasted, which would make wind power itself economically very unattractive (and consequently the whole system).

Further analyses have shown that even marginal decreases in the costs of wind power plants, electrolyzer, etc. will reduce hydrogen production costs enormously [17].

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