Wind Energy Future - Offshore and Offgrid -

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1. Introduction

Today wind energy is used for one purpose only: the grid connected operation normally combined with the obligation of the energy-taking utilities to buy all energy generated. We can call this the most simple way of application. With more than 26 000 MW installed capacity world-wide, wind energy in some countries is already reaching certain installation limits, not only concerning the availability of sites for wind farms but also the limits of capacity and regulation possibilities of the existing grid. The status reached leads to the question, if grid connection will be the only meaningful application for wind energy, or if other application options exist as well. Taking into consideration the manifold technical and economical aspects, a further diversification in the use of wind energy could happen in the following sequence: Grid connected operation (the actual use), then offshore application (the upcoming use), followed by wind-diesel-systems to save fuel (a potential market in remote areas) and last but not least wind energy powered hydrogen production (the real future option) using the hydrogen for example in fuel cell driven cars.

For grid connection, wind turbines must change from an energy producer to an energy supplier, and therefore have to fulfil fundamental grid requirements to avoid grid stability problems. Offshore is an option for the expansion of the market for all those countries which have limited space onshore, but one of the main problems will be the answer to the question where and how to feed several ten thousand MW into the grid and later distribute the energy according to the needs. Using wind energy in remote wind-diesel-systems will be a chance for a further considerable market expansion. The combination of wind turbines with existing diesel electric generators for the supply of isolated grids is an option which has been investigated already many times but never could be transformed to a real market application. The main hindrance was the existing economical risk for the manufacturers in delivering a small number of in general small wind turbines to areas far away from their homeland. The 4th development step, which will reach totally new energy consumer fields, will be offgrid wind energy produced hydrogen. At the automobile fair 2001 at Frankfurt, a representative of a large German car manufacturer explained that the real request for renewable energies will come up with the hydrogen powered cars using fuel cells.

2. Grid Connected Operation

Germany is a very good example for upcoming grid operation problems caused by a high share of wind energy in the grid. With today nearly 10 000 MW, mainly installed in the north of Germany, some regions are exporting electric energy. In the northernmost state of Germany (Schleswig-Holstein) wind energy reached 25% of the electric consumption. With a capacity factor of about 25% the installed power of wind energy reaches or surpasses the consumer peak load on windy days. Especially at night, the energy produced by wind may be higher than needed, but nevertheless has to be taken over by the grid. The problems in the future are even more severe and can be easily understood with the following example. Assuming the political plans for wind energy can be realised, Germany will have at least 47 GW installed in wind in about 25 years, roughly estimated

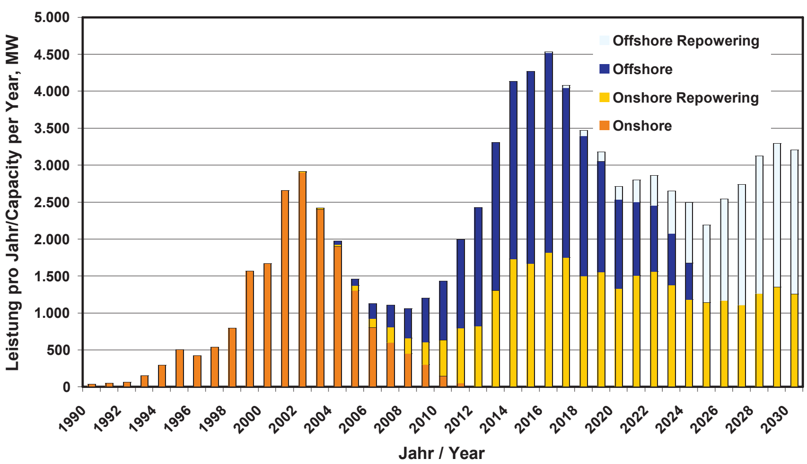

Fig. 1: Prediction of the development of the annual growth of wind energy in Germany [1]

fifty per cent onshore and another 50 per cent offshore, but both mainly installed in the north of Germany (Fig. 1, 2). The peak power needed in Germany today is in the range of 70 to 75 GW and probably will be less in 25 years due to a more rational use of energy. Comparing these two figures clearly shows that all the wind electricity produced on- and offshore cannot be simply fed to the German grid. For such quantities a European grid solution will be necessary in which wind energy has to contribute to the stability of the grid. Further on not only offshore high voltage transportation lines are necessary, but also new onshore high voltage lines must be built, to transport the high amount of wind produced electric energy from the coast to the energy consuming regions. This shows that Germany in the near future will reach the same critical situation which already exists today in the weak grids of the so called developing countries. Under such conditions one has to think about other applications for wind energy than only grid connected operation on- or offshore

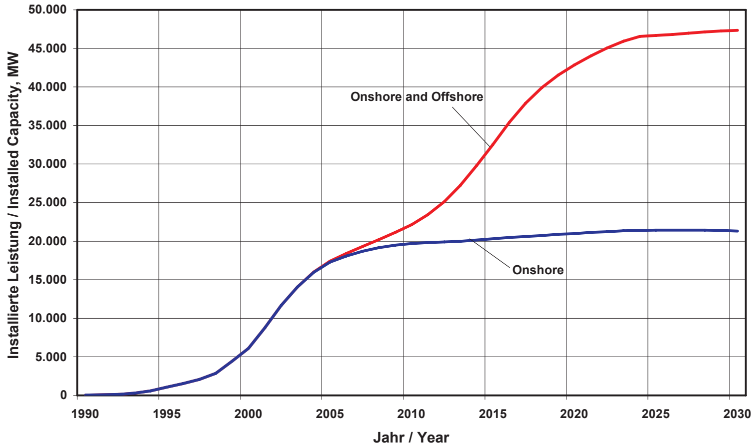

Fig. 2: Expected development of on- and offshore wind energy in Germany until 2030 [1]

3. Offshore Application

Generally speaking, offshore wind energy application is an option for all those countries which have lack of space onshore. Consequently offshore is developed today by countries with existing onshore site restrictions. Offshore in Germany can be divided into two applications. Near to the coast, where the water depth is within less than 10 m, valid also for most of the Danish offshore projects in operation or to be developed, and wind farms far off the coast with water depths of more than 30 m, as they will be developed mainly in Germany, forced by the protected shallows sea park along the north German sea coast and due to the concerns of the island administrations that tourism could be negatively affected by the visual impact of the wind turbines. Wind farms in such water depths are considered to be the real offshore challenge for engineers. Special foundations, dynamic influences by high waves, accessibility during high wind conditions and grid connection are some of the problems which have to be solved without loosing the desired economic advantages of the high winds available.

Very large wind turbines of about 5 MW and perhaps also some few MW more in the future should be used to reduce the number of turbines within a wind farm, an absolute necessity to achieve a positive cost-benefit relation of the additional expenses for foundation, grid connection and maintenance of the turbines. One of the many questions arising with large wind turbines is if these wind turbines can be manufactured at economically acceptable costs, or if due to the enormous turbine size the cost per kWh will increase already with the wind turbine itself. As shown in Fig. 3 the relation of the real list prices of wind turbines divided by their annual energy yield generated at a site of 5.5 m/s measured at 30 m height, Rayleigh distribution and roughness length of 0.1 m (the reference site definition of the German Renewable Energy Sources Act, EEG) still has the tendency of a further reduction with increasing rotor size [3]. The tendency line is derived from the superposition of two tendency lines which are wind turbine price and generated annual energy both related to the tower head mass (= nacelle plus rotor). These values show a clear development with size and therefore create a trustworthy base for the possible wind turbine price development in the future. The tendency shown opens the chance that at least the very large offshore wind turbines themselves can be developed within the desired economical cost limits. Assuming that also economical solutions for the foundations in deep water exist, the technical problems of wind turbines under offshore conditions seem to be solvable.

Unfortunately offshore means also offgrid, with all related problems. These are not only technical problems but also economical and environmental ones. With the prognosis of more than 25 GW installed in offshore wind farms in Germany until 2030 and another at least 22 GW onshore at the same time the energy produced in the North Sea and in the northern onshore regions of Germany has to be taken over, transported and distributed by the grid. Today only four grid connection points with the corresponding grid lines for distribution exist that are strong enough, but this is not enough for the above considered final development goal [4]. Until now it is unclear, how to fulfil the political request to cross the national shallows sea park by the politically desired one transmission line only. The technical as well as the economical conditions are speaking against this solution, but for environmental reasons, any other solution is likely to result in an unpredictable licensing procedure. Not much different is the problem of how to get the license for the additional overhead power lines onshore required for transporting the energy to the centres of high electric energy demand. Looking at this situation, the license for the necessary constructions of undersea and overhead grid connection lines seem to be the major hindrance for offshore wind farms in Germany under the existing nature protection laws, especially because any compromise generally will drive the grid connection cost higher and higher. Besides this problem the question arises who will pay for the construction of the lines. Their transportation capacity has to be sufficient for several large wind farms, but they certainly will not be built and ready at the same time period. The first wind farm developer will never construct and pay a grid connection with more than the capacity he needs for his own. On the other hand nature protection does not permit unlimited numbers of crossings of the shallows sea park. Therefore the lines have to have the maximum capacity technically possible. But who pays? It would need many years of pre-financing until the last wind farm is connected and at least today no practical solution exists.

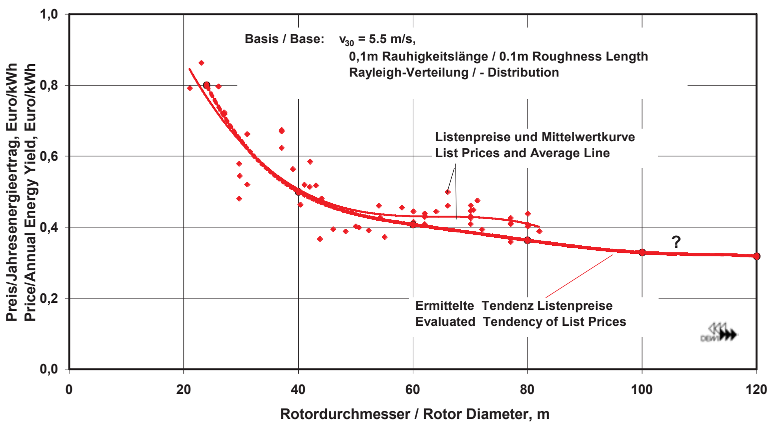

Fig. 3: Wind turbine price divided by the annual energy yield produced at the reference site which is defined in the German Renewable Energy Sources Act (EEG) [3]

This grid situation is not only typical for offshore application. For the very large areas with high wind resources existing world-wide (South Argentina, North-East of Brazil, Asia, etc.) which are often situated far away from the necessary high voltage distribution grids, the same situation exists. To be able to refinance the grid connection cost for distances to the grid of some hundred kilometres, the wind farms have to be in the size of some hundred megawatts. Assuming that several different investors want to install such large wind farms in one region, perhaps along the coast line, one cannot imagine that each wind farm will get the licence for its own high voltage overhead transmission line, which finally would be running in parallel to one another. Also in this onshore situation a joint solution for the different wind farm developers would be necessary. But again the question is arising, who is going to carry the initial investment for the joint overhead lines if the wind farms will be constructed at different times? Offgrid situations therefore are not only related to offshore applications but also exist onshore.

Another important need appears with the growing penetration of wind energy in the grids. Today (summer 2002) wind energy with its 10 GW in Germany sums up to more than 3.8 per cent of the total electricity consumption in Germany. The estimated more than 47 GW [1] will generate around 28 per cent of the German electric energy demand, assuming that offshore wind farms have a two fold better average energy yield than the onshore ones. Such a high

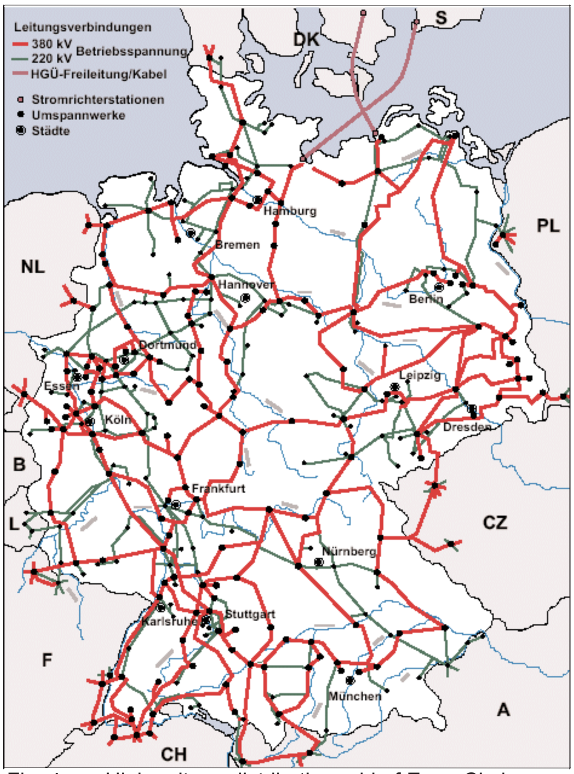

Fig. 4 High voltage distribution grid of E.on. Circles indicate the possible grid feed-in points in northern Germany [2]

share needs appropriate storage possibilities especially under the assumption that Germany will not be the only country with high wind energy penetration in the European grid system. That means wind farms have to become not only an energy producer, but also an energy supplier who contributes to the stability of the grid. Wind energy will not be able to fulfil this requirement alone. Power controlled combinations with other environmentally friendly energy producing systems like bio-mass, co-generation and hydropower perhaps together with special storage systems must be considered and introduced in our grids. This situation makes clear that the today existing electricity generating and distribution systems must be changed towards more decentralised systems which includes the use of dispersedly offered renewable energy sources. The many decentralised power plants could be controlled jointly as a "virtual power plant", which fulfils the existing supply dynamics to cover the electricity demand under a generally accepted supply security [4].

4. Wind-Diesel-Systems

Offgrid applications of wind energy can be small or very big ones, as the offshore example shows clearly. Small scale offgrid examples are diesel-electric grids which exist in numberless cases all over the world. Until now the many efforts to open up this market for wind energy by installing pilot wind-diesel plants with the wind turbine as fuel saver have not succeeded. Main hindrance is the remote location of such systems to which manufacturers normally do not like to deliver small quantities of small wind turbines without having a local service infrastructure.

Today this situation starts to change, because in more and more countries large wind farms with grid connected wind turbines are in operation, which need a service structure for maintenance and, if the market is big enough, are followed by inland wind turbine manufacturers. Wind-diesel systems therefore have a real chance to become a market sector, if companies have their production and service structure near to the existing diesel systems. In addition a sufficiently large market for grid connected wind turbines will generate competition between several turbine suppliers which then will automatically look for new application possibilities to increase their own business. The first steps towards this situation can be recognised and certainly will be accelerated in the next few years with the fast spreading of wind energy around the world.

Wind-diesel-systems have their special control problems, because supply and demand have to match at any time, if the grid shall be operated in a stable condition. Interesting to see, that the very same problems in relatively near future can occur in very large grids like in Germany, where the wind energy share in the grid will reach dimensions which are equal to those in wind-diesel-systems.

5. Wind-Hydrogen-Systems

As mentioned already in chapter 3, the offshore wind electric energy production will be difficult to integrate in the national German grid. Until now wind energy only is used for electricity production distributed by large supply grids. The offshore application of wind energy consequently must be the starting point for other considerations concerning the use of wind energy in the future. Until now wind energy not reached an application in the transportation and heating field in which most of the valuable energy is used by mankind today.

Different solutions for offshore or offgrid hydrogen production could be considered. Offshore electric energy generation with the transportation by cable to the continent with an onshore production and storage of hydrogen for the use in cars, or the offshore hydrogen production with the following transportation in ships to the consumer centres. In addition to offshore applications, large areas of high wind resources but without consumers are often situated in countries where local investors cannot provide the sufficient capital to install large wind farms so that these areas would remain unused for wind energy. In case of producing hydrogen for cars, multinational companies will be involved which are able to invest the necessary capital to install, operate and transport hydrogen and to use it in a world with a decreasing resource of fossil fuels for keeping up the mobility of mankind. Remote areas are also far offshore areas, for example in the North Sea, where hydrogen could be produced and then transported by ship to the harbours around. This option avoids the necessity of strong grid feed-in points with additional onshore high voltage power lines and long and expensive sea cables, but needs a hydrogen distribution and consumption infrastructure which does not yet exist. Another disadvantage is that the product cycle efficiency is not very high, so that much more energy is wasted than in the case of grid connection. On the other hand wind energy can enter in new applications like transportation systems and heating.

6. Conclusions

The very fast development of wind energy, especially in Germany raises the question what to do with the high amount of wind produced electric energy. The grid will reach its control and transportation limits, new joint offshore and additional onshore high voltage transportation lines will be necessary, which are not only difficult to succeed in the licensing procedure but also in organising the necessary prefinancing. Wind energy therefore needs application forms which are not based only on grid connection. Offgrid solutions open up the chances to reach new application fields like hydrogen-using fuel cell driven cars, house heating, water desalination and wind-diesel-systems.

Important is that the medium produced by wind energy is a final product which does not have to be transformed again for its further use. Hydrogen, if used in fuel cells of cars or in heating systems, is such a product. Desalinated water or the storage of high pressure air needed in gas turbines for the electricity generation are other "products", which can be used directly without further transformation losses. Only if wind energy is able to develop offgrid applications, the full capacity of wind energy on earth can be used in the future. The time to start the development of new application forms of wind energy has already arrived, because any technical development in the energy field needs at least 20 to 30 years to become an integrated part of the energy supply system. The forecasted optimistic further growth of wind energy during the next 30 years will be possible only if wind succeeds to open up new application fields.

7. References

[1] WindEnergy 2002. Market Development Expected by the Industry until 2010. Press release of the Hamburg Messe- und Congress GmbH, March 2002

[2] Grid map by courtesy of E.on Netz.

[3] Molly, J. P.. Technical Trends in Wind Turbine Development. DEWI Magazin no. 20, Feb. 2002, DEWI, Wilhelmshaven

[4] Santjer, F., Teichmann, K., Steinert, W.. Basics and conception of a virtual power plant in Germany. DEWI Magazin no. 20, Feb. 2002, DEWI, Wilhelmshaven