Integration of Wind Power by DC-Power Systems

Ola Carlson and Stefan Lundberg

Abstract-- The world climate changing is driving the electric power production towards renewable energy sources. The development of wind turbines has reached the power level of 5 MW and wind farms up to 1000 MW are planned. Investigations have shown that the cost for production of wind energy is in the same level as coal and gas. The large amount of hydro power in the Nordic countries can be used to compensate for the irregularity of producing wind power in Europe. High voltage direct current connections between Sweden and Germany, with a wind farm between can be a solution in the future.

I. INTRODUCTION

The world climate is changing, the temperature has increased by one degree Celsius lasting the past 100 years and the CO$_2$ concentration in the atmosphere is rapidly increasing. The use of fossil fuels has to decrease to save the world from more increase in temperature. To achieve this electric power must be produced using renewable energy sources, such as hydro, wind and solar power. This paper is a contribution to the panel session on PowerTech 2005.

II. WIND TURBINE DEVELOPMENT

The development of the modern wind turbine started in the early 80s. During that time the power of a typical wind turbine was 50-100 kW and the diameter of the turbine was typically 15-25 meter. The tower height was 20 meter. The largest prototypes of wind turbines of today are over 100 m in diameter, with a hub height of 100 m and power output close to 5 MW. There are still design efforts exploring solutions for even larger turbines.

The driving force behind this development is the cost per produced kWh. For this reason and to avoid spreading wind turbines over a very wide area in the landscape, wind turbines are today planned and erected in large groups called wind farms. These wind farms have a total installed power of 10-1000 MW. The produced power of a wind turbine greatly depends on the wind speed at the site. This can clearly be seen in the Nordic countries where wind turbines are placed in the western part of Denmark southern part of Sweden and on the island Gotland in the Baltic Sea. In Norway, large wind farms are being installed on the west coast. Today close to 20 % of the, the electricity of Denmark is produced by wind power, this is also valid for Gotland. For the rest of the Nordic countries the figure is less then 1 %. During high wind and low load there is a surplus of wind power on the west part of Denmark, on these occasions wind power has to be exported to Sweden, Norway and Germany.

The Danish company, BTM Consultant, has published on their website that the annual growth of wind power has been 26 % during the last five years. The total amount of installed wind power by mid 2004 was 42,000 MW. BTM Consultant predicts the amount of wind power to be 95,000 MW by 2008 and 194,000 MW by 2013, [1].

The cost of producing electric power with newly built production plants has been investigated by the Swedish research organisation Elforsk, [2]. The result of the investigation shows that wind power has the lowest cost in Sweden if taxes and Green certificates are taken into account. The cost of production is 20 Euro/MWh for wind power and about 50 % more for biomass and gas. Without taxes and subsidies, the cost is more equal, about 40 Euro/MWh, see Figure 1.

III. COMBINATION OF WIND AND HYDRO POWER

In the Nordic countries, the electric power mixture is as follows: Hydro:54 %, nuclear: 23 %, fossil fuels: 22 % and wind power 1 %. In Sweden, the power mix is about 50 % hydro and 50 % nuclear.

The use of renewable energy sources, such as, hydro, wind and solar will always give an uncertainty of possible energy production. The energy of hydro will vary +/- 30 % on a yearly base during a period of 30 years, wind will vary +/- 20 %. The capacity factor (one year production divided by one year production with rated power) of hydropower in Sweden is about 50 % and wind power is 25 % on shore and up to 40 % off shore.

These figures clearly show that hydro and wind energy can complement each other in a good way. When there is a lot of wind the water is saved in dams, and when there is no wind, power can be produced using water. In Sweden,
the use of electricity is 150 TWh per year. Investigations have shown that with 30 TWh of wind power in the system there will be no extra costs due to the irregularity of producing wind power. Another study treated the combination of wind and hydro in a river, in the northern part of Sweden. It shows that if 30 MW wind power are installed close to the hydro power station the wind turbine spillage out of possible production will be 1.5 %. Out of 90 MW wind power the spillage will be 7.3 %. Hydropower generation is 250 MW, which is also the power limit of the grid. Similar studies are carried out in [3].

Bipolar Transistors (IGBT). The IGBTs are connected to form a Voltage Source Converter (VSC) and thereby the power can flow in both directions with the same voltage polarity, both active and reactive power can be controlled. It is also possible to build a multi terminal scheme, see Figure 2. The HVDC-VSC is also of compact design and suitable for operation from an offshore platform.

The layout in Figure 2 illustrates the potential to transmit 500 MW in any direction between the two countries or to transmit 500 MW of wind power to Sweden and at the same time transmit 500 MW to Germany.

Fig. 2. HVDC Wind farm connection.
V. CONNECTION BETWEEN THE SCANDINAVIAN COUNTRIES AND THE MAIN LAND OF EUROPE

As suggested in Figure 3, the Scandinavian countries should be connected to the main land of Europe by HVDC-VSC connections and offshore wind farms should be connected in between. This will allow the transmission lines to be used for several purposes as follows:

- Trading of electric power between Scandinavia and main land of Europe.
- Optimal use of the hydropower in the northern Scandinavian countries to balance the wind and solar power of Europe.
- Transport of wind energy to onshore consumers.
- The risk of voltage stability problems in the grid is reduced due to the control of reactive and active power.

VI. WIND FARM LAYOUT

The grid within the wind farm can be designed with AC-voltage and one HVDC-VSC connection to the DC-cable. It is also possible to have a single rectifier connected to each wind turbine generator and make a DC-grid within the wind farm. To control the torque of the wind turbine and the rise of voltage for transmission of the power, there is a need for at least two types of DC/DC-converters. In [5] a Boost Converter is suggested for the current control and a Full Bridge Converter for the increase of voltage. It is also possible to connect the rectified voltage from several wind turbines in series and thereby increase the DC-voltage. In [6] it is shown that a wind farm with series connected wind turbines can be the most economic solution for a offshore wind farm, for the electrical layout see Figure 4. Although, there are several new technology challenges to overcome, such as the following:

- To design a transformer for high frequency, 5-10 kHz, and high voltage with the rated power of 5 MW
- Type of insulation of the windings
- What type of material should be used in the core of the transformer?
Due to the electrical model the fast transients are neglected in the simulations. The wind turbine model is a third order model with a mechanical two mass model. In the IEA, Annex XXI, “Dynamic models of wind farms for power system studies” similar research is being carried out. Previous research on this subject is presented in References [7] and [8].

Fig. 5. Measured and simulated active power of a wind turbine during a voltage dip.

VIII. REFERENCES


IX. BIOGRAPHIES

Ola Carlson is associate professor in the department of Energy and Environment, division of Electric Power Engineering at Chalmers University of Technology, Gothenburg, Sweden. He received his M.Sc. degree from Chalmers University of Technology in 1980. He has been working in industry for three years with variable speed systems for wind turbines. In 1988 he received the PhD-degree and in 1999 the associate professor position. His major interests are electrical systems for renewables and hybrid electric vehicles.

Stefan Lundberg was born in Gothenburg, Sweden in 1976. He received his M.Sc. in 2000 from Chalmers University of Technology. He is now working towards his Ph. D at the department of Energy and Environment, division of Electric Power Engineering. His area of interest is the control and modeling of wind turbine parks.