First International Workshop on Feasibility of HVDC Transmission Networks for Offshore Wind Farms

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The workshop consisted of four sessions spread over two days.

- Session 1: HVDC Transmission Systems – New Converter and Cable Technologies
- Session 2: Advances in Offshore Wind Energy Technology
- Session 3: Systems aspects and Grid Interconnection
- Session 4: Business Models for the Operation of Offshore HVDC Transmission Networks

Each session consisted of 1-2 hours of presentations and at least 1 hour of discussions.

Session 1: HVDC Transmission Systems–New Converter and Cable Technologies

The first presentation was given by Gunnar Asplund of ABB Power Systems, Ludvika, Sweden, entitled 'Overview of New HVDC Technology'. The presentation gave an overview of the new Voltage Sourced Converter (VSC) HVDC technology, which is now being produced commercially by ABB under the brand name 'HVDC light'

This technology uses Insulated Gate Bipolar Transistors (IGBTs) as opposed to the thyristors used in traditional HVDC systems. The IGBTs switch very fast between two fixed voltages. Pulse width modulation (PWM) and low pass filtering are used to achieve the desired AC waveform. PWM allows control of both active and reactive power flow. Less components are required than for traditional HVDC systems, this means that the converter stations for the new technology take up about 20% of the area required for traditional converter stations for the same power level. The converter stations are constructed as self-contained modules and are therefore easily installed.

In conjunction with the converter stations ABB has also developed triple extruded cables for HVDC light applications. Cables are operated in bipolar pairs which are laid close together to eliminate magnetic fields.

So far seven converter systems have been ordered for different applications from flicker mitigation to windpower applications. The same converter stations are used, but with different control set ups. So far only units with power ratings up to 65 MW have been constructed, but the next generation is expected to be up to 200MW units.

The second presentation was given by Olof Martander from Chalmers University of Technology in Göteborg, Sweden, entitled 'Power DC/DC converters, solutions for a HVDC wind park'

Suggestions for four configurations of power collection systems for offshore wind farms were made:

- AC bus and AC Transmission
- AC bus and DC Transmission
- DC bus and DC Transmission
- Multiple level DC

The last two options would allow individual variable speed operation of the turbines, but one of the principle components required would be DC/DC converters. Three different topologies for DC/DC converters were suggested

Boost
Half Bridge
Full Bridge

However, present technology DC/DC converters are not able to cope with high powers and development in this area is still required. Losses and costs are also high and research in this area is continuing.

The discussion at the end of session 1 was very interesting and a number of points were raised.

Questions about the reliability and maintenance of the HVDC light system were raised. The response to this was that there is redundancy incorporated into the switching circuits with multiple components in series which are designed to fail to short circuit so that operation can continue with up to a certain number of components failed. The maintenance interval was unclear, as no systems have been in long enough to determine this interval reliably. The manufacturers are aware of the importance of the maintenance period and are aiming for one year or longer. The cooling system of water and antifreeze is contained within the unit. The response to a query on protection was that work on fast semiconductor DC breakers was continuing.

The question of flicker was also raised, and it was noted that the better reactive power and voltage control provided by the HVDC light system will lead to a reduction in flicker. The same converter stations, but with different control set ups are being used to reduce flicker. One point raised was that most flicker problems at present are close to fundamental frequency, flicker nuisance peaks at 10 Hz. Could higher frequency flicker, caused by the fast switching IGBTs lead to different problems in the future? The issue of high losses due to the switching of the IGBTs was also raised.

DC connection could lead to a change in the possible operating options of offshore wind farms, for example the ability to optimise power by using variable speed, either individually at each turbine or collectively for the entire wind farm.

One complaint was that no price information was given for the new HVDC light technology, this makes the costing and financial comparison of different options difficult.

Questions on the advances of AC technology and whether it could compete with the new DC technology were raised, but there was little representation in this area and it was not possible to have a discussion comparing the two technologies and optimum transmission distances. However this was noted as a possible topic for future workshops.

Session 2: Advances in Offshore Wind Energy Technology

The first presenter of this session was Paul Gardner from Garrad Hassan & Partners, UK, on ‘Offshore Wind Energy: Resources Technology and Grid Connection’

The first section of the presentation discussed the offshore resource available within the European seas. It was stated that it is not the lack of resource that was preventing development of offshore wind, but political and financial reasons. A review of five existing offshore wind projects was given with a summary that they are all in shallow water, close to shore and use relatively small turbines. A summary of some proposed projects was then given and the contrast in turbine size was the most notable difference, with turbines in the 2+ MW range being proposed for these new wind farms. Predictions were made that in the future turbines would get larger, with specialised offshore wind turbines being developed.

A breakdown of predicted costs for an offshore wind farm was given, and the transmission system is likely to account for about 18% of costs, one of the largest costs in the project. This means that optimisation of costs in this area would be very beneficial.

The point was raised that tip-speed could be increased for offshore wind farms in order to reduce torque and optimise energy costs. This is possible due to less restriction on noise offshore. The benefits of variable speed operation were also discussed along with three possible connection options.

- Conventional: AC/DC/AC within turbine
- Possible: use DC bus within wind farm
- Possible: use DC link to shore to give 'grouped variable speed'

The principal differences between offshore and onshore electrical systems were discussed and the options for AC electrical systems within a wind farm, including voltage levels, cable installation, configuration and redundancy.

Queries about DC transmission and possible options including the DC connection of multiple offshore wind farms, effectively an offshore DC network, were raised.

The second presentation was by Koen Macken of TU Delft, Netherlands on 'DC Transmission Systems in Offshore Wind Farms'. This presentation proposed some configurations for DC bus collection systems. These included radial and loop configurations of clusters, either to collection points onshore or offshore. Suggestions for the connection of DC sources were

- Series connection
- Separate connection
- Parallel connection

A technical comparison of a DC step-up converter and an electronic DC transformer was undertaken, including the utilisation of active switches and diodes, size of magnetic circuit and the size of the filter capacitors.

The third presentation was on 'Computer Models of Grid Connected Wind Turbines' by Vladislav Akhmatov of NESA, Denmark. Results from a study of various computer models were presented. This included the modelling of networks using different simulation packages, PSS/E and EMTDC, as well as studies of two different shaft models, one with lumped inertia and the other with two rotating inertias.

Conclusions drawn were that in order to achieve results from studies of systems containing large numbers of induction generators, the generator should be modelled to include a DC offset and better representation of the rotor shaft.

In the discussion following session 2, one of the main topics raised was that of variable speed operation of the wind farm. Variable speed allows flexibility in power production and can benefit the network, but who pays for this benefit?

There were a number of benefits of variable speed operation discussed, including the ability to overcome the problem of varying tower resonance, caused by differing conditions on the sea bed. There is less loading on the tower and on the gearbox. In combination with pitch regulation variable speed turbines can keep generating at high speeds, but below rated power. This can avoid sudden cut out with a drop from maximum power to zero power, which could cause difficulties on networks with large wind farms. The question was raised that if variable speed machines already convert to DC with power electronics would it be possible to connect as a DC bus at this point. However, the point was raised that in variable speed machines not all of the power necessarily passes through the power electronics of the DC converter.

There was a further discussion of the power collection systems within the wind farm, including using the variable speed DC control for the entire wind farm or cluster rather than for individual machines, which a DC link could provide. This would reduce the mechanical benefits of variable speed due to the differing sea bed conditions at each turbine and turbulence fluctuations. However, if grouped as a ‘soft’ network the frequency should be closer for all turbines than onshore, due to the more even topography offshore.

There was also a discussion on harmonics, which included queries as to the clarity of rules and standards in this area. The Voltage Source Converter (VSC) HVDC system has 6kHz pulse and therefore has less harmonics and cheaper filtering that traditional HVDC systems.

Session 3: Systems aspects and Grid Interconnection

The third session started with a presentation by Peter Christenson of NVE HVDC Group on ‘The Integration of Large Offshore Wind Power Plants – System Aspects, STATCOM, Stabilisation and VSC HVDC Connection.

The targets for Danish wind power are 1950 MW of onshore wind by 2000 and 4000 MW of offshore wind by 2030. This will inevitably affect the transmission and distribution system in Denmark. The main problems were split into three groups.

- Global Power System: Frequency regulation, Voltage regulation, Transient stability, Stationary stability and Low Frequency oscillations (0.3 – 2 Hz)
- Regional Transmission Systems: Thermal Capacity, Losses , Need for new lines
- Local Transmission Systems: Voltage collapse, Stability, Flicker

Advantages of using STATCOM were highlighted. Results of simulations with combinations of onshore wind farms, offshore wind farms and models containing shaft dynamics were presented.

VSC HVDC connections were considered next. Simulation results were presented and the conclusions drawn were

- The system can cope with longer failure times than with the AC-STATCOM solution, an increase from 100 ms to 250 ms
- The mechanical stress on the wind turbines appears to be less than with the AC-STATCOM solution.

The next section discussed the advantages and disadvantages of both AC and DC power collection systems for offshore wind farms. The fact that AC transmission is proven technology, where VSC HVDC is not, is a strong point in favour of the AC option. However, VSC HVDC has a number of advantages in terms of system control.

Other technologies suggested as possible solutions were doubly fed induction generators and hybrid HVDC schemes, however technical and financial constraints of these methods were recognised.

The conclusions of the presentation were:

- Today’s technology is not optimal when used for large-scale offshore application and development will be required in the future.

- VSC HVDC technology solves most of the problems at the same time and therefore has a good potential for future use. However demonstration projects and verification will be required.

The second presentation was on the application of 'HVDC Light on the Swedish Island of Gotland' by Ana Díez Castro from Vattenfall Utveckling, Sweden. The presentation began with a description of the electrical system on Gotland.

Gotland currently has 60 MW of wind power based in the south of the island and the main load is to the north, where there is also a conventional HVDC link to the main land. The loads on the island are min 47 MW and max 175 MW. There is a demand to increase the wind power production possibly up to 300 MW this could lead to a number of problems including overloaded AC lines, deficient power quality including flicker, dynamics and losses. Improvement of the system was therefore required. The system requirements were

- Increase in power transmission capacity
- Reactive power support for wind power plants
- Improve and maintain power quality
- Reduction of voltage dips under short circuit and dynamic stability
- Power loss minimisation

The two main alternatives were AC with voltage stabilisation equipment, either with overhead lines or underground cables, however this would result in problems with reactive power; the other option was HVDC light with either overhead lines or underground cables. There are often problems getting permission for overhead lines so the cable option is preferred. The advantages of HVDC Light include

- Independent controllability of active and reactive power
- Fast AC voltage control
- Fast installation
- Possibility of running isolated

The two converter stations are identical and at no load situations can either be blocked or voltages reduced to decrease no load losses in the cables.

Simulation results showed improvements in fault and short circuit response with the HVDC Light system included, even with twice the existing wind power. Flicker predictions also showed an improvement from the existing system, which had caused complaints from customers in the past.

The protection system includes

- Temporary blocking
- Chopper
- Permanent Blocking, tripping of AC breaker
- Back up protection
- Voltage arrestors
- AC grid integrated protection

The HVDC light system fulfilled the system requirements and had the further advantages of minimisation of environmental impact, redundant feeding to Visby and protection for the AC grid integrated into the HVDC light station.

The third presentation was on 'System Aspects of Large Amounts of Offshore Wind Power' by Lennart Söder who is a professor in the Electric Power Systems department at KTH. The presentation began with the benefits of offshore wind power in terms of the wind regime. There is less turbulence offshore and changes in wind direction have less effect than onshore due to the topography and lack of obstacles.

The rest of the presentation was based around the ‘value’ of offshore wind as a power source. This included both ‘True’ value and ‘Market’ value. The values discussed were

- Operation cost value of wind power, which was positive due to replacement of highest cost generation
- Energy reliability value of wind power, which is positive in dry years when hydro power is low
- Control Value
- Primary control value was negative
- Secondary control value was negative
- Daily regulation was negative
- Seasonal Planning and scheduling was positive as both wind power and load are higher in winter.
- Loss reduction value is positive due to the wind power being closer to the load
- Grid investment value varies from project to project

The last presentation of this session was by Hans Knudsen from NESA, Denmark on ‘Offshore Wind Farms in the Danish System’. With the target 4000 MW for offshore wind power in Denmark by 2030 there are a number of technical challenges to be tackled.

- Voltage Quality
- Voltage Stability
- Transmission Capacity Requirements
- Production Planning
- System ‘Stiffness’ and Reserves
- Network losses

Results from the modelling of the entire network, including onshore and offshore wind farms and CHP plant were presented. The alternatives available for the connection of offshore wind farms are

- AC connection of wind farms
- HVDC connection of wind farms
- HVDC reinforcement
- Combination of HVDC and AC

NESA have developed models in co-operation with ABB for SVC, STATCOM and VSC HVDC. The technical solutions to the voltage collapse problem were

- Shunt Compensation
- SVC STATCOM
- Synchronous Condensers
- Synchronous generators
- Transmission reinforcement
- HVDC (VSC) radial grid connection

The solution decided upon was to connect the first two offshore wind farms using conventional AC technology with reactive power compensation as required. This is the cheapest solution for the first two wind farms and uses proven technology. New technical developments will be taken into consideration when the connection of the third offshore wind farm is being considered.

The discussion at the end of the session included a number of issues on system aspects. One of these of particular relevance in Denmark, where there is high wind power penetration is that of 'Where does the system reserve come from?' With wind farms reducing the need for existing synchronous generation there is a loss of system inertia and reserve generation. What can be done to solve dynamic problems? Denmark currently uses transmission from other countries, such as Sweden which has a large hydro capacity, in these situations, but in the future and in other countries this may not be possible.

The current practise of switching out wind farms when there are system problems will not be practical in the future as the large loss in production by switching out large wind farms will lead to system problems. Therefore, wind farms should be able to sustain any given fault without removal of large amounts of production.

Other issues raised were in the regulation of power from wind farms. In the future wind power may not have priority in terms of unit commitment and this must be considered.

Suggestions were made about the possibility of moving short-term frequency control to customers by having some form of load control which is linked to price. However, this would require a great deal of technical and market research.

Questions raised about the HVDC light system included how prioritising between active and reactive power takes place. In Gotland at the north end active power is given priority in order to maintain the DC voltage. In order to come up with a solution to system problems the requirements and characteristics must be specified and possible solutions assessed for each individual case as carried out in Gotland.

Session 4: Business Models for the Operation of Offshore HVDC Transmission Networks

Session four started with a presentation titled 'Some thoughts on Market Regulation and Business Models for HVDC Networks for Offshore Wind Farms', this was presented by Jens Hobohm of Prognos AG, Berlin, Germany and Thomas Ackermann of KTH. This presentation introduced the concept of offshore HVDC networks. The incentive behind the idea is that there are several plans for large offshore wind farms and a large potential for more. However, there are only a limited number of grid connection points available. Advantages of HVDC networks include

- Smaller number of cables going ashore, less grid connection points required, also less environmental impact at shore, particularly valid in Germany where much of the coastline is national park.
- Power quality equipment can be at the connection points rather than at each turbine
- Better load factors of HVDC lines
- Higher redundancy
- Higher flexibility at feed-in points
- Possible reduction in cost of grid extension onshore

Cost estimations were based on those from the Viking cable project. For a 70 MW, 100 km HVDC Light project the cost estimation, including the converter stations but not the cable laying, was 30 Million US dollars (£18.9 Million), which works out at 4300 US dollars per MW km (£2700 per MW km).

A basic calculation for 600 MW, 300 km system came out with a transmission line fee of 5.4Pfennig (1.7p) per kWh. The feed-in tariff in Germany is about 16 Pfennig (4.9p).

The load factor of the network can be up to 30%-35% and can be increased by linking numerous wind farms. Connection to the Scandinavian hydro system could double the load factor.

The changing regulations and differences in each country could lead to difficulties in trading wind power internationally and in funding long-term investments such as an offshore HVDC network.

The barriers to investment are

- High investment costs
- Singular long-term planning for each wind farm
- Changing regulations
- New technology
- Need long-term political support
- Environmental concerns
- Competing interests
- Acceptance by authorities and other groups

The conclusions to the presentation were

- The economical advantage of a HVDC network is uncertain due to high investment costs
- Broad agreement including grid companies is needed for realisation (possibility of grid companies being the operators)
- In depth analysis is needed for each country

The final presentation was by André Bitén of Vattenfall, Sweden on 'The Baltic Ring Study - What can we learn from it?' More information on the study is available on the website (www.BalticRing.com). The aim of the Baltic ring study was to investigate the possibilities for gradually developing a common electricity market in the Baltic region and to improve the socio-economic and environmental conditions of the countries involved. There were about 18 companies involved in the project, many of which were utilities companies from the various countries.

The ring should lead to benefits to customers and producers and improved trading of electricity. Running costs should be reduced and investment can be reduced due to capacity sharing to cope with peak power and reserve capacity. There already exists a surplus of generating capacity and the more polluting sources of generation can be reduced or replaced with more environmentally friendly forms of electricity generation. Existing transmission lines are sufficient for optimising power trading, except for a link required between Poland and Lithuania. However, disadvantages may include the danger of environmental dumping, where cheap electricity is imported from countries with less strict emissions control, such as Poland. Other problems are that subsidies for the reduction of pollutants vary between countries and EU subsidy would probably be required to run the system.

Issues raised following this session were about connection costs. It has been found to be difficult to get prices for equipment and installation costs, such as cable laying. Suggested costs for transmission for 400 MW over 100 km were 230 Million Marks (£71 Million), broken down into 160 Million marks (£21.6 Million) for the converter stations and 70 Million marks (£49.4 Million) for the cables. This equates to about one-third of the total cost of the wind farm.

Questions about corrosion problems and magnetic fields of DC cables were raised, however laying cables in dipolar pairs in close proximity can reduce these problems.

Some paper cables can be converted between AC and DC. The same cable can be used for 150 MW AC and can then be used for 600 MW DC, as the insulation can withstand higher DC voltages than AC voltages. This raised the suggestion that it may be possible to lay AC cables initially for a smaller wind farm, then if the wind farm were to be extended the same cable can be used but for DC transmission.

Suggestions were made that the first offshore wind farms could incorporate a small DC transmission section as a demonstration project. For example if four connections to shore were going to be made maybe one could be DC.

It was suggested that any future workshops should include discussion of AC transmission options as well as DC options in order to give a better overall picture of the options available. This aspect was not covered by the workshop and there was little representation from people in the field of AC transmission.

An e-mail discussion group has been set up for people interested in the topics covered in this workshop. If anyone would like to join the discussion group please refer to the following website: www.egroups.com/group/Transmission-S-F-Offshore-Wind-Farms or e-mail Thomas Ackermann at Thomas.Ackermann@ieee.org.

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