Innovation Challenges and Economics for HVDC Stations

Projektleiter
Prof. Dr.
Karl-Josef Diederich

Kooperation
Ferdinand Lutz
IPL Technology GmbH
Kempen
Peter Steinfeld
Essent Wind
Deutschland GmbH
Hannover

Kontakt
Prof. Dr.
Karl- Josef Diederich
Fachbereich
Informations- und
Elektrotechnik
Fachhochschule
Dortmund
Sonnenstraße 96
44139 Dortmund
Tel.: (0231) 9112-327
E-Mail: diederich
@fh-dortmund.de

Abstract

Electrical schemes discussed for the connection of offshore wind parks include AC and DC technology. Overall costs are the decisive factor, and this includes planning, investment, and operational costs. When the distances increase, HVDC becomes the attractive option. In this paper, some published data on investment costs, losses, and reliability for HVDC technology are presented and discussed. It seem possible on all three aspects, and then overall cost reduction exceeding the investment for the stations might be achieved. In the author's opinion, innovations and technical improvements in HVDC station technology are most challenging and rewarding.

Introduction

Various schemes for AC and DC connection of offshore wind parks are discussed since long. Data on component costs, on losses, and on technical feasibility are, however, often loaded with high uncertainties, e.g. over the question whether costs or prices are presented and compared. Often, results from one study can hardly be compared with those from another, due to different assumptions and conditions. In principle, three technology options are discussed: AC (50/60 Hz), "classic" HVDC-LCC (line commutated converter) technology, and "new" IGBT-based HVDC-VSC (voltage source converter) technology. When the distances increase, and due to some technical advantages, HVDC is an attractive option.

Cost analysis for offshore wind parks clearly shows, that low losses and high reliability are of key importance. Up to now, the fairly novel HVDC-VSC technology shows considerable losses within the station itself, and reliability (unavailability) of HVDC-VSC stations is not yet proven. Reliability data collected for on-shore electrical equipment may not be valid for off-shore installation. Measures to upgrade T&D equipment for more severe environmental conditions (climate, electrical conditions) of off-shore installations are necessary.

Not only existing HVDC technology has been analyzed, but also alternative schemes are discussed [1,3,8]. DC grids, e.g., require DC/DC converters, and may result in a further loss reduction in cables. Also, they may allow favorable operation options for the turbines. However, technical and economic questions for realization remain [8].

So, real innovations in HVDC station technology may be necessary to achieve further overall cost reduction. IEA has identified HVDC station costs as a bottleneck and claimed the necessity for further R&D already 10 years ago [4]. This paper focuses on possible overall cost reductions through innovations in HVDC station technology.

Investment, Costs, Losses and Unavailibility

Investment costs can be directly compared with losses and unavailability, when their economic effect is taken.

Published data on component costs, on losses, and on technical feasibility are often very specific. In some cases, there is a focus on special components, without an overall system analysis. Manufacturers as well as universities have published cost estimates. Some are given below as reference, to allow some quantitative analysis for identifying innovation potentials.

A paper by Wensky [2] gives a comparison on investment and installation costs and on losses to be expected for AC and DC schemes, and how losses must be valued cost-wise.

Wensky discusses three major cost blocks: capitalized losses (taking net present value), investment costs, and cable installation costs. Estimates are given not only for these blocks, but also for the individual components that make up the blocks. Cost of unavailability is not looked at in this paper.

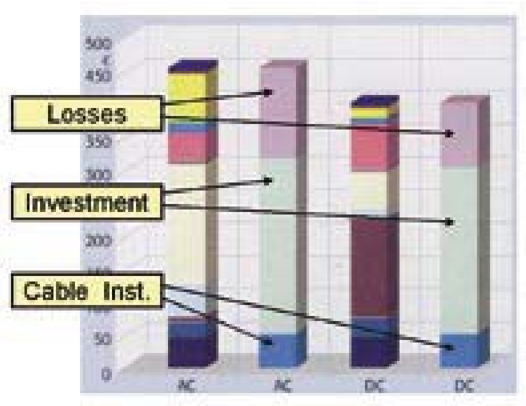


Fig. 1: cost element comparison for AC and HVDC-VSC electrical connection (taken from [2], and modified)

Components considered for investment costs include:

- transformers (for AC & DC)

- cables (for AC & DC)
- valves (for DC)
- shunt reactors & filters (for AC & DC)
- station platform (for AC & DC)
- switch gear (for AC & DC)

In the analysis, investment cost for HVDC VSC technology is the same or less than for AC technology. Analysis from Brakelmann [3], however, finds that for a 2 GW offshore project investment costs for AC would be roughly half of the costs required for DC schemes.

Some valuable information on costs can also be taken from [5] and [6].

Investment costs for HVDC VSC stations are estimated at 110 thousand € per MVA [6]. For an offshore wind park connection, two stations are required, bringing necessary station investment to 220 thousand € per MVA.

For HVDC LCC stations, the cost is reduced to some 80 thousand € per MVA, bringing necessary station investment down to 160 thousand € per MVA.

Comparable values can be found in [5]. Cost for one AC/DC 420 MW converter station with VSC technology is estimated (2004 prices & currency exchange rate) at 62 million US$. Platform costs are estimated to increase by roughly 32 thousand US$ per MVA over the platform costs for AC technology.

Summarizing the findings in the papers cited, it can be concluded:

A major cost block in AC schemes is cables (onshore, offshore, and park cabling; investment and installation). HVDC schemes have considerable lower costs for this.

The major investment cost block in DC VSC schemes is, by far, the converter station ("valves"). Any innovation aiming at a reduction on investment cost may start here.

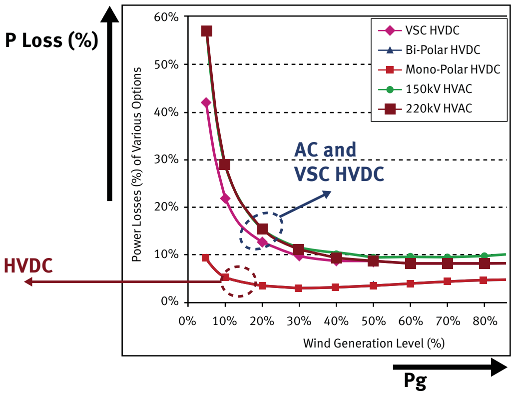
Components contributing to losses considered in [2] are:
- transformers (AC & DC)
- cables (AC & DC)
- valves (DC)
- shunt reactors (AC)

Ranking the estimated losses, AC cable losses are followed by DC converter losses. Third are AC shunt reactor losses.

Both AC cable losses and AC shunt reactor losses are depending on transmission distances, while DC converter losses are not. This is a reason, why also from a loss perspective AC is the preferred solution for short transmission distances.

In HVDC schemes, cable costs might be further reduced, when DC grid technology (DC/DC converters) are introduced, and then also within the park AC cables can be replaced by DC cables. DC/DC converters have been discussed since some years [1]. Still, technical and economic issues seem to remain a challenge [8].

A more detailed analysis on losses in AC and DC transmission solutions is given by MacLeod [7]. He shows, that the loss percentage is depending on the wind park loading. Especially for AC and HVDC VSC, losses are high at small loading. For HVDC LCC, they are almost not. Here is a challenge for innovation.



Assume:

Transformer copper losses:	0.5 % @400MW
Transformer iron (no-load) loss:	0.1 % @400MW
LCC HVDC Converter loss:	0.75 % @400MW per converter (CIGRE)
VSC HVDC Converter loss:	2 % @400MW per converter (CIGRE)
	1 % @0MW per converter (CIGRE)

Fig. 2: losses comparison for AC and HVDC-VSC electrical connection (taken from [7], and modified)

Summarizing the findings in the papers cited, it can be concluded:

The major losses in AC schemes are with cables and, second, with shunt reactors.

The major losses in HVDC VSC schemes are with valves. They are today considerably higher than for HVDC LCC technology, due to high frequency switching. With respect to losses, an innovation challenge can be seen here.

On reliability and unavailability of HVDC technology, there is few information available. CIGRE has published, over years, reliability records on “classic” HVDC LCC technology. But, these data may hardly be taken for offshore installations and for HVDC VSC technology. There is concerns expressed in some publications on the reliability of HVDC VSC technology, installed in offshore sites.

A master thesis by Lazaridis [6] shows an analysis on the expected unavailability for different technologies.

Reliability data on STATCOMs (published by Canadian Electricity Association CEA) were taken, assuming, that HVDC-VSC stations have a similar reliability as STATCOMs. The question remains, among others, whether offshore installation will make a significant difference.

Reliability issues on turbine performance or others were not looked at in this analysis. So, the data presented address solely electrical transmission unavailability issues.

The following graph has summarized some of the findings.

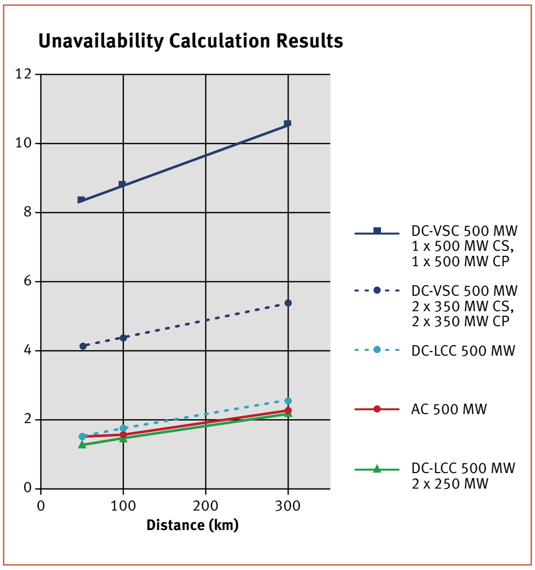


Fig. 3: unavailability comparison for AC and HVDC (VSC and LCC technology) electrical connection (taken from [6], and modified)

The unavailability is plotted against the transmission length. The risk of unavailability does increase with transmission distance. This will, however, be largely influenced by site conditions. The influence on station technology can clearly be identified.

In the example, AC stations and HVDC LCC stations are supposed to provide the highest reliability. Expected unavailability is around 1%.

In contrast, unavailability for 2 HVDC VSC stations goes up to 8%, when a single converter station at each side and only one cable pair are considered. The expected unavailability is reduced to 4%, when redundancy is introduced by taking two converter stations and two cable pairs.

Innovation Challenges and Value Estimation

From the above, the following goals may be seen for technology innovations on HVDC stations:

- reduction of investment cost for the station itself
- consecutive reduction of investment cost for other components
- reduction of losses
- improvement on availability

The economic value of such achievements has to be measured against overall cost.

Losses and unavailability reduction contribute to operating cost reductions and to earnings improvements. The financial impact can be capitalized, and compared with the initial investment. In such calculations, assumptions on life-time, on interest rates, or on inflation change the results.

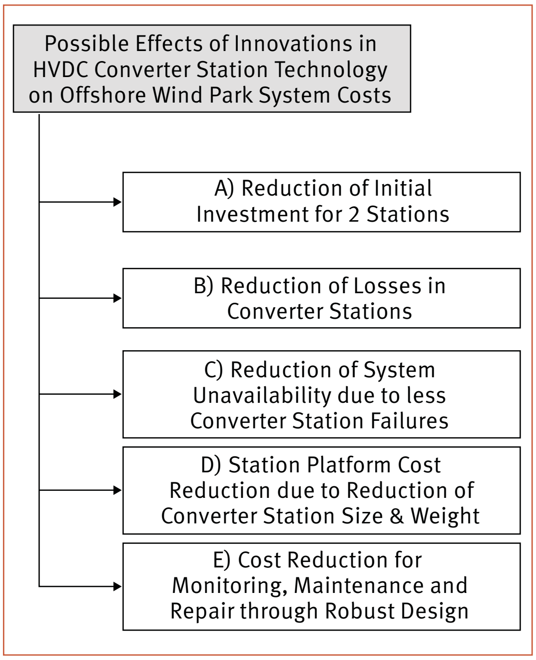
A more simple and rough estimate may start from total investment costs for a given project. As an example, it is assumed that for a 400 MVA offshore wind park 800 million € have to be invested. This covers cost for planning, project management, all components, and their installation.
In order to compensate for estimated 5% unavailability, one may increase the project size by 5%, and install 420 MVA instead of 400 MVA. Assuming, that total costs go linear with installed power, now total cost is 840 million €. As 2000 € / kVA total investment cost are calculated, 1% reduction of unavailability would be worth 20 € / kVA.

The same logic can be taken to estimate the value of loss reduction. The value of 1% reduction of losses would again be 20 € / kVA.

With this calculation logic, some speculation is made on how much value innovations in HVDC station technology can create, from a wind park investor's perspective.

Starting is from the numbers in the order of magnitude given in the previous chapter. It is assumed that an HVDC station has a cost of 110 € / kVA, and that the total losses in the system are 8%, from which 4% are attributed to the stations. Unavailability is assumed to be 5%, from which 4% are attributed to the station.

Innovations in the HVDC station technology has potential to create the following effects:



A) Cost reduction of the station down to 50%: value 0....50 € / kVA

110 € / kVA is an actual value which is, for comparison, high against estimated 10 € / kVA for a power transformer. Reduction by 50% would still mean a considerable investment. Two converter stations are required in a project.

B) Loss reduction in the stations down to 50% of previous level: value 0....40 € / kVA

Reduction of average losses from 4% down to 2% would bring them into the order, where HVDC LCC technology already is.

C) Unavailability reduction down to 25% of previous level: value 0...60 € / kVA.

Any station technology innovation for offshore installation must aim to bring unavailability down to almost 0%!

D) Station size reduction, thus reducing necessary platform costs in direction of AC station platform level: value 0....10 € / kVA.

E) Often technology innovations are quite sophisticated, and need suitable monitoring and environmental conditions. Current HVDC technology is seen as such. A robust design approach may have the potential to reduce costs for monitoring, maintenance and repair: value 0 ...10 €/kVA.

Assumed are chances for cost reduction, but with uncertainties, whether or not these goals can be reached. However, the goals set up seem possible. When all cost reduction goals could be reached, this would sum up to 230 €/kVA, exceeding the cost for two converter station of 220 €/kVA.

When uncertainties are considered, probabilities of cost reduction can be calculated and plotted in a graph. The graph below gives the probability estimate of the above proposed achievable cost reduction through HVDC station innovations.

As is expected, a range of possible cost reduction is given. The graph can be understood as follows: With a probability of 30% cost reductions of higher than 90 €/kVA will be achieved. And with a probability of 1-30%=70%, it will be less than 90 €/kVA.

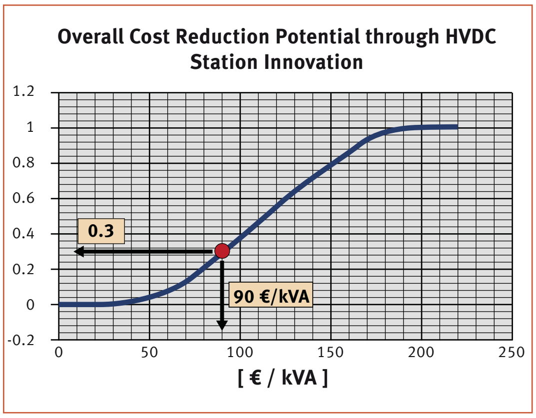


Fig. 4: cumulative probability of cost reductions through innovation effects A) to E)

Of course, these figures are only qualitative, at this point. However, the estimates show that with innovations in HVDC station technology, value may be created from a wind park investor's perspective, which reaches today's costs for the converter stations.

Conclusions and Outlook

HVDC stations are a substantial cost factor in offshore wind park electrical connection schemes. This is valid for initial investment, but may also be true when station losses and costs of unavailability are looked at.

Taking the reported values for losses and unavailability attributed to HVDC stations, there is an attractive innovation potential. Theoretically, the value of such innovations might reach those of the initial investment for converter stations. A very attractive innovation challenge, from a wind park investor's perspective.

The authors have co-operated in a study in 2005, which aimed at identifying such innovation potentials. Potential to reduce the size of HVDC converter stations as well as to reduce the necessity of filters has been demonstrated.

In a new project of IPL Technology GmbH, they continue their co-operation. This new project is co-funded by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety. Results will be published. A summary of the project goals is available under www.ipltechnology.com

References

[1] O. Martander: DC Grids for Wind Farms, Thesis Chalmers University of Technology, Göteborg, 2002

[2] D. Wensky: Gleichstrom-netzanbindung großer Offshore-Windparks, ew, 104 (2005), H9, S. 60 ff.

[3] H. Brakelmann: Bipolare HVAC- und HVDC-Hochleistungsübertragungssysteme mit VPE-isolierten See- und Landkabeln, ew, 106 (2007), H10, S. 26 ff.

[4] Energy technologies for the 21st century, International Energy Agency (IEA), 1997

[5] USACE study, Appendix 3-C: Transmission Issues for Offshore Wind Farms [2004), www.nae.usace.army.mil/projects/ma/ccwf/app3c.pdf

[6] L.P. Lazaridis: Economic Comparison of HVAC and HVDC Solutions for Large Offshore Wind Farms under Special Consideration of Reliability, Master's Thesis X-ETS/ESS-0505, Royal Institute of Technology, Stockholm, Sweden (2005)

[7] N. MacLeod: Overview of the Technical Issues of Connecting Wind farms to the Grid, IEA/DTI, London (2007)

[8] L. Max and S. Lundberg: System efficiency of a DC/DC converter based wind turbine grid system, Nordic Wind Power Conference, Espoo, Finland (2006)