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Annex to D3.1 - Technology Assessment Report

Transmission Technologies: HVDC Overhead lines

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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

Document information

General purpose

This document is an annex of deliverable D3.1 focusing on the technology assessment (technical and economic performances) of generation, storage, transmission and demand-side technologies. It includes the assessment and outlook of the following key components of the HVDC OHL technology. It provides an explanation of the key variables selected by Amprion, the methodology for the data construction as well as a technical outlook as of today and 2050.

Change log

Revision	Date	Changes description	Authors
V1	13 August 2014	Creation	Amprion
V2	29 August 2014	Final version further to review	Amprion

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Table of content

This report focuses on the key components of HVDC overhead lines, i.e. conductors. It provides an explanation of the line design hypothesis made for this study.

1 Introduction

DC Overhead lines are commonly used for the transmission of large amounts of power and distances. Today, the biggest transmission lines exceed a voltage level of 800 kV with a distance of more than 2000 km [1]. The main components of an overhead line are towers, conductors, and insulators. These components are designed for the required voltage level, transmission capacity and type of current (AC or DC). This means that the selected geometry of the line and conductor will impact the maximum voltage level (with respect to the emission law), the current capacity and the electric losses. The insulation of the conductor is performed by air.
Over the decades of OHL business, typical lattice tower configurations have been developed, which are optimized in terms of material, transportation, erection, maintenance, costs, lifetime and appearance. But during the last decade, as the public acceptance has been getting harder, alternative design of towers has been coming up, changing the costs known for standard overhead lines.
The main technical improvement in an overhead line during the last decade lies in the development of different technologies to reduce the sag caused by temperature elevation (and induced conductor extension) on existing lines and new conductors with a higher fill factor.

2 HVDC OHL performance characteristics

2.1 Performance of HVDC OHL related to the technology

The main variable that can affect HVDC OHL performance characteristics is the voltage level. The voltage level defines the diameter of conductor, the type of bundle and the tower design. A distinction of different types of conductor (e.g. ACSS, ACCR, TACSR, etc.) is not considered. These kinds of conductors are used to reduce the sag caused by temperature elevation (and induced conductor extension). The number of circuits is already optimized considering safe grid operation.

2.1.1 Voltage level

In contrast to the classical AC system, the voltage level is defined by the converter. For this study 4 different DC voltage levels are considered: ±320 kV, ±500 kV, ±800 kV and ±1100 kV.
Depending on the voltage level, the conductor diameter, the number of conductors per bundle and the geometry of the tower are different. The higher the applied voltage the higher is the border field strength (compared with same parameters (conductor diameter, bundle type etc.). If the border field strength exceeds a certain value (~28 kV/cm) streamer discharges occur. These streamer discharges cause acoustic disturbances, radio disturbances and corona losses. Thus, the streamer discharges have to be avoided due to a suitable selection of the conductor diameter, bundle type and tower design [2].
Unlike the classical model AC system there is no direct limitation to the length of the transmission corridor. Thus, the maximum length of a HVDC OHL is given by economically constraints.

2.1.2 Conductor technology

ACSR (Aluminium-conductor steel-reinforced), Standard conductor: good compromise between technical and economic aspects; well-known technology (over 80 years of field experience). The diameter of the conductor is defined by the voltage level (see Chapter 2.1.1). The first number indicates the area of the conductor and the second number indicates the area of the steel soul. For example, an 800 kV tower in the excel sheet is given the conductor: 6 x 720/50. The number "720" correlates to the area of the conductor and the number "50" correlates to the area of the steel soul. The number "6" indicates the number of conductors for one bundle.

2.1.3 Number of conductors per bundle

The number of conductors per phase will greatly impact the performance of the line. It is obvious that if more conductors are present, more capacity is available and the efficiency increases (considering losses). But it is more important to choose the number of conductors to the applied voltage.
As described in Chapter 2.1.1 the layout of towers is mainly defined by the generation of emission, e.g.: Although the maximum power of a converter in 2050 is P = 9.6 GW (@VDC = ±800 kV), the transmission capacity of the related HVDC OHL has to be 11.2 GW. The design of the HVDC OHL is calculated by the amount and diameters of conductors to undercut the critical border field strength.
However, the mechanical constraints are increased on the towers with a higher number of conductors or rather a higher diameter, which induces more cost. For this study a bundle of 4-8 conductors per phase has been considered.

2.1.4 Number of circuits

The performance of the line is also affected by the number of circuits installed per tower. The common usage is 1-2 circuits per tower. Increasing the number of circuits per tower could have a good effect on land use in increasing the transmission line capacity.
But a safe grid operation requires that a single failure (n-1) has to be limited, which leads to a controllable effect. A transmission capacity on a single tower of more than P = 8 GW would lead to risks of high electrical constraints in case of failure. Moreover, the shape of the tower would be very massive with such a visual impact that public acceptance will not be fulfilled.

2.2 Performance of HVDC OHL related to the conductor

2.2.1 Maximum current capacity

Maximum current capacity of a conductor technology depends on the following conductor properties:

- Conductor design (stranding, type of wire, cross-section, diameter, etc.)
- Maximal allowable conductor temperature at continuous operation

Computation by the help of "Thermal behavior of overhead conductors" from Cigré [3] with the following meteorological parameters:

- Wind speed: 0.6 m/s
- Wind direction: 90°
- Ambient temperature: 35°C
- Global radiation: 900 W/m²

2.2.2 Specific losses

The specific losses due to the line are calculated at the maximum current capacity of the used conductors for the desired voltage. For this study, the following nominal currents have been considered:

- I_{max} (for V_{DC} = ±320 kV tower) = 2.72 kA
- I_{max} (for V_{DC} = ±500 kV tower) = 4.00 kA
- I_{max} (for V_{DC} = ±800 kV tower) = 7.00 kA
- I_{max} (for V_{DC} = ±1100 kV tower) = 11.6 kA

The dissipated specific power depends on the specific resistivity of the conductor as a function of the desired current. The specific resistivity is calculated by the required aggregate diameter (avoiding streamer discharges). For the considered voltage levels the following specific resistivities are calculated:

- R_{320} (for V_{DC} = ±320 kV tower) = 0.0274 Ω/km
- R_{500} (for V_{DC} = ±500 kV tower) = 0.0132 Ω/km
- R_{800} (for V_{DC} = ±800 kV tower) = 0.0067 Ω/km
- -R_{1100} (for V_{DC} = ±1100 kV tower)= 0.0042 Ω/km

2.2.3 Failure rate and mean time to repair failure

It is expected that the availability of the transmission overhead lines will be just as big in 2050 as today. Thus, the data are collected on the results from [4]:

- Failure rate per 100 km : 0.353
- Mean time to repair failure : 2.94 h

2.3 Assumptions for the expected evolutions of technical data from 2013 to 2050 for conductor technology

2.3.1 Technical outlook at 2050

In the long term, AAAC (All Aluminum Alloy Conductors) will become a mature technology. It will probably have better performances compared to the nowadays ACSR. The resistance should be lower and therefore the efficiency increases. However, the selection of a conductor depends on the aggregated diameter. The higher the aggregated diameter the lower is the border field strength (see Chapter 2.1.1.)

In future, nanotechnology could emerge, providing a great enhance in conductor performances (ampacity, weight, mechanical behavior, etc.) This field is under beginning investigations, and it is really difficult to make reasonable prognostics for the development into an industrial product.

3 Technology readiness and maturity

All the conductor technologies selected for the study are mature.

4 Costs

Based on the experience of Amprion, the cost data for the operations and maintenance (O&M) per year and installation for the HVDC OHL is evaluated for the four reference cases in 2014:

- ±320 kV tower: 1.2 M€/km with 7.2 t€/year (O&M)
- ±500 kV tower: 1.6 M€/km with 9.6 t€/year (O&M)
- ±800 kV tower: 2.0 M€/km with 12.0 t€/year (O&M)
- ±1100 kV tower: 2.5 M€/km with 15.0 t€/year (O&M)

Note: The calculation is based on lattice towers in mixed areas. For the calculation of cost in mountain areas due to higher mechanical constraints, an additional factor of 1.7 has to be integrated.

References

[1] ABB Ltd., "Jinping - Sunan: The most powerful transmission line in the world," Abb Ltd., http://new.abb.com/systems/hvdc/references/jinping---sunan, 2014.

[2] B2/B4/C1.17, Joint Working Group, "Impacts of HVDC lines on the economics of HVDC projects," Cigré Brochure, 2009.

[3] Working Group 22.12, "Thermal behavior of overhead conductors," Cigré, 2002.

[4] Working Group 22.13, "Management of Existing Overhead Transmission Lines", Cigré, 2000.