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Physics Procedia 36 (2012) 1149 – 1152

Physics Procedia

Superconductivity Centennial Conference

AC HTS transmission cable for integration into the future EHV grid of the Netherlands

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Abstract

Due to increasing power demand, the electricity grid of the Netherlands is changing. The future grid must be capable to transmit all the connected power. Power generation will be more decentralized like for instance wind parks connected to the grid. Furthermore, future large scale production units are expected to be installed near coastal regions. This creates some potential grid issues, such as: large power amounts to be transmitted to consumers from west to east and grid stability. High temperature superconductors (HTS) can help solving these grid problems. Advantages to integrate HTS components at Extra High Voltage (EHV) and High Voltage (HV) levels are numerous: more power with less losses and less emissions, intrinsic fault current limiting capability, better control of power flow, reduced footprint, etc. Today's main obstacle is the relatively high price of HTS. Nevertheless, as the price goes down, initial market penetration for several HTS components is expected by year 2015 (e.g.: cables, fault current limiters). In this paper we present a design of intrinsically compensated EHV HTS cable for future grid integration. Discussed are the parameters of such cable providing an optimal power transmission in the future network.

Keywords:national transmission grid; potential bottlenecks; high temperature superconducting cables; compensation of reactive power, intrinsically compensated cable

1. Introduction

Power demand in the Netherlands is increasing 2% each year, and potential grid bottlenecks in the future are expected. The bottlenecks due to insufficient power capacity need to be identified timely because full integration of new grid components such as: overhead lines, cables, transformers and substations often take more then 10 years. HTS coated conductors show their capability in various pilot projects. When the HTS conductor price will decline in the coming years, HTS components will penetrate the market starting likely with cables and fault current limiters. The western and middle area of the

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doi:10.1016/j.phpro.2012.06.192

Netherlands is most populated and here more grid bottlenecks are expected. HTS cables have the advantage to transmit a high power together with low electrical loss and are a suitable candidate to strengthen the future grid. In this paper we discuss an electrical design of a 380 kV HTS cable for strengthening future Dutch transmission grid as further discussed in [1]. We assume that the cable cooling is mature technology and the outer diameter of the cable can be selected freely. Electrical design parameters of HTS cable (e.g., self- and mutual inductances, capacitance, resistance) are required to study its grid interaction. Grid interaction studies usually include: voltage drop between substations, active and reactive power flows, switching actions, resonances between cable and lines, reliability aspects fault currents and for the HTS cable results of such study will be presented elsewhere.

2. Electrical parameters of EHV HTS transmission cable

Performance of power connection depends on the intrinsic capacitance and inductance ratio. This ratio is the characteristic impedance (Z_0) of a connection, see Table 1. The characteristic impedance of the connection determines the nature of the power flow (active, reactive). The surge impedance loading (*SIL*) of a connection is the active power delivered without reactive power. In this case the capacitive cable energy equals to and compensates the cable inductive energy. Transmission system operators (TSO) define the power flow through a connection in terms of per unit SIL. If the operating active power is below SIL there is a deficiency of shunt capacitive energy, if the operating power above SIL, there is an excess of shunt capacitive energy. Basically, the power between the operating point and SIL is the reactive power absorbed or produced by the cable or line. The reactive power needs to be minimized for grid stabilization and saving in costs. In Table 1 typical electrical parameters for OHL, XLPE and HTS underground cables for EHV connection are listed.

Overhead lines are commonly used due to their low costs, technical simplicity and ability to transmit high power flows over long distances. Due to Dutch regulations, the total OHL length may not increase anymore, thus for future use is required of alternative connections such as underground cables. The XLPE cable can be selected as an alternative to OHL, but a compensation of reactive power is often needed then. Therefore, a HTS cable can be applied as further described in [1]. The maximum current rating of the HTS cable is 10 kA, assuming that in year 2030 the tape critical current I_c is increased sufficiently.

It is clear from Table 1 that for HTS cable *SIL* can be matched to S_{nom} by changing inductance L and/or capacitance C. In practice, it is easier to vary the capacitance, as varying the twist pitch (in order to change L) is usually more costly. Cable capacitance can be varied by changing the permittivity of the insulation and/or the insulation thickness when possible. The HTS cable shown in Table 1 has an inner radius of 26.8 mm, the outer retour conductor radius of 76.8 mm and the insulation thickness of 50 mm where the dielectric loss can be considered similar to that of conventional cable systems.

In [1] an example to integrate an HTS EHV cable into the future grid of the Netherlands is presented. The HTS cables are laid in parallel to existing overhead lines between Krimpen and Geertruidenberg. This connection is part of the Dutch EHV-ring operated at 380 kV. The advantages are: no additional EHV towers needed, HTS cables can use the right of way of existing OHL and no additional permits are required; due to the HTS cables, OHL carry less power and have less EM emissions. HTS cable can be designed to match level of transported power to SIL as shown in Table 1. In Table 1, electrical transmission parameters for 380 kV overhead line and underground cables are compared.

Table 1. Electrical transmission parameters for 380 kV overhead line and underground cables

Parameter	OHL [3]	XLPE Cable [3,4]	HTS cable
Transmissible power (S_{nom}) [MVA]	1645	1185	3290
Nominal current rating (I_{nom}) [kA]	2.5	1.8	5
Maximum current rating (I_{max}) [kA]	3	/	10
Inductance [mH/km]	0.879	0.47	0.215
Capacitance [µF/km]	0.0132	0.202	0.106
Resistance [mΩ/km] [2, 3]	23.3	10.9	3.73e-4
Characteristic impedance (Z_0, Ω), ($\sqrt{L/C}$)	258	48	45
Surge impedance loading (*SIL*), (U^2/Z_0) [MW]	559	2994	3200
Critical length* [km]	2749	122	686

* The critical length comparison is defined by the capacitive charging current

3. Critical cable length

When EHV OHL will be replaced by cables, reactive power often becomes an issue. If a connection could be made lossless and operated at SIL, theoretically an infinite cable length can be obtained. A critical length indicated in the bottom row of Table 1 is based on an active power flow of zero, this is where the capacitive reactive is maximum. The critical length based on the capacitive charging current for the HTS cable is 5.5 times larger then for the XLPE cable and 4 times shorter then for the OHL. In fig. 2a, the reactive power as function of transmitted power for a connection length of 33.7 km is compared and indicates that high SIL can be obtained by using cables with proper parameters. When the HTS cable operates above SIL less capacitive reactive power is needed compared to XLPE and OHL.

(a) (b)

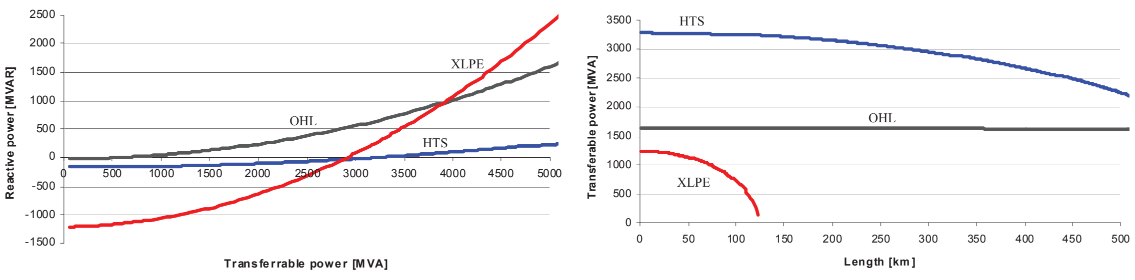

Fig. 2. (a) Reactive power as function of the active power flow for 33.8 km long connection: OHL (black), XLPE (red) and HTS (blue) cables. (b) Transferable active power as function of the connection length for cosφ = 1: OHL (black), XLPE (red) and HTS (blue).

In fig. 2b, the active power flow as function of the connection length is shown for a typical value of $cos\varphi=1$ and indicates that by selecting proper cable parameters sufficient HTS lengths are possible for HTS integration in future EHV-grids.

4. Conclusion

Integration of HTS transmission cables to strengthen the future grid network can be more efficient when cable parameters are selected in a way allowing the cables to operate at surge impedance loading (SIL) most of the time. When operating at SIL, the reactive power of the connection is negligible and the power flow is optimal. To operate at SIL, use of HTS allows selecting cable parameters more easily in comparison to conventional high power transmission cables.

5. Acknowledgement

This project is funded by the Agentschap.NL

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