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Integration of HTS cables in the future grid of the Netherlands

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Abstract

Due to increasing power demand, the electricity grid of the Netherlands is changing. The future transmission grid will obtain electrical power generated by decentralized renewable sources, together with large scale generation units located at the coastal region. In this way electrical power has to be distributed and transmitted over longer distances from generation to end user. Potential grid issues like: amount of distributed power, grid stability and electrical loss dissipation merit particular attention. High temperature superconductors (HTS) can play an important role in solving these grid problems. Advantages to integrate HTS components at transmission voltages are numerous: more transmittable power together with less emissions, intrinsic fault current limiting capability, lower ac loss, better control of power flow, reduced footprint, less magnetic field emissions, etc. The main obstacle at present is the relatively high price of HTS conductor. However as the price goes down, initial market penetration of several HTS components (e.g.: cables, fault current limiters) is expected by year 2015. In the full paper we present selected ways to integrate EHV AC HTS cables depending on a particular future grid scenario in the Netherlands.

Keywords:national transmission grid; potential bottlenecks; high temperature superconducting cables

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1. Introduction

The future power grids need to adjust due to the expected increase in electrical energy consumption. Today the Dutch grid is not capable to handle the expected power increase in the year 2030. Most EHV grid components are in operation for over more then 30 years. Since their expected lifetime is 30 years, a replacement wave is expected. To be capable to handle to power demands in year 2030 the Dutch grid needs to be strengthened. Since the Dutch grid needs the replacement wave anyway, the use of HTS is an option. Identification of aged and inadequate EHV/HV grid components must be timely since the replacement may need more then 10 years. Special attention is needed when innovative solutions like HTS are considered. Several HTS pilot projects are completed and ongoing aiming to assure a reliable and efficient

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network operation. Today coated conductors are most promising due to their current carrying capability, mechanical strength, low AC losses and ability to limit fault currents. The Dutch network operator TenneT (TSO) estimated the future energy demand and indicated expected grid bottlenecks by load flow calculations. Places which form potential bottlenecks are indentified according to four most likely future grid scenarios. Depending on each scenario, HTS can be selected to strengthen the future grid.

2. General trends in the Dutch power grid

The Dutch transmission grid operates at voltage levels up to 380 kV. Depending on the connection lengths, several voltage steps can be taken (220, 150, 110 and 50 kV) towards end users. By means of the extra high voltage ring and connections (EHV, 380 kV) larger distances are covered, such as to large scale generation, to neighbor countries and to the HV-grid, see fig. 1a (EHV indicated by the orange, and HV by the blue lines). General future developments on transmission level are: more power import and export through interconnections, additional large scale generation units mostly installed at coastal regions and increase of renewable power generation. In Europe by 2030 the available wind power will increase to 300 GW, where 150 GW is onshore and another 150 GW is planned offshore wind power capacity. In the Netherlands, 6 GW offshore and 4 GW onshore wind power are planned [1]. The yearly load growth in the Netherlands is around 2%, on average in Europe after 2015 also 2% is predicted by UCTE. The load increase is mainly concentrated in western and central part of the Netherlands. Figure 1b indicates corresponding expected grid change for year 2030.

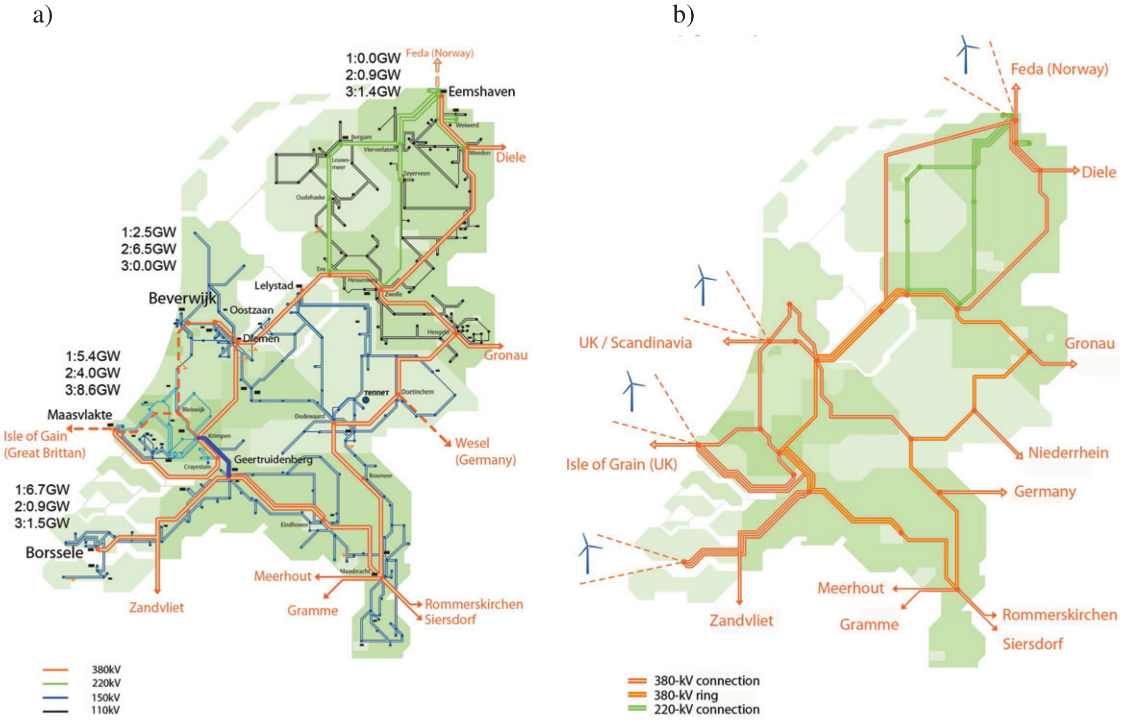

Figure 1. (a) Dutch electricity network in year 2007; (b) Dutch transmission grid in year 2030

3. Towards Dutch power grid of 2030

Parts of the transmission grid that need to be strengthened in the future are identified by TenneT in four possible scenarios of how the Dutch power grid could change in the coming decades [2]. Each scenario reflects on environmental and market dimensions together with the estimated power capacity of the four large production units in year 2030. In fig. 1a, black rectangles represent production units, where the four large production units are at coastal regions: Borssele, Maasvlakte, Beverwijk and Eemshaven. Potential bottlenecks of the Dutch transmission grid in the year 2030 are further detailed in [3]. In this paper we illustrate the advantages of HTS cable integration for one particular location Krimpen-Geertruidenberg, fig. 1a. This location is a potential bottleneck for three of the four TenneT scenarios [3]. Advantages of HTS cables compared to OHL are: savings on land and right of way, higher transport capacity and better environment, and compared to conventional cables are: lower losses, longer lengths between compensation stations and intrinsic ability to limit fault currents. In the following example we indicate the possibility to strengthen the EHV-ring by connecting HTS cable in parallel to existing OHL.

4. Example of future grid study

Currently, connection Krimpen-Geertruidenberg has two OHL with a nominal power capacity of 2 x 1645 MVA and there are plans to upgrade each OHL to 5 kA. The nominal future power demand is estimated to be 6.8 GVA [4], where 2% of yearly power increase is assumed from year 2009. In TenneT's network study load flows are estimated based on grid voltages and nominal currents. To integrate a new grid component, a grid structure, switching actions, stability studies, short circuit currents, use of generation units and divided load over substations have to be considered [4]. For the required future power 5 OHL for *N*-1 redundancy during maintenance criteria and 6 OHL for the *N*-2 criteria are needed. Table 1 shows that under the *N*-1 criteria 4 OHL are needed in parallel to 1 HTS cable, whereas 2 HTS cables are needed when OHL are not an option (the Dutch law states that total length of OHL can not increase [3]). N-2 criteria is also studied which indicated that six OHL are needed whereas five OHL in parallel are needed in parallel to one HTS cable and 3 HTS cables when OHL is not an option. Obviously, when 6 OHL will operate, they will have about 2 times more spatial magnetic field pollution as compared to the existing 2 OHL. On the other hand, when 5 OHL operate in parallel with HTS cable, the spatial magnetic field pollution will not change as compared to the existing situation, as almost 1/2 of the total power is transmitted by HTS cable in this case, see Table 1.

In Table 1 starting from left to right column are calculated: transmitted power flow P, reactive power for respectively the source and load site Q_1, Q_2, current I, voltage drop ΔU, electric loss per circuit in *kW*, and total loss per circuit in *GWh* assuming 2628 hours/year of full load time and 8256 hours/year of availability time. Assumed for the three phase HTS cable are: cold dielectric design, a cryostat heat leak of 3 kW/km, cooling penalty of 15; loss of 0.4 kW/kA for two sets of three phase terminations, the dielectric loss of 1 kW/km/phase [5], the ac loss at 5.2 $\mathrm{kA_{rms}}$, 4.7 $\mathrm{kA_{rms}}$ and 3.4 $\mathrm{kA_{rms}}$ is respectively 1.4 kW/km, 1.1 kW/km and 0.63 kW/km at the conductor critical current of 14 kA [6]. In [3, 7] HTS cable parameters are presented used for the calculations. Table 1 indicates that one HTS cable operated in parallel to four OHL transmits most of the power (due to the low impedance) and at lower loss (reduced from 129 GWh to 67 GWh). The magnetic field emission in this case is reduced 2 times (as compared to the case when in total 5 OHL are used). Alternatively, two (two) 5-kA OHL in parallel to two (three) 6 kA HTS cables can be used in compliance with the *N*-1(*N*-2) redundancy criteria and with the restriction on the total OHL length. The advantages are: no additional OHL towers needed, no additional permits, no additional occupation of land, reduced ac-loss, and no need for reactive power compensation (as in case when XLPE cable is used). For a distant future we include the case when existing OHL are replaced fully by HTS cables, this creates an opportunity for TenneT to build OHL of the same length elsewhere and to use the land for other purposes.

Table 1. Example of the grid study to strengthen the connection at Krimpen-Geertruidenberg with OHL and HTS cables

Criteria	L km	Type	Inom (kA)	P (MW)	Q1* (MVAr)	Q2 (MVAr)	I (A)	ΔU (kV)	Loss (kW)	Tot.Loss (kW)	Loss (GWh)	Tot.Loss (GWh)
N-1	33.7	5xOHL	5x2.5	6708	483	0	10225	4	49246	49246	129	129
		4xOHL	4x2.5	3348	-66	166	5084	1	15235	18524	40	67
		1xHTS	1x5.3	3431	174	-166	5233		3290		27	
		2xHTS	2x5.3	6800	5	0	10332	0	6544	6544	54	54
N-2	33.7	6xOHL	6x2.5	6732	368	0	10248	3.1	41234	41234	108	108
		5xOHL	5x2.5	3726	-89	168	5660	0.9	15103	18340	40	66
		1xHTS	1x5.3	3056	136	-167	4662		3238		27	
		3xHTS	3x5.3	6811	-295	0	10341	-0.3	9497	9497	78	78

*calculated for cosφ=1 of the load

5. Conclusion

In the framework of the national project Supernet, major potential bottlenecks in the future Dutch grid were identified (using TenneT vision of year 2030) and one of them is dealt with in this paper. It is shown that timely integration of HTS cables in a part of the EHV-ring can eliminate a potential bottleneck for three of the four TenneT scenarios. HTS cables in parallel to existing OHL offer a suitable solution to strengthen the future grid. The advantages of such integration are the following: higher power capacity, lower losses, reduction of EM-field emissions in OHL, no additional occupation of land and permits needed, a possibility to keep 380 kV voltage level in the future grid for as long as it will be wanted.

6. Acknowledgement

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