This manuscript was submitted for possible publication in the Special EUCAS 2009 Issue of Superconductor Science and Technology (SuST)

Long length HTS cable with integrated FCL property

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Abstract. The past years have shown the growth of bottlenecks in electric power grids, among other reasons caused by the increasing demand of energy in the form of electricity and by the large-scaled integration of renewable sources. As solving of these challenges by means of traditional solutions appears to be more and more problematic, the need for new technology solutions has become apparent. The HTS cable technology demonstrates a great potential in solving of grid congestion issues. In addition to their large power transport capacity and low losses, modern-generation HTS cables also have an integrated fault-current limiting (FCL) property. Applications of such cables in power grids will help to solve fault-current issues when connecting new generators, and dispersed and large-scale renewable sources. As HTS cables, used in current projects, are limited to hundreds of meters in length, they have still not been used for energy transport over long distances. The Dutch DSO Alliander, together with Ultera, is working on the development of a 6 km FCL HTS cable for installation in the Alliander's HV grid. In order to get the low-loss benefits of the HTS technology, a cooling system with a high efficiency is needed. The FCL HTS cable will be cooled by one cooling station at each end of the cable, using a liquid nitrogen coolant. Alliander and Ultera have established and work to achieve technical performance targets believed to be required to realise a 6 km long, 50 kV retrofit system with a power rating of 250 MVA with cooling stations only at the two ends of the cable system. These targets aim to reduce the superconductor's AC loss at a nominal current, reduce the heat leak of the thermally insulating envelope, increase the voltage rating and reduce the friction coefficient of the coolant flow.

1. Introduction

The past years have shown a stable growth of bottlenecks in electric power grids. Present distribution networks face nowadays enormous challenges. Continuous improvement of the quality of life and the integration of new technologies, among others the new environmentally friendly technologies like e.g. heat pumps and the Plug-In Hybrid Car, lead to an increase of electrical power demand. The increasing penetration of distributed energy sources together with expanded large-scale renewables lead in their turn to numerous technical weak spots. As solving of these challenges by means of traditional solutions appears to be more and more problematic, the need for new technology solutions has become apparent. The Dutch DSO Alliander, in a combined effort with Ultera – A Southwire / nkt cables Joint Venture, has found HTS technology to be ideal in solving the grid congestion issue.

2. HTS cables solve challenges

The HTS cable technology demonstrates a great potential in solving of grid congestion issues [1-9]. Such properties as low energy losses, large power transport capacity at low voltage levels, reduced reactive power and negligible electromagnetic heat emissions make HTS cables very attractive for utilities. However, widespread use of low-impedance superconducting cables will contribute to an increasing level of fault currents in electrical grids.

A conventional solution for reducing of the fault currents level by means of installing additional fault current limiting (FCL) devices such as choking coils or power-electronic systems is not effective due to extra costs, higher losses and extra space demand at the substations. An efficient solution will be the modern generation HTS cables with integrated FCL property, even if this solution still requires a fair amount of development before it is technically perfected.

The latest generation of HTS cables with their improved non linear voltage-current characteristics behave intelligently by intrinsically adapting their impedance to the actual needs of the network. This means low impedance during normal operation and large impedance at increasing current (Figure 1)

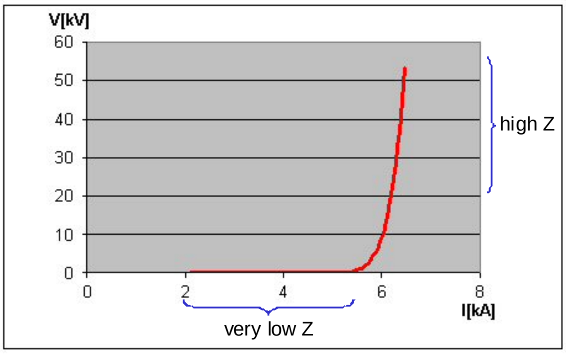

Figure 1. A schematic of the non-linear voltage vs. current characteristics of HTS cables

This intelligent adaptive impedance is why FCL HTS cables do not only reduce short-circuit currents but also contribute to a stable voltage profile in grids. The application of such cables in power grids helps in this way to solve fault-current issues when connecting new generators, and dispersed and large-scale renewable sources (Figure 2).

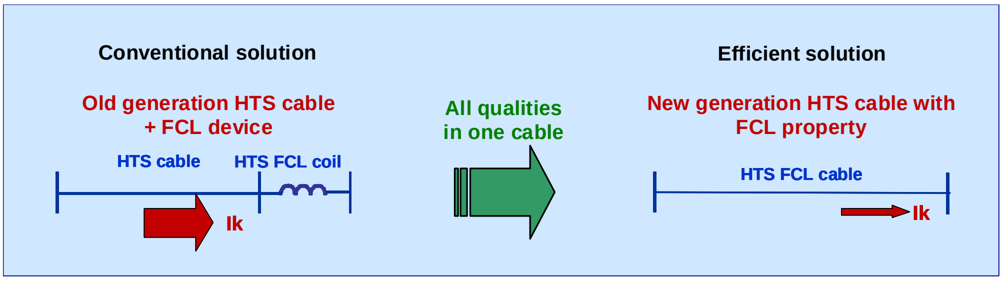

Figure 2. Schematic showing the advantages of HTS cable with integrated FCL property

3. Long-length HTS cables are needed

HTS cables still have not been used for energy transport in power grids over any considerable lengths. Transport networks imply electrical circuits of a several kilometres in length. Even in such a small country as The Netherlands, most of the HV circuits are about 5 to 20 km long (Figure 3). Until now, all HTS cables, used in current projects, are limited to 200-600 m [1-2]. The integration of HTS cables in transport networks demands the increase of the cable's length to several kilometres.

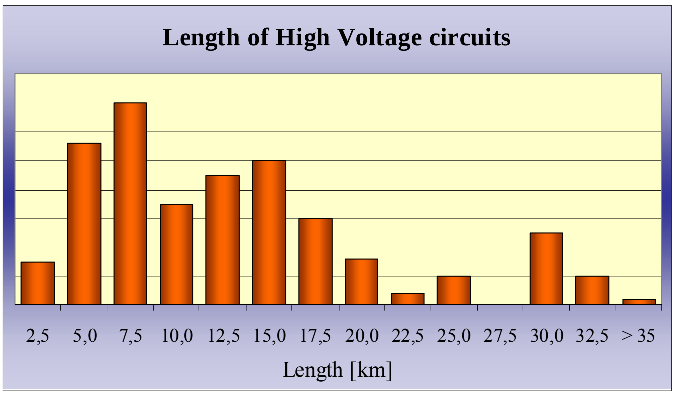

Figure 3. Length of HV circuits in Alliander's grids

A breakthrough in the cooling system and important developments in the HTS cable are needed in order to make a long length HTS cable possible. With the present performance parameters, described in Table 1, a practical system length, as measured between two cooling stations, is limited to an estimated 2-3 km. A simulated temperature profile of a 2.5 km system using the present-status performance values for AC loss and cryostat loss is shown in Figure 4. In order to get the low-loss benefits of the HTS technology, in addition to the longer system length, a cooling system with a high efficiency is needed.

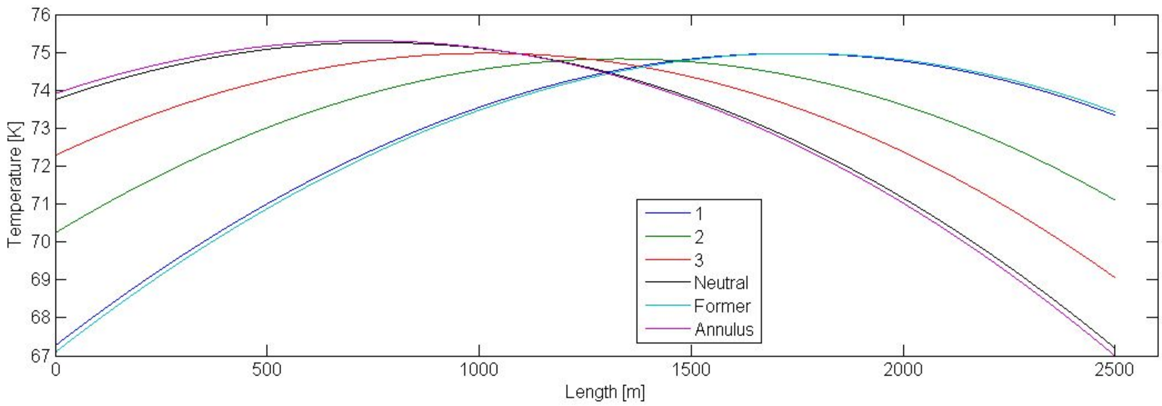

Figure 4. Simulated temperature profile of a 2.5 km long 50 kV HTS Triax® FCL cable using the present-status performance values for the AC and cryostat losses. The modeled system has one cooling station at each end

4. 6 km HTS cable project in Amsterdam

The Dutch DSO Alliander, together with Ultera, is working on the development of a 6 km FCL HTS cable, to install it at the Alliander's HV grid. In the following sections, the various technical aspects and motivations are described.

4.1. *Grid architecture and cable design*

The planned application involves retrofitting of three complete three-phase systems into three existing steel ducts, all with an inner diameter of 160 mm. These ducts run though heavily populated areas in the northern part of Amsterdam and into central Amsterdam. The right-of-way is integrated with other infrastructure such as roads, canals and tunnels. Presently, three older 150 kV gas presure paper cables, each with a power rating of 100 MW occupy these ducts. The proposed upgraded system has two conventional 150 kV bundled XLPE cable systems of the City Cable® model in two of the ducts and a 50 kV HTS Triax® FCL cable in th third duct. The HTS Triax® design is selected due to the compactness of this system, the high power rating and the possibility for counter-flow cooling.

4.2. *Grid evaluation*

Three different HTS scenarios were investigated in detail and were compared with a traditional base. The proposed system solution has the following advantages:

1) Most of the load flows through the low-impedance low-loss HTS cable system;
2) The 150/50 kV transformers can be distributed between the two end stations;
3) N-2 redundancy for the full power need of 200 MW using dynamic rating;
4) No increase in the total available fault current compared to the existing system.

4.3. *Cooling*

The HTS Triax® FCL cable, used in the Amsterdam project, must be cooled by only two cooling systems, one at each end, using a liquid nitrogen coolant (Figure 5). The two systems have to be optimized to get a compact construction at both substations.

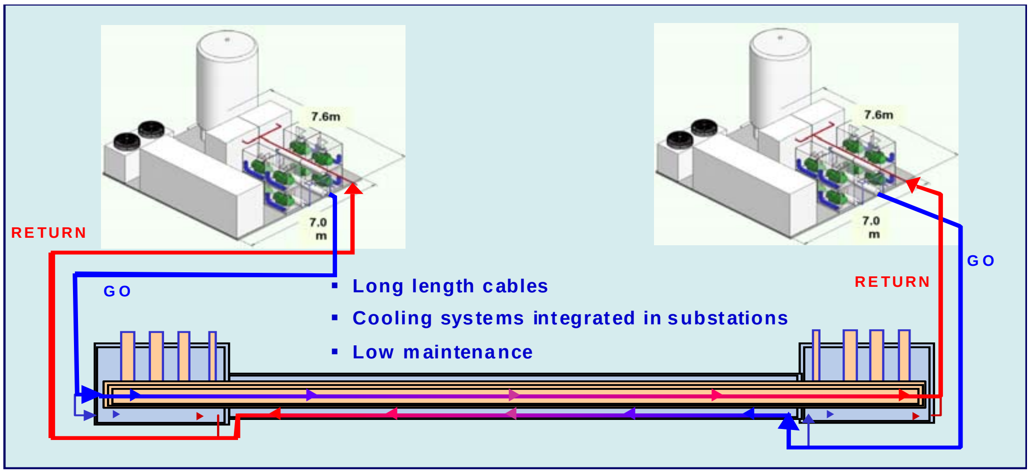

Figure 5. Cooling system

The thermal behaviour of this system has been modeled numerically in a steady-state approach with temperature-dependent variables. This modelling shows that to make it possible to have cooling systems only at the ends of the cable, the cooling of the cable and of the terminations must be split. Normally, a major part of the energy losses is caused by temperature gradients in the terminations, whereas using a separate loop for cooling of terminations will allow the cable cooling loop to keep the cable temperature stable over a longer length. The resulting thermal profile is shown in Figure 6.

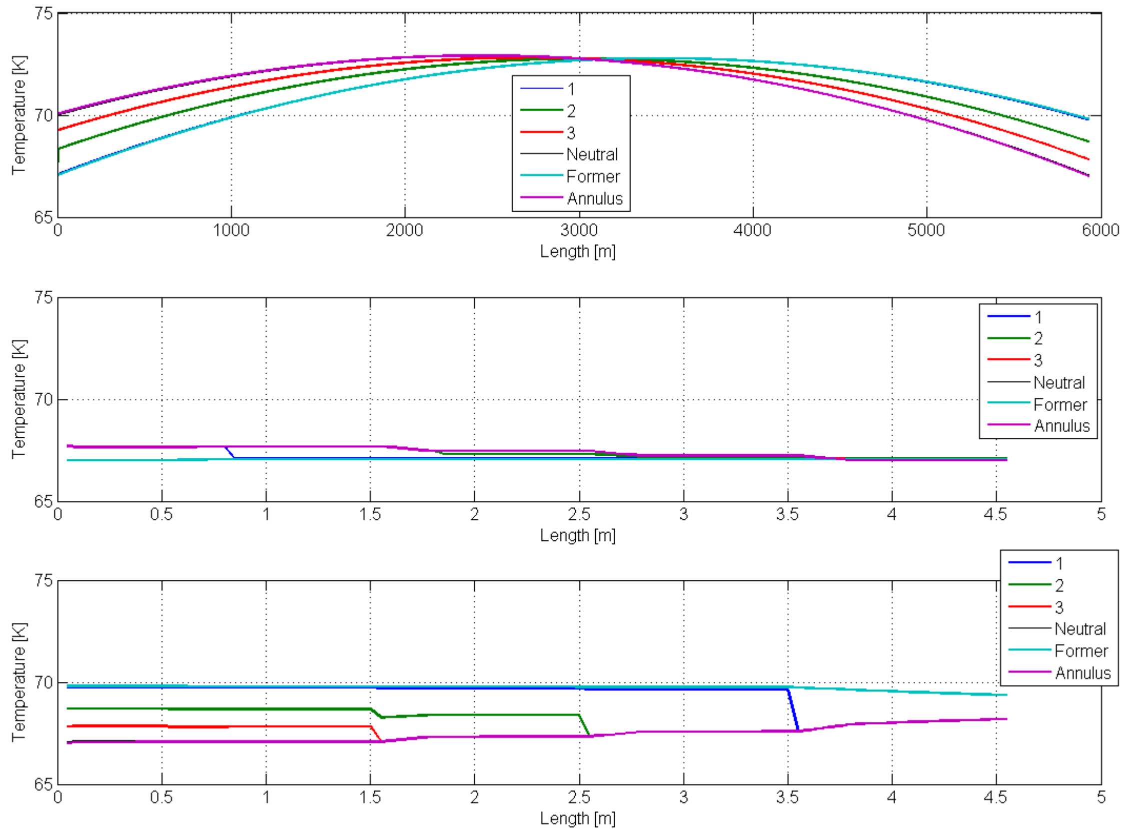

Figure 6. Thermal profile of a 6 km long 50 kV HTS Triax® FCL cable using the target performance parameters shown in table 1. The temperature profiles inside the terminations are shown separately with a different length scale.

4.4. *Performance targets*

Through this thermal modelling, Alliander and Ultera have established definite performance goals for the HTS FCL cable technology in the form of required AC loss, heat leak of the thermal insulation, fault-current behaviour and coolant flow friction that are required to render the 6 km long 50kV installation feasible with cooling stations installed only at each end of the system. These performance target are shown in Table 1.

System parameter	Present status	Project target
Voltage rating	15 kV [1]	50 kV
AC loss at 2.9 kArms, 77 K	1.4 W/m/phase [8]	0.2 W/m/phase
Cryostat heat loss at 77 K	1.5-2.0 W/m [9]	0.5 W/m
ID	97 mm	> 95 mm
OD	163 mm	< 150 mm
Cooler:		
Pumping pressure drop	4-5 barg	9-10 barg

Nr. of cooling stations	3-4	2
Cooling power per station	11-22 kW	6-8 kW
Service interval	6 months	> 2 yrs

Table 1. The present status of different performance parameters compared to the project targets

5. Summary

The major conclusions can be summarized as follows:

- The HTS cable technology demonstrates a great potential in solving of congestion issues and other weak spots in power grids. Compared with the traditional technologies, HTS cables have enormous technical and environmental advantages.
- For integration of HTS cables in transport networks the cable's length should be increased to several kilometres. A breakthrough in the cooling system and important developments in a cable are needed to make a long length HTS cable possible.
- The pilot project in the city of Amsterdam demonstrates feasibility of the 6 km FCL Triax HTS® cable, provided that the performance targets can be reached.

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