EFFICIENT CONNECTION OF LARGE-SCALE DER WITH INTELLIGENT SUPERCONDUCTING CABLES

Irina MELNIK
Alliander – the Netherlands
irina.melnik@alliander.com

Alex GESCHIERE
Alliander – the Netherlands
alex.geschiere@alliander.com

Dag WILLÉN
nkt cables - Denmark
dag.willen@nktcables.dk

Oleg CHEVTCHENKO
TUDelft – the Netherlands
O.Chevtchenko@tudelft.nl

Heidi LENTGE
nkt cables – Denmark
heidi.lentge@nktcables.dk

Vandana MEHAIRJAN
Alliander – the Netherlands
vandana.mehairjan@alliander.com

ABSTRACT

High penetration of large-scale Distributed Energy Recourses leads to numerous technical bottlenecks in electric power grids, such as high level of fault currents, increasing of produced reactive power, unstable voltage levels and overloading. Also environmental issues determine additional targets to ways of transport of high amount of electrical power to urban and density areas. Need of new technology solutions, able to manage these complex challenges, has become evident.

High temperature superconducting cables offer convincing advantages in connection of large-scale DER, such as extreme high load-capacity at lower voltage levels, very low energy losses, no thermal pollution, very low electro magnetic (EM) emission and integrated FCL property.

A consortium of Alliander, Ultera™ and TUD develops a long length FCL Triax HTS® cable to demonstrate high performances of the HTS cables technology in a real grid. The already achieved project results in FCL properties modelling, reducing of the heat leakage, improving of the thermal behaviour of the cryostat, and tests results with considerable reduction of AC loss confirm that the stated targets to develop a such cable system will be reached.

INTRODUCTION

Large-scale Distributed Energy Recourses (DER) are gaining to be a mainstream energy supply technology across of many countries. However effective integration of large-scale conventional power sources remains to be still a challenge for electrical power systems. High penetration of large-scale DER leads to numerous technical bottlenecks in electrical grids, such as high level of fault currents, increasing of produced reactive power, unstable voltage levels and overloading. Also environmental issues play significant role when high amount of electrical power has to be transported to urban and density areas. Limited space, available for the installation of underground cable connections, and the reduction of acceptance of overhead lines make the connection of large-scale DER to electrical power grids even more complicated. The need for new technology solutions, which can manage above listed challenges, has become apparent.

This paper highlights a role of intelligent high-temperature superconducting (HTS) cables with integrated fault current limitation (FCL) in efficient connection of large-scale distributed generation to electrical power grids.

Present in-grid demonstrated high-temperature superconducting cables are limited to the lengths of 100-600 m. This superconducting cable technology is still in immature state with certain restrictions to be widely implemented in real electrical networks. A consortium of the Dutch DSO Alliander, Ultera™ (A Southwire/nkt cables Joint Venture) and Delft University of Technology (TUD) has developed an intensive R&D program with intention to develop and install in Alliander's grid a 6 km FCL Triax HTS® cable to demonstrate high performances of the HTS cables technology in a real grid.

BENEFITS OF THE FCL TRIAX HTS® CABLES TECHNOLOGY

HTS cables offer convincing advantages at connection of large-scale DER to electrical grids. Below the most important properties of this cable technology are listed.

High transport capacity

An important characteristic of HTS cables is their high transport capacity. HTS cables can transport up to 10 times more power than conventional cables of comparable radial dimension. This feature is supported by the fact that nowadays a long-length commercial HTS tape conductor of the latest generation (see Figure 1) can carry 300 A/mm2 when cooled to 77 Kelvin.

Figure 1 A sample of HTS tape with FCL properties

Reducing of transformer steps

Due to very low energy losses HTS cables can transport more power, than conventional cables, at lower voltage levels. In consequence of this, a number of costly transformer steps off-shore and on-shore can be reduced.

Less reactive power producing

HTS cables produce remarkable less reactive power, than conventional cables. This is especially essential in case of connection of large-scale DER with intermittent generation character by long cables.

Small footprint

Owing to the high power capacity, no thermal pollution and very low electro magnetic (EM) emission of HTS cables, these cables have a very small footprint, which makes them suitable for dense and urban areas with expanded underground infrastructures (see Figure 2).

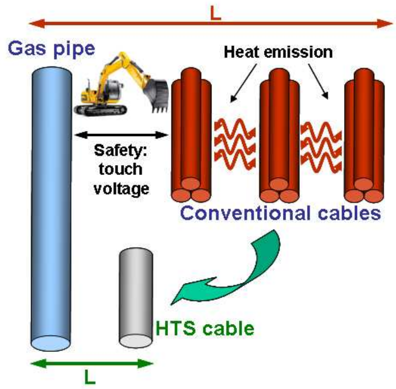

Figure 2 Smaller footprint of HTS cables in comparison to conventional cables

Reduced voltage fluctuations

Bidirectional loadflows cause voltage problems in MV grids. The low-impedance superconducting cables will significantly reduce voltage fluctuations (in the order of 30 %) and improve the grid performance.

Fault current limiting

Large integration of DER increases fault current levels in electrical grids. Additional devices and adapted system configurations should be applied in grids in order to limit short-circuit currents. As distinct from this, HTS cables of the latest generation with the integrated fault current limiting (FCL) property allow to restrict fault currents without necessity of applying of additional devices.

Due to their unique qualities superconductors offer a way to solve system design constraints by presenting an impedance to the electrical system, which varies depending on operating conditions. The latest generation of HTS cables with FCL properties has improved non linear voltage-current characteristics (Figure 3). This means low impedance during normal operation and large impedance at increasing current.

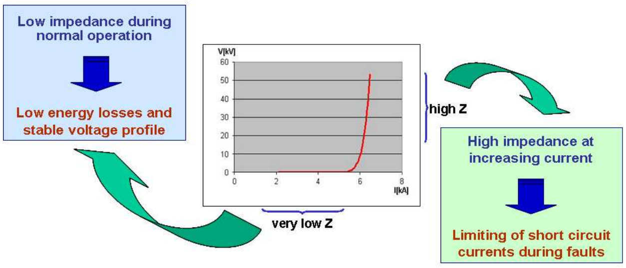

Figure 3 A schematic of the non-linear voltage vs. current characteristics of HTS cables

Such cables behave intelligently by adapting their impedance to the actual needs of the network. That's why smart HTS cables also contribute to a stable voltage profile in grids, while reducing short circuit currents. The transition from the superconducting state to the normal state, the so-called quench, takes place automatically.

In order to demonstrate the abilities of FCL HTS cables in limiting of fault a number of simulations were performed.

The connection of a large power source to a grid through a step-up transformer was modelled by a) a conventional cable and by b) a HTS cable with the integrated FCL property.

Simulations were carried out with the symmetrical three-phase short circuit, occured at 100 ms (t = 0 ms at the beginning of the simulation). The total simulation time was 250 ms, and the time step was 2,5 µs in order to properly see the transient. The current during a normal operation is 2 kA.

The investigations were performed to a three-phase short circuit current from the generator to the point of the fault, during a fault between the grid and the cable.

In the model with conventional cable, the peak value of the fault current, fed by the generator, reaches 13.7 kA (Figure 4).

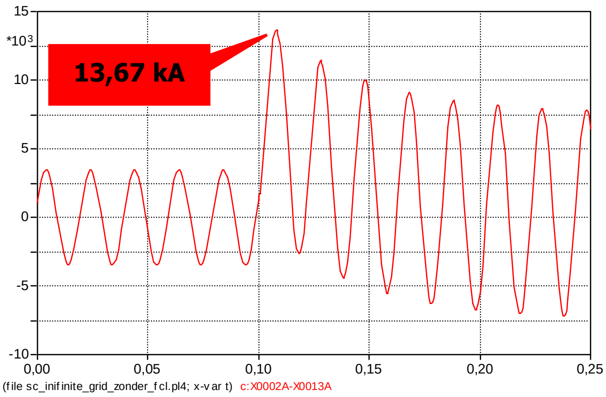

Figure 4
Three-phase fault to earth with a conventional cable (x-axis: time in s; y-axis: current in A)

In the model with a FCL HTS cable, the peak fault current was limited to 7,7 kA (Figure 5), which is only three times higher than the nominal current of the FCL HTS cable. After a cycle the fault current was further reduced to 6,7 kA.

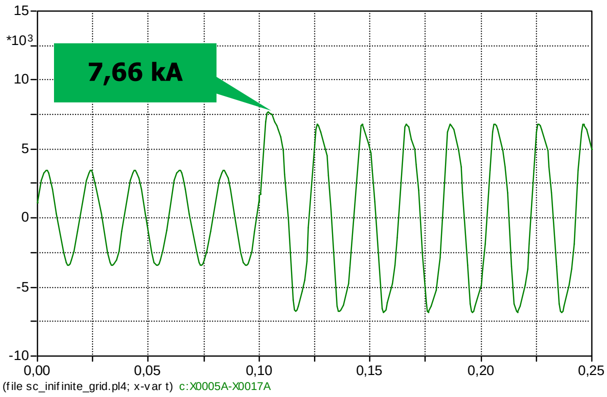

Figure 5
Three-phase fault to earth with a FCL HTS cable (x-axis: time in s; y-axis: current in A)

NEW ACHIVEMENTS IN DEVELOPING OF A LONG LENGTH FCL TRIAX HTS® CABLE

The new functionality of integrated FCL adds extra requirements on the cooling of these HTS cables due to extra heat developing at the FCL state. Therefore a strong development on heat management is needed.

Alliander, Ultera™ and TUD are performing investigations in their project on this aspect in two directions: significant reduction of AC loss and considerable improving of thermal insulation. Also cooling channels will be optimized for more efficient flow of the cooling liquid nitrogen.

The project goals are to achieve a cryostat heat leak below 0.5 W/m, an AC loss in the order of 0.2 W/m/phase at 2.9 kArms, and a flow friction of 0.04.

A number of substantial breakthroughs in development of a long FCL Triax HTS® cable is already made:

- The developed FCL modelling proves that the stated targets for short current limiting properties will be achieved in the project
- Calculations demonstrate evidential reducing of the heat leakage and improving of the thermal behavior of the cryostat.
- The latest tests have shown considerable reduction of AC loss.

Reduced AC loss

In an effort to increase the possible length between cooling stations in HTS cable systems, HTS cable samples were made that show a drastically reduced AC loss. The low loss was achieved by using appropriate pitch angles in the two-layer cable conductor, by minimizing the gaps between the HTS tapes, and by using narrow HTS tapes that conform well to the roundness of the underlying former. Losses of 0.11 W/m at 3 kArms were measured at 60 Hz and at a temperature of 77 K.

A simulated temperature profile of a 6 km HTS Triax® FCL cable system, using the present-status performance values for AC loss and cryostat loss, is shown in Figure 6. The modeled system has one cooling station at each end.

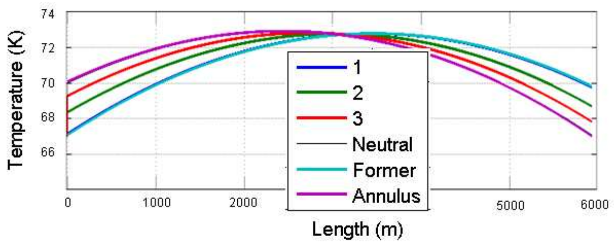

Figure 6 Simulated temperature profile of a 6 km long 50 kV HTS Triax® FCL

Low flow friction

A 45 m long cryostat was manufactured consisting of alternatively straight rigid sections and corrugated flexible sections (see Figure 7).

Figure 7 45 m long cryostat with cable model during hydraulic testing

A dummy cable was inserted into this cryostat, and liquid nitrogen was circulated in the annulus between the dummy cable surface and the inner cryostat surface. The pressure-drop was measured to be only a few mbar at a flow of 300 g/s of LN2. This indicates a friction coefficient that is sufficiently low to realize long-length HTS cable systems by using a large fraction of straight, rigid thermal insulation ducts. This is realistic in cases, where there is access through an open cable trench, and in cases, where the cable route consists largely of long straight sections of rigid steel ducts.

Reduced heat leakage

Performed calculations and tests of several cryostat models demonstrate reduction of the heat leakage and improvement of the thermal and hydraulic behaviour of the cryostat. Namely, the heat leak into the cryostat is down to 0.5 W/m.

CONCLUSIONS

The new HTS cable technology with intelligent built-in FCL solves many of the grid operators' most severe problems. The achievements, already made in the Dutch project, confirm that the stated ambitious targets to develop of a 6 km FCL Triax HTS® cable will be reached. This is a large step to maturing the technology towards it's large-scale use.

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