LONG DISTANCE TRIAX HTS CABLE

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ABSTRACT

Until now, HTS cables are barely hundreds of meters long. To give them a significant use in a high voltage (HV) network their length has to be increased to at least several kilometres. This represents a big challenge in HTS technology. The utility Nuon, nkt cables and Praxair are working together to develop a long distance HTS cable to be used for transmission in the High Voltage grid in Amsterdam. An existing 6 km long High Voltage circuit with capacity problems has been chosen. This circuit will be retrofitted by replacing a 150 kV Gas Pressure cable with a 50 kV HTS cable. The Gas Pressure cable will be removed from the steel pipe, where the HTS cable will be placed. To fit in the steel pipe a special cable design, the so called Triax cable, will be used .

In order to get the benefits of the HTS technology, an efficient cooling system is needed. That's why for this project a new generation of coolers called "Pulse Tube Coolers" will be used.

Advantages to be enjoyed by this application are: no electro-magnetic emissions, transport of much more power at a lower voltage level, very low energy losses, no negative thermal influence on other infrastructure and low civil costs. This ambitious project is the beginning of a breakthrough in HTS technology and will open the doors for a real commercial market for HTS cables.

INTRODUCTION

HTS cables used in current projects are limited to 200-600 m of length [1-7]. They have still not been used for energy transport over long distances. An important characteristic of transport networks is long circuit lengths. For instance in The Netherlands, which is a relatively small country, most of the circuits are about 5 to 20 km long (figure 1). This means that to give HTS cables a significant use in HV-grids their length has to be increased to several kilometers.

The utility Nuon, nkt cables and Praxair are working together to develop a long distance HTS cable to be used for transmission in the HV-grid in Amsterdam. At this moment a feasibility study for this pilot project is being carried out. Details of this study will be presented in this paper.

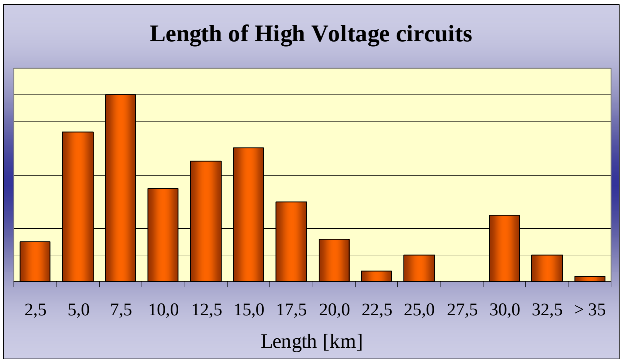

Figure 1. Length of HV-circuits in The Netherlands

PILOT PROJECT LOCATION AND DESIGN

To develop an application that fits in an existing HV-network an appropriate location for a pilot project has to be chosen. In the city of Amsterdam there is an important 150 kV substation fed by three gas pressure (GP) cables with capacity problems. Each of these three circuits is 6 km long with a capacity of 100 MVA (figure 2).

The 150 kV substation "Hoogte Kadijk" has a load of about 200 MVA, which means that the feeding of this substation is not completely safe by all contingencies. By fault during normal operation in this network the load of the cables stays just under the limits, whereas by fault of one circuit during maintenance it might reach two times the rated load. To solve this problem the circuits will be retrofitted.

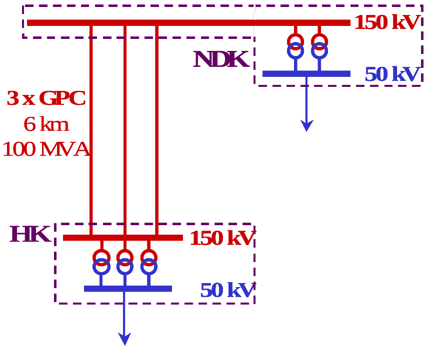

Figure 2. HV-network for pilot project

The three GP cables will be removed from the steel pipe Two of them will be replaced by special XLPE 150 kV cables with a transport capacity of 200 MVA each. The third will be replaced with a 50 kV HTS cable with a transport capacity of 250 MVA. (figure 3).

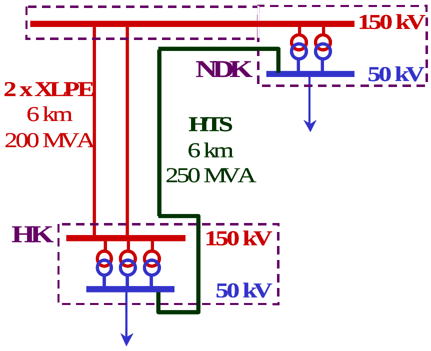

Figure 3. HV-network after installation HTS cable

One of the advantages we will enjoy in this project is the low civil costs due to the reuse of the existing steel pipe (figure 4). Digging in the downtown of Amsterdam is very costly and often a real nightmare. The fact that the steel pipe in which the GP cables lie will be used for the HTS cable makes digging unnecessary. Therefore the time, efforts and costs related to this activity will be saved.

Figure 4. Gas Pressure Cable in steel pipe

To fit in the steel pipe of the GP cable a special three phase design of HTS cable will be used for this project. This cable design is called “Triax” cable [2] (figure 5).

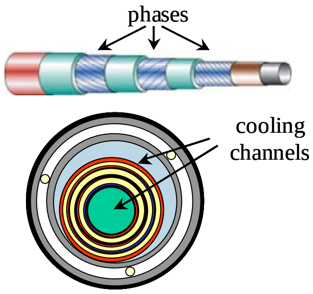

Figure 5. Triax cable

A preliminary design has been made of a 50 kV, 250 MVA Triax cable with an outer diameter of 139 mm suitable for pulling into steel ducts of 150 mm inner diameter. This cable consists of three coaxial superconductors with an isolation layer between them. It is also provided with an inner and an outer cooling channel (figure 5). As a result of the coaxial arrangement of the conductors there will not be any electro-magnetic emissions to the outside of the cable.

AN EFICIENT COOLING SYSTEM

The Triax HTS cable will be cooled by one cooling station at each end of the cable, using a liquid nitrogen coolant. Operation parameters such as temperature, flow rate and pressure drop will be optimized as a function of performance parameters such as the efficiency of the thermal insulation, the operating current loss and the efficiency-vs-temperature profile of the cooling machine. The operating temperature range is between 65 K and 80 K.

In order to get the low-loss benefits of the HTS technology, a cooling system with a high efficiency is needed. A new generation of coolers called “Pulse Tube Coolers” are evaluated for this project [8]. The Pulse Tube Cryocooler employs a thermal cycle similar to the Stirling cycle [9]. Oscillating helium molecules undergo compression, cooling, expansion and warming during a single oscillation. In Praxair’s high-frequency pulse tube cryocooler shown in Figure 6, the oscillations are produced by an oil-free, dual-opposed linear motor and combined with a coldhead containing no moving parts. These units should be maintenance free and highly reliable and are ideal for distributed refrigeration applications. Smaller units of up to 200 W refrigeration are being demonstrated in non-superconducting field applications. A unit capable of 1000W of lift at 70K is under development, and will be demonstrated at the Bixby Road Superconducting Demonstration site [2]. The inherent reliability of these cryocoolers, combined with their efficiency, make them natural candidates for superconducting power applications.

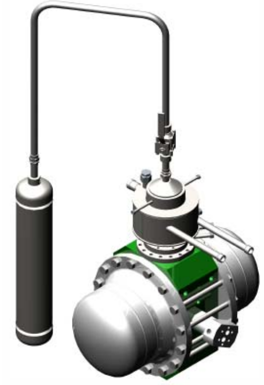

Figure 6. A pulse tube cryocooler designed to provide 1000W of refrigeration at 70K.

The pulse tube cryocoolers are modular building blocks in the refrigeration system. Larger refrigeration stations such as that shown in Figure 7 contain cryocoolers to cover the heat loads of terminations, cryogenic pumps and the HTS cable. The station includes a liquid nitrogen tank that contains back-up liquid. Smaller refrigeration stations may include only cryocoolers or cryogenic pumps and can be located where needed along the length of the cable.

Since each cryocooler supplies a fraction of the load, it can be isolated if maintenance or repair is needed without requiring the entire system to be shut down.

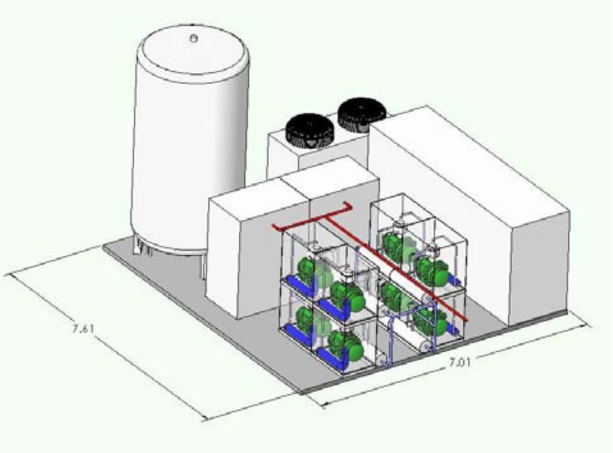

Figure 7. A refrigeration system for long-length superconducting cables. The refrigeration is provided by an array of pulse tube cryocoolers, shown in the foreground. The tank provides reserve liquid nitrogen.

INTEGRATION IN THE HV-GRID

Besides the benefits already mentioned there are some other advantages to enjoy. First of all it is possible to transport much more power at a lower voltage level and the energy losses are very low. Furthermore the cable will not have negative thermal influence on other infrastructure, like adjacent circuits, what could otherwise reduce the total transport capacity.

Nevertheless integrating a new technology in an existing system often requires adjustments to be made. In this case there are some bottlenecks to be solved in order to get all advantages of the HTS technology in the HV-network of Amsterdam.

At first we have to modify the impedances in the grid to let a large part of the power flow through the HTS cable instead of through the other two circuits. By just installing the HTS cable without further changes in the network it will only carry about 30% of its rated capacity. This is caused by the ratio between the impedance of the transformers of both 50 kV substations. In this network the impedances of the transformers are dominant thus the cables do not play a significant roll in this question.

Another important issue in this discussion is that the coupling between the 50 kV substations thought the HTS will result in an increase of the short circuit currents. To keep them below the short circuit withstand of the busbar and other components some measures have to be taken.

Also the voltage control scheme in both substations has to be reviewed. At this moment the voltage regulation in the substations occurs independently of each other. The voltage is separately measured at each 50 kV busbar and regulated by the tap changer of the power transformers connected in the respective substation. Keeping this voltage control scheme after coupling the 50 kV substations will result in the flow of a large amount of reactive power through the HTS cable. This phenomenon is brought about by the difference in the voltage levels of the substations. In order to prevent such a differences a “combined” voltage control has to be developed and implemented.

The last point to be taken in account is the effect of the cable design in the symmetry of the electrical quantities. Because the cable consist of concentric conductors, the capacitance and inductance of each phase to the ground and mutually are different. As a consequence asymmetry of the current and the voltage can be expected. This could potentially result in a too large current through the neutral of the cable or unacceptable large voltage asymmetry on the power transformers, causing damage to the equipment. In order to eliminate this effect transposition of the phases in the cable may have to be considered.

A more detailed consideration and comparison of the possible measures to be taken to solve these issues is currently being carried out.

CONCLUSION

Installing a long distance HTS cable in an existing HV-grid represents a big challenge and is a very ambitious project to be developed and carried out.

None of the technical feasibility studies until so far give indication of any insurmountable obstacle. By using a very efficient cooling system with a new generation of coolers and making appropriate adjustments in the HV-network it will be possible to enjoy all the advantages HTS technology has to offer.

The pilot project in the city of Amsterdam shall open the doors for a real commercial market for HTS cables.

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