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INSTALLING A LONG-DISTANCE HTS CABLE

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ABSTRACT

Nuon, nkt cables and Praxair will install a long HTS cable in Amsterdam. An existing HV circuit will be retrofitted by replacing a 150 kV gas pressure Cable with a 50 kV HTS Triax cable. The Triax design will be used to fit in the steel pipe.

The cable will be located within an existing steel cable conduit, which will reduce digging activities and minimize cable costs. The cable construction consists of 16 cryostat sections and 3 cable sections. As a result the pulling forces can be kept within the acceptable tolerances. Closed loop cooling systems will be installed at each end of the cable.

KEYWORDS

HTS, Triax, cable, cryostat, civil, cooling, retrofit.

INTRODUCTION

One of the first applications for HTS cables is within urban cores. This requires long cables with limited cooling systems. The utility Nuon, nkt cables and Praxair, Inc. are working together to install a 6 km long HTS cable in the city of Amsterdam. An existing high voltage circuit will be retrofitted by removing a 150 kV gas pressure cable from the steel pipe and replacing it with a 50 kV HTS cable.

Several financial and technical challenges must be overcome. New cable designs and better cooling systems are needed. A special designed three-phase cable, called Triax cable, will be used. To fit in the steel pipe, this cable will be provided with both inside and outside cooling channels.

This article will focus on all the civil aspects of the installation of this long distance HTS application. Due to limited space and other practical issues in urban areas, several cooling systems along the cable are not allowed. Therefore, only two cooling systems (one at each end) will be used.

REASON FOR INVESTMENT

In Amsterdam's electrical network, an important cable lacks adequate capacity. This 150 kV gas pressure (GP) cable is 6 km long and has a capacity of 100 MVA. In recent years the load fed by this cable has considerably increased. Due to the increased load, this portion of the network lacks full (N-2) reliability (figure 1).

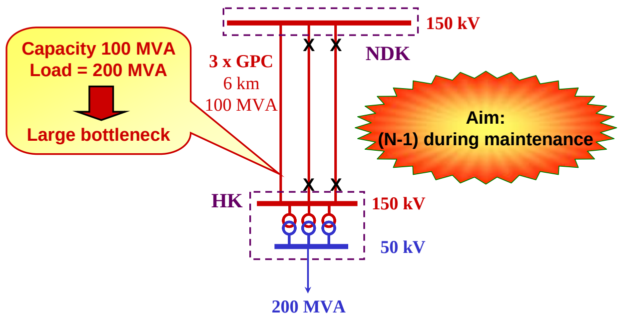

Figure 1. Capacity bottleneck in the network of Amsterdam

To solve this capacity bottleneck, a major investment is required. Because the cable will have to cross a very crowded downtown with numerous canals, a conventional cable installed in a new trench in Amsterdam is prohibitively expensive (figure 2). Additionally, obtaining permits for a project of this magnitude will be expensive, time consuming, and difficult.

Figure 2. Substations in crowded down town Amsterdam

RETROFITTING WITH HTS CABLE

A solution which reuses the existing steel conduit avoids many civil issues. A technology with large power capacity that will fit into this pipe was necessary. HTS cable, due to its very large power handling capacity in a small diameter, is the most promising solution.

The existing 150 kV GP cable will be removed from the steel duct (figure 3) and replaced with a new 50 kV HTS cable with more than twice the power carrying capacity.

Figure 3. Gas Pressure cable in steel pipe

Triax cable (figure 4) is an optimum design for this application. Due to the concentric alignment of the three phases, it is a very compact cable. The preliminary cable design has an outer diameter of 139 mm, suitable for pulling through the existing 150 mm inner diameter steel duct.

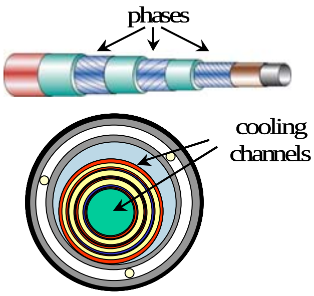

Figure 4. Triax cable

After installing the HTS cable and adjusting the network as shown below (figure 5), the capacity problem is solved.

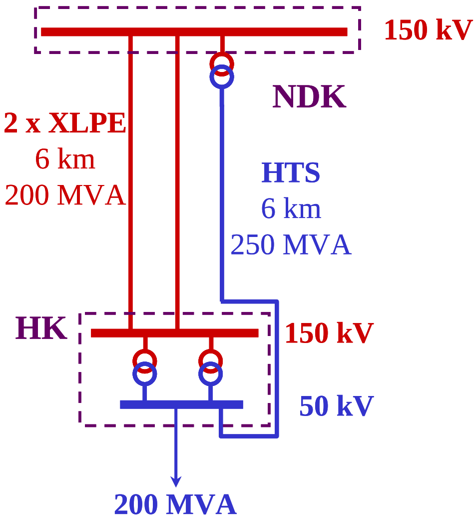

Figure 5. Network after installation HTS cable

CABLE INSTALLATION

The existing external-gas-pressure oil-filled cables are installed in 16 sections with 15 joints and three single-phase terminations at each end. First, the joint bays must be opened and the joints cut away. Then, the cables can be removed by pulling them out of the ducts.

The most cost-effective and least labor-intensive plan is to install 16 sections of cryostats with the same lengths and joint locations as the old gas-pressure cables. The pulling forces for these sections are shown in Table 1.

Table 1. Cryostat pulling forces

Section [nr.]	Direction [N/S]	Force [kN]	Length [m]
1	South	11	500
2	South	11	500
3	North	**12**	**550**
4	Any	11	475
5	South	11	420
6	Any	7	355
7	South	6	275
8	South	7	440
9	North	5	310
10	South	4	250
11	Any	8	425
12	South	10	280
13	South	11	560
14	South	4	170
15	Any	6	340
16	North	11	351

Figure 6. Pulling of a cryostat section into a duct

The cable core is then installed in three sections of about 2 km length each. The pulling forces are shown in Table 2. Each pull is assisted by constant-force cable pushers in each of the old joint bays.

Table 2. Cable-core pulling forces

Section [nr.]	Direction [N/S]	Max force [kN]	Length [m]
A	South	**9**	2024
B	South	7	2051
C	North	8	**2150**

Figure 7. Pulling of a cable section into a cryostat

Following the pulling, two cable joints are made between cryostat sections 4-5 and 10-11. The three-phase joints are encapsulated in pressure chambers (figure 8). The other cryostat sections are joined by simpler connectors. To complete the cable installation, each end is terminated using an outdoor-grade three-phase termination (figure 9).

Figure 8. Three-phase cable splice with housing

Figure 9. Three-phase cable termination

COOLING SYSTEM

Because of the limited space and other practical issues in the city of Amsterdam, several cooling systems along the cable are not allowed. Therefore, only two cooling systems, one at each substation, will be used (figure 10). These two systems have also to be optimized to get a compact construction at both substations. This will be achieved by an efficient array of the system's components.

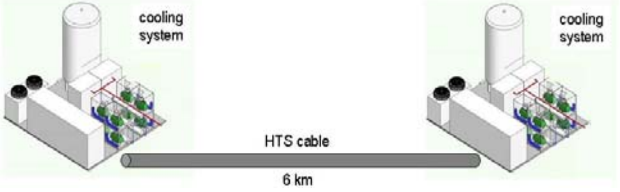

Figure 10. Cooling systems at both ends of the cable

The role of the cooling system is to provide sub-cooled liquid nitrogen at an adequate pressure to suppress gas bubble formation throughout the entire loop. An example cooling loop from the 200 m pilot study [1] is shown in Figure 11.

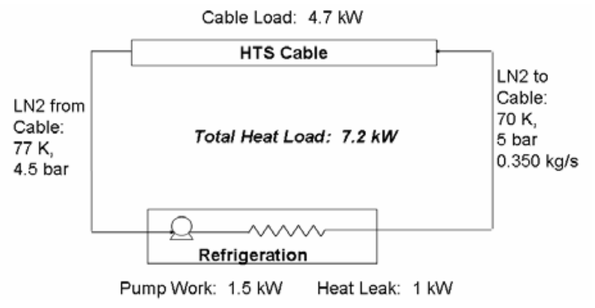

Figure 11. Schematic for cooling loop for 200 m pilot

The cooling system must overcome four loss terms, including the cable heat leak and AC losses, the termination losses within the terminations, heat leaks within the cryocooler system, and compensating for the energy input due to pumping. As the cable length increases, both the pressure drop and the heat leak increase, while the coolant flow rate stays roughly the same for a given Triax diameter. The inlet pressure for the system must be increased to avoid approaching vaporization conditions. This is illustrated on figure 12 with a sample calculation for a 6.2 km cable, which shows that for approx 12 bar(a) inlet pressure, the outlet fluid is still well below the liquid-vapor equilibrium line.

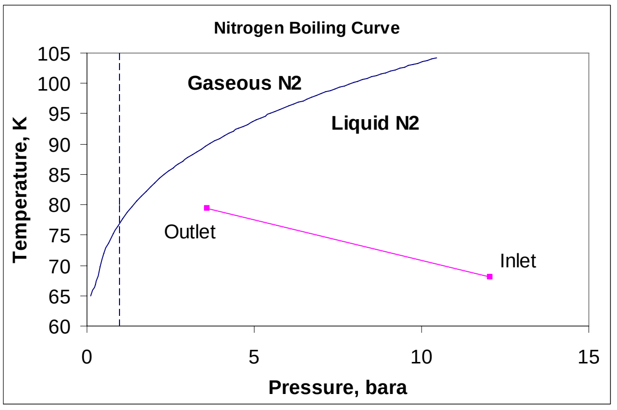

Figure 12. Inlet vs. outlet fluid conditions for planned cable installation.

In this example, the cooling requirement is divided between the two end stations with a capacity of about 5 kW each. The inlet temperature is 68K, which is slightly above the melting point of nitrogen (63.2K). The pressure drop for the system is assumed to be about 8.5 bar.

Cooling may be provided by a variety of technologies, including Stirling-type pulse tubes, Stirling engines, and reverse Brayton refrigeration cycles. Pulse tubes [2] have the advantage of no moving parts at cryogenic conditions and minimal planned maintenance requirements, ideal for a utility application. Figure 13 shows a drawing of a 1-kW class electrically driven pulse tube designed for HTS applications, and Figure 14 shows a photograph of the pressure wave generator (PWG) being used to drive the pulse tube. The PWG consists of two linear motors, each with 10 kW input power. The cryocooler system design includes multiple cryocoolers to provide N+2 redundancy for

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the cooling system.

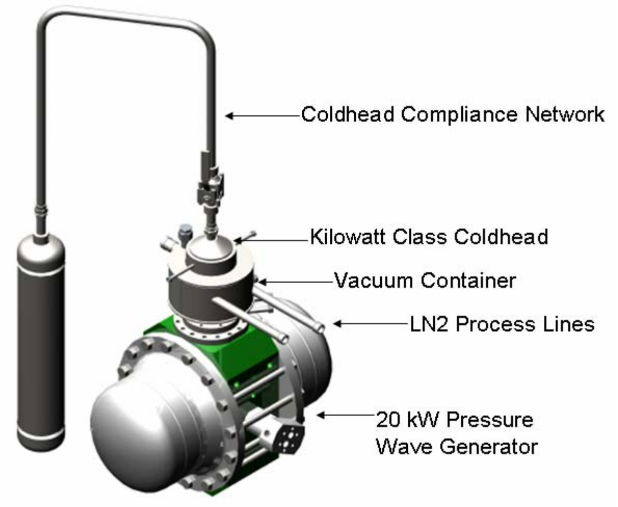

Figure 13. 1-kW Pulse tube cryocooler design.

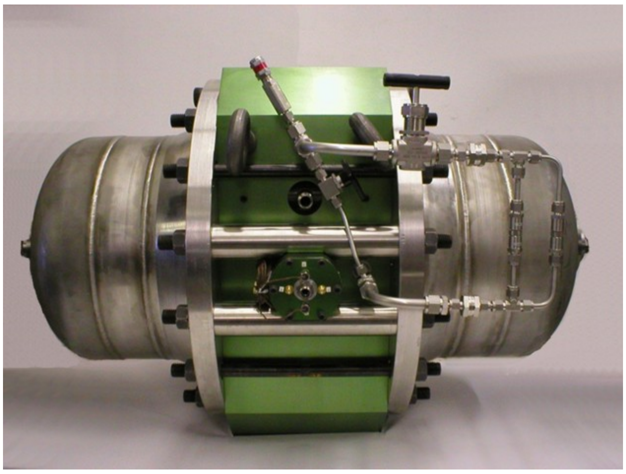

Figure 14. 20 kW input power pressure wave generator.

CONCLUSION

A 50 kV, 250 MVA HTS cable of the Triax design can be used to remove capacity bottlenecks in the crowded Amsterdam city center. This project will employ Installation methods which have been tested in a 200 m pilot test. Based upon the pilot test, the installation forces for 16 cryostat sections and three cable sections have been calculated and are feasible.

The cooling system will provide the required refrigeration at each end of the cable, as well as the pumping energy for the cooling loop. Use of highly reliable pulse tube cryocoolers will provide closed-loop cooling within the small footprint required for an urban installation.

The next phases for the project include detailed design of all subsystems and type testing of all components at 50 kV, followed by construction and testing of the system.

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GLOSSARY

HTS: High Temperature Superconductor