

## AMPACITY PROJECT – WORLDWIDE FIRST SUPERCONDUCTING CABLE AND FAULT CURRENT LIMITER INSTALLATION IN A GERMAN CITY CENTER

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### ABSTRACT

*In recent years significant progress has been made in the development of high temperature superconducting (HTS) power devices, in particular cables and fault current limiters. Several field tests of large scale prototypes for both applications have been successfully accomplished and the technologies are getting closer to commercialization.*

*In this paper the German AmpaCity project will be introduced and its objectives will be described. Furthermore, the conceptual design of the HTS cable system and the major developments which have been achieved so far, as well as the current status of the project will be reported.*

### INTRODUCTION

In most European countries the power supply within cities is predominantly ensured through high, medium and low voltage power cables. A large fraction of these cables as well as the associated substations are approaching the end of their lifetime and therefore need to be refurbished in the upcoming years. Usually, old power devices will be simply replaced by new ones, and if there are major load changes, substations will be adapted by up- or downgrading.

The application of medium voltage HTS systems consisting of a concentric three phase HTS cable connected in series with an HTS fault current limiter (FCL) offers attractive alternatives to conventional systems. Replacing conventional high voltage cables by medium voltage HTS systems with the same power rating enables a considerable reduction of the number of inner city substations. Since HTS cables are in general more compact than conventional cables, the required right of way is much smaller and the installation is easier. Moreover, there are many other advantages of HTS cables. Besides the increased power density there is no thermal impact on the environment. In addition, HTS cables do not exhibit outer magnetic fields during normal operation and in combination with HTS fault current limiters the operating safety in the grid is increased as a result of reduced fault current levels.

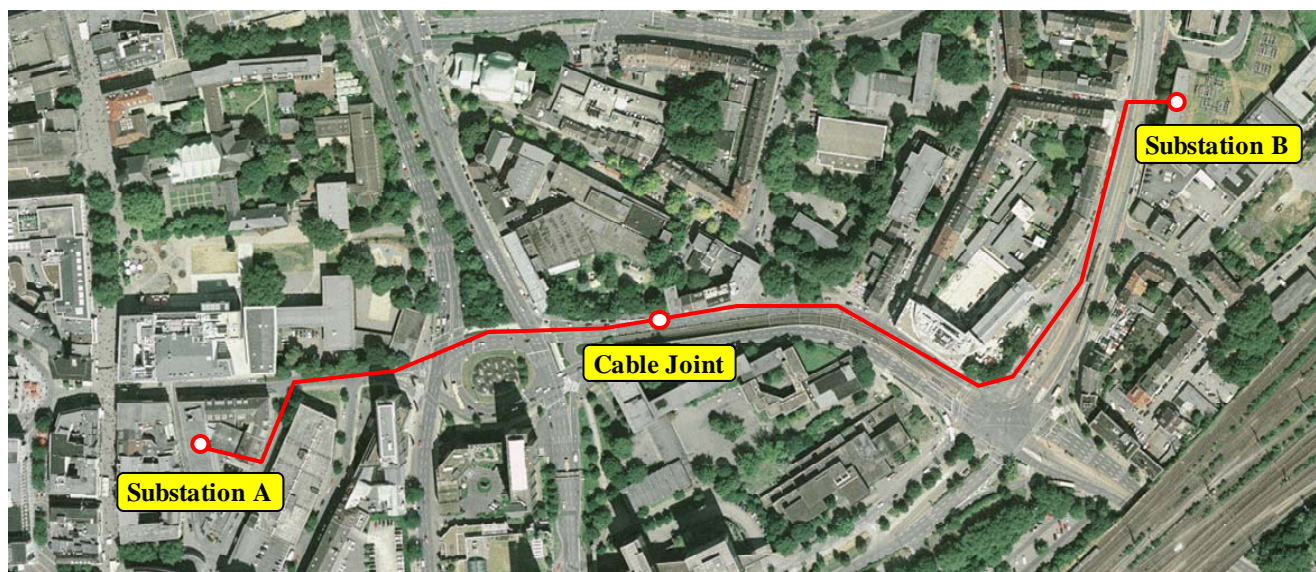
Over the last few years, high temperature superconductors have matured, especially due to the technical progress achieved in the manufacturing of these materials, and are now on the verge of industrial scale production. Furthermore, several superconducting cables [1-5] as well as superconducting fault current limiters [6-8] for power systems have been tested during the last years in real grid applica-

tions worldwide and are now on the threshold of commercialization. The experience gathered in these tests shows that all technical requirements are fulfilled so far and a high reliability of these new power devices can be achieved. Nevertheless, for distribution system operators an economical feasibility of such superconductor systems is required as well, to take the new technologies into account for future grids in their role as regulated asset owners.

At present, the main reason preventing wider use of the HTS technology lies in the fact that the capital cost of HTS systems is still higher than that of conventional devices, and that the technology is still relatively unknown. However, an economic advantage of the HTS technology can generally be achieved already today, wherever positive secondary effects are present. Regarding the design of the electricity distribution networks, this would include higher power density, space savings, integration of renewable energy based feed-ins at the medium voltage level and additional space gains especially in congested urban areas. Dismantling of substations would also result in additional space gains with the option to use or sell the spaces gained in prime locations for other uses.

Between December 2009 and December 2010 a feasibility study had been conducted under guidance of the Karlsruhe Institute of Technology (KIT) on behalf of the German utility RWE [9,10]. Together with superconductor cable and fault current limiter specialists from Nexans as well as other partners, it was investigated whether the electric power supply with medium voltage superconductor systems in city centers offers technical and economical advantages compared to conventional high voltage technology. The German city of Essen was chosen for the study and the key result is, that four out of ten 110/10 kV transformer substations become dispensable in the downtown area by using 10 kV cable systems. Conventional 10 kV cables do not constitute a viable alternative because of the large routing requirements and the high losses involved. In comparison to 110 kV cables, 10 kV HTS systems allow a much simpler grid structure, which requires less space for cable routing and smaller areas for equipment installations. In addition, the grid with 10 kV HTS systems exhibits lower overall costs than the grid with conventional 110 kV systems.

Subsequent to the positive results of the feasibility study RWE, Nexans and KIT started a pilot project, also referred to as “AmpaCity”, with the objective to install an HTS system in the downtown area of a German city to demonstrate the technology under technical and economical aspects.



**Figure 1** Planned route for the installation of the superconductor cable system in the city of Essen [11].

## AMPACITY PROJECT

Due to the innovative character of the AmpaCity project an application for funding was submitted to the German Federal Ministry of Economics and Technology by the consortium consisting of RWE, Nexans and KIT. After being approved by the ministry, the demonstration project started in September 2011.

As for the feasibility study the downtown area of the city Essen was chosen for the installation of the HTS system consisting of a concentric three phase cable and a fault current limiter. The system will be introduced as a connection between the medium voltage busses of two substations replacing a conventional high voltage system. The HTS system will be rated for a transmission power of 40 MVA (2310 A) at 10 kV and the planned route for the installation with a length of approximately 1 km is shown in figure 1. Substation A is located in the downtown area of Essen in close proximity to the main pedestrian shopping street and the main railway station, whereas substation B with an outdoor switchyard is further away from the downtown area. The superconducting fault current limiter as well as the cooling system will be installed in substation B in order to maximize the space reduction in substation A.

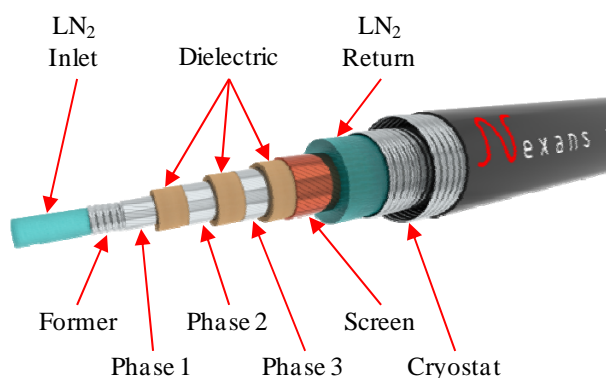
Within the AmpaCity project RWE is responsible for the specification of the system, the location for the field test and the system implementation. The development, testing and manufacturing of the HTS cable system and the fault current limiter is under the responsibility of Nexans. Karlsruhe Institute of Technology supports the HTS system development with characterization and tests of HTS materials and is also in charge of establishing a simulation model for the AC losses of a three phase concentric cable as well as for a test setup for precise measurements of these losses on short sample cables.

The beginning of the project was dedicated to the design phase and specification of the system requirements. In May 2012 a manufacturing trial for the concentric HTS cable took place in order to qualify the manufacturing process. A prototype cable was manufactured in the second half of 2012 and it will be type tested in Nexans' Hannover facility beginning of 2013. After completion of all relevant tests the manufacturing of the cable system will start in early 2013. At about the same time in spring 2013 the civil works in Essen are planned to begin. Polyethylene pipes are going to be installed in the ground into which the HTS cable can be pulled in later. The installation of the complete HTS system consisting of the concentric three phase cable and the fault current limiter as well as the cooling system is scheduled for the third quarter of 2013. After commissioning of the system at the end of 2013 a field test period until at least the end of 2015 is foreseen.

## AMPACITY HTS CABLE

### Cable Design

In figure 2 the superconductor cable design for the AmpaCity project is presented. The basis of the cable core is a hollow former, in this case a corrugated tube, which is used as a cooling channel for liquid nitrogen ( $LN_2$ ). Around the former all three phases and a common screen are concentrically arranged, each of them separated by a lapped dielectric of polypropylene laminated paper (PPLP). The three phase layers consist of stranded wires containing HTS material, and the common screen is made of stranded copper wires. The cable core is placed into a cryostat, which is composed of two corrugated tubes in concentric arrangement with vacuum insulation in between. Another cooling channel for liquid nitrogen is provided between the cable core and the cryostat.



**Figure 2** HTS cable design for the AmpaCity project

The concentric arrangement of all three phases and the connection in series with a superconducting fault current limiter allows a very compact cable design and is therefore perfectly suited for medium voltage applications under space constraints. In addition, the amount of superconductor material is significantly reduced compared to other superconductor cable designs. Another major benefit of the compact concentric design is the integrated return channel for the cooling medium, which does not require a separate return line. Further, the fault current limiter protects the cable as well as the downstream grid from high short circuit currents. In case of a short circuit somewhere in the grid, excessive heating of the cooling medium inside the cable is prevented and the cable can revert to normal operation almost immediately after the fault is cleared. The combination of a superconducting cable and a resistive type superconducting fault current limiter within the AmpaCity project will be the first implementation of this kind worldwide. During normal operation of the cable system the currents in the three concentric phases are balanced, exhibiting the same absolute value at a 120° phase shift, and consequently no current flows in the screen. Therefore, no magnetic stray field appears outside the HTS cable system. Additionally, due to active cooling with liquid nitrogen inside the thermal insulating cable cryostat, the system is thermally independent from the environment. This unique thermal behavior and its very high electromagnetic compatibility leads to a simplified siting as well as easier installation of the HTS cable system.

### **Manufacturing and mechanical testing**

After designing the cable, a pre-prototype cable was manufactured in the first stage. The pre-prototype cable was mainly used to verify the manufacturing procedure and the cable design with respect to high voltage constraints. Since the HTS material is still quite expensive, only a few HTS tapes were used for each phase layer of the cable. Copper tapes exhibiting the same dimensions as the HTS tapes were used to replace the remaining HTS tapes.

In order to verify the manufacturing procedure the most important mechanical test is the bending test of the cable. For this test a 20 m section of the pre-prototype cable was unspooled from the drum, as shown in figure 3, and then

spooled back on the drum. After repeating the spooling a few times, the cable section was cut into 2 m pieces. Each cable piece was then carefully dissected while especially examining the lapped PPLP dielectric and recovering the HTS tapes. Further, the critical current of all recovered HTS tapes was checked in a liquid nitrogen bath.



**Figure 3** Bending test of pre-prototype HTS cable

The mechanical testing for the pre-prototype cable was successfully completed, the lapped PPLP dielectric was determined to be alright and the measured critical current of the HTS tapes was in agreement with the specification.

### **High voltage testing**

For verification of the cable design with respect to high voltage constraints, an approximately 30 m long section of the pre-prototype cable was set up in Nexans' Hannover laboratory including cable cryostat and terminations, see figure 4. In the project it was agreed, that the voltages applied during type testing have to be in agreement with the German standard DIN VDE 0276-620. For the type testing basically three different tests with high voltage are mandatory, the partial discharge test, the lightning impulse test, and the AC voltage withstand test. Since two of the dielectrics in the cable separate two different phases, the phase to ground voltage  $U_0$  was replaced with the nominal phase to phase voltage  $U$ . For the partial discharge measurements, these modifications lead to a test voltage of 20 kV after previously having raised the voltage to 24 kV for one minute. The lightning impulse test is performed with ten shots of 75 kV for both polarities, and for the AC voltage withstand test a voltage of 30 kV is applied across the different dielectrics.



**Figure 4** Setup of pre-prototype cable in the laboratory

As for the mechanical testing, all high voltage tests were successfully completed on the pre-prototype cable. Therefore, the cable design as well as the manufacturing process was validated. Subsequently a prototype cable was manufactured with the phase layers containing HTS tapes only. The setup of the prototype cable with two terminations and one joint is currently being finished in the high voltage laboratory, and the type testing including high current testing is expected to start soon.

## CONCLUSIONS

The application of concentric medium voltage HTS systems enables very attractive grid concepts for urban area power supply. Expanding the grid using HTS cables is from the current perspective the only technically and economically appropriate option for avoiding the expansion of inner city power grids using high voltage cables, and reducing the number of high voltage transformer substations in downtown areas. Further, concentric HTS cable systems for medium voltage applications are very compact, exhibit a very good electromagnetic compatibility, and are thermally independent from the environment. For these systems the required right of way is much smaller and the installation is easier compared to conventional cable systems. In combination with superconducting fault current limiters the fault current levels in the downstream grid are reduced in addition, thus increasing the grids operating safety.

The authors are of the opinion that the AmpaCity project in Germany is world's first in terms of both content and scope. Up to date, the project is running well on track, the prototype cable will be tested soon, and the commissioning of the system in Essen is scheduled for late 2013.

The HTS technology is still rather unknown, since today no large scale demonstration projects have been realized in particular in Europe. The AmpaCity project represents a worldwide unique reference, and therefore could act as a potential catalyst for initiating the expansion of production capacities in the HTS materials, cryogenic systems and HTS cable technology sectors. When the target innovation objectives are reached, the electricity supply of major population centers requiring high power may be simplified in the mid to long term through the partial substitution of high voltage to medium voltage transformer substations.

## Acknowledgments

The authors would like to thank all their colleagues who contributed to this paper as well as the German Federal Ministry of Economics and Technology which is supporting the pilot project in Essen under the grants 03ET1055A, 03ET1055B, 03ET1055C and 03ET1055D.

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