Overview of the Underground 34.5 kV HTS Power Cable Program in Albany, NY

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Abstract—**A team consisting of SuperPower, Inc. (HTS systems manufacturer), The BOC Group (global industrial gases company), Sumitomo Electric Industries (cable manufacturer), and Niagara Mohawk (electric utility) is developing a 34.5kV HTS cable for installation in the distribution network in downtown Albany, NY. Energization is projected for the winter of 2005. The cable will be rated for 800Arms, with all three electrical phases in one cryostat. The 350m long cable will be pulled through a duct that includes a 90° bend. A field installed underground cable joint will allow for the replacement of a 30m section of the original first generation BSCCO-2223 HTS cable with a section manufactured utilizing 2nd generation YBCO, in 2006. This paper will summarize the progress made to date and outline future development work.**

Index Terms—**Superconducting cables, High-temperature superconductors, Cryogenics**

I. Introduction

To prove the feasibility and reliability of underground HTS cables, demonstration projects are presently underway around the world. [1-2] These projects, all with slightly different objectives and specifications, are trying to address the fundamental questions of how HTS cables will perform in a typical utility setting. HTS cables need to be able to be installed in existing ducts, run for hundreds of meters between cooling stations, successfully transition to conventional connections, be cooled by a reliable cryogenic system, and be remotely monitored and protected by standard utility monitoring facilities, all of which will need to be accomplished at costs comparable to conventional cables.

The project is structured in a modular fashion, with each team member primarily responsible for a subsection of the project. All team members assist in all aspects of the project to ensure a cohesive end product. The modularity of the design also facilitates transition to commercial production. More than simply creating a physical HTS cable, it is necessary to prove that such cables can operate in a manner that is acceptable to the utility industry, including any necessary scheduled maintenance or monitoring. The complementary nature of the backgrounds and services that each company can provide are instrumental to the success of this new technology.

A. Cable Manufacturer

Sumitomo Electric Industries (SEI) has long experience in designing, manufacturing, and selling high voltage power cables, including PPLP and XLPE insulated cables. A long time practitioner in the HTS device area, they have demonstrated several large superconducting magnets, SMES, and cables. Their most recent HTS cable was 100m, 136mm outer diameter, three-phase, cold dielectric cable; operating at 66kV and 1kA. [7] This is the highest voltage and the only known successful 3-in-1 field demonstration to date. For the Albany cable project, SEI will leverage its experience to manufacture the cable, joints and terminations; and all internal instrumentation.

B. Industrial Gas Company

The BOC group is one of the world's largest industrial gases companies with global coverage. They will rely on their extensive background in cryogenic engineering to design and operate the Cryogenic Refrigeration System (CRS) for the project. They have extensive capabilities for continuous remote monitoring and control of both large air separation plants, as well as smaller onsite systems. This existing remote operations infrastructure will enable them to provide overall control and communication infrastructure for the project.

C. HTS manufacturer

SuperPower uses capabilities in materials, cryogenics, and magnetics to develop HTS electric power components such as fault current limiters and transformers. They are currently developing and scaling up to manufacture surface coated 2^{nd} generation (2G) HTS conductors based on YBCO (yttrium barium copper oxide). Samples that carry over 100A in a cross-section of approximately $1mm^2$ have been demonstrated in lengths of tens of meters. [6]

For the Albany cable project, SuperPower will provide the project management, prepare the site infrastructure, and

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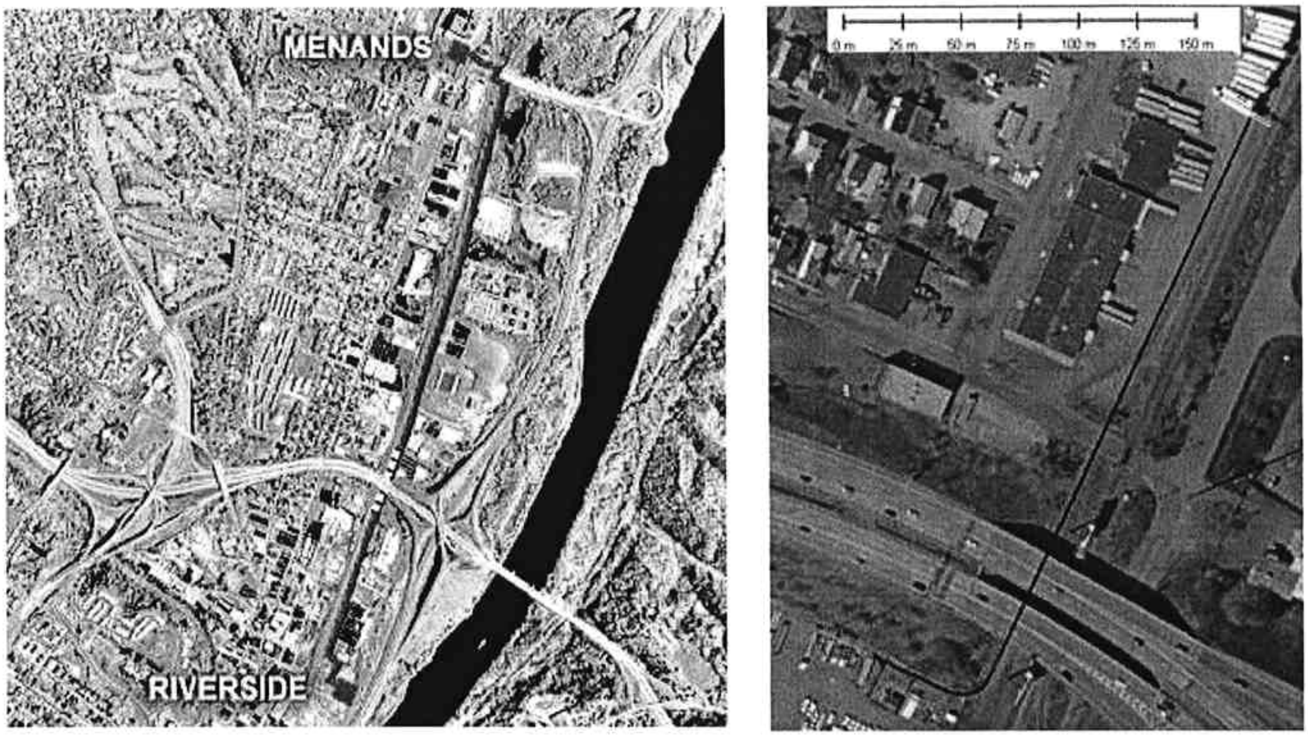

Fig. 1. (a) New 34.5kV underground/overhead link between Riverside and Menands substations. The HTS portion is shown in dashes. (b) Route of HTS cable; 30m long portion from lower end to be replaced with YBCO-based cable section.

provide the 2G YBCO superconductor.

D. Electric Utility

Niagara Mohawk provides electric service to 1.5 million customers in a 24,000 square mile area, covering 669 cities, towns, and villages in 37 counties, delivering a total of 42.7 million MW-hr annually. A utility of at least this magnitude is viewed as desirable to demonstrate the unique capabilities of the HTS cable as compared to conventional cables. National Grid, the global parent company, operates transmission and distribution networks (solely or with joint ventures) in the US, UK, Argentina, and Zambia, as well as interconnects in France, Australia, and Canada. [3]

For the Albany cable project, Niagara Mohawk will integrate the HTS cable into their existing system and provide the relay protection scheme for the HTS cable. They will also perform a system impact study to determine the effect of installing HTS cables in their existing network.

TABLE I
SCHEDULE OF KEY MILESTONES

Milestone	Date
Site preparation	Summer 2004
Cable fabrication	Spring 2005
Installation of CRS	Winter 2004
Installation of cable	Summer 2005
Energize cable	Winter 2005
Retrofit with YBCO section	Fall 2006
Completion of project	Summer 2007

II. Program Objectives

The objective of this project is to design, fabricate, install, test, and operate an HTS underground cable system that demonstrates significant progress toward future commercial targets. Achieving this objective requires addressing real-world utility concerns about implementing a new technology; including installation, maintenance, reliability, and compatibility with the existing grid. To alleviate these concerns, conventional technology and techniques will be utilized to the fullest extent feasible, especially during installation and operation.

III. Location

Multiple potential sites in downtown Albany, NY were evaluated. Niagara Mohawk has two main substations in Albany (Menands and Riverside) feeding power into the 34.5kV distribution ring. A new link at 34.5kV was being installed between those two substations to handle projected load growth, with a portion of the link going underground beneath a major highway.

It was decided to parallel this portion of the underground installation with the HTS cable. The cable will be 350m long, installed in two sections of 30m and 320m respectively, and have a 90° bend. The conduit for the cable will be installed using conventional techniques of directional drilling for the straight sections and trenching for the bend. Splitting the cable into two portions allows for the field installation and testing of an underground cable joint. Joining technology will allow lengths of HTS cable to be connected together for the longer runs necessary for practical use.

Conditions at the installation site are typical and include the normal mix of problems encountered for underground conventional installations. Many existing structures must be avoided and a diverse mix of soil conditions is present. The cable will also run parallel to an active rail line.

A. Cryogenic Refrigeration System

The Cryogenic Refrigeration System (CRS), described in more detail in [5], will have as a critical component a cryocooler operating at temperatures down to 65 K. The HTS cable itself will be cooled using a pumped closed loop of subcooled liquid nitrogen. The CRS will be designed with features required for cost-effective and reliable commercial operation. This will include a streamlined system design that includes backup and hot maintenance features. Certain key elements of the CRS will be made reliable through simple redundancy. However, the cryocooler is a particular component of the CRS that is not cost-effective to simply duplicate. Instead, backup cooling is accomplished through a novel hybrid arrangement that allows for transparent use of bulk liquid nitrogen in the event of a cryocooler failure.

The CRS will provide a nominal 6 kW closed cycle refrigeration at 77 K, and have a lower operating temperature of 66 K. The CRS, as well as the overall HTS cable system, will be continuously monitored using the existing remote operation facilities of the industrial gas company.

B. HTS Cable system

The cable is rated for a normal operation current of 800Arms at 34.5kV. The HTS cable system consists of the underground cable, the terminations, and the underground cable joint, described in more detail in [4]. The cable will be a cold dielectric, three cores in one cryostat, with a stranded copper former to carry the fault current. The cooling of the cable, terminations, and underground joint is handled by a single cryogenic circuit.

The HTS cable is installed as a portion of the tie between the two main substations in Albany. As such, it is expected to see a worst case fault current of 23kA. The cable specification requires the cable to survive a first contingency fault of 23kA for 8 cycles, a second contingency fault of 23kA for 20 cycles due to breaker failure, and a third contingency fault of 23kA for 38 cycles due to primary relay failure. Over the length of time that this cable will be in service, projected increases in available power on the Albany grid are included in the fault current calculations.

C. Remote Monitoring and Control

The HTS cable system, including the CRS, will be monitored continuously by BOC's Remote Operations Center. All pertinent system parameters will be available. Certain key data will also be transmitted directly to the utility, and because of the demonstration nature of this project, alarm conditions in these parameters will lead to automatic removal of the HTS cable from the circuit by way of Niagara Mohawk's Eastern Regional Control Center.

IV. 2ND GENERATION HTS CONDUCTOR AND CABLES

One of the accomplishments of this project will be to include a retrofitted section of the HTS cable fabricated from 2nd generation (2G) YBCO superconductor. After the initial BSCCO cable has successfully operated for several months to a year, the 30m BSCCO cable section between the underground cable joint and the termination will be removed and replaced with a 30m 2G-based section. The existing 320m cable will be joined to the new section with a field joint in the underground vault. The 2G conductor for this 30m section will be delivered to SEI by the end of 2005. The first step toward developing this 2G cable section was recently completed. A sample cable core was wound using 60 meters of 2G tapes supplied by SuperPower. AC losses for this sample at the operating current for the Albany Cable were less than 0.07W/m.

Second generation superconductors will enable cable manufacturers to provide HTS cables with higher current densities, improved operating characteristics, and in smaller packages than are being demonstrated today. For example, low operating losses are necessary to allow for long lengths between cooling stations. In order to maintain low levels of losses, HTS cables require a certain surface area of superconductor per meter of cable length; the ideal situation being a very thin perfectly round current carrying sheet. Improving the current carrying properties for the same width conductor will not, therefore, automatically reduce the amount of superconductor required for the cable. The surface coated nature of 2G superconductors results in a wider, thinner current carrying layer, while still maintaining the high critical current density necessary to achieve the benefits of superconductors. In this case, fewer conductors can be used, and the superconductors themselves are less expensive. This results in lower costs per meter for HTS cables fabricated from

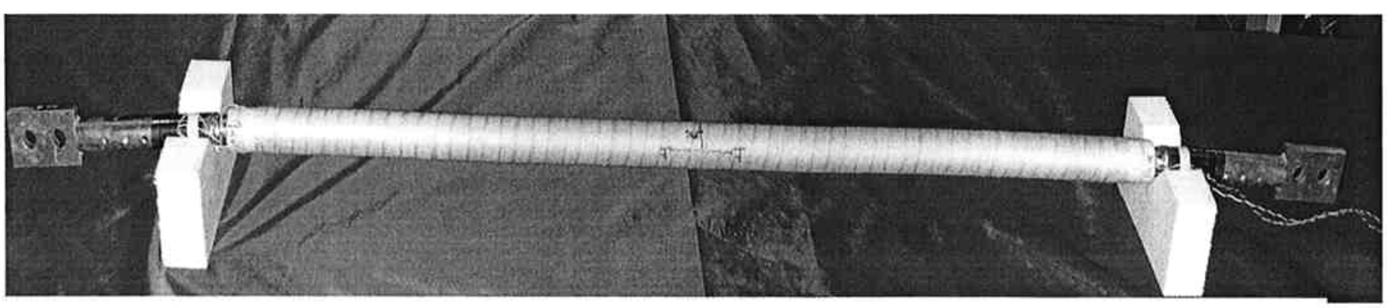

Fig. 2. Sample of 2G cable core, 1 m long; Tapes spiral wound with HTS layers in tension

these superconductors.

Another important factor to consider, particularly where an HTS cable is going to replace an existing conventional cable, is the package size or outer diameter of the cable. The three primary drivers affecting the cable diameter are the starting diameter, or core size; the dielectric insulation thickness (dependent on material and voltage requirements); and the thermal insulation, or cryostat. 2G conductors have a minimal impact on the electrical or thermal insulation thicknesses, however, due to their mechanical properties and better performance in electric fields, which tend to increase as the diameter decreases, 2G conductors can enable the use of substantially smaller core diameters.

Another benefit to cable manufacturers is the improved mechanical proprieties of 2G conductors. 2G IBAD-based superconductors are twice as robust as the 1st generation tapes. The minimum diameter that such conductors can be wound on with 95% Ic retention is 11mm, and the maximum tensile stress is greater than 600 MPa at 77 K and greater than 400MPa at room temperature. [8-9] Additional testing has shown that the critical current does not degrade until greater than 0.5% axial strain, even though this is greater than the yield point of the substrate. [9] This strength allows for winding 2G tapes on a smaller diameter and for surviving greater forces during manufacturing, installation and cooldown.

In practical designs to date, the more stringent limitation on core diameter is the need to carry excess fault currents. However, this limitation can be handled external to the cable through various measures, including the use of a fault current limiter at either end of the cable. The incorporation of superconducting fault current limitation into the cable termination would provide protection to both the HTS cable system, as well as the surrounding electrical grid. This may prove to be the ideal solution.

All of these benefits lead to the possibilities of ultra-compact YBCO cables, particularly if we are able to rely on some of the new low ac loss winding schemes that are being developed. In the near future, the limitations on cable size will, therefore, become driven by electric field considerations instead of fault current design.

V. Progress to Date

To date, work is nearly completed on the installation of the underground conduit system and vault. The majority of the conduit was installed by horizontal directional drilling (see Fig. 3). This allowed the conduit to be installed without having to interrupt traffic on Erie Street as the conduit was pulled back underground. Only the 90° bend and the ends of the run were dug.

The depth profile is controlled by the rotation of the drill head. The majority of the cable runs at about 6' below the surface of the ground. Portions of the conduit run, however, descend to nearly 16' depth to avoid underground obstacles.

Fig. 3. Horizontal directional drilling of the conduit path parallel to the railroad.

The conduit runs into an underground vault where the cable joint will be installed. The vault is a pre-cast cement structure, deliberately oversized to allow flexibility in case of unexpected complications during joint installation. Two standard size manholes allow access to the vault. A remote camera system will be placed in the vault to enable visitors to the site to see the underground joint.

The vault (shown in Fig. 4) is located in the Niagara Mohawk parking lot. When the vault installation was completed, the area was returned to use for the storage of large utility construction vehicles.

Fig. 4. Installed underground vault waiting for blacktopping.

The next steps for the cable system infrastructure include the fabrication of the onsite CRS control building. This building will house all of the cryogenic equipment, as well as a visitor center and conference room for project participants. The building is expected to be completed this winter, at which time the CRS system will be installed and tested with a dummy load.

VI. References

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