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Superconducting transmission 23kV/2kA cable – first in Latin America

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Two superconducting models of transmission cables were designed, constructed and tested for the first time in Mexico, the 1m model and 5m model with parameters of practical applications 23 kV/2kA. For this purpose also a new cryogenic laboratory was built and equipped with all necessary devices and instruments. For construction of both models, a high critical temperature superconducting Bi-Sr-Ca-Cu-O tape was used. The design, construction and performed tests are briefly described and some preliminary results of test measurements are presented.

Keywords: Bi-2223 tape; HTS cable models; construction and testing; preliminary test results.

Por primera vez en México, se han diseñado, construido y probado dos modelos superconductores de transmisión de energía eléctrica de una longitud de 2 m y de 5 m con parámetros prácticos para aplicación de 23kV/2kA. Con este propósito se construyó también un laboratorio de criogenia nuevo, equipado con todos los dispositivos e instrumentos requeridos. En la construcción de ambos modelos, se utilizó cinta superconductora de Bi-Sr-Ca-Cu-O. Se presentan la descripción y construcción del diseño, así como las pruebas realizadas y los resultados preliminares de las mediciones efectuadas son presentados.

Descriptores: Superconductividad de alta Tc; aplicaciones de potencia; propiedades eléctricas; diseño de cables.

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1. Introduction

Currently, the transmission of electrical energy in many dense populated urban areas is approaching its upper limits of saturation and new upgrades to the energy transmission are therefore needed. It is already recognized by various important companies round the world that the reliable solution of this problem might be the use of high temperature superconductors (HTS) with the existing current densities much higher than the operating current densities in conventional cables. Today, it is also already well known that the use of HTS cables enables us to transfer two to five times more energy than the conventional ones of the same size.

Various models of HTS cables with different working parameters were already built and tested. On the base of these results it seems that the first applications of HTS power cables especially in dense populated areas will probably be retrofits and upgrades of existing conventional cables. Also environmental considerations in connection with overhead transmission lines may play an important role in making decisions as to use underground HTS cables.

Two basic construction concepts are currently used to build various models of HTS cables, the so called "warm dielectric design" (WD) and/or "cold dielectric designe" (CD). Because of a single conductor, the initial cost of a WD cable is lower, with its capacity of energy transfer being about twice of that of a conventional cable of the same size. This is already of interest in replacing those cables. On the other hand, the efficiency of the CD cable with two parallel HTS conductors is higher, with its transmission capacity up to five times of that of conventional circuits. Also losses and the environmental influence are lower which means a rather high degree of transmission capacity and efficiency.

Today, a number of groups around the world are working on R and D of HTS transmission systems (cables, transformers, current limiters) with the aim to understand their performance and thus, to enable them to be transferred from ideal laboratory conditions into the hard every-day practical use in the field. Of the most important programs currently on the way we may mention those performed at Southwire, USA [1], Siemens, Germany [2], Tokyo Electric, Japan [3,4] but also projects which are on the way in France and Denmark. Perhaps the most active in this field was up to recently Pirelli Cavi e Sistemi Italia and Pirelli Cables and Systems North America [5-8]. Of the most important Pirelli projects we may mention the 50m model of 115kV/400MVA cable in cooperation with EPRI (Electric Power Research Institute) and DOE (US Dept. of Energy), Detroit Edison 120m 24kV/100MVA cable system, also in cooperation with EPRI and DOE. The Bi-2223 tape superconductor for these projects was supplied by ASC (American Superconductor Company) [9]. Other important Pirelli projects are 30m 132kV/3kA Pirelli – ENEL - Edison cable system and 10km 225kV/3000MVA cable with Electricité de France. In order to cover all these HTS cable projects, Pirelli has built also a production facility with its cable production capacity estimated as 12km/year, which should cover all the experimental needs in the near future.

In Mexico, we are also facing similar problems of increased energy demand and energy transmission especially in our large cities of which Mexico City with its more than 20 millions of inhabitants is perhaps the first or second largest and most populated urban area in the world (an estimation for the year 2025 is about 45 millions). Already today, the available underground space here is very limited one, complicated especially by the underground public transport. Under these circumstances we decided to start also with R and D of HTS transmission systems. In the presented paper, our first steps are described in this sense, namely building the necessary laboratory facilities and the design, construction and preliminary test results obtained on 1m training and 5m 23kV/2kA cable models.

2. Bi-2223 tape used

A number of producers of superconducting Bi-2223 tape were contacted in order to buy a suitable material. Of the obtained offers we chose two tape suppliers, namely Vacuumschmelze (VAC) Germany, and Nordic Superconductor Technologies (NST) Denmark. After verifying the tape properties by measuring the control samples we decided to purchase the NST tape for 1m model and the VAC tape for the 5m model. The basic parameters of these tapes from which the cable conductors were constructed are summarized in Table I.

3. HTS laboratory and equipments

For the working and testing purposes, a new laboratory was built and equipped with all the necessary equipments, devices and instruments needed for construction and testing of the HTS cable models. As a DC-power supply for test measurements we used 10kA/8V National Instruments. AC tests were performed by home made power supply giving current up to 5.4 kA. To study the V-A characteristics and transient processes, a Data Acquisition System was used with the sensor frequency up to 200 kHz, number of channels up to 80 with the gain 1.5×10^8. As far as the cryogenic system is concerned, we used horizontal cryostat produced by Nexans Co. Germany with the cooling power 2 kW. The temperature range of the supplied LN_2 of this system is 66 to 90 K at the controlled pressure range 1 to 10 bar and the LN_2 flow range 0.05 to 0.3 kg/sec.

TABLE I. Basic parameters of the VAC and NST Bi-2223 tapes from which the cable models were constructed.

Tape parameters	**VAC**	**NST**
I_c (A/77K) at 1μV/cm	62.0 – 70.6	39.6 – 42.0
Tape size (mm^2)	3.95×0.22	2.95×0.24
J_c engng. (kA/cm^2)	7.1 – 8.1	5.23 – 6.75
Number of filaments	121	37
Filling factor (%)	about 31	30
Twist pitch	untwisted	untwisted
Matrix composition	pure Ag	Ag alloy
Tape sheeth material	AgMg	Ag alloy
I_c degradation when bending to D = 50 mm (A)	61.6 – 68.2	none
I_c degradation under the stress of 100 Mpa (%)	< 5	none
I_c inhomogeneity along the tape length (%)	2.25	2.8 – 5.1

The 1 m testing cable model was wound by hand, for the 5 m model we used specially designed tapping machine. In the new laboratory we have also measuring plant for measurements of electromagnetic properties of Bi-2223 tapes and laboratory space for general purposes.

4. Design and production of the cable conductors

For both cable models, *i.e.* 1 m and 5 m long, the warm dielectric design was chosen (a schematic of which may be seen in Fig. 1) with the HTS tapes wound in layers in two directions. In case when WD construction is applied, the two-direction winding system is more convenient because the axial component of magnetic field inside of the crysostat may be reduced substantially. The main purpose of construction of 1m model was to gain a sufficient experience in handling all working processes. The cable conductor was in this case hand-wound and consisted of 4 layers (2 left +2 right) of NST tapes wound on SS tube former. The total number of HTS tapes was 185 with the expected critical current up to 6.5 kA.

To wind the 5 m model, a special tapping machine was developed. In this case the conductor consisted of 6 layers wound also in two directions (3 left + 3 right) onto flexible corrugated tube. Based on calculations, the current flowing through the first layer was 17% of the total cable current, in case of the 2^{nd} layer it was also 17%, 18% in the 3^{rd} one, 18% in the 4^{th} layer, 16% in the 5^{th} one and 14% of the total cable current was flowing through the upper 6^{th} layer. Altogether 233 VAC tapes were used with the expected critical current being 12 kA. Potential taps were used to determine resistance between the layers, the calibrated Rogowski coils

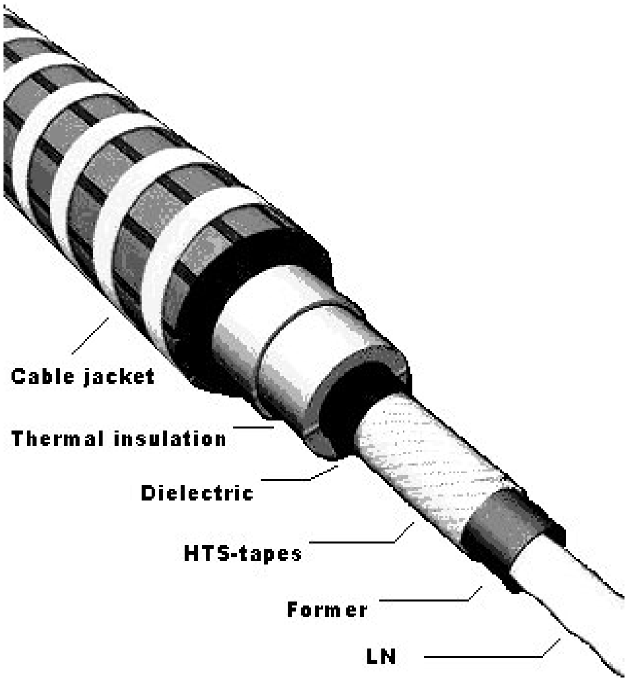

FIGURE 1. Schematic of the warm design (WD) cable system.

were applied to study the current distribution among the layers. Thermosensors were installed to control the temperature distribution. The high voltage section of the cable was produced according to AEIC CS-5 specifications using the following materials: insulation was made from PE, the semiconductor shield was made from PE sc, metallic shield was made from Cu-wires and the overall jacket was made from HD PE. More details about the whole conductor design and construction may be found in Ref. 10.

5. Cable model tests and preliminary results

The 1 m conductor was tested in a vertical cryostat at the temperature of boiling LN$_2$. The 5m model was tested in horizontal cryostat. A schematic of the measuring arrangement may be seen in Fig. 2. As we mentioned above, the expected critical current of the 1 m model was up to 6.5 kA. We found that the current distribution among the layers was homogeneous up to about 0.5 kA. Because of a partial damage of the layer 2, higher current was then redistributed to other layers. Also, because of a rather high resistance of the mechanical connection between the cable and the current leads being about $10^{-5}\Omega$, a severe heating emerged at currents above 5kA. After soldering the joint this resistance dropped to $10^{-9}\Omega$. More complete results of a measuring test of 1m cable will be published in [10].

In case of the 5 m model, the expected critical current was 12 kA. Also in this case we used mechanical contacts to the current leads, however, with a sufficiently larger contact area as to lower the resistance value. Such type of contacts allowed us then to work with currents up to 8 kA in DC mode. The current distribution among the layers was investigated and the obtained results are plotted as a histogram in Fig. 3 (outlet wires from the first layer Rogowski coils were damaged during the test preparation). As we can see from this figure, the measured current values are rather close to the calculated ones with a larger deviation in the layer No. 4. The reason why is not quite clear to us at the moment but we suppose that rather high number of various sensors and Rogowski coils inside of the layers may introduce local distortions in the cable geometry with a possible partial mechanical damage of some of individual Bi-2223 tapes.

A short time ramp (Fig. 4) was performed up to 10kA which was also the highest current available from the used power supply. No voltage drop was observed at 10 kA at the sensitivity of 20μV/cm (the current value 10 kA means about 80% of the cable current carrying capacity). More complete test results will be published in Ref. 10.

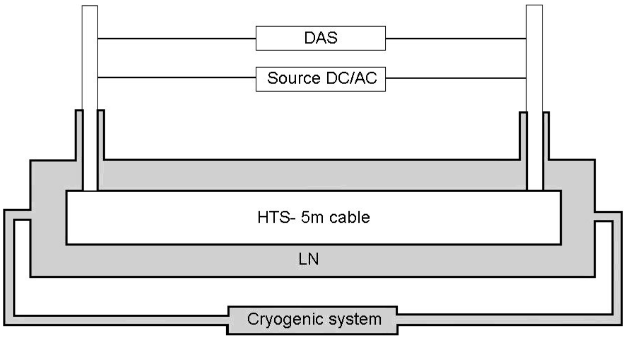

FIGURE 2. Shematic of the 5 m-model measuring arrangement.

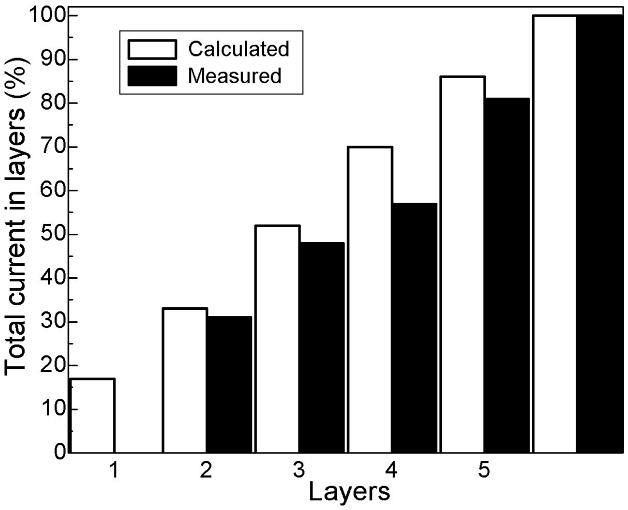

FIGURE 3. Calculated and measured currents flowing through 5 m-model layers.

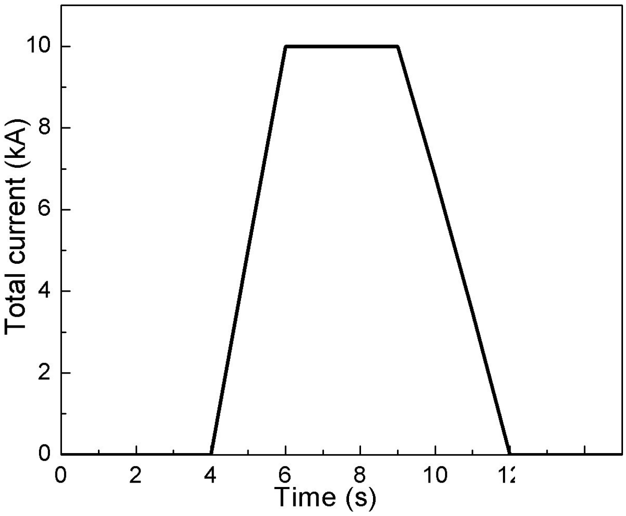

FIGURE 4. First short-time ramp up to the total current value 10 kA in case of 5 m model.

6. Conclusions

Because of steadily increased requirements for consumption and transmission of electrical energy in large mexican cities it is inevitable to introduce new technologies into the construction of energy transmission systems. With the constantly improved properties of high critical temperature superconductors (HTS) able to operate at temperatures of LN2 it seems that their use is a real possibility to solve these problems at least to some extent.

Following this idea we started with building the cryogenic laboratory needed for initial tests of these new technologies, equipped with all the necessary facilities, followed then by design, construction and testing of 1m and 5m long models of HTS transmission cables of the warm designe type. Parameters of the 5m model, i.e. 23kV/2kA, were determined in cooperation with Comision Federal de Electricidad (CFE). The purpose of construction of 1m model was to gain basic knowledge in handling HTS cables. The 5m model was already constructed and tested under the conditions of practical applications. Results of preliminary tests of our 5m model are very encouraging and therefore our interest in R and D of HTS transmission systems will continue.

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