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Recent advances of HTS power application research at IEE

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Abstract. Recent advances of high temperature superconductors (HTS) for power applications in the Institute of Electrical Engineering (IEE), Chinese academy of Sciences are presented. A 75 meter, 10.5 kV/1.5 kA three phase HTS transmission cable has been successfully demonstrated in a live distribution grid in northwest China. A 10.5 kV/200A bridge-type fault current limiter (FCL) prototype based on Bi-2223 tapes is being tested in a Hunan power plant since August 2005. A 400V/16V/26 kVA three phase HTS transformer was designed, built and tested, and the on site system installation of a 10.5 kV/400V/630 kVA HTS transformer will be finished at Tebian Electric Ltd. soon. In addition, the progress of design and test of SMES is also given.

1. Introduction

Demand for electric power in China continues to grow dramatically year-over-year. Therefore, new technologies are needed throughout the electric system in order to improve the reliability and efficiency of electric power. Since high temperature superconductors (HTS) has the potential to be effective in an electric power system, the Ministry of Science and Technology of China and Chinese Academy of Sciences (CAS) are focusing on the development of new HTS technologies. As a part of the Chinese national project, which is named “Research and development of high temperature superconductors for power applications”, developments of efficient electrical systems such as transmission cables, transformers, and current limiters that use HTS wires have been carried out. Indeed, full-scale prototypes of electric power cables, motors, transformers, and other heavy electrical components made with HTS wire in the USA, Japan, Europe and China have been built so far, primarily using the Bi-2223 conductors [1-6]. This paper briefly reviews the recent progress and the future prospect of large-scale applications of HTS in the Institute of Electrical Engineering (IEE), CAS, China.

2. Power cable

Because of the rapid growth of the national economy in China, the electric utility is faced with an ever rising demand for electricity and the problem to solve large capacity power transmission. Under the support of the High-Tech Research & Development Program of China (863 project) and Gansu Changtong Cable, Co. Ltd, a R & D project of a 75-m long, 3-phase, 10.5 KV/1.5KA HTS power cable system is carried out by the Institute of Electrical Engineering (IEE), Chinese Academy of Sciences (CAS) in close collaboration with the Technical Institute of Physics and Chemistry, CAS, and Gansu Changtong Cable, Co. Ltd. Since April 2005, the 75-m, 10.5 kV/1.5 kA HTS cable completed by IEE has been successfully demonstrated in a live distribution grid in northwest China. The AC cable operates at 6.6 kV. In preliminary tests, the cable's rated voltage is up to 10.5kV, and it has conducted up to 1,600 Amperes (at 400 volts) of alternating electrical current -- limited only by the load available at the factory. It was tested by CAS engineers and the critical current was found to be as high as 5,300 Amps (DC) and up to 3,500 Amperes (AC). Table 1 gives characteristics of the 75-m HTS power cable that is shown in Fig. 1.

Table 1. Main design parameters of a 75m cable

Rating of cable	AC 1500 A/ 10.5 kV
Outer diameter of former	32.7 mm
Length of conductor	75 m
Inner diameter of conductor	32.8 mm
Outer diameter of conductor	34.6 mm
Total length of tapes	10800 m
Copper shield layer	0.2 mm
Total diameter of cable:	117.7 mm

Figure 1. 75-m, 3 phase, 10.5 kV/1.5 kA HTS power cable installed at a substation.

The 10.5 KV/1.5 KA HTS power cable consists of a 75 meter-long, three-phase system, and features a warm dielectric design. Thin Kapton tape was used for insulation between conductor layers to reduce ac loss due to the electromagnetic coupling of each layer. The cable core was housed in a cryogenic envelope. Sub-cooled liquid nitrogen flowed through the inside of former and the space between the cable core and the inner pipe of cryogenic envelope. The warm dielectric construction, a copper shield and a PVC cover were applied over the cryogenic envelope. HTS tapes for the 75 m HTS cable were multifilamentary Bi-2223/Ag tapes supplied from ASC. The critical current of Bi tape is more than 100 A at 0T and 77K.

The cables were wound according to the designed parameters. The HTS tapes were soldered to the copper terminals using the low-melting-point alloy solder. The skid wires were wound on the conductors for protection. The cryogenic envelopes comprised double stainless steel corrugated tubes that provide high vacuum and super-insulation without maintenance. The cross-linked polyethylene insulation triple-extruded, the copper shield and PVC cover were applied over the cryogenic envelope. There were the semiconductors on each side of the dielectric to smooth electrical field.

3. Transformer

IEE collaborating with Tebian Electric Apparatus Stock CO., Ltd (TBEA) is developing a 630 kVA/10.5 kV 3-phase transformer for utility applications, supported by the national "863" project. In 2003, a three-phase 26kVA HTS transformer with room temperature iron core was developed and tested at 77K. The primary winding was a solenoid coil and the secondary coil consisted of 24 double pancakes connected in parallel, and the strand of windings consisted of two parallel transposed stainless steel-enforced Bi2223/Ag tapes which were insulated by wrapping with polyimide films. The rated primary and secondary voltages are 400V and 16V, and rated currents are 37.5A and 938A respectively. Short circuit impedance is 2.8% and the excited current is 1.26%.

In 2004, a single-phase 45kVA HTS transformer with room temperature iron core was developed and tested, as shown in Fig.2. The main aim is to improve the basic technology for near future 630kVA distribution HTS transformer with amorphous cores which would be operated in fields in TBEA, China. The rated primary and secondary voltages are 2400V and 160V, and rated currents are 18.55A and 281.25A respectively. The impedance is 2.47% and the excited current is 2.6%. Characteristic tests, over-current tests, lighting impulse tests and sudden short-circuit tests of the HTS transformer were performed in 77K of LN_2 and 50Hz. It has lower AC losses in rated operation and high performances for sudden short-circuit current and lighting impulse voltage.

At present, the 630 kVA, 10.5 kV/400V 3-phase transformer is being installed at a transformer substation in Urmqi. Main parameters of the 630 kVA transformer are summarized in table 2. Operational tests on 630 kVA/10.5 kV unit are under way. Tests on grid would start at the end of 2005.

Figure 2. 45kVA single phase HTS transformer.

Table 2. Main designed parameters of a 630 kVA, 10.5 kV/400V HTS transformer

	Primary	Secondary
Capacity (KVA)	630	630
Vector group	Y	yn0
Rated voltage (V)	10500	400
Rated current (A)	34.641	909.326
Impedance Xcc		2.47%
Flux density		1.1 T
Height (Hw)		740 (mm)
Width (Mo)		690 (mm)

4. Fault current limiter

In March 2002, an improved bridge-type SFCL with capacity of 400V/25A was demonstrated. This program was supported by the Knowledge Innovation Program of CAS. Recently, IEE has developed a 10.5 kV/1.5kA, three phase SFCL based on Bi-2223 tapes. This prototype is now being operated in a Hunan substation after successful short circuit test in August 2005. In test, a prospective fault current of 3.5 kA was limited to 635 A, the reduction ratio of short current reached up to 0.82. Fig.3 shows the 10.5 kV/1.5kA SFCL installed at a transformer substation of local distribution grid in Loudi, Hunan province. Three-phases short-circuit test has been done on Aug.14, 2005, as shown in Fig. 4.

Figure 3. The 10.5 kV/1.5kA SFCL installed at a substation.

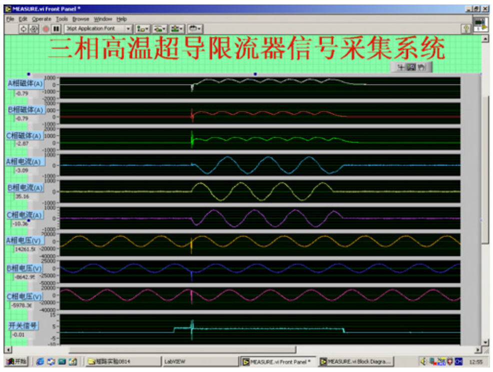

Figure 4. Curves of short circuit test at a substation for the 10.5 kV/1.5kA SFCL

5. SMES

Recently, a 100 kJ/25 kW SMES has been constructed and tested, as shown in Fig.5. In addition, as a new equipment, it integrates the common diode bridge SFCL and SMES together by replacing the bias voltage source for SFCL with a new current regulator. It improves the limiting function of bridge SFCL and compensates the sags caused by the fault, reducing largely superconducting coil capacity at the same time. Based on this, a single phase 220V/100A/6kW bridge Fault Current Limiter-SMES (FCL-SMES) demonstrator was developed, and the primary experiment was done. The system consists of a series linking transformer, a 6kW IGBT voltage converter with 20kHz PWM control method, a 6 kW IGBT current regulator with 20kHz phase-shifted control method, a 26mH/25A Bi-2223 coil, a rectifying diode bridge and a DSP-based controller. The current regulator can not only charge the HTS coil, but also absorb the energy from the system and the coil to compensate the voltage sags through the converter. In the controller of the system two very fast DSPs are used to implement the control algorithms for FCL-SMES. A 1 MJ/0.5MW SMES is now being designed by IEE, with installation at a substation expected to occur in early 2006.

Figure 5. Overview of 100 kJ SMES HTS magnet.

6. Conclusions

In China, the small-scale demonstrators for HTS power application have been successfully tested, and FCL, SMES, HTS Power Cable and Transformer will be tested at real substation within 1-2 years. Once its feasibility has been demonstrated in actual field conditions, it appears increasingly likely that electric utilities will seek to gain a competitive edge by using this promising new technology with its efficient, loss free generation, transmission and distribution of electricity.

By far, these full-scale prototypes made with HTS wire have been demonstrated, primarily using the Bi-2223 conductors. However, the limited potential of Bi-2223 for low cost production and still high AC-losses are the major obstacles for wide applications. Another hindering problem is high cryogenic costs. A general drawback for all power applications is the need for an expensive and maintenance intense cooling system, especially in a utility environment. Therefore, 1) More economical cooling systems should be developed; 2) For widespread application, it appears that YBCO coated conductor and MgB_2 are the obvious candidates of low cost of HTS materials [7].

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