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Design of a 1MVA Single-Phase HTS Power Transformer

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Abstract

In this paper, the design of a 1MVA single-phase high temperature superconducting(HTS) power transformer with BSCCO-2223 HTS tapes is presented. The rated voltages of each sides of the transformer are 22.9 kV and 6.6 kV, respectively. The winding of 1MVA HTS transformer is consisted of double pancake type HTS windings, which have advantages of insulation and distribution of high voltage, and are cooled by subcooled liquid nitrogen of 65K. Four HTS tapes were wound in parallel for the windings of low voltage side and the four parallel conductors are transposed. The design of 1MVA HTS transformer, a shell type core made of laminated silicon steel plate is chosen, and the core is separated with the windings by a cryostat with a room temperature bore. The cryostat made of non-magnetic and non-conducting material and a liquid nitrogen sub-cooling system is designed in order to maintain the coolant's temperature of 65K. For electromagnetic analysis of 1MVA HTS transformer, a finite element method of an axis of symmetry is used. The maximum perpendicular component of magnetic flux density of pancake windings is about 0.15T. And through analyzing the magnetic field distribution, an optimal winding arrangement of 1MVA HTS transformer is obtained.

Keywords : HTS, 1MVA, Transformer, BSCCO-2223, Double pancake HTS windings

I. Introduction

HTS transformers are more attractive than conventional transformers because there are more energy efficient, lighter in weight, smaller in size, and environment friendly [1]. So HTS transformer is expected to be one of the superconducting power devices that will be installed in the power system at the first stage of commercialization. And many kinds of development program of HTS transformers are in progress by major power companies and research institutes [2][3].

This paper presents the design of a 1MVA single phase HTS power transformer with BSCCO-2223 HTS tapes. Double pancake HTS windings, which have advantages of ease of insulations and uniform distribution of surge voltage in the windings, were adopted. An FRP cryostat with a room temperature bore were designed conceptually in order to separate the HTS windings from room temperature iron core. A configuration of the cryostat with a liquid nitrogen sub-cooling system was presented. And in order to choose optimal winding arrangement of 1MVA HTS transformer, the electromagnetic field analysis of 1MVA HTS power transformer was performed [4].

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II. Specification of the 1MVA HTS power transformer

The structure of the HTS transformer is similar to conventional transformer. The rated primary voltage of the HTS transformer designed in this paper is 22.9kV and the rated secondary voltage is 6.6kV. Table I shows the specification of the 1MVA HTS power transformer.

A. HTS tape

BSCCO-2223 HTS tape, which is made by American Superconductor Corporation (ASC), is going to be used in the windings of the HTS transformer. The critical current of HTS tape is 115A at 77K, self-field. The specification of the HTS tape is shown in table II.

Table I. Specification of the 1MVA HTS power transformer

Specification	Value	Unit
Phase	1	
Capacity	1	[MVA]
Rated primary voltage	22.9	[kV]
Rated secondary voltage	6.6	[kV]
Rated primary current	44	[A]
Rated secondary current	152	[A]

Table II. Specification of BSCCO-2223 HTS tape manufactured in ASC

Specification	Value	Unit
Thickness	0.203	[mm]
Width	4.1	[mm]
Critical Current*	115	[A]
Max. Stress	85	[Mpa]
Max. Strain	0.15	[%]
Min. Bending Dia.**	100	[mm]

* 77K, self-field
** 95% Ic Retention

B. HTS windings

Reciprocally arranged double pancake windings were adopted for HTS windings of each side of 1MVA HTS power transformer. The winding of double pancake compared with solenoid winding has some several advantages such as ease of manufactured and maintenance caused by simple structure, uniform distribution of surge voltage caused by large capacitance between turns of windings, and good insulation. But there is a high leakage flux between high voltage and low voltage. This kind of leakage flux causes much of AC loss of HTS material as well as reduction of critical current of the HTS tape. So in order to compensate this effect, HTS windings is cooled by 65K using sub-cooled liquid nitrogen.

The total number of turns of the primary winding and the secondary winding are 888, 256 turns, respectively. The primary winding is made of 8 double pancake HTS windings and is connected in series. The secondary winding is composed of 4 double pancake HTS winding connected in series. And the double pancakes of the secondary winding are wound with 4 HTS tapes in parallel. In order to prevent unbalanced current flowing, the secondary windings are transposed three times between double pancakes.

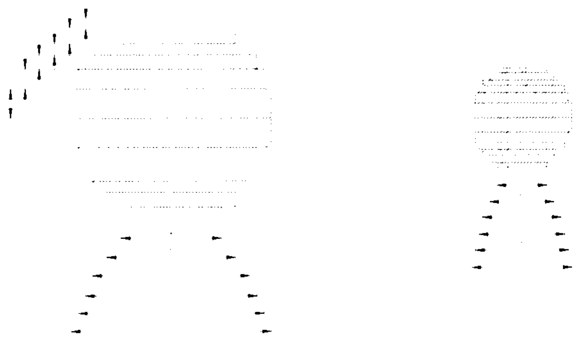
Each pancake will be wound on bobbins made of GFRP and will be insulated by Kapton film between turns.

C. Iron core

In the core design of the HTS 1MVA power transformer, the conventional processes were applied. A shell-type iron core made of silicon steel plate was designed. The number of step of core is six, the thickness of sheet steel is 0.291 mm, the maximum magnetic flux density of core is about 1.7 T, and the cross section area of core is about 590 cm^2. The configuration of lamination of the core is shown in Fig. 1. And considering the windings and cryogenic structure, the window size of the core can be designed. Fig. 2 shows the dimension of shell type core for 1MVA HTS power transformer.

D. Cryogenic system

The conceptual design of a Fiberglass Reinforced Plastic (FRP) cryostat and liquid nitrogen sub-cooling system for 1MVA HTS power transformer was performed. The cryostat has a room temperature bore at the center of it to exclude iron core from the low temperature region. Only HTS windings will be cooled down to 65K with sub-cooled liquid nitrogen and the liquid nitrogen temperature of 65K is maintained by a cryocooler. The cryostat is a vacuum chamber with an tank inside that contains liquid nitrogen, which is cooled by conduction heat flow of a cryocooler. And a single-stage cryocooler will be used in vacuum cryostat. Fig. 3 shows the conceptual design of the cryostat and sub-cooled system with a cryocooler. The design parameters for 1MVA HTS power transformer are shown in Table III.



(a) (b)

Fig. 1. Configuration and dimension of the core cross-section of the iron core (a) limb, (b) yoke.

Fig. 2. Dimension of the shell-type core for the 1MVA HTS power transformer.

Fig. 3. Conceptual design of the sub-cooling system using a single stage cryocooler for 1MVA HTS power transformer.

Table III. Design parameters of 1MVA HTS power transformer.

Specification		Value	Unit
Rating	Capacity	1	[MVA]
	Voltage	22.9/6.6	[kV]
	Current	44/152	[A]
HTS windings	No. of turns	888/256	[turn]
	Voltage/turn	25.8	[V/turn]
	Length of tape	1,248/1,454	[mm]
	No.of bobbin	8/4	EA
	Outer diameter	472/488	[mm]
	Inner diameter	416/416	[mm]
Iron core	Material	Silicon steel plate	
	Height	1,384	[mm]
	Width	998	[mm]
	Cross section area	590	[cm^2]
	Max. flux density	1.7	[T]
Cryostat	Material	FRP	
	Outer diameter	698	[mm]
	Inner diameter	300	[mm]
	Height	1,089	[mm]

III. Electromagnetic field analysis of HTS transformer

In order to reduce the applied perpendicular component of magnetic flux density (B_r) of HTS tapes, the various reciprocal winding arrangements of 1MVA HTS transformer was presented. Fig. 4 shows the arrangements. The voltage per pancake on high-voltage side is reduced to half. The voltage per pancake on low-voltage side was not changed because of difficulty of jointing for 4 HTS tapes in parallel. Dimension of core and total number of turns of the transformer winding were fixed. And Fig. 5 shows the B_r distribution on the low voltage by various reciprocal arrangements of 1MVA HTS power transformer. In case of Fig. 4 (c), the maximum B_r applied on tapes is about 0.15 [T].

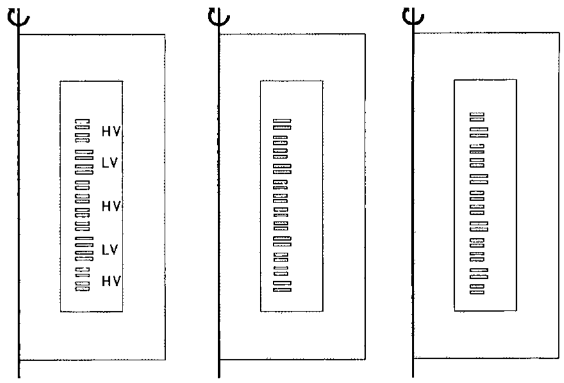


Fig. 4. Various reciprocal arrangements of 1MVA HTS power transformer in which the voltage per pancake on high-voltage side reduces to half. In this figure, long bars represent low-voltage coils and short bars represent high-voltage coils.

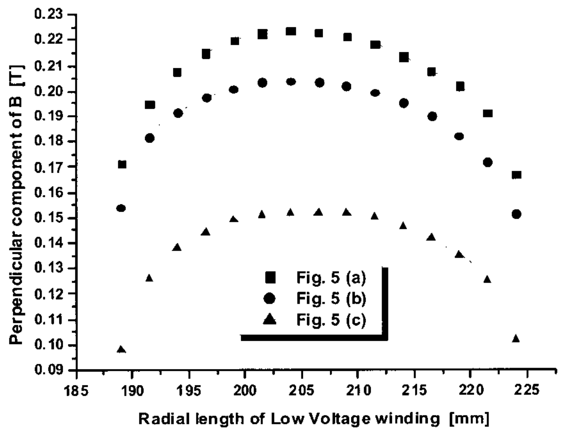


Fig. 5. B_r distribution on the low-voltage coil by various reciprocal arrangements of 1MVA HTS power transformer.

IV. Conclusion

This paper presents the design of the 1MVA HTS power transformer with BSCCO-2223 tape. The rated primary and secondary voltages are 22.9kV and 6.6 kV, respectively. The winding part is consisted of double pancakes and is sub-cooled to 65K by liquid nitrogen using cryocooler. The shell-type iron core was designed. A cryogenic system using a single-stage cryocooler for sub-cooling was conceptually designed. And through analyzing the magnetic field distribution, an optimal winding arrangement of 1MVA HTS power transformer is obtained. On the basis of the results, the 1MVA HTS power transformer will be manufactured in near future.

Acknowledgments

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