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Assembling and Insulation Test of 1MVA Single Phase HTS Transformer for Power Distribution

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***Abstract*--1MVA high temperature superconducting (HTS) transformer with double pancake windings made of BSCCO-2223 HTS tapes was designed and manufactured. And prototype transformer with the same capacity was manufactured also. The each rated voltage of the HTS transformer is 22.9 kV and 6.6 kV. Four parallel BSCCO-2223 HTS tapes were wound in the double pancake windings of low voltage side. In order to distribute the currents equally in each HTS tapes, the three times transposition was performed between the double pancake windings. The windings of prototype transformer were wound using copper tape with the same size as BSCCO-2223 HTS tape. The core of the transformer was designed and manufactured as a shell type core made of laminated silicon steel plate. The several characteristics tests for the prototype transformer were performed in liquid nitrogen and insulation tests were accomplished also.**

1. INTRODUCTION

HTS transformers offer several advantages compared to conventional transformers because there are reduced sizes, weight, energy losses, and the potential fire and environment hazards [1]. And HTS transformer withstands overload without loss of its life and possesses inherent self-protecting capability during the fault of the power system. 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 commercialisation. And many kinds of development program of HTS transformers are in progress by major power companies and research institutes [2]-[6].

In this paper, 1MVA 22.9 kV/6.6 kV HTS transformer with double pancake winding(DPW) made of BSCCO-2223 HTS tapes is designed and manufactured. In order to distribute the currents equally, the three times transposition is performed between low voltage windings using the four parallel HTS tapes. Prior to manufacture 1MVA HTS transformer, prototype transformer with winding made of copper tape the same size as BSCCO-2223 HTS tape is manufactured also. And the characteristics tests and insulation tests for 1MVA prototype transformer are accomplished in liquid nitrogen, respectively.

2. DESIGN AND MANUFA CTURE OF 1MVA SINGLE PHASE HTS TRANSFORMER

Design of 1MVA HTS transformer with DPW is performed. The rated primary voltage and the rated secondary voltage of the HTS transformer are 22.9 kV and 6.6 kV respectively. This HTS transformer is composed of HTS windings, iron core and cryogenic system. Table I shows the specification of 1MVA HTS transformer.

2.1. HTS Winding of Double Pancake Type

The winding of double pancake type is adopted in 1MVA HTS transformer. And BSCCO-2223 HTS tape is used in the DPW. This HTS tape is made by American Superconductor Company (ASC). The critical current of HTS tape is 115A in self-field at 77K. The specification of the HTS tape is shown in Table II.

Winding arrangement of 1MVA HTS transformer is reciprocal type. And the HTS winding of 1MVA HTS transformer has four modules, that each module is made of high-low-high winding. The total numbers of turns of each side HTS transformer are 832 turns for high voltage winding and 240 turns for low voltage one. The high and low voltage winding consist of 8 and 4 double pancake HTS windings respectively. And four parallel BSCCO-2223 HTS tapes are wound in the double pancake windings of low voltage side. In order to distribute the currents equally, the three times transposition is done between low voltage windings. Each bobbin of HTS winding is made of GFRP and assembled by mechanical support. Fig. 1 shows 3-D model of the HTS winding of 1MVA HTS transformer.

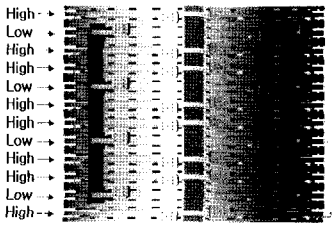
TABLE I
SPECIFICATION OF 1MVA SINGLE PHASE HTS TRANSFORMER

Specification	Value
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

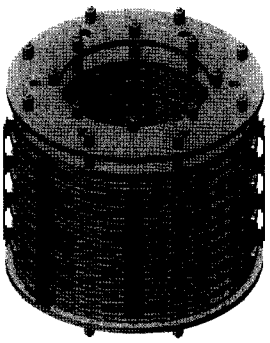
TABLE II
SPECIFICATION OF 1MVA SINGLE PHASE HTS TRANSFORMER

Specification	Value
Material	BSCCO-2223
Type	Reinforced HTS wire
Thickness	0.31 mm
Width	4.1 mm
Critical current	115 A*
Max. Stress	265 MPa**
Min. Bending dia.	70 mm**

* at 77K, self-field
** With 95% I_c Retention

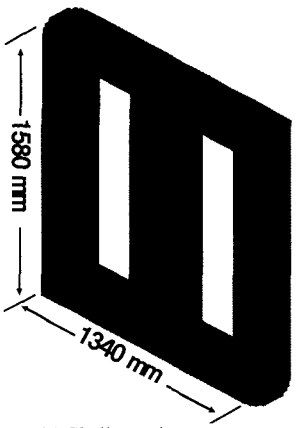


(a) Arrangement of HTS winding

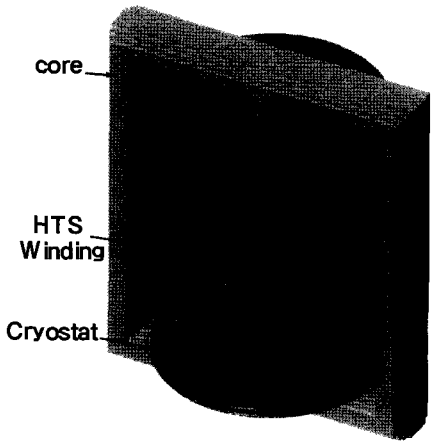


(b) Assembled HTS winding

Fig. 1. 3-D model of HTS winding of 1MVA HTS transformer. (a) The winding of 1MVA HTS transformer consists of reciprocal arrangement (high-low-high winding). (b) Each bobbin of HTS winding is assembled by mechanical support made of GFRP.



(a) Shell type iron core



(b) Total design

Fig. 2. (a) Design of shell type iron core and (b) Total design of 1MVA HTS transformer with DPW.

TABLE III
DESIGN PARAMETERS OF 1MVA SINGLE PHASE
HTS TRANSFORMER WITH DOUBLE PANCAKE WINDING

	Specification	Value
	Phase	1
Rating	Capacity	1 MVA
	Voltage	22.9 kV / 6.6 kV
	Material	BSCCO-2223 HTS tape
	No. of turns	832 turn / 240 turn
HTS winding	Voltage / turn	27.5 V/turn
	No. of bobbin	8 / 4
	Outer dia. of bobbin	646 mm / 646 mm
	Inner dia. of bobbin	412 mm / 412 mm
	Material	Silicon steel plate
	Height	1,580 mm
Iron core	Width	1,340 mm
	Cross section area	715.16 cm^2
	Max. flux density	1.488 T
	Material	G(10)FRP
Cryostat	Outer dia.	948 mm
	Inner dia.	334 mm
	Height	1,200 mm

2.2. Iron Core

A shell type iron core for 1MVA HTS transformer using design processes of conventional core is designed and manufactured. The number of step of core is four and the cross section area of core is 715.16 cm^2. And the maximum magnetic flux density of core is 1.488 T. The height and width of manufactured iron core is 1,580 mm and 1,340 mm. Fig. 2-(a) shows the configuration of the laminated core of 1MVA HTS transformer. The design parameter of 1MVA HTS transformer with DPW is shown in Table III.

2.3. Cryogenic System

A cryostat and sub-cooling system of 65K liquid nitrogen for 1MVA HTS transformer are designed and manufactured. The cryostat is made of GFRP and has a room temperature bore. HTS windings will be cooled down to 65K with sub-cooled liquid nitrogen. And the total design of 1MVA HTS transformer with DPW is shown in Fig. 2-(b).

2.4. Manufacture of Prototype Transformer and 1MVA Single Phase HTS Transformer with DPW

Prior to manufacture 1MVA HTS transformer, prototype transformer with winding made of copper tape the same size as BSCCO-2223 HTS tape is design and manufactured. The design parameters of prototype transformer are the same as one of 1MVA HTS transformer. Fig. 3 shows the photos of manufactured copper winding, core and cryostat for insulation test. The manufactured cryostat for insulation test has not vacuum shields at the inner wall, the outer wall and the bottom. And 1MVA HTS transformer with DPW is also manufactured using design parameters. The photos of both the HTS winding made of BSCCO-2223 HTS tape and the cryostat with vacuum shield are shown in Fig. 4.

3. CHARACTERISTICS TEST AND INSRLATION TEST OF 1MVA SINGLE PHASE HTS TRANSFORMER

The several kinds of characteristics tests and insulation tests for manufactured prototype transformer were performed. The test method of oil transformer is applied to the prototype transformer. Liquid nitrogen was used for cooling down the copper winding of the prototype transformer. The applied characteristics tests and insulation tests are the following

Characteristics tests :

(1) Turn ratio test
(2) Meggering test
(3) No-load test
(4) Load test

Insulation tests :

(1) Lightening impulse test
(2) Power frequency voltage test
(3) Induced voltage test

The obtained results through characteristics test and insulation test are shown in Table IV and V respectively. And Fig. 5 shows the characteristics test and insulation test of prototype transformer in liquid nitrogen. As shown in Table V, (1) lightening impulse test : insulation break was occurred at high voltage windings because there were some mistakes in making high voltage bushing. But insulation of low voltage winding did not break. (2) Induced voltage test : when 180 Hz and twice rated voltage is applied to low voltage winding, we ascertained that insulation break did not happen for 40 seconds. (3) Power frequency voltage test : when 22 kV is applied to the low voltage winding, insulation break did not occur. But in applying 55 kV to the high voltage winding, insulation of high voltage winding was broken after 4 seconds.

TABLE IV
RESULTS OF CHARACTERISTICS TEST OF PROTOTYPE TRANSFORMER IN LIQUID NITROGEN

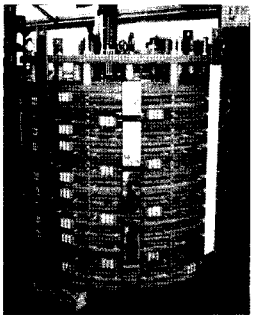
Specification		Value
Turn ratio	Rated ratio	3.47
	Measured ratio	3.535
Meggering test	HV-LV	> 2,000 MΩ
	HV-E (earth)	> 2,000 MΩ
	LV-E (earth)	> 2,000 MΩ
Resistance	1st	3.10 Ω (20.64 Ω)
	2nd	0.2216 Ω (1.477 Ω)
No-load test	No-load loss	(2,145 W)
	No-load current	0.531 A
%Iz	LN_2	4.7 % (8.7 %)

( ) : Room temperature

TABLE V
RESULTS OF INSULATION TEST OF PROTOTYPE TRANSFORMER IN LIQUID NITROGEN

Specification	Winding	Spec.Vtg.	Spec.Time	Result
Lightening impulse test	HV_0	150 kV	-	142 kV
	HV_1	150 kV	-	142 kV
	LV_0	60 kV	-	S
	LV_1	60 kV	-	S
Induced voltage test	$2\times V_N$	180 Hz	40 sec	S
Power frequency voltage test	HV	50 kV	1 min	F
	LV	22 kV	1 min	S

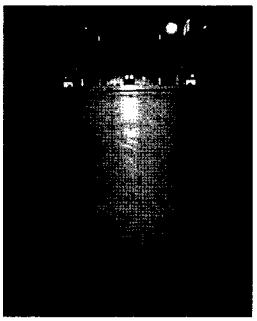
F : Fail
S : Success



(a) Winding made of copper tape

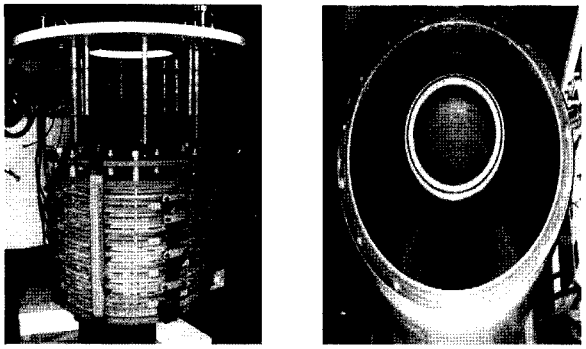
(b) Shell type iron core

(c) Cryostat for insulation test



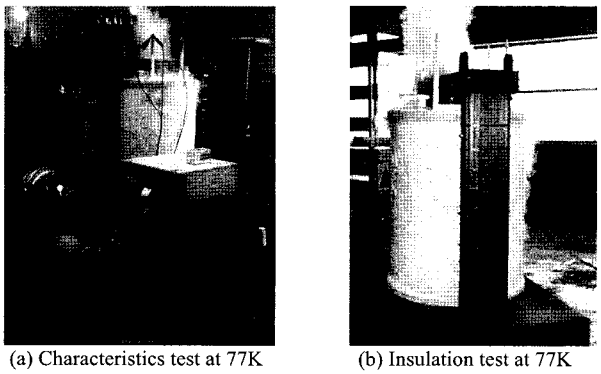
(d) Prototype transformer

Fig. 3. Manufacture and assembling of prototype transformer. (a) Winding part made of copper tape, (b) Shell type iron core, (c) Cryostat for insulation test with no vacuum shield, (d) Total configuration of prototype transformer.



(a) Winding part made of HTS tape (b) Cryostat with vacuum shield

Fig. 4. Manufactured 1MVA single phase HTS transformer. (a) Tope plate made of G(10)FRP and winding made of HTS tape, (b) Cryostat with vacuum shield is made of G(10)FRP.



(a) Characteristics test at 77K (b) Insulation test at 77K

Fig. 5. Experiment of prototype transformer. (a) Characteristics test and (b) Insulation test in liquid nitrogen.

4. CONCLUSIONS

22.9 kV / 6.6 kV, 1MVA HTS transformer with DPW made of BSCCO-2223 HTS tapes was designed. The three times transposition was performed to distribute the current equally between low voltage HTS windings of 1MVA HTS transformer. And prior to manufacture 1MVA HTS transformer, prototype transformer with copper winding was designed and manufactured also. For the manufactured prototype transformer, the several kinds of characteristics and insulation tests were accomplished in liquid nitrogen respectively. From results of tests of prototype transformer, the validities of the design parameters and insulation of 1MVA HTS transformer were ascertained. On the basis of the results of this experiment, 1MVA HTS transformer was manufactured. And the manufactured 1MVA HTS transformer will be assembled completely and characteristics and insulation tests will be performed in near future.

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