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Comparison of Reciprocal and Concentric Winding Arrangement of HTS Transformer

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고온초전도 변압기의 교호 배치 권선과 동심형 배치 권선의 비교

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Abstract

In HTS transformer with double pancake windings, the perpendicular component of leakage magnetic flux density (B_r) applied to HTS tapes of double pancake windings of HTS transformer acts as a cause to decrease the critical current in HTS tape. So, in this paper, HTS transformer with reciprocal arrangement winding is designed. And in order to investigate the B_r applied to HTS windings, the 2-D non-linear electromagnetic analysis of HTS transformer is performed by using the OPERA 2D. The maximum B_r applied to winding of HTS transformer is 0.112 T and the characteristics of HTS transformer were also obtained. But in this type of winding arrangement, reciprocal arrangement, the generated ac-loss to the HTS windings is very high because of the applied B_r to HTS windings. Therefore, in order to reduce the generated ac-loss to the HTS windings, the new design of HTS transformer with concentric winding arrangement is presented in this paper and the 2-D non-linear electromagnetic analysis and the ac-loss for HTS transformer with the concentric winding arrangement is also carried out.

Keywords : HTS, Transformer, reciprocal winding, concentric winding

I. Introduction

High temperature superconducting (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]. HTS transformer withstand 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 commercialization. And many kinds of

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development program of HTS transformers are in progress by major power companies and research institutes [2]-[4].

This paper presents the comparison of HTS transformer with several kinds of winding arrangements, such as solenoid, reciprocal and concentric winding. 2-D non-linear electromagnetic analysis for each winding arrangement is performed by using the OPERA 2D. And the generated ac-losses to the HTS windings are calculated by the electromagnetic field analysis of HTS winding.

II. HTS transformer with several kinds of winding arrangement

The design of 1MVA HTS transformer with three kinds of winding arrangements is accomplished. And the type of each winding is classified into solenoid (helical) and pancake type. "E-core" shell type with three limbs is adopted into each design of HTS transformer. The conceptual design parameters of 1MVA single-phase HTS transformer for each winding arrangement are shown in Table 1. And Fig. 1 shows conceptual design of each HTS transformer.

A. Solenoid (Helical) winding

The model of solenoid winding is composed of two layers of high voltage winding and four layers of low voltage winding, respectively. This model is similar to the developed 1MVA HTS transformer in Japan (Fuji Electric Co./Kyushu University) [3].

This type of solenoid winding arrangement is used to the conventional transformer design in general. However, there is not proper winding arrangement for high voltage HTS transformer because of insulation break of winding, transposition of parallel HTS tapes, high window height of core and etc.

B. Reciprocal winding

Design of HTS transformer with reciprocal winding arrangement of double pancake type is also performed. The winding of this model has four modules and each module consists of high-low-high winding.

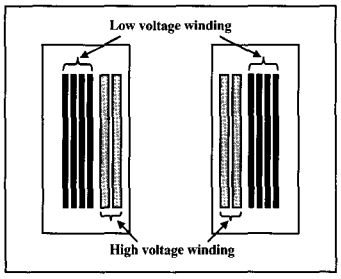
This winding arrangement with double pancake type compared with solenoid winding has several advantages such as good distribution of voltages through windings, ease of fabrication, ease of maintenance, small size and good insulation between windings. However, there is a high leakage magnetic flux between high voltage winding and low voltage winding. And this kind of leakage magnetic flux causes much of AC loss in HTS winding as well as reduction of critical current of HTS winding.

C. Concentric winding

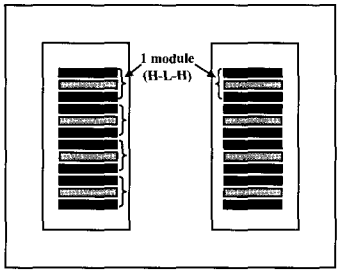
In order to reduce the generated AC loss of HTS winding of reciprocal winding arrangement, in this paper the design of HTS transformer with concentric winding arrangement is accomplished. The type of winding is double pancake type. The bobbin of high and low voltage winding is divided into 16 respectively.

Table 1. Design parameters of HTS transformer with solenoid winding, reciprocal winding, concentric winding arrangement.

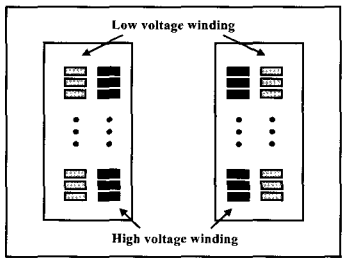
Specification		Value
Solenoid winding		
Rating	Capacity	1 MVA / single phase
	Voltage	22.9 / 6.6 kV
	Current	43.67 / 151.51 A
Winding	No. of turns	832 / 240
	No. of layers	4 / 2
	No. of conductors	1 / 4
Core	Type	Shell type (E core)
Reciprocal winding		
Rating	Capacity	1 MVA / single phase
	Voltage	22.9 / 6.6 kV
	Current	43.67 / 151.51 A
Winding	No. of turns	832 / 240
	No. of bobbin	8 / 4
	No. of conductors	1 / 4
Core	Type	Shell type (E core)
Concentric winding		
Rating	Capacity	1 MVA / single phase
	Voltage	22.9 / 6.6 kV
	Current	43.67 / 151.51 A
Winding	No. of turns	832 / 240
	No. of bobbin	16 / 16
	No. of conductors	1 / 4
Core	Type`	Shell type (E core)



(a) solenoid winding arrangement

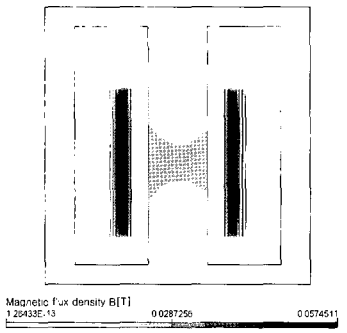


(b) reciprocal winding arrangement

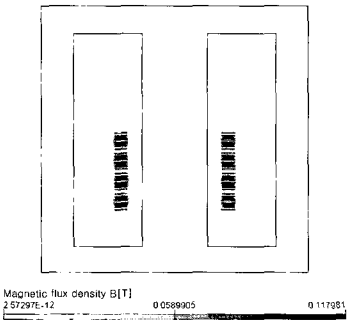


(c) concentric winding arrangement

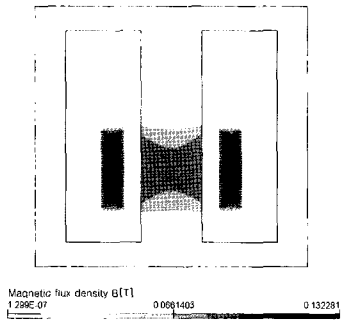
Fig. 1. Conceptual design of HTS transformer with several types of winding arrangement. (a) Solenoid winding arrangement. (b) Reciprocal winding arrangement. (c) Concentric winding arrangement.



(a) solenoid winding arrangement



(b) reciprocal winding arrangement



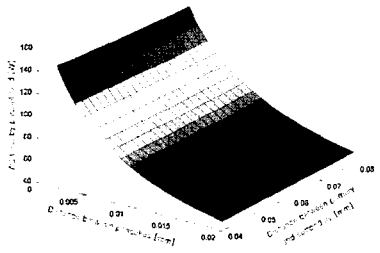
(c) concentric winding arrangement

Fig. 2. Magnetic field distribution of HTS transformer when the phase of applied AC voltage is 0 degree.

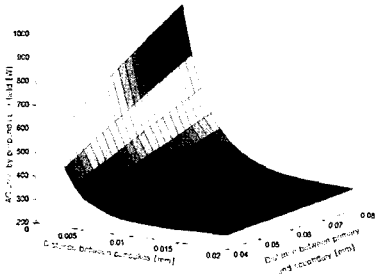
III. Electromagnetic field analysis

In this section, non-linear electromagnetic field analysis for HTS transformers with three kinds of winding arrangement as shown in Fig. 1 is performed. The time-harmonic analysis of voltage source circuit method is used. Fig. 2 shows the magnetic field distribution around the core and the windings of HTS transformer when the phase of applied AC voltage is 0 degree. And the applied magnetic flux density to the HTS winding is very high at this phase.

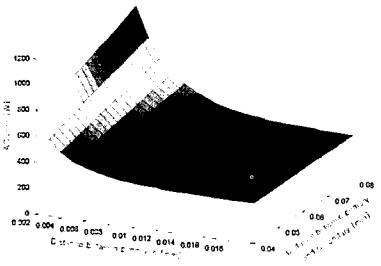
The maximum flux densities to the three kinds of winding arrangements are 0.0574, 0.1179 and 0.1322 [T] respectively. And through analyzing the magnetic field distribution for each model, AC-losses are calculated. The AC-loss of HTS transformer with solenoid winding arrangement is the least value (150 W), but this type winding arrangement is not suitable to the high voltage HTS transformer because of electrical insulation between windings. And HTS transformer model with reciprocal type winding arrangement has the highest AC-loss value (800 W).



(a) AC-loss for parallel magnetic field



(b) AC-loss for perpendicular magnetic field



(c) Total generated AC-loss for HTS winding

Fig. 3. AC-loss calculation of HTS transformer with concentric winding arrangement of various distances. (a) AC-loss for parallel magnetic field. (b) AC-loss for perpendicular magnetic field. (c) Total generated AC-loss of HTS winding

Therefore in this paper we recommend the model with concentric winding arrangement of double pancake type profitable to the high voltage transformer. So, in this paper, AC-loss calculations for concentric winding arrangement with the various distances, such as between pancake windings and between high and low voltage winding, are carried out. Fig. 3 shows the AC-loss calculation in HTS transformer with the concentric winding arrangement of various distances. The optimal distance between pancake windings and between high and low voltage winding of concentric winding arrangement is 8mm and the 60mm, respectively.

IV. Conclusion

The design and non-linear electromagnetic field analysis of HTS transformer with several kinds of winding arrangement are given in this paper. And the AC-loss calculations for three kinds of HTS winding arrangement are also performed. Through calculating the AC-loss of each model, in this paper the model with concentric winding arrangement is recommended to the high voltage HTS transformer. And Through the AC-loss calculations for concentric winding arrangement with various distances, the optimal values of concentric winding arrangement of HTS transformer are also obtained.

Acknowledgments

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