PSCAD/EMTDC를 이용한 초전도 변압기의 모델링과 시뮬레이션

Modeling and Simulation of Superconducting Transformer using PSCAD/EMTDC

임채형*, 박민원**, 유인근*

Chae-Hyung Lim*, Min-Won Park**, and In-Keun Yu*

Abstract: This paper presents an effective simulation method for the high temperature superconducting (HTS) transformer using PSCAD/ EMTDC. Although researches and developments are performed for the HTS technologies, problems such as AC loss and quench phenomenon need to be solved for efficient design of HTS transformer. In addition, pre-study on the HTS transformer is a sort of time and cost consuming work, thus it is very worthy of being analyzing the characteristics of the HTS transformer in advance through a proper simulation method. It is very important to analyze the HTS devices by the simulation for seeking suitable and reasonable parameters for the practical application of those apparatuses in advance. A software- based component is suggested for the simulation of the HTS transformer using PSCAD/ EMTDC and the numerical results are analyzed in detail in this paper.

Key Words:High Temperature Superconducting (HTS) transformer, PSCAD/EMTDC simulation

1. Introduction

The advent of high-temperature superconducting (HTS) materials has opened up many new prospects for the practical application of superconductivity in utility power equipments. Recently, with the progress of superconducting wires for ac use, investigations on the HTS transformers are increasing. Power transformers with superconducting windings are superior to conventional ones from small size and light weight, non-oil and non-flammable, high efficiency even including refrigeration penalty, and reduction in life cycle cost [1, 2].Furthermore, the HTS transformer withstands overload without loss of its life and possesses inherent self-protecting capability during the fault of the power system [3, 4].

* 비 회 원 : 창원대 대학원 석사과정
* 정 회 원 : 창원대 공대 전기공학과 교수
** 정 회 원 : 차세대초전도응용기술개발사업단
원고접수 : 2003년 12월 19일
심사완료 : 2004년 03월 06일

The 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. Major power companies and research institutes worldwide are working for the development of the HTS transformers. However, problems such as AC loss and quench phenomenon need to be solved for proper design of a superconducting transformer [5, 6]. In addition, pre-study on the HTS transformer is a sort of time and cost consuming work, thus it is very worthy of being analyzing the characteristics of the HTS transformer in advance through proper simulation method. In this article, an effective simulation of the HTS transformer is performed using PSCAD/ EMTDC in which a software-based component is suggested for the simulation. The effectiveness of the proposed simulation scheme is demonstrated through numerical analysis of the simulation results in detail.

2. Modeling of the HTS transformer

The HTS transformer has the same operation principle and fundamental structure as conventional transformers, however, winding conductor is exchanged to high temperature superconductor (resistance = 0). Although the HTS transformer has a low % impedance and high power density by having lower operating losses, AC losses and quench phenomenon that superconductor loses the superconductivitycharacteristic must be worthy due consideration.
A schematic diagram of the HTS three phase transformer under consideration in this paper is presented in Fig. 1.

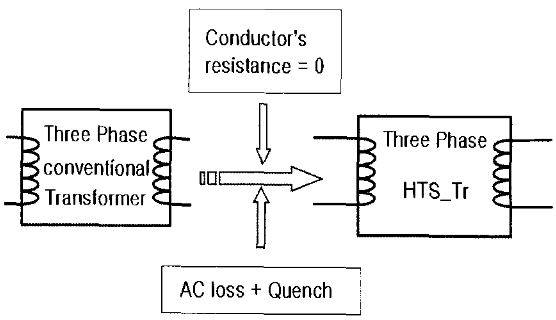


Fig. 1. Schematic diagram of the HTS transformer

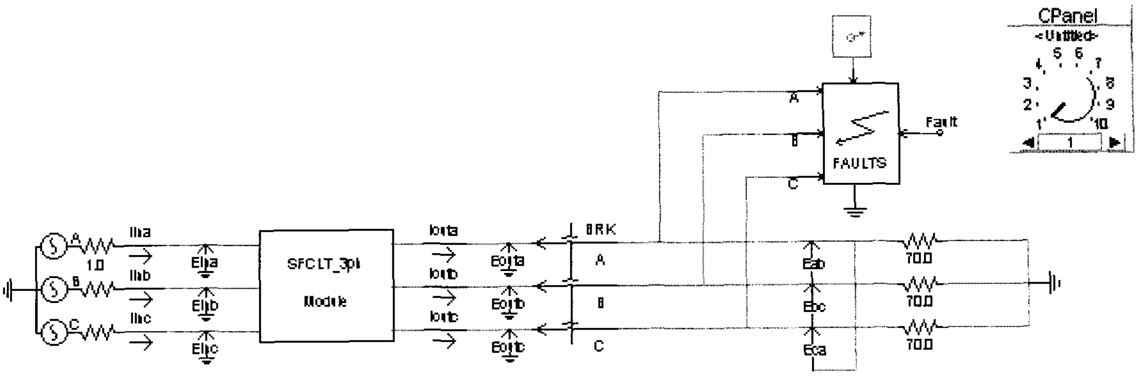


Fig. 2. Model power system.

2.1. AC losses

Although the HTS transformer has low losses compared with conventional transformer, cooling system must be established for maintaining superconductivity of transformer. AC losses, which have a bad effect in cooling, of 0.618[kW] in the windings were evaluated by an electrical method [5] through the short circuit test under rated current condition of 1[MVA] transformer.

2.2. Quench phenomenon

Quench phenomenon is occurred due to one of the critical elements exceeds the basic critical values; critical current, critical temperature and critical magnetic flux density. The HTS transformer has a fault current limiting function because of increasing internal resistance during quench. Quench-induced impedance of the HTS transformer is positively utilized as a current limiter in the fault condition. Limiting impedance of the HTS transformer is activated and leakage impedance of a transformer can be reduced compared with that of conventional transformers [7].

2.3 The HTS transformer model

Table 1 depicts input parameters for the simulation of three-phase HTS transformer of 1[MVA] capacity, and the primary and secondary voltages are 22.9 and 6.6[kV], respectively. Fig. 2 shows the model power system used in this paper.

Table 1. Design parameters of transformer for simulation

	HTS transformer	Conventional transformer	[unit]
Phase	3	3	
Capacity	1	1	[MVA]
Voltages	22.9/6.6	22.9/6.6	[kV]
Connection type	Y-△	Y-△	
No load losses	9.6	22.5	[kW]
%Impedence	5.0	15.0	[%]
Operation temperature	77	298	[K]
AC loss	0.618	Ignored	[kW]

The component of HTS transformer is modeled and developed on the PSCAD/EMTDC using characteristics of transformer, such as %Impedance, no load losses, and AC losses.

Fig. 3. shows the PSCAD/EMTDC component of HTS transformer. As given in Fig. 3, the component of HTS transformer consists of two parts. One is the HTS_Tr_3ph that is for conventional transformer and the AC losses part of HTS transformer. The other is the RSFCL that is for quench characteristic of the HTS transformer.

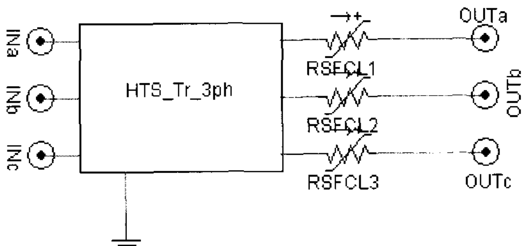


Fig. 3. PSCAD/EMTDC component of the HTS transformer.

Fig. 4. shows the simulation algorithm for analysis of the HTS transformer characteristics, in which the simulation processes using the HTS transformer component developed on the PSCAD/EMTDC are presented as well. The "HTS transformer decision" is for selection of the superconducting or conventional characteristics. If the HTS transformer model is selected, the component of HTS transformer has the characteristics of HTS transformer, such as %Impedance, no load losses, and AC losses. Finally, the "Quench occurrence" is for giving the quench characteristic of HTS transformer when quench is occurred.

3. Simulations and Results

The simulation consists of two processes. First one is a process that concisely constitutes a three-phase power system for simulation using the component of HTS transformer. The other is a process that

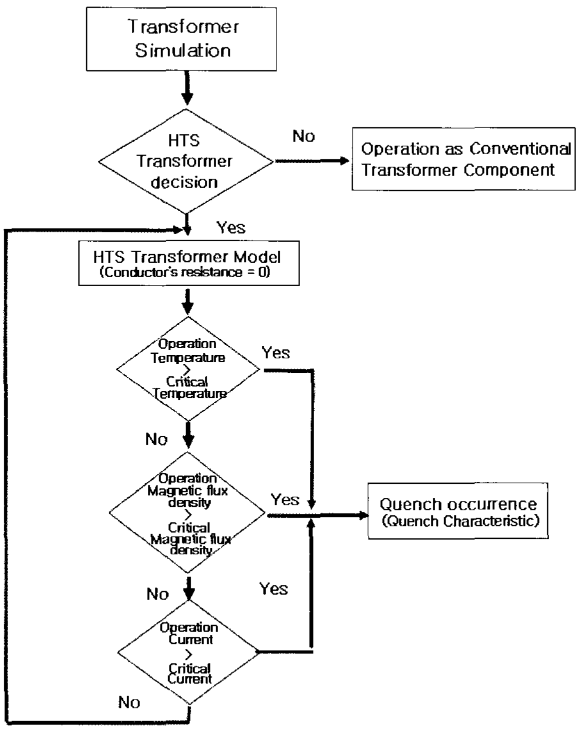


Fig. 4. Algorithm of the proposed simulation.

simulation is performed for both under fault condition and steady state, and analysis of the results obtained will be followed.

For the simulation of HTS transformer, a single-line-to-ground fault (phase-a) is assumed at 0.2 [sec] and CB is operated at 0.05 [sec] after fault.

Fig. 5 and Fig. 6 depict the secondary current and voltage waveforms during the fault of three-phase conventional transformer described in Table 1, respectively.

The secondary current and voltage waveforms during the fault of three-phase HTS transformer (without quench) are given in Fig. 7 and Fig. 8, respectively. The efficiency of HTS transformer increased about 1[%] due to the HTS transformer has lower no load losses and %Impedance than the conventional transformer.

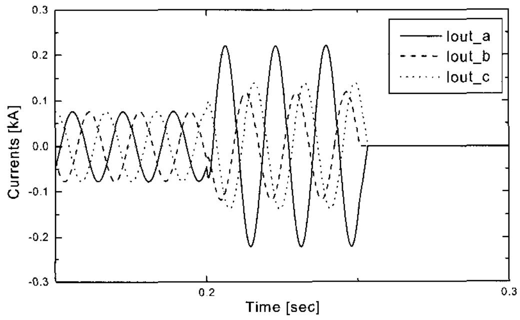


Fig. 5. Secondary current waveforms of conventional transformer.

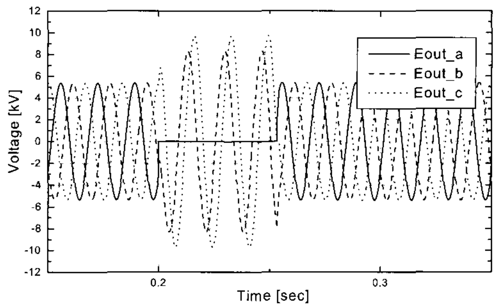


Fig. 6. Secondary voltage waveforms of conventional transformer.

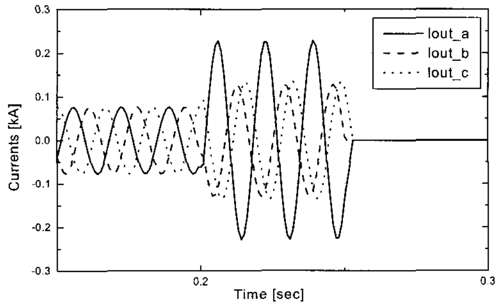


Fig. 7. Secondary current waveforms of HTS transformer.

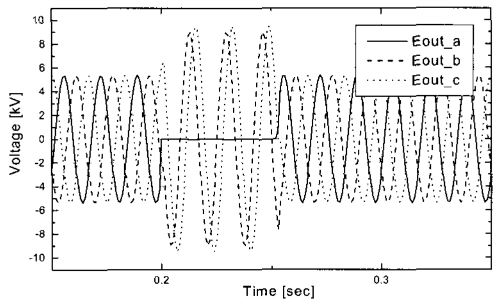


Fig. 8. Secondary voltage waveforms of HTS transformer.

Fig. 9 and Fig. 10 show the secondary current and voltage waveforms during the fault of

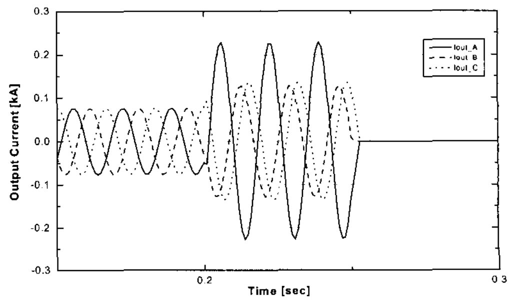


Fig. 9. Secondary current waveforms of HTS transformer (AC loss).

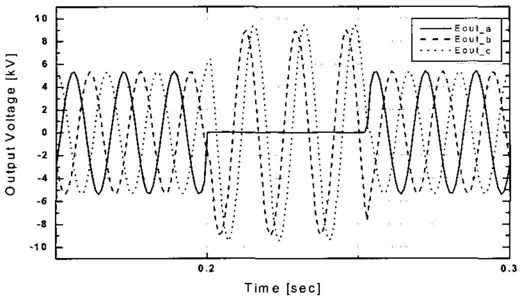


Fig. 10. Secondary voltage waveforms of HTS transformer (AC loss).

three-phase HTS transformer for the case of 0.618[kW] AC losses applied, respectively. As shown in Fig. 9 and Fig. 10, about 1.3[%] of the current and about 2[%] of voltage drop of the voltage have been increased compared with those of given in Fig. 7 and Fig. 8 due to the AC losses.

For the quench phenomenon analysis, the characteristic equation of limiting resistance of the HTS transformer (1), which is presented in [7], is used in this paper.

$$R(t) = R_{sc}\left\{1 - \exp\left(-\frac{t-t_0}{\tau}\right)\right\} \qquad (1)$$

where, Rsc represents resistance of superconductor, and the limiting resistance R(t) will be increased exponentially up to Rsc (0~10) with the time constant after the quench-onset (t=to).

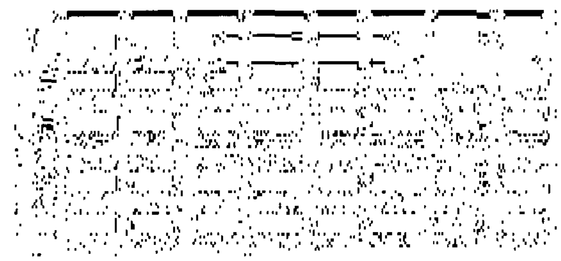


Fig. 11. Resistance curve of HTS transformer with quench.

Through the comparison of the output current and voltage when quench occurred due to a single-line-to- ground fault with those outputs under steady state operation, the quench characteristic of HTS transformer can be clearly recognized. There is a quench phenomenon in 0.2[sec] caused by the fault current. As results, about 3 ~ 7[%] decrease of the fault current at the inception of fault and about 22[%] decrease after 0.05[sec] of the fault inception are given with the quench activation.

Finally, the output current and voltage

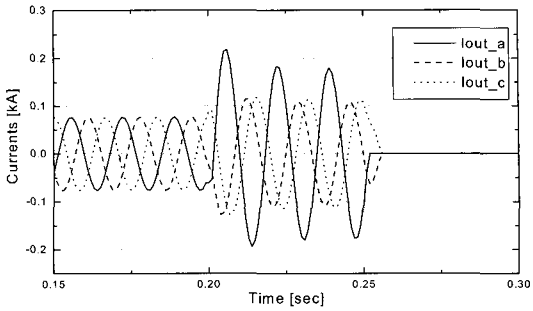


Fig. 12. Secondary current waveforms with quench.

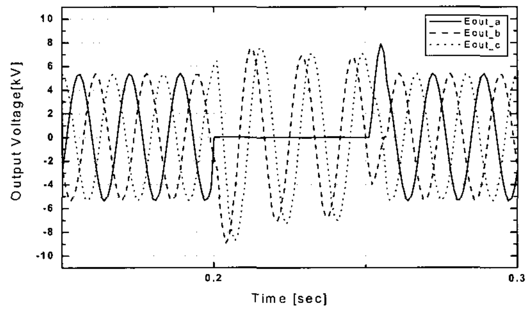


Fig. 13. Secondary voltage waveforms with quench.

waveforms generated through the analysis of HTS transformer under a fault condition after which quench is followed in the HTS transformer are represented in Fig. 12 and Fig. 13, respectively.

4. Conclusions

An effective modeling and simulation of a three-phase HTS transformer are performed using PSCAD/EMTDC, and the operation characteristic of the HTS transformer is analyzed in this paper. A software-based component is suggested for the simulation of HTS transformer and the numerical results are described in detail. In addition, the quench characteristic of HTS transformer caused by fault current is investigated and the current limiting function of HTS transformer is also simulated.

The effectiveness of the proposed simulation modelis demonstrated through numerical analysis and the simulation results are summarized as follows.

1) HTS transformer works as a transformer in the normal condition, and also as a fault current limiter in the fault condition.

2) Quench induced resistance is positively utilized as a current limiter in the fault condition.

3) The suggested component can be applied

under various conditions for the simulation and characteristic analysis of HTS transformers.

감사의 글

본 연구는 21세기 프론티어 연구개발 사업인 차세대 초전도 응용기술 개발 사업단의 연구비 지원에 의해 수행되었음.

참 고 문 헌

[1] S. P. Mehta, N. Aversa, and M. S. Walker, " Transforming transformers", IEEE Spectrum, Vol.34, No.7, pp. 43-49,July, 1997

[2] C. T. Reis, S. P. Mehta, B. W. McConnell, and R.H. Jones, "Development of High Temperature Superconducting Power Transformers", IEEE Power Engineering Society Winter Meeting - Volume 2, 432-437, 2001

[3] S. Hornfeldt, O. Albertsson, D. Bonmann, and F. Konig, "Power Transformer with superconducting winding", IEEE Transactions on Magnetics, Vol. 29, No. 6, November, 1993

[4] H. J. Lee, G. S. Cha, J. K. Lee, K. D. Choi, K. W. Ryu, and S. Y. Hahn "Test and Characteristic Analysis of an HTS Power Transformer", IEEE Transactions on Applied Superconductivity, Vol.11, No. 1, March, 2000

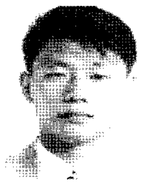
[5] K. Funaki, M. Iwakuma, K. Kajikawa, M. Hara, J. Suehiro, and T. Ito, "Development of a 22kV/6.9kV Single-Phase Model for a 3 MVA HTS Power Transformer", IEEE Transactions on Applied Superconductivity, Vol.2, No.1, March 2001

[6] T. Ise, Y. Marutani, and Y. Murakumi, "Characteristics of a 40kVA Three Phase Superconducting Transformer and its parallel operation with a conventional transformer", IEEE Transactions on Applied Superconductivity, Vol.5, No.2, June 1995

[7] N. Hayakawa, H. Kagawa, and H. Okubo, "A System Study on Superconducting Fault Current Limiting Transformer (SFCLT) with the Functions of Fault Currents Suppression and System Stability Improvement", IEEE Transaction on Applied Superconductivity, Vol.2. No.1, March, 2001

저 자 소 개

임채형 (林采亨)
1976년 6월 19일생, 2002년 창원대 공대 전기공학과 졸업, 현재 동대학원 전기공학과 석사과정



박민원 (朴敏遠)
1970년 2월 12일생. 1995년 창원대 공대 전기공학과 졸업. 1997년 동 대학원 전기공학과 졸업(석사). 2002년 오사카대학 전기공학과 졸업(박사). 현재 차세대초전도응용기술개발사업단

유인근 (劉仁根)
1954년 2월 18일생. 1981년 동국대 공대 전기공학과 졸업. 1983년 한양대 대학원 전기공학과 졸업(석사). 1986년 한양대 대학원 전기공학과 졸업(박사). 1985년 6월~1988 년 2월 한국전기연구원 지중송전연구실장. 1990년 12월~1992년 2월 University of Texas at Arlington (Post-Doc.). 1996년 12월~1998년 2월 Brunel University, UK(Visiting Scholar). 1998년 3월~현재 창원대학교 전기공학과 교수