APP3-1

Three-Dimensional Thermal Analysis of an SFCL REBCO Coil Immersed in Liquid Nitrogen

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A resistive type SFCL using REBCO tapes has high potential to limit fault currents quickly and to improve the reliability of a power system for its compactness and rapid increasing of resistance [1]. We have studied the thermal characteristics of a SFCL REBCO coil by numerical analysis using more precise analysis models. Influence of bubbles of boiling nitrogen is also considered in some cases. If bubbles are generated under fault conditions, a rapid local temperature rise may occur and even result in a permanent degradation of J_C of REBCO layer.

In this paper, we upgrade the previous FEM analysis model [2] for 3D thermal analysis of a REBCO coil in a resistive type SFCL (Fig.). Coupled problems of electromagnetic and thermal fields are solved for studying thermal characteristics of an SFCL REBCO coil immersed in liquid nitrogen. In computation of current distribution in the SFCL coil, a thin-plate approximation is applied to the REBCO tapes and FEM based on current vector potentials $\boldsymbol{T}$ is utilized. Current density $\boldsymbol{J}$ is defined by $\boldsymbol{J}=\nabla\times\boldsymbol{T}$. The governing electromagnetic equation is given by $\nabla\times(\rho\nabla\times\boldsymbol{T})=-\partial\boldsymbol{B}/dt$ (ρ: electric resistivity; $\boldsymbol{B}$: magnetic flux density) [2]. In thermal analysis, the 3D structure of SFCL coil is modeled and the temperature rise is calculated under the condition of Joule heating, heat conduction, heat transfer, and cooling characteristics of liquid nitrogen.

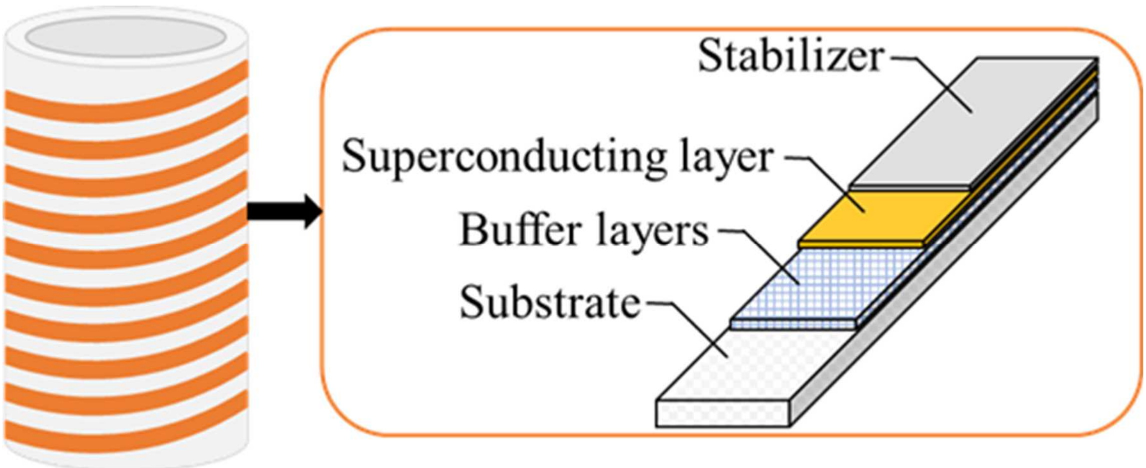

Fig. Schematic drawing of a solenoid coil wound with REBCO tapes for resistive type SFCL

[1] H. S. Ruiz, et al., "Resistive-Type Superconducting Fault Current Limiters: Concepts, Materials, and Numerical Modeling," IEEE Transactions on Applied Superconductivity, vol. 25, no. 3, pp. 1–5, 2015.
[2] H. Ohsaki, et al., "Characteristics of Resistive Fault Current Limiting Elements Using YBCO Superconducting Thin Film with Meander-Shaped Metal Layer," IEEE Transactions on Applied Superconductivity, vol. 19, no. 3, pp. 1818–1822, 2009.

Keywords: superconducting fault current limiter, finite element method (FEM), coated conductor, thermal analysis

APP3-2

Combined Use of SFCL and SMES for Augmenting FRT Performance and Smoothing Output Power of PMSG Based Wind Turbine

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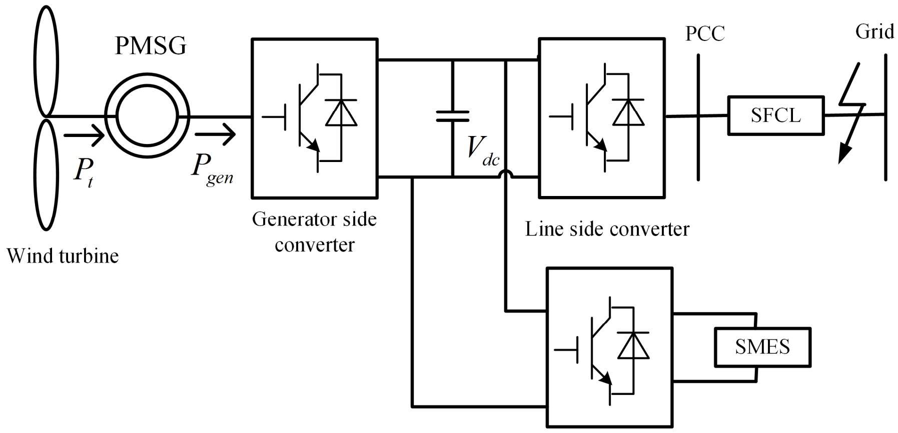
Concerning the integration of wind energy in the power grid, some key technical issues should be given enough attention, such as the capability of fault ride through (FRT) and the smoothness of output power. In this paper, the combined use of a resistive-type superconducting fault current limiter (SFCL) and a superconducting magnetic energy storage (SMES) is proposed, and it is expected to improve the transient performance of a permanent magnet synchronous generator (PMSG) based wind turbine system under fault conditions. The SFCL is installed near the line side converter (LSC) of the wind turbine system, and its functions are to suppress the fault current and compensate the terminal voltage. The SMES is coupled to the wind turbine system's DC-link, and it aims to alleviate the power difference between the generator side converter (GSC) and the LSC. Thus, the output power can be smoothed, and the DC-link overvoltage will be mitigated. Related theoretical analysis and control strategy are conducted, and further a detailed simulation model of 1.5 MW PMSG-based wind turbine integrated with the SFCL-SMES is built in MATLAB/SIMULINK. The simulations are performed to check the effects of the SFCL-SMES on handling different fault cases. From the results, the effectiveness of the proposed approach on augmenting the FRT capability and smoothing the power fluctuation of the PMSG can be well confirmed.



Keywords: Superconducting fault current limiter, Superconducting magnetic energy storage, Permanent magnet synchronous generator, Wind turbine system

APP3-3

HILS of Transmission Line Protection System for the application of the SFCL to Korean power system

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In Korea, a 154 kV SFCL system was developed and installed at the Gochang Power Test Center of Korea Electric power Corporation (KEPCO) in 2016. Korea Electrotechnology Research Institute (KERI) proposed a novel protection algorithm for the application of the 154 kV SFCL to a real power system and designed a protection scheme of the Gochang Power Test Center.

This paper verified the protection scheme using the Hardware In the Loop Simulation (HILS) that a commercial protective relay system with the novel algorithm is tested by Real Time Digital Simulator (RTDS). The commercial relay system was installed and operated at a real power system in the Gochagn Power Test Center after the PHILS verification.

Keywords: SFCL, HILS, Protection scheme, Protective relay system

APP3-4

A feasibility study of smart high-temperature superconducting cable to improve stability of KEPCO system

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The Korean system is a very tightly coupled island system. The installed capacity is about 100 GW and the load demand is gradually increasing. Especially in metropolitan areas where the load is concentrated, the system fault current often exceeds the breaker capacity due to the strong connection. The system operator limits the fault current by bus split operations considering the breaker capacity but this reduces system stability. Therefore, various efforts have been made using a fault current limiter to overcome these problems. A smart superconducting cable is a type of superconducting power transmission cable. It has not only standard structure of the existing superconducting power cable but also a fault current limiter. The cable has a superconducting characteristic in a normal state, while when a fault occurs, it can limit a fault current through generating impedance that adjusts electrical and thermal properties of superconducting cable and material and cross-sectional area of superconducting cable. In this paper, a technique is proposed to reduce system fault current while improving the system stability using a smart high-temperature superconducting cable. In addition, the appropriate cable capacity and locations are selected to improve the reliability of the Korean power systems using smart superconducting cables. The proposed locations and capacities will be applied to the smart superconducting cable development project that started in May.

Keywords: fault current limiter, power system stability, superconducting cable, smart superconducting cable

APP3-5

Study on Configuration of a Single-phase Air-core Bi2223 High Temperature Superconducting Transformer for a Large AC Current Supply

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The authors have developed a large AC current supply with a high temperature superconducting transformer to grasp current conduction characteristics of high temperature superconductors [1] [2]. The supply consists of a primary current supply and a superconducting transformer. Small current flows thorough a primary coil of the transformer from a primary current supply and then large current is outputted from its secondary coil. One of the developed supplies consists of a single-phase Bi2223 air-core superconducting transformer and its volume and weight are respectively about 1/20 and 1/14 of a commercial supply and can output current of 200 A [3]. Moreover, efficiency of the transformer is almost same as that of an iron-core Bi2223 superconducting transformer. However magnetic coupling between a primary coil and secondary one of the air-core transformer is weak and therefore more primary current is needed to output secondary current than that of the iron-core transformer. That means to need a primary current supply with a large capacity. In this presentation, the authors propose configuration of the air-core transformer for stronger magnetic coupling than that of the conventional transformer and show its usefulness through experimental results.

[1] N. Nanato, Y. Kobayashi, Quench Detection and Protection for High Temperature Superconducting Transformers by Using the Active Power Method, Physics Procedia, Vol. 58, pp. 264-267 (2014)
[2] N Nanato, S Nakamura and S Tanaka: Detection of normal transitions in a hybrid single-phase Bi2223 high temperature superconducting transformer by using the active power method and a magnetic flux detection coil, Journal of Physics: Conference Series, Vol. 871, 012085 (2017)
[3] N Nanato, N Kishi, Y Tanaka and M Kondo: Basic study for a large AC current supply with a single phase air-core Bi2223 high temperature superconducting transformer, Journal of Physics: Conference Series, Vol. 871, 012101 (2017)

Keywords: Large AC current supply, Air-core HTS transformer, Magnetic coupling

APP3-6

Design and Performance analysis of a 1,500 A, 400 mH Class Superconducting DC Reactor Coil using 2G Multi-ply HTS wire

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A DC reactor is a power system application device that reduces current ripple and harmonics generated by thyristors during AC-DC conversion. It is usually used in high-voltage direct current systems. Conventional DC reactor has been manufactured using metal conductors. However, there are some disadvantages when using metal conductors. First, a metal conductor has a resistance, which inevitably causes electrical loss. As the current increases, the power loss also increases. In addition, when DC reactors are made using metal conductors, the volume and weight become very large, which limits the installation space and insulation structure. These disadvantages can be overcome by using a superconducting wire that has zero resistance and high current density.

This paper deals with the design and performance analysis of a superconducting DC reactor using multi-ply HTS wire to increase the critical current.

In the fabrication, 2G multi-ply HTS wire (SuNAM Co., Ltd.) is used for high ampacity. The critical current was measured according to the bending radius to confirm the bending characteristics of the two-ply and three-ply wires. The HTS coils for 1,500 A, 400 mH class superconducting DC reactor was designed considering multi-ply HTS wire banding radius. The target is based on the same current capacity and higher inductance as compared with a copper conductor DC reactor used in a conventional HVDC system. Coils were wound with D-shape double pancake type bobin, then 30 DPC coils were arranged in a toroidal form. The performance of the toroidal magnet was measured in a liquid nitrogen vessel. The performance analysis results were compared with the results obtained by the finite element method analysis.

The measured critical current of each coil was about 350 A at a temperature of 77 K according to the design value, and the target performances of 1500 A, 400 mH were achieved.

The results will be effectively utilized for design and fabricate of a superconducting DC reactor that can be used in real power systems.

Keywords: DC reactor, Two ply HTS wire, Bending radius

APP3-7

Design and Demonstration of a Double-Pancake Coil for SMES using MgB_2 multi-strand cable

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MgB_2 round wires are now commercially available with applicable critical current density in magnetic field up to 5 T. One of promising application using MgB2 is Superconducting Magnetic Energy Storage (SMES) coil. In our project, multi-strand cables with 600 A nominal current are designed for double-pancake (DP) coils with 400 mm in inner diameter. The coil production processes in our project are wind-and-react (W&R) and react-and-wind (R&W) method, in which Rutherford type cable consists of ten wires with specific twist pitch is reacted then used to wind DPs, to investigate the suitable manufacturing process for MgB2 coils. The final goal is to fabricate five stacked DP coils, in which four DPs by R&W method and one DP by W&R method with total number of turn is 512, forming 30 kJ SMES coil to demonstrate compensation of DC voltage fluctuation in a micro grid consists of renewable energy source and liquid hydrogen supply system. The first DPs made by two manufacturing process are constructed and tested their property such as critical current density in liquid helium to keep uniform temperature distribution throughout the coils. We will report the results including small test coil results, feasibility study of the manufacturing processes for MgB_2 SMES coil.

Keywords: MgB2, double-pancake coil, SMES, Rutherford cable