APP4-1

Estimation of Machine Parameters in Superconducting Transformer using Differential Evolution

*Tomohiro Yonenaka[1], Tatsuki Muraoka[1], Yuto Ichiki[1], Edmund Soji Otabe[1], Yoshitaka Tokunaga[2]

Kyushu Institute of Technology Japan[1]
Okayama Prefectural University Japan[2]

When a transformer is energized in the power system, an exciting inrush current occurs, which affects the power quality, such as unnecessary operation of the protective relay and malfunction of the control device. In order to grasp and solve these problems, it is necessary to analyze the waveform at the time of occurrence of the inrush current under several conditions. It is believed that the same problem is applied to superconducting transformers. In previous researches, we used Genetic Algorithm (GA) to estimate the machine parameters of superconducting transformers from excited inrush current. In this study, the estimation technique was further developed using Differential Evolution (DE).

As a result of estimation by DE, the calculation time is reduced to 1/10, the evaluation value representing the difference between the estimated value and the measured value is reduced to about half, and the estimation accuracy is improved, compared to GA.

Fig. (1) shows the measured value and the estimated values of the waveform of the excitation inrush current. It can be seen that the estimation result of DE is closer to the measured value.

The influence of differences in parameters was investigated on the DE estimation results. Fig. (2) shows the changes in the evaluation values for various CR and F, where CR is the crossover ratio and F is the scaling factor, respectively. As the CR is larger, crossover takes place actively to search a wide range, so it is easier to find an optimal solution and the evaluation value becomes smaller. As the F is small, the search range is narrow and the evaluation value is large. On the other hand, if it is large, detailed search can not be performed near the optimum solution, and the evaluation value becomes large. As described above, it is important to set parameters such as the CR and the F appropriately for estimation using DE. In this estimation, the CR was 1.0 and the F was 0.6 for best results.

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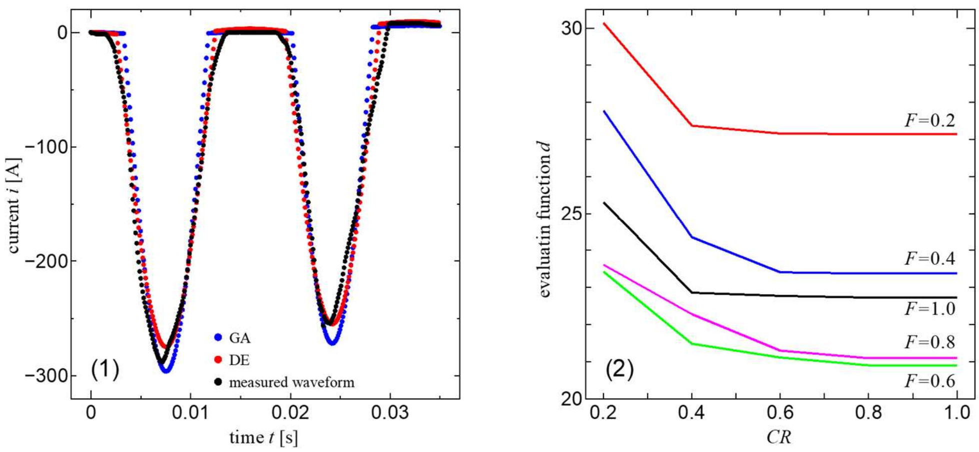

Fig. (1) Inrush current waveform calculated by GA and DE, (2) Values of the d at various CR and F

Keywords: Superconducting Transformer, Machine Parameter, Algorithm, Differential Evolution

APP4-2

Development of a High Temperature Superconducting Transformer for a 1 kA - 1 kHz Class Compact Power Supply

*Takahito Yamanishi[1], Nozomu Nanato[1], Masaya Okamoto[1]

Okayama University(Japan)[1]

Development of a High Temperature Superconducting Transformer for a 1 kA - 1 kHz Class Compact Power Supply

*T. Yamanishi, N. Nanato, M. Okamoto

Okayama University

We have been developing a compact power supply with a single-phase high temperature superconducting (HTS) transformer [1-3]. Our goal is to develop the variable voltage variable frequency power supply with a rated frequency of 1 kHz and rated current of 1 kA. We have achieved 1 kHz-850 A class HTS transformer so far [4]. The transformer had some leakage inductance and therefore the maximum output current was limited to 850 A. In this presentation, we report an HTS transformer with less leakage inductance based on the structural study of the transformer and the 1 kHz-1 kA class power supply. In addition, we will report a protection system for normal transitions in the 1 kHz-1 kA class HTS transformer.

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[2] N Nanato, T Ono, T Adachi and T Yamanishi, Protection System for Normal Transitions in a Single-phase Bi2223 Full Superconducting Transformer by the Active Power Method under Flowing Currents of Various Frequencies, Journal of Physics: Conference Series, Vol. 1054, 012068 (2018)

[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)

[4] T Adachi, N Nanato, T Yamanishi, Development of Single-phase Bi2223 High Temperature Superconducting Transformer with Protection System for High Frequency and Large Current Source, Journal of Physics: Conference Series (in press)

Keywords: HTS transformer, Leakage inductance, Large AC current source, Normal transitions

APP4-3

Basic Study for an Air-core Hybrid Bi2223 High Temperature Superconducting Transformer for a Compact Current Source and its Protection System for Normal Transitions

*Shota Tenkumo[1], Nozomu Nanato[1], Kouki Matsuda[1]

Okayama University. of Japan[1]

A compact current source for supplying large AC current is useful for measuring current transport characteristics of HTS sample tapes. We focus on small weight and volume of a high temperature superconducting (HTS) transformer and have studied and presented the source with an HTS transformer [1-3]. The source outputs large current from its secondary coil by supplying small current to the primary coil. In order to reduce the weight and volume much more, we have been trying to develop an air-core hybrid Bi2223 HTS transformer. The transformer has a primary copper coil, a secondary HTS coil and no iron core [2, 3]. In this presentation, we will firstly report the structure of the transformer and characteristics of the large output current. The hybrid transformer needs a protection system for normal transitions in the secondary HTS coil for safe operation. Secondly, we will propose an appropriate protection system for the hybrid and air-core transformer. This work was supported by JSPS KAKENHI Grant Number 18K04080.

Keywords:　current source,　large AC current, HTS transformer, protection system

APP4-4

Comparison of several types of fault current limiter introduction into frequency converters of Shinkansen

*Takahiro Akahori[1], Yutaka Terao[1], Hiroyuki Ohsaki[1]

The University of Tokyo[1]

The Tokaido Shinkansen travels through both 50 Hz and 60 Hz electric power system regions, and the trains run on 60 Hz. Therefore, the Tokaido Shinkansen has equipped frequency converters to convert electric power from 50 Hz into 60 Hz in eastern area of Japan. There are two types of frequency converters, rotary frequency converters (RFCs) and electronic frequency converters (EFCs). RFCs have mainly been used and, recent years, the replacement from RFCs into EFCs is progressing, due to merits in maintenance. However, the EFCs have no overcurrent (such as fault current) tolerance and this problem has to be solved to replace all the RFCs into the EFCs. One of the solutions is introduction of fault current limiters (FCLs).

There are various types of FCLs, such as resistive type, saturated iron-core type, bridge type and so on, and each of those has different advantages and disadvantages. The FCLs for frequency converters of Tokaido Shinkansen have to reduce fault current less than 2.2 p.u. And this low allowable current brings difficulties for FCLs to protect EFCs. Therefore, there is a need to discuss which type of FCLs is suitable for this severe condition.

In this research, the Shinkansen systems which equipped various types of FCLs for EFCs were analyzed by using Psim. And fault current reduction effect, size, loss, fail safe and recovery time of each FCLs were compared.

The resistive type is smaller in size, lower loss and fail safe. However, it cannot reduce fault current less than the maximum allowable current and its recovery time is long. The bridge type can reduce fault current less than the maximum allowable current and its recovery time is short. However it tends to be bigger, larger loss and lower fail safe.

Keywords: Frequency converter, Fault current limiter, Superconductivity

APP4-5

Electromagnetic and Thermal Coupled Analysis of an SFCL REBCO Coil Immersed in Liquid Nitrogen Considering Boiling Phenomenon

*Kezhen Qian[1], Yutaka Terao[2], Hiroyuki Ohsaki[2]

Graduate School of Engineering, The University of Tokyo, Japan[1]
Graduate School of Frontier Sciences, The University of Tokyo, Japan[2]

A resistive type SFCL using REBCO tapes has shown high potential in limiting fault currents rapidly and improving the power system reliability. Temperature during and after the limiting operation is a key parameter when designing a SFCL, because the superconductor is sensitive to high temperature [1]. A detailed thermal analysis is helpful to study the transient distribution of the temperature. However, it is still a subject to precisely simulate the transient characteristics of coolant, which cannot be neglected and plays an important role in recovering from normal state to superconducting state [2].
In this paper, we have developed a 3D electromagnetic and thermal coupled FEM analysis model to study the transient characteristics of an SFCL REBCO coil immersed in liquid nitrogen. A thin-plate approximation and coordinate transformation (from cylindrical coordinate system to orthogonal coordinate system) is utilized to conduct the electromagnetic analysis of REBCO coils in 2D calculation space which have 3D structures. The governing electromagnetic equation is given by $\nabla\times(\rho\nabla\times\boldsymbol{T})=-\partial\boldsymbol{B}/dt$ ($\boldsymbol{T}$: current vector potential; ρ: electric resistivity; $\boldsymbol{B}$: magnetic flux density), where $\boldsymbol{T}$ is defined by $\boldsymbol{J}=\nabla\times\boldsymbol{T}$ ($\boldsymbol{J}$: current density). In thermal analysis, the 3D structure of REBCO 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. Moreover, the boiling phenomenon of nitrogen and hysteresis in the heat transfer coefficient are approximately modeled in this work. With this analysis model, we studied the transient temperature distribution and recovery of REBCO coils with the cooling of liquid nitrogen that considers the influence of boiling hysteresis phenomenon.

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Keywords: superconducting fault current limiter, finite element method, coated conductor, electromagnetic and thermal analysis

APP4-6

An Approach to Development of the HTS Magnet for SMES at JINR

Hamlet Khodzhibagiyan[1], Valeriy Drobin[1], Gennadiy Dorofeev[1], Victor Karpinskiy[1], Alexandr Shurygin[1], *Mikhail Novikov[1], Dmitriy Kashaev[1], Maxim Zaslavskiy[1], George Kachlishvili[1]

Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna, Moscow Region, Russia[1]

Particle accelerator complex NICA comprises Booster and Nuclotron accelerators which dipole magnets operate at pulse mode in opposite phase with a period of about 4 seconds. Summary energy of Booster and Nuclotron dipoles will vary from 1 to 2.6 MJ during the period. NICA power supply system can be significantly improved by Superconducting Magnetic Energy Storage (SMES) application that will help to move the energy back and force between Booster and Nuclotron. The useful energy at this SMES must be about 1.6 MJ so the maximum total SMES energy should be 3-5 MJ. SMES with this energy should have several Tesla magnetic fields to keep a reasonable size. SMES operating current can be not less than Booster and Nuclotron dipoles currents so it might be 10-12 kA. It is better to make such a SMES magnet from an HTS cable for the sake of stability at 6-7 T 4 s pulse mode. SMES magnet is planned to be wound as a short solenoid (Brooks coil) of cables optimized for several coaxial sections. HTS cables with a helical structure similar to well-known CORC cables are under the development at JINR. The HTS cabling technology is based on the same principle as nuclotron type cable manufacturing technology. HTS tapes, cables and magnets experimental study and testing methods are being developed on the base of the existing test facility at LHEP. JINR is also going to develop high field fast cycling dipole magnets for accelerators of HTS cables of the same type.

Keywords: supeconducting magnetic energy storage, high temperature superconductor, superconducting cable, fast cycling magnets

APP4-7

Theoretical and experimental investigation of R&W and W&R SMES coils wound with large-scale MgB2 Rutherford cables operated around liquid hydrogen temperature

*Moeto Hira[1], Tsuyoshi Yagai[1], Tomoaki Takao[1], Naoki Hirano[2], Takakazu Shintomi[6], Yasuhiro Makida[6], Toshihiro Komagome[3], Taiki Onji[4], Atsushi Ishihara[4], Masaru Tomita[4], Makoto Tsuda[5], Takataro Hamajima[5]

Science and Applied Technology, Sophia University, Tokyo, Japan[1]
NIFS, Toki, Japan[2]
Mayekawa MFG, Moriya, Japan[3]
Railway Technical Research Institute, Kunitachi, Japan[4]
Tohoku University, Sendai, Japan[5]
KEK, Tsukuba, Japan[6]

We have been developed the system called Advanced Superconducting Power Conditioning System (ASPCS) composed of Superconducting Magnetic Energy Storage (SMES), fuel cell and water electrolyzer for effective use of renewable energy such as wind and solar power generation. The SMES coils are wound with superconducting cables with large current capacities of kiloamperes (kA). We have been investigating about the SMES coil using large-scale Rutherford-type conductors made of commercially-available MgB_2 wires. The MgB_2 wires has critical temperature above boiling temperature of hydrogen, showing enough critical current (I_C) for practical application in self field of energy storage devices. Due to strain sensitivity even before heat treatment for MgB_2 production, the design for large-scale Rutherford cables both in wind and react (W&R), react and wind (R&W) method applied to coil fabrication has to be done cautiously to prevent the degradation of the I_C by optimizing design parameters such as twist pitch and cable compaction. Especially for the R&W method using heat-treated wires, other factors like handling during coil production process which might affect the conductor and coil I_C should be also considered. To evaluate the applied strains during manufacturing process, we conducted theoretical investigation on strains applied to individual filaments caused by wire-bending. We developed a test coil designed for R&W method based on analyzing those factors and the result of experiment. Furthermore, we have measured the coil I_C-B-T characteristic, which will be compared to those of other test coil made with W&R method.

Keywords: MgB2, SMES, Rutherford cable, Ic-B-T characteristic

APP4-8

Heat leak measurement of the cryogenic pipe for the superconducting power transmission at different surface temperatures

*Hirofumi Watanabe[1], Toru Takeuchi[1], Katsuya Miyake[1], Satarou Yamaguchi[1]

Chubu University[1]

Heat leak of the cryogenic pipe constituting a transmission line of the superconducting power transmission is one of the key characteristics, because it affects the efficiency of the transmission strongly. Since the heat leak is mainly caused by the radiative and conductive heat transfers, it depends on the surface temperature of the cryogenic pipe, which can vary with the changes of atmospheric temperature, weather, and direct sunlight hours. Thus, the heat leak can depend on the environmental conditions, where the transmission lines are installed.

We have measured the heat leak of the cryogenic pipes for the superconducting power transmission in the wide range of their surface temperatures to investigate the effect of the temperature variation and to obtain data for the installations of cables in different places with different environmental conditions. The cryogenic pipe used for the measurement was a 12 m long test pipe, which was the same type of the cryogenic pipe used in the Ishikari project [1]. This cryogenic pipe contains two inner pipes within an outer pipe. One of two inner pipes is for the installation of the cable and another is used to return the liquid nitrogen for circulation. The measurement was performed with the boil-off method. The obtained data was compared with the results obtained during the cooling tests of the actual transmission lines in the Ishikari project [2,3,4]. The heat leak characteristics of the cryogenic pipe will be discussed based on the results.

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Keywords: Heat leak, Cryogenic pipe, Superconducting power transmission