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NUMERICAL MODELING OF HIGH TEMPERATURE SUPERCONDUCTING APPLICATIONS

PhD Thesis

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BUDAPEST, 2011

1. Introduction

Nowadays the use of numerical computational methods is essential. The analytical calculation methods are not accurate enough for the study of applications that include many geometrical varieties, material nonlinearities and transient processes. Numerical simulations are suitable for simultaneous handling of these phenomenons.

The commercial simulation softwares have no or very limited ability to model superconducting materials. On the basis of all this there are two possibilities for the simulation of superconducting applications: first we can use commercial software that is suited for outer programming that has the advantage that most difficulties of the numerical methods are solved by the software developers. The other possibility is to develop a totally self made program. In this case we have to solve all the problems appear during the development of the code, however we can change any part of the code, so modelling possibilities have less limits. I programmed self made code for each developed modelling methods.

The main object of my work was to develop modelling methods for helping the design process of electrotechnical applications; superconducting magnetic bearings, superconducting fault current limiters and self limiting transformers that contain superconducting materials and parts. The two types of applications (bearings, fault current limiters) need different calculations and analysis, so I strongly separate them in my thesis.

For the analysis of inductive type HTS fault current limiters and self limiting transformers complex multiphysical transient simulations have to be made in consequence of the special behaviour and the usage near the limits of the superconducting material. Both electromagnetic and thermal phenomenons have to be considered. Coupled finite element modelling technique was used implemented in self made code. The model contains 2D magnetic finite elements directly coupled with electric network and sequentially coupled 3D thermal finite elements.

In case of the levitated HTS magnetic bearings the simulations were confined to the levitation forces and the stiffness. For the calculation of these quantities special static magnetic simulation techniques were developed. I developed a self made model based on real physical phenomenons that can be mapped with the known critical state model. The model was implemented using the finite difference method.

My work was strongly connected to the research of experimental superconducting applications at the Department of Electric Power Engineering of BUTE. In each case there were possibilities to compare simulation and test results.

2. Motivation

In the elementary school I was very interested in programming and physics (mainly the electric network calculations). During the high school I improved my knowledge of programming, I made many programs for my entertainment. It became clear that I would like to be an electric engineer. During the university I joined the researches of high temperature superconducting applications at the Department of Electric Power Engineering. As I was very interested in electromagnetic theory, my first task was a software development for the simulation of HTS magnetic bearings. I finished my studies in Electric Machines and Drives Faculty, besides numeric simulation of HTS applications, I also absorbed in rotating machine design. I also started designing of electric drives and power electronics. I made three papers for Scientific Students' Association conference. After graduation I was a PhD student for three years at the Department of Electric Power Engineering. During that period I proceeded with the researching of numerical modelling of HTS applications. I also took part in a professional design companies (Hyundai Technologies Centre Hungary) work where I made design and analysis of rotating machines. After finishing the PhD course I started full time working at this company. With some of my friends, we founded an association called EV-SPORT. We are dealing with building of electric racing cars in our free time. In the association my tasks were design and development of electric rotating machines, drives and power electronics.
For me the researches, developments, designs and constructions in connection with electrical engineering sciences are not only work, but also hobby, game and pleasure.

3. Method of research

The numerical modelling of high temperature superconducting materials and applications is a significant area of the research of numerical calculations. For the implementation and verification of each calculation methods and models that were developed by me I developed self made numerical codes. Theoretical models and procedures can only be developed efficiently if someone has high level knowledge about theoretical and practical electromagnetic and computational problems. The development of numerical softwares is a very complex task by itself, in many cases very hard problems have to be solved that are not available in details from the literatures. The results of the developed modules (magnetic, network, thermal) were compared with commercial softwares' results with various geometries and arrangements. Of course the final calculations including the self developed HTS models were not compared as they are not available in commercial products. My thesis is strongly in connection with the research of experimental HTS applications (HTS bearings, HTS inductive type fault current limiters), so there were possibilities in each case to compare simulation and test results. The expectations and requirements for simulation methods were formulated based on the design and development problems and test experiences.

4. Using the results

My research results belong to applications that are also in the research state, the use of the results in the industry is not available now. However the improvement and further research of the models and simulation techniques that were developed by me are possible.

5. Summary of new scientific results

- I created a new numerical modelling method that is suitable for transient coupled finite element modelling of HTS rings, the model include 2D magnet finite elements, 3D thermal finite elements and electric network. I implemented the nonlinearity of HTS based on its E-J characteristic into the numeric simulation that was solved by the method called Newton-Raphson procedure. In the simulations I also considered the nonlinearity of the iron core. I created two methods for the simultaneous solution of the coupled magneto-electro-thermal equation system. [1], [12], [13].

- I simulated the behaviour of HTS fault current limiters and self limiting transformers with the developed modelling technique. With the simulation results I showed the effects of temperature rise on the superconducting-normal state transition that determines the characteristics of the applications, especially the on the processes of current limitation. I validated my calculations by comparing them to test results that proved both quality and accuracy. [1], [12], [13].

- I made a physical material model and its mathematical derivation referring to the critical state of superconductors that is suitable for magnetic field calculation with both FC and ZFC cooling methods, furthermore it is able to handle the flux distribution change and the specific hysteretic behaviour in case of slow motions. The model is well suited to the finite difference method. The model was implemented into 2D and 3D finite difference formulations. The connection between my model and the known critical state method was proved. [9], [10], [11].

6. Publications

[1] Tihanyi V, Vajda I, Györe A „Multiphysical finite element modeling of inductive type fault current limiters and self limiting transformers"IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY 19:(3) pp. 1922-1925. (2009)

[2] Viktor Tihanyi,István Vajda (szerk.), XVI. Technical Report for E.ON Nordic: „Modeling of fault current limiters with FEM"BME VET(2007)

[3] Gyore A, Semperger S, Tihanyi V, Vajda I, Gonal MR, Muthe KP, Kashyap SC, Pandya DK, „Experimental Analysis of Different Type HTS Rings in Fault Current Limiter.", IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY 17:(2) pp. 1899-1902. (2007)

[4] Viktor Tihanyi, István Vajda (szerk.), XV. Technical Report for E.ON Nordic: „Modeling of fault current limiters.", BME VET(2006)

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[6] Tihanyi Viktor, Vajda István (szerk.), Új technikák alkalmazása kis-és középfeszültségű hálózatok zárlati áramának korlátozásában: „Szupravezetős induktív típusú zárlati áramkorlátozó 2D modellezése" Kutatási jelentés, EON-Északdunántúli Áramszolgáltató Zrt. , BME VET (2006)

[7] Tihanyi Viktor,Vajda István (szerk.), Új technikák alkalmazása kis-és középfeszültségű hálózatok zárlati áramának korlátozásában: „Szupravezető anyagok és tulajdonságaik", Kutatási jelentés, EON-Északdunántúli Áramszolgáltató Zrt, BME VET (2005)

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szupravezetős induktív típusú zárlati áramkorlátozó elméleti modellezése", Kutatási jelentés, EON-Északdunántúli Áramszolgáltató Zrt. , BME VET (2005)

[9] Kohari Z, Tihanyi V, Vajda I, „Loss Evaluation and Simulation of Superconducting Magnetic Bearings", IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY 15:(2) pp. 2328-2331. (2005)

[10] Viktor Tihanyi, István Vajda (szerk.), XII. Technical Report for SYDKRAFT AB R&D DEPARTMENT: „Modeling superconducting bearings with finite difference method", BME VET, (2004)

[11] Viktor Tihanyi, István Vajda (szerk.), X. Technical Report for SYDKRAFT AB R&D DEPARTMENT: „Magnetic field simulation of superconducting bearings in 3D", BME VET, (2003)

[12] Tihanyi Viktor, Vajda István (szerk.), SZUPRAVEZETŐS ZÁRLATI ÁRAMKORLÁTOZÓ FEJLESZTÉSE: „Szupravezetős induktív típusú zárlati áramkorlátozó multifizikális véges elemes modellezése" Kutatási jelentés, EON-Hungária Zrt. , BME VET (2008)

[13] Tihanyi Viktor, Vajda István (szerk.), SZUPRAVEZETŐS ZÁRLATI ÁRAMKORLÁTOZÓ FEJLESZTÉSE ÉS NAGYFORDULATSZÁMÚ, ÁLLANDÓMÁGNESES MIKRO-TURBINA GENERÁTOR FEJLESZTÉSE: „magashőmérsékletű szupravezető huzallal ellátott induktív zárlatiáram-korlátozós szimulációs programjának fejlesztése" Kutatási jelentés, EON-Hungária Zrt. , BME VET (2010)

Important presentations

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[3] Tihanyi Viktor, Erősáram a fiatalok szemével: „Magashőmérsékletű szupravezetős zárlati áramkorlátozók és önkorlátozó transzformátorok csatolt véges elemes modellezése”, Szóbeli előadás, BME, 2010.04.07