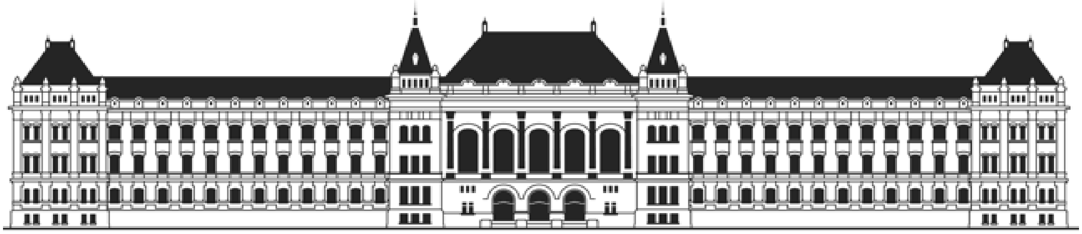

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ANALYSIS, DESIGN AND IMPLEMENTATION OF SUPERCONDUCTING INDUCTIVE TYPE FAULT CURRENT LIMITER AND SELF-LIMITING TRANSFORMER WITH DIVIDED SECONDARY COILS

Doctoral Dissertation Theses

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1. Introduction and objectives

Nowadays the growing energy demands are associated with the increasing electrical power of the electric transmission networks. This growing energy requires the expansion and the increasing of the reliability in the electric network. The increasing of the transferred power can barrier to physical and economic limits, and therefore may require the use of other new solutions.

Primary tasks are to increase the transmitted power on the cross-section of the wire, to increase the reliability of the transmitted power, the reduction of peak fault currents. An adequate alternative may be the application of superconducting technology: the superconducting cable to increase the power, fault current limiters to reduce the fault currents. The reducing of the fault current is priority to increase the lifetime of the circuit breakers [k1]

In the dissertation I deal with the inductive type high temperature superconducting (HTS) fault current limiter (FCL) and its improved versions: self-limiting transformer with divided and undivided secondary coils.

Important requirement for the current limiters are that: in case of normal operation mode the device is invisible and in case of fault the device can reduce the fault current.

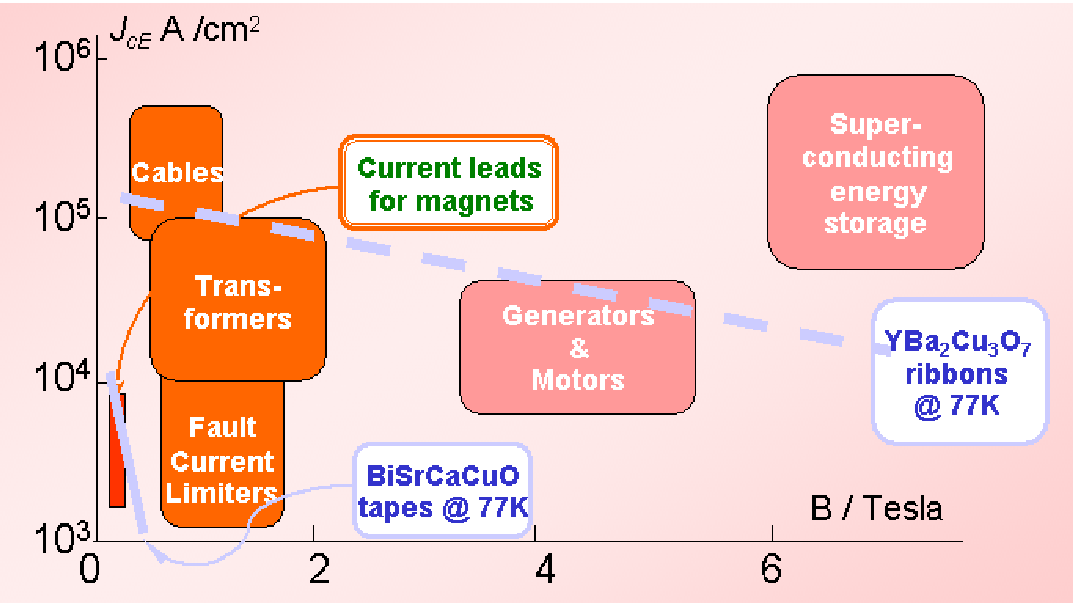

Fig. 1. Windows of the applications of the superconducting electrical devices [a1]

Fig. 1. shows the places of the superconducting fault current limiters and the transformers on the windows of the applications. As it shown that they are in the place with lower magnetic field because they use ironcore and they do not need elements with high current density. On the y axes the engineer critical current is shown.

In spite of the simplicity of the operation principle of the superconducting fault current limiter and the self-limiting transformer, the they are a very complex systems, so the design and the analysis of them need various knowledge of engineering and physics.

The most important of them:

- low temperature technique,
- physics of the superconductors (critical currents),
- thermal parameters of the superconductors,
- theory of the magnetic circuit,
- theory and design of the transformers.

Detailed examination of each region is not be the subject of my dissertation, just the necessary connections, theories of the above fields are mentioned.

2. Motivation

As a child I got close to the field of electricity I could know many things with my father, so I graduated electrical secondary school. Due to my good results I studied on the Budapest University of Technology. I knew that I wanted to deal with the power engineering, so I chose to my specialty the field of the electric power systems. Later I changed my field to the superconductors. I started to exam a superconducting synchronous machine, and I wrote my diploma on this machine. During my work I was a member of group. In this group we organized seminars and summer schools. with these background I had more help than if I read the books alone.

To the field of my Ph.D work I chose the field of the flywheel energy storage. I had handled this field, but it was not suit for me. After one year I had a chance to change my field to the fault current limiter.

With the good connections of the superconducting group, I had an opportunity to disseminate my knowledge to the public. So I could show my model of the fault current limiter on the exhibition of B001 in Malmö, Sweden, later this model was exhibit in the main hall of electric supply company of South Sweden. I would like to thank for the technical, moral and financial support to Lars Sjunnerson and György Sárosi and the earlier Sydkraft company, now E.ON-Nordic. I could create a fault current limiter for demonstration to the exhibiton of Superlife, which was exhibit in the more important superconducting center in Europe: Jena, Barcelona, Caen and Oxford. I made fault current limiter unit for New Delhi Technical University (IIT Delhi) which is included to the education.

3. The research methodology, overview of the work

The unknown phenomena can be approached from many sides. It may to meet any subsequent phenomenon and try to understand it, but we may to pre-thought out, and check what we would expect. I usually used a combination of both: I experienced some kind of phenomenon: I tried to explain, justify and explain the new experiments and measurements. Of course, the explanation was also involved in production of the planning process, and I did so many times.

The beginning of my research I got to know the fault current limiter, I saw the first models of it. I carried out many measurements on a practical model, and it was the base of our next generation device.

On this model I achieved the limit of the power increasing, because the size of the ybco ring limits it. So I started to exam the possibility of the power increasing: fault current limiter with two or three rings; series, parallel and matrix connections of the units; using of the superconducting tape. With the using of superconducting tape, we have not got any limit to increase the power of the FCL unit; we are able to upscale the device.

After the first successful test I increased the power, at this moment we are over the test of a 15 kVA unit. I do not give the details of this test; it is the paper of [1] and [2].

Parallel with my research of the current limiters I made a self-limiting transformer, which combine the functions of current limiting and transformer. First I had some idea for the construction, and then I made a FEM simulation on order to filter out the good construction. I have built up the good version and I tested the device with one or more rings.

Based on the construction of the inductive type fault current limiter, with one additional coil the device can improved to self-limiting transformer. I call this device as self-limiting transformer with undivided secondary coil, because on the secondary side has one secondary coil. I had examined various construction of the device, with one or more rings.

With the link of a project founded by EC I got acquainted with a self-limiting transformer with divided secondary coils. This device not only has the function of current limiting and transformer but it is an inductive terminal. The inductive terminal can connect the room temperature device with the low temperature device. Based on the title of the project this unit can call Slimformer.

After the construction of the small scale device I have investigated the variants of the construction in order to choose the optimal construction. Based on my investigation I created a calculating process to get the main design of these type self-limiting transformer. Meanwhile another member of the project created the mean data of a 20 kVA device, which was existed. The primary and the secondary coils of this device are made of copper. I have carried out quite large number of measurements on this pre-prototype device and I have created a test protocol for it. The creation of the test protocol is based on theoretical investigation in order to get the most relevant results. I got information about the steady state (transformer) activation current or activation current during suddenly short circuit.

With the results and experience of the pre-prototype device I have developed my calculating process for the main design of a self-limiting transformer, such as I have added that superconducting ring electrically opens with 50% during the fault.

The next stage is the 100 kVA pilot plant device which contains secondary side with superconductors. After the drawing of the main design and the making of the elements, I have assembled the device in the lab of department. I have carried out a lot of measurements based on the test protocol, and the device is able to operate as a transformer and current limiter.

During my work my aim was always to build up the device and to verify the theory with the measurements.

Great results for me are that I can show operating devices, that all of which carry a new target for development and implementation.

4. Summary of the new results

<u>1. thesis group, based on the examination of the small scale device</u>

1. *I have stated interaction of the series and parallel connected fault current limiter devices and th eset of the activation current of them. [3].*

2. *I have stated that based on the comparative tests of the fault current limiter with the same geometry of the ybco and bscco rings, the activation and recovery times of the fault current limiter with ybco ring are half than the time in case of the device with bscco ring [4].*

3. *I have stated that the small size ybco and bscco-2212 rings are in resistive mode in the transient mode of the fault current limiter, more than 5 periods without the damage of the rings. I have verified this with the measurements on several rings (ybco, < ø 60 mm and bscco-2212 < ø 100) [5].*

4. *I have verified the operation of the 1 kVA self-limiting transformer with divided secondary coils according to the theory. I have realized various constructions and I have chosen the optimal construction [6].*

<u>2. thesis group, based on the theoretical examination of the devices</u>

1. *I gave the explanation of the operation of th esel-limitng transformer based ont he magnetic and thermal diffusion of the superconductor ring [8].*

2. *I have showed that static and dynamic activation current of the dia 200 mm BSCCO-2212 stabilized superconductor ring are as a function of homogeneity of the ring, magnetic and thermal diffusion, the ramp of the current; and the currents are significantly different [8].*

3. *I have stated that the dia 200 mm BSCCO-2212 superconductor ring with no stabilization is not able to electrically open (be in normal mode) during 5 periods without damage [7, 8, 16].*

4. *I have defined the detection process of the AC static activation (quench) current of the superconductor ring with mechanical and thermal stabilization. I have verified it with the measurements of the dia 200 mm BSCCO-2212 superconductor rings [7, 8].*

<u>3. thesis group, based on the experimental investigation of the self-limiting transformer with divided secondary coils</u>

1. *I have verified that the superconductor ring with mechanical and thermal stabilization is able to activate within half period in the self-limiting transformer with divided secondary coils and to limit the current in case of fault with not more than 5 periods. I have verified them with experimental investigation with more superconductor rings (ø 100 mm, ø 200 mm) [7, 8, 16].*

2. *I have verified that the superconductor ring with mechanical and thermal stabilization is able to operate in steady state of the self-limiting transformer with*

divided secondary coils. I have verified it with experimental investigation with more superconductor rings (ø 100 mm, ø 200 mm [7, 8, 16].

3. *I have stated that in case of the deep limitation of the self-limiting transformer the superconductor ring is not able to recovery after the fault [8, 16].*

4. *I have verified that in case of the design of the self-limiting transformer the lowest magnetization current should be set. [8, 16].*

4. thesis group, based on the main design of the self-limiting transformer with divided secondary coils

1. *I have created a calculation process to determine the main design of the self-limiting transformer with divided secondary coils, which contains the specialty of the construction and the superconductor [8].*
2. *I have verified that in case of the design the result of the characteristics on AC of the superconducting coil should be use instead of the DC [8].*
3. *I have verified with experiments that the rule of the superconductor ring electrically opens with 50% is correct in case of design conception of 100 kVA power self-limiting transformer [8].*

5. My relevant publications

[1] Györe A., Vajda I. Szupravezetős zárlatiáram-korlátozók fejlesztése, Kutatási jelentés, EON-Északdunántúli Áramszolgáltató Zrt., BME VET, 2009

[2] Györe A., Vajda I. Megújuló energiaforrásokat hasznosító szupravezetős mikroerőmű koncepcionális terve és egyes komponenseinek fejlesztése, Kutatási jelentés, EON-Északdunántúli Áramszolgáltató Zrt., BME VET, 2010

[3] Gyore A, Vajda I, Meerovich V, Sokolovsky V, „Experimental determination of optimal construction of current limiting transformers using HTS tapes and rings", IEEE Transactions on Applied Superconductivity Vol 19:(3) pp. 1976-1980. Paper 5109534. (2009)

[4] A. Gyore, S Semperger, I Vajda et al, "Experimental analysis of different type HTS rings in Fault Current Limiter", IEEE Transactions on Applied Superconductivity, Vol. 17. No. 2, June 2007 pp. 1899-1902

[5] A Gyore, I Vajda, Technical Report D.1.2 Review of theoretical and experimental results, BME VET 2007

[6] A. Gyore, S Semperger, I Vajda et al, "Investigation of High Temperature Superconducting Self-limiting Transformer with YBCO cylinder", IEEE Transactions on Applied Superconductivity, Vol. 17. No. 2, June 2007 pp. 1887-90

[7] Györe Attila Szupravezetős zárlatiáram-korlátozók és szupravezetős önkorlátozó transzformátor tesztelése a felhasznált szupravezető gyűrű szempontjából. Elektrotechnika 101:(9) pp. 11-14. (2008)

[8] I. Vajda, A. Hyde, A. Gyore, G. Nador, T. Trollier, B. Sailer, R. Bohm, „Slimformer - Self-Limiting Transformer Pre-prototype and Pilot Plant Design, Construction and Tests", IEEE Transactions on Applied Superconductivity, 2011, megjelenés alatt

[9] I. Vajda, A. Györe, T. Porjesz, V. Sokolovsky, V. Meerovich, Duration Tests of an Experimental High Temperature Superconducting Fault Current Limiter, International Journal of Applied Electromagnetics and Mechanics, Vol. 14., Numbers 1-4/2001/2002, pp 121-126I.

[10] I. Vajda, A. Gyore, A. Szalay, V. Sokolovsky, W. Gawalek, „ Improved Design and System Approach of a Three Phase Inductive HTS Fault Current Limiter for a 12 kVA Synchronous Generator", IEEE Transactions on Applied Superconductivity, Vol. 13. No. 2, June 2003 pp. 2000-

[11] A. Gyore, L. Farkas, I. Vajda, V. Sokolovsky and W. Gawalek, Topologies of Inductive HTS Fault Current Limiters, Proc. 6th European Conference on Applied Superconductivity, Institute of Physics, Conference series No. 181, A. Andreone, G. P. Pepe, R. Cristiano and G. Masullo (eds), pp. 827-32 (2004)

[12] A. Gyore, S. Semperger, L. Farkas, I. Vajda, "Improvement of Functionality and Reliability by Inductive HTS Fault Current Limiter Units", IEEE Transactions on Applied Superconductivity, IEEE Transactions on Applied Superconductivity, Vol. 15. No. 2, June 2005 pp. 2086-2089

[13] A. Gyore, L. Farkas, I. Vajda, "Series and Parallel Connections of Inductive HTS Fault Current Limiters", Superconductor Science and Technology, 18 No 2 S82-S85 (2005)

[14] A. Gyore, G. Péter, I. Vajda, System investigation of High Temperature Superconducting Self-Limiting Transformer, 7th European Conference on Applied Superconductivity, Institute of Physics, Conference series Vol 43, 2006 pp966-970

[15] A Baker, A Hyde, I Vajda, A Gyore et al, „A Novel Device Protecting a Superconducting Cable anf its Connection to a Conventional Distribution Network", CIRED 19 th International Conference on Electrricity Distribution, pp 1-4, Vienna, 21-24 May 2007

[16] I Vajda, A Györe, Self-Limiting Transformer Pre-prototype and Pilot Plant Design, Construction and Tests, Final Report, Project no.518310, Kutatási jelentés, BME VET, 2010

Important oral presentations

[1] Györe Attila, „Szupravezetős zárlatiáram-korlátozó elmélete és kísérleti megvalósítása, előadás az MTA Elektrotechnikai Bizottság ülésén, 2008.05.27
[2] Györe Attila, „Szupravezetős önkorlátozó transzformátor tervezése", Fiatal oktatók fóruma, BME VIK rendezvény, 2010. 04. 07.
[3] Györe Attila, Szupravezetős Önkorlátozó Transzformátor, MEE Szakmai Nap, 2008. 04. 09.
[4] Attila Györe, „On the Way Towards an All Superconducting Mini Power Plant", CIGRE előadás, 2009. 09. 22.
[5] Attila Györe, „Matrix arrangement of Inductive Type Fault Current Limiters", Workshop on Superconducting FCLs, RWE Limiter Symposium , Siegen, 2004. 06. 29.

6. Outside publication

[k1] Dán András, Vajda István: Új technikák alkalmazása kis- és középfeszültségű hálózatok zárlati áramának korlátozásban, Kutatási jelentés, EON-Északdunántúli Áramszolgáltató Zrt., BME VET, 2005

7. Figure

a1 „K. Salama, lectrure notes at ASSE'2003