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SIMULATION OF SUPERCONDUCTING FAULT CURRENT LIMITER BEHAVIOUR IN MATLAB/FEMLAB/SIMULINK ENVIRONMENT

In this paper 3-dimensional, nonlinear model of thermal and electrical processes in resistive superconducting fault current limiter is presented. Implementation of the model was developed with Matlab/Femlab/Simulink environment, that allows to integrate the model to existing CAD system build with Matlab/Simulink.

Keywords – superconducting fault current limiter, thermo-electrical processes, simulation analysis.

1. Introduction

Increases in the installed capacity and the interconnection of the transmission networks lead to possibility of fault currents. Fault currents results from various kinds of high voltage stresses caused by lighting and short circuits or other system disturbances, which send a surge power through the grid.

One of the usages of superconductors is protecting electronic devices and systems from short circuit [1]. There are three types of superconductors fault current limiters (SFCL): resistive, inductive and hybrid. Protection of scheme from current overload by resistive SFCL is based on nonlinear current-voltage characteristic of the superconductor. When current density exceeds some critical value, superconductor come to normal state and its electrical resistance rapidly increases.

In order to design SFCL for practical applications, knowledge of SFCL parameters such as maximum load, response time and thermal recovery time is essential [2]. On the other hand, the electromagnetic and thermal response of a SFCL to a fault involves very high voltages and currents at very short times, and therefore there is a formidable challenge for experiments. Computer simulations are obviously helpful, since they allow to research on arbitrary time scales and power levels. Modelling and analysis of superconducting fault current limiter include simulation of thermo- and electrical behaviour. Thermal properties deal with resistive heating caused by current losses, increasing resistance etc. Electrical conductivity nonlinearly depends on temperature and current density. Thus, simulation of SFCL is complicated due to interdependence of thermal and electrical properties, and nonlinear dependence of electrical characteristics from temperature and current density. Many models of superconductor fault current limiter were implemented and evaluated [3, 4, 5]. But there are still unsolved problem of integration these models to existing CAD systems.

In this paper we present a simulation of the resistive SFCL behaviour with Matlab/Femlab/Simulink environment. Mathematical model built in Femlab can be easily integrated with existing designing systems built with Matlab/Simulink.

2. Mathematical model of thermal and electrical processes of resistive SFCL

Schematic representation of SFCL construction is shown in Fig 1. The superconductor current fault limiter as high-temperature thin film YBCO on a sapphire substrate is connected with scheme by gold nanocontacts. Superconductor element YBCO is cooled by liquid nitrogen to keep the temperature level below the critical.

Electrical processes in superconductor are defined by equations:

$$div(\sigma(i,T)gradV)=0\,,\ E=gradV\,,\ \sigma(i,T)\cdot E=i\,, \qquad (1)$$

where i is current density, $\sigma(i,T)$ is electric conductance, V is electric potential, E is electric intensity.

At insulated surfaces the electric intensity will be equal zero $E = 0$. Difference of electric potential for boundary condition of contacts surfaces will depends on voltage drop on SFCL $\Delta V = U_{sfcl}$.

Thermal processes in superconductor are governed by nonlinear equation:

$$c(T)\rho\frac{\partial T}{\partial t} = div(\lambda(T)gradT) + \sigma(i,T)E^2, \quad (2)$$

where $c(T)$ is superconductor thermal capacity, $\lambda(T)$ is superconductor thermal conductance, ρ is density of superconducting material, i is current density. Electrical conductivity of superconductor can be given as:

$$\sigma(i,T) = \begin{cases} \sigma_s, & \left(i < i_c(T)\right) \\ \dfrac{\sigma_n}{1+\alpha_\rho(T-T_c)}, & \left(i > i_c(T)\right) \end{cases} \qquad (3)$$

where σ_s is electrical conductivity of superconductor in superconducting state, σ_n is electrical conductivity of superconductor in normal state, T_c is critical temperature of superconductor, α_ρ is coefficient that defines change of electrical resistance with heating, $i_c(T)$ is critical current of superconductor, that can be approximated by function:

$$i_c(T) = \begin{cases} i_c(T_0)\dfrac{T_c - T}{T_c - T_0}, & T < T_c; \\ 0, & T > T_c. \end{cases} \qquad (4)$$

where T_0 is temperature of liquid nitrogen. For substrate thermal equation can be given as:

$$c_s\rho_s\frac{\partial T}{\partial t} = \lambda_s\nabla T, \qquad (5)$$

where c_s is thermal capacity, λ_s is thermal conductance, ρ_s is density of substrate.

At surfaces that touches liquid nitrogen, we assume next boundary condition: $\beta(T)\times(T-T_0) = \dfrac{\partial T}{\partial n}$, where $\beta(T)$ is coefficient of cooling of liquid nitrogen, that depends on temperature, $\dfrac{\partial T}{\partial n}$ is normal derivative to the surface of the temperature. At surface substrate-superconductor thermal flows are equals: $\lambda(T)grad(T) = \lambda_s grad(T)$.

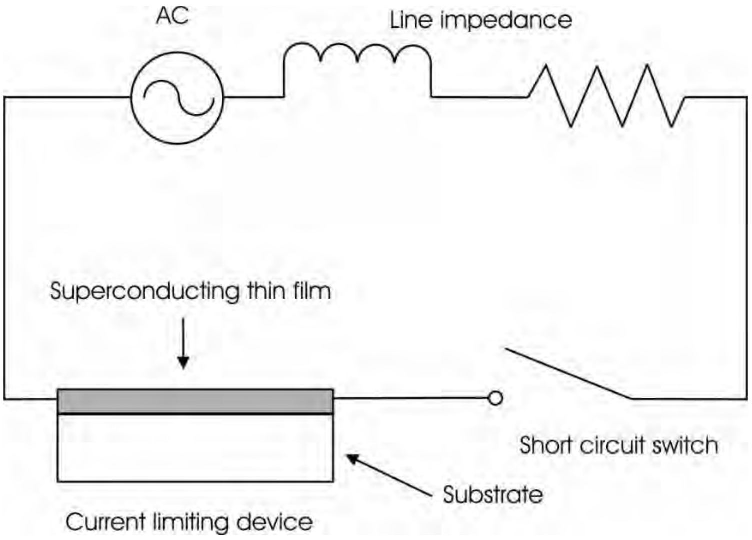

Fig. 1 Scheme with resistive SFCL element.

3. Simulation of SFCL with Matlab/Femlab/Simulink

Two geometries should be created in FEMLAB environment: substrate and superconductor thin film. Thermal and electrical processes in superconductor are interdependent, so thermo-electric coupling should be applied to the FEMLAB model. The thermo-electric coupling is two-way: volume currents inside the superconductor, which are proportional to the conductivity, act as a distributed heat source, while at the same time the temperature affects the superconductor's electrical conductivity. These kinds of dependencies make it necessary to create a multiphysics model in FEMLAB.

Properties of the scheme and fault current were defined in Simulink. Dynamic analysis of model is allowed by export FEMLAB electro-thermal model to Simulink. Schematic realization of MATLAB/FEMLAB/Simulink is shown on Fig.2.

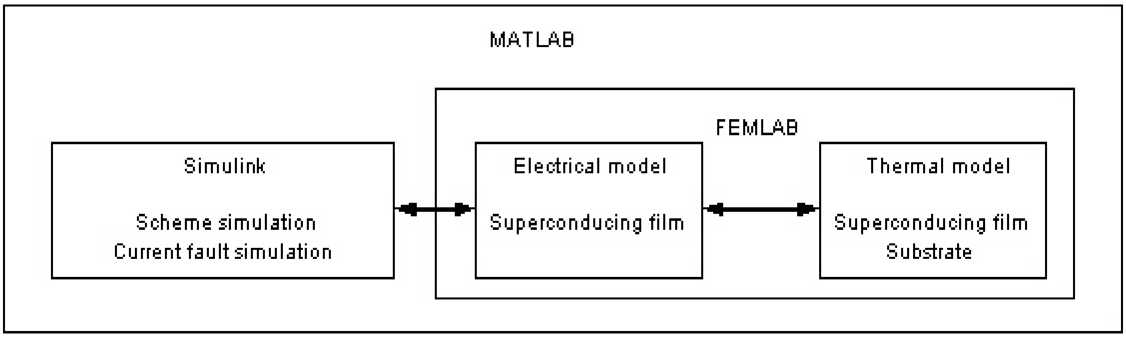

Fig. 2 Schematic realization of SFCL behaviour with MATLAB/FEMLAB/Simulink environment.

As test sample, next parameters were taken for simulation: substrate of material MgO, superconductor film material - YBCO, cryogen cooler – liquid nitrogen. Parameters of scheme: resistance of scheme in normal state – 0.1 Ohm, voltage in normal regime – 5 V. Parameters of critical regime: critical voltage – 300 V, time of critical load – 0.15 ms. Parameters of SFCL construction: superconductor film height – 0.1 mm, substrate height – 10mm, substrate and superconductor film width – 10 mm, substrate and superconductor film length – 50 mm.

Results of simulation are illustrated on Fig.3.

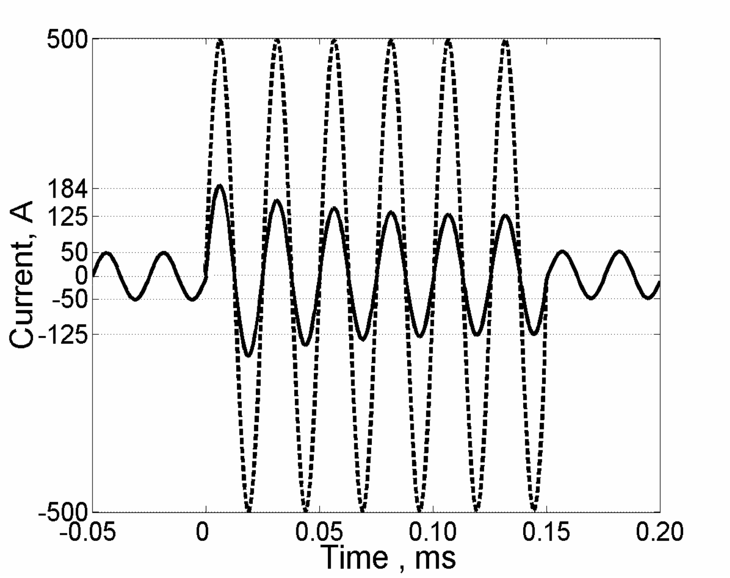

Fig. 3 Fault current in scheme without SFCL (dashed line) and in scheme protected by resistive SFCL (solid line).

Maximum of voltage for scheme without SFCL is reached at the point of 500V. Instead, in scheme with SFCL surge current is about 184V, then due to superconductor heating it falls to 125 V. This way, SFCL with given parameters reduce fault current by a factor of 3-4.

For this numerical parameters of influence of restore regime can be neglected, as superconductor film almost immediately comes into the normal state after overload. Temperature in superconductor reaches its maximum at about 84 K, and after critical regime it takes about 0.003 ms for superconductor film to cool down to the temperature of nitrogen 77.3 K

4. Conclusion

An effective modelling and simulation scheme of a resistive type SFCL using Matlab/Femlab/Simulink is proposed in this paper.

Realization of the SFCL electro-thermal model can be exported to Simulink, and it gives the possibility to implement the proposed simulation scheme to the grid system readily under various system and their conditions. Model of thermal and electrical processes of SFCL was developed in Femlab and can be integrated with existing CAD system built with Matlab/Simulink.

An actual numerical experiment is developed and applied to simulation. The simulation results demonstrate the effectiveness of the proposed model and simulation scheme.

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