Study of the current limiting capacity of 2G HTS tapes

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***Abstract*—Recent years have seen an increasing interest in high temperature superconducting (HTS) cables as they provide a large current carrying capability as well as a potential current limiting feature that can increase the reliability of urban power networks. Within this context, this article investigates current limiting in HTS tapes for new current limiting DC cables by studying both the theoretical and experimental behavior of HTS tapes behavior when subjected to a sudden rise in current. The experiment consists of a sudden discharge of a capacitor bank in a coil connected through an HTS tape. This will allow the dynamic regime of the strip to be studied well above its critical current. A shunt placed in parallel with the HTS tape will allow us to vary the current in the different layers of the superconducting tape in order to strengthen both our different theoretical models and to give us a better practical knowledge of the tape which will then be used in the desired HTS cable.**

Keywords*—*current limiting, 2G HTS tape, superconducting cable, coupled electro-thermal model.

I. Introduction

In recent years, the interest for high temperature superconducting (HTS) cables has grown as several cable projects are being deployed [1], [2]. Indeed, the large current carrying capacity of HTS cables allows to increase network capacity in urban environment there is limited room. An additional interesting feature of HTS cables is the current limitation in case of fault [3], [4]. In order to properly design a current limiting DC HTS cable, it is important to properly model its behavior in limitation mode, i.e. when the current temporarily reach a current higher than the critical current I_c, and especially the current and temperature distribution between the different layers composing a tape [5], [6]. To this end, this article aims to compare the current limiting behavior of several commercial HTS tapes with different layer thicknesses and topologies. The present study establishes a coupled dynamic electro-thermal model of a single HTS tape considering the main layers. Once the model of the 2G HTS tape is well understood, a second step will be to model a whole cable by assessing its current limiting capabilities in its working environment.

II. Study of the current limiting capacity of 2G HTS tapes

A. Experimental setup

Firstly, we aim to model and analyze the dynamic behavior of a single HTS tape. In order to create a large current rise in the tape, a discharge system is set up. As shown in Figure 1, the experimental system consists of a capacitor with a capacity

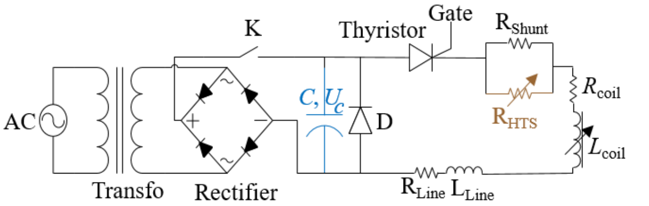

Figure 1. Circuit diagram of the pulse current supply for a HTS tape.

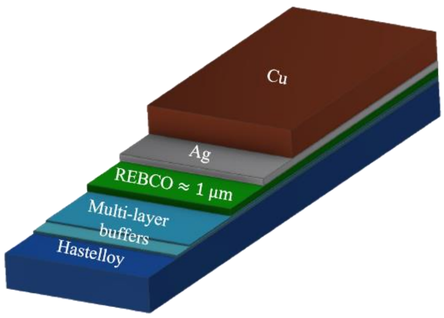

Figure 2. View of the different layers of a typical 2G HTS tape.

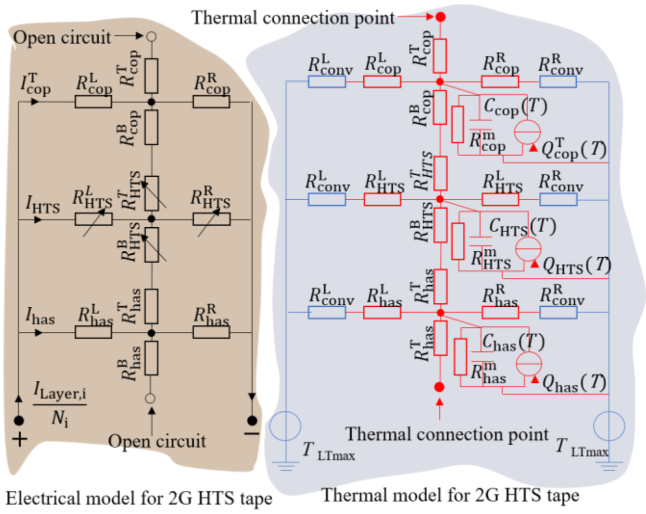

Figure 3. Diagram of the electro-thermal model of a 2G HTS tape.

of 5 mF and a supply voltage of up to 2 kV, resulting in peak current of up to 30 kA. The superconducting tape is placed in series with a coil, where the maximum value and rise time of the current depend mainly on its inductance, the value of the capacitor being fixed. Furthermore, two scenarios will be studied, the first one consists in placing only a superconducting tape in series with the coil, where the coil

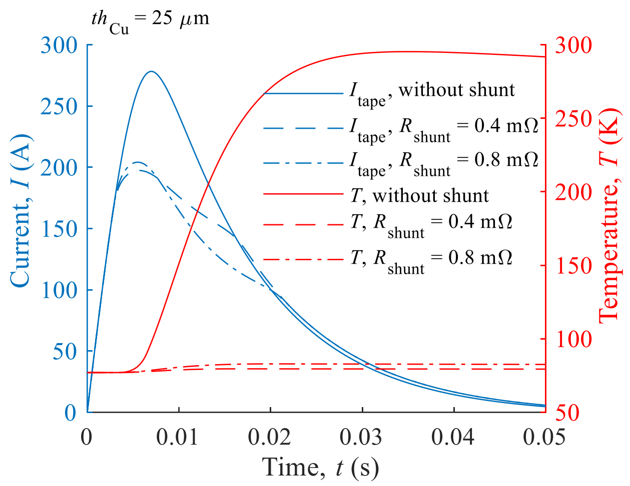

Figure 4. Tape current and temperature as a function of time, with a copper layer thickness of 25 µm, without shunt in parallel to the HTS tape and for two different values of R_{shunt}.

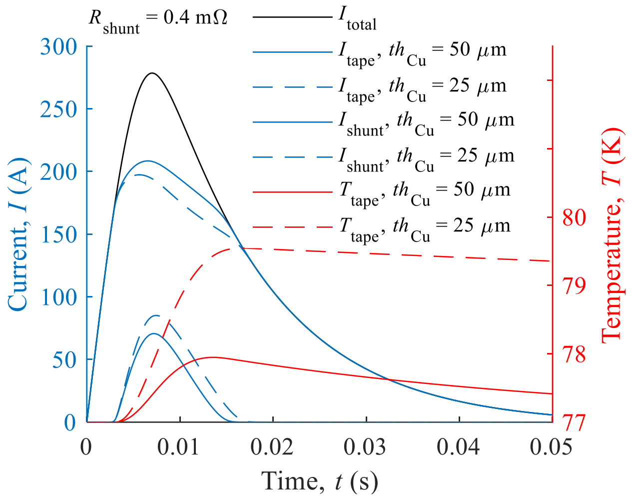

Figure 5. Tape, shunt and total current and temperature of the tape versus time, for two different copper thicknesses and R_{shunt} = 0.4 µm.

current I_{total} and the tape current I_{tape} are equal. In the second configuration, a conventional copper cable is placed in parallel with the tape, which we will later call "shunt". All accessible currents, i.e. those flowing through the coil and the shunt for the second scenario, are measured and analyzed to better understand the current distribution in the different layers of the tape, where $I_{total} = I_{tape} + I_{shunt}$.

A sample holder is designed to ensure electrical connection with the superconducting tape and the flow of high current. Each connection terminal consists of two solid copper plates to ensure good contact between the samples and the power supply. The contact area on both sides is equal to 50 mm × 4 mm. The whole system is immersed in a liquid nitrogen container at a temperature of 77 K and at atmospheric pressure.

B. *Electro-thermal modelling of 2G HTS tapes*

2G HTS tapes used in superconducting power cable applications are typically 4 mm wide. As shown in Figure 2, the first layer of the tape is the substrate, which typically contains the nonmagnetic Hastelloy C-276. Depending on the manufacturer, the thickness of this layer can vary from 50 to 150 µm to provide mechanical resistance. The second is a stack of buffer layers of about 0.5 µm, on which the superconducting layer is deposited. The thickness of the REBCO layer can also vary from 1 to 3 µm depending on the number of deposition steps. Finally, there is a silver layer of a few micrometers thick and a copper layer whose thickness depends on the tape application case.

In this part of the work, several tapes from different manufacturers will be evaluated, each sample having its own electro-thermal model and parameters considering its different layers and its geometry. As shown in Figure 3, each layer of the tape is described by electrical and thermal resistances. Both are composed of two pairs of resistors, i.e., in the x and y directions. By connecting the different elements forming the tape, the electric current and the heat flow can circulate in a 2D (xOy) plan. In addition, at each time step $t+\Delta t$, the electrical model exchanges the losses value with the thermal model, and in return, the thermal model sends the value of the temperature to the electrical model in order to consider the temperature dependence of the electrical parameters.

III. Results and Discussion

Figure 4 shows the current and temperature of the HTS tape during the capacitor discharge for the two scenarios, i.e., with and without shunt and for a 10 cm in length tape immersed in liquid nitrogen with a power law index equal to 25, a critical current of 200 A and a copper layer thickness th_{Cu} equal to 25 µm. For the shunted tape scenario, one can observe that the tape temperature stays below 79 K and 82 K throughout the pulse for the two shunt resistors of 0.4 and 0.8 mΩ respectively. In contrast, without shunt, the current beyond the tape critical current must flow through the other layers of the tapes, resulting in higher losses during the pulse. As a result, the tape temperature reaches 295 K.

Thus, the proposed electro-thermal model will be validated using both scenarios. The first scenario, where the shunt is present, will allow to evaluate the accuracy of the electrical model. Indeed, as shown in Figure 5, the temperature rise being limited ($\Delta T < 2$ K), the thermal model has only a limited impact on the results. However, in the second scenario without shunt, the thermal model has a significant influence on the results. Thus, the study of the two proposed scenarios makes it possible to discriminate separately the errors or uncertainties caused by the thermal and electrical models.

In the final version of the paper, the above study and the corresponding experiment will be performed on several commercial HTS tapes with different copper thicknesses. In addition, the proposed electro-thermal model will be compared with a more detailed 2D quench model based on the **T-A** formulation. Besides, after the validation of the single tape model, a whole cable model will be considered, and the different elements and the behavior of the cable will be discussed.

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