Modelling SuperOx Power Cables to Predict the AC-Losses of a Double Layered Triaxial Cable

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***Abstract*—With the advancement of high temperature superconducting power cables and continued research on the three-phased concentric configuration, this paper focuses on cables manufactured by the Russian Cable Institute (VNIIKP). Specifically the 2G-HTS power cable and the double layered triaxial cable published in 2018 and 2021 respectively. Computationally, the AC-losses from the 2018 cable are replicated by utilizing the so-called H-formulation of Maxwell equations in a 2D model. Due to both cables being composed of tapes designed by SuperOx and no data of the AC-losses produced by the 2021 cable, the method from the first model is duplicated to predict the AC-losses for the triaxial formation.**

***Index Terms*—Triaxial Cables, COMSOL, H-Formulation, AC-Losses**

I. Introduction

As the demand for power increases, the transmission technology must also be able to supply to the masses. This is possible through high-temperature superconducting (HTS) cables where three-phase prototype cables have been produced with both first and second generational tapes [1]–[3]. To combat the demand, both a team in South Korea [4] and Russia [5] have done research into using multiple layers of tapes utilized within individual phases. This is the ideal solution for increasing the power transmitted while also keeping the cable as compact as possible.

In this paper, the focus will be on two cables produced by the Russian Cable Institute (VNIIKP) designed with the same SuperOx tapes. With the first cable being the 2G-HTS cable produced in 2018 [6], which is made up of three layers in the core and surrounded by a shield of two layers. The second cable is a triaxial cable made up of two layers of tapes per phase [5] and this cable currently has no AC-loss data. The 2G-HTS power cable will be replicated with particular focus on the AC-losses, this same method will then be applied to the double layered triaxial cable to predict the AC-losses, of which could be compared to the real life cable in the future. With both cables being composed of the same SuperOx tapes and multiple layers, the interaction between the tapes will be similar and therefore a reliable source for the AC-loss prediction.

II. Geometry of the Cables and H-Formulation Method

Both cables are made up of the 4 mm width SuperOx tapes, with their physical properties and dimensions being reported in [6]–[8]. The first cable [6] is a single phase power cable and accommodates a total of 24 tapes placed within a three layer concentric formation to create the core of the power cable. The shield is then made up of 26 tapes within two layers with further details of the cables included in Table I.

With the second cable [5], each phase is arranged into two layers with the same number of tapes involved with both of the layers. A total of 90 tapes are used with 28, 30 and 32 tapes in the A, B and C phases respectively. The twist pitch of each layer can also be seen in Table II.

TABLE I
Parameters of the 2G-HTS Cable.

Layer	Inner Diameter (mm)	Twist Pitch (mm)	Winding Direction	Number of Tapes
		Cable Core		
1st	11.3	200	+1	8
2nd	12.2	109	+1	8
3rd	13	109	+1	8
		Cable Shield		
1st	18.4	330	-1	13
2nd	19.6	110	+1	13

TABLE II
Parameters of the Double Layer Triaxial Cable.

Phase	Layer (mm)	Inner Diameter (mm)	Twist Pitch of Tapes	Number
A	1st	19.3	324	14
	2nd	19.8	-171	14
B	3rd	21.4	200	15
	4th	21.8	-161	15
C	5th	23.35	191	16
	6th	23.75	-146	16

Through COMSOL Multiphysics 5.6, both cables are replicated and can be seen in 2D format within Fig. 1. It is worth noting that the thickness of each superconducting layer of the SuperOx tapes is increased by a factor of 50 to overcome issues created by the aspect ratio and is normalized through the critical current density J_c [9], [10]. The critical current density is also dependable on both the magnetic field and angle $J_c(B, \theta)$ [8].

Each model features the cross-section surrounded by an air domain, which is a non-magnetic highly resistive media. Simulations are run for a duration of 1.25 and 3.75 cycles for the respective models to avoid convergence issues created by the magnetic fields initial conditions across the domain. The AC-losses are then calculated across a period of the simulation.

Due to the 2D setting, the magnetic field is only considered in the x and the y direction. Whilst the current density flows perpendicularly, i.e., along z-axis. Through the Partial Differential Equation (PDE) module, these values are implemented into COMSOL and are calculated through Faraday's law below.

$$\begin{vmatrix} \partial_y E_z \\ -\partial_x E_z \end{vmatrix} = -\mu \begin{vmatrix} \partial_t H_x \\ \partial_t H_y \end{vmatrix}, \quad (1)$$

These conditions are them applied to Ampere's law.

$$J_z = \partial_x H_y - \partial_y H_x \quad (2)$$

As is standard, the electrical behaviour of the superconducting material is defined as the $E - J$ power law model [10],

$$\boldsymbol{E} = E_0 \frac{\boldsymbol{J_z}}{|\boldsymbol{J_z}|} \left(\frac{|\boldsymbol{J_z}|}{J_c} \right)^n, \quad (3)$$

The electric field criterion of 1 μV/cm is used alongside an n-value of 34.4 according to the experimental measurements stated earlier for the critical current density dependence $J_c(B, \theta)$ for the 4 mm SuperOx tapes [8].

AC-losses of the superconducting tapes are calculated by the integration of the local density of power dissipation (**E** · **J**) across the superconducting tapes (S), and then over the time span for a full hysteretic cycle (*f.c*).

$$Q = \omega \int_{f.c} dt \int_S \boldsymbol{E} \cdot \boldsymbol{J} dS \,. \quad (4)$$

The transport current are applied as pointwise constraints for each one of the tapes, where they satisfy the condition that the integral function of the superconducting domain minus the applied current per tape.

III. Results

Initial results show an ability to replicate the 2G-HTS power cable, as can be seen in fig. 1. This method is to be further improved to show a closer relationship between the simulated results and the data produced in [6] before then being applied to the triaxial cable.

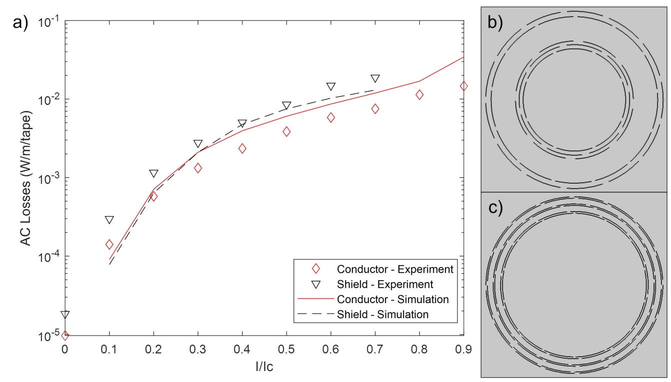

Fig. 1. The initial AC-loss comparison between the experimental and simulated results alongside the 2D representation of both the 2G-HTS cable (b) and the the double layered triaxial cable (c) using the parameter values stated in table I and II. Both images are zoomed in independently so do not show a direct comparison in size.

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