



**HAL**  
open science

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

Matthew Clegg, Harold Ruiz

► **To cite this version:**

Matthew Clegg, Harold Ruiz. Modelling SuperOx Power Cables to Predict the AC-Losses of a Double Layered Triaxial Cable. 8th International Workshop on Numerical Modelling of High Temperature Superconductors (HTS 2022), Kévin Berger (Université de Lorraine - GREEN), Jun 2022, Nancy, France. hal-03791295

**HAL Id: hal-03791295**

**<https://hal.science/hal-03791295v1>**

Submitted on 15 Dec 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

M. Clegg  
Department of Engineering  
University of Leicester  
Leicester, United Kingdom  
mlc42@le.ac.uk

H. S. Ruiz  
Department of Engineering  
University of Leicester  
Leicester, United Kingdom  
Dr.Harold.Ruiz@le.ac.uk

**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 (VNIKP). 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.

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

In this paper, the focus will be on two cables produced by the Russian Cable Institute (VNIKP) 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 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.

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

These conditions are then 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],

$$\mathbf{E} = E_0 \frac{\mathbf{J}_z}{|\mathbf{J}_z|} \left( \frac{|\mathbf{J}_z|}{J_c} \right)^n, \quad (3)$$

The electric field criterion of  $1 \mu\text{V}/\text{cm}$  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 ( $\mathbf{E} \cdot \mathbf{J}$ ) across the superconducting tapes (S), and then over the time span for a full hysteretic cycle ( $f.c$ ).

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

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.

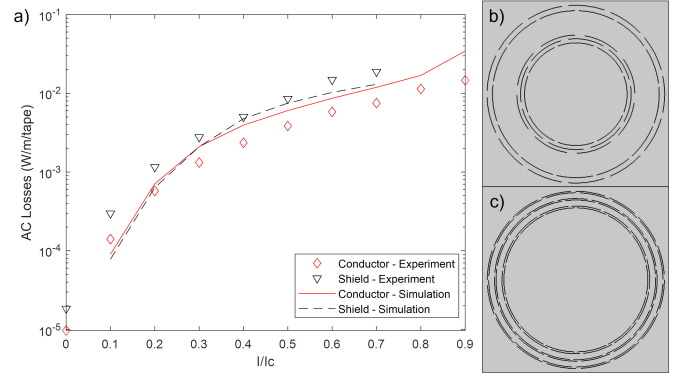


Fig. 1. The initial AC-loss comparison between the experimental and simulated results alongside the 2D representation of both the 2G-HTS cable (b) and the double layered triaxial cable (c) using the parameter values stated in table I and II. Both images are zoomed in independently so do not show a direct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

### ACKNOWLEDGMENT

This work was supported by the UK Research and Innovation, Engineering and Physical Sciences Research Council (EPSRC), through the grant Ref. EP/S025707/1 led by H.S.R. All authors acknowledge the use of the High Performance Computing facility ALICE at the University of Leicester.

### REFERENCES

- [1] J. Demko, C. Nielsen, I. Sauers, D. James, M. Gouge, D. Lindsay, M. Roden, J. Tolbert, D. Willen, and C. Traeholt, "Triaxial hts cable for the aep bixby project," *IEEE Transactions on Applied Superconductivity*, vol. 17, no. 2, pp. 2047–2050, 2007.
- [2] M. Stemmler, F. Merschel, M. Noe, and A. Hobl, "Ampacity - advanced superconducting medium voltage system for urban area power supply," in *2014 IEEE PES T D Conference and Exposition*, 2014, pp. 1–5.
- [3] S. S. Fetisov, V. V. Zubko, S. Y. Zanegin, A. A. Nosov, S. M. Ryabov, and V. S. Vysotsky, "Study of the first russian triaxial hts cable prototypes," *IEEE Transactions on Applied Superconductivity*, vol. 27, no. 4, pp. 1–5, Jun 2017. [Online]. Available: <https://ieeexplore.ieee.org/document/7817781>
- [4] S.-J. Lee, S. Y. Kang, M. Park, D. Won, J. Yoo, and H. S. Yang, "Performance analysis of real-scale 23 kv/60 mva class tri-axial hts power cable for real-grid application in korea," *Energies (Basel)*, vol. 13, no. 8, p. 2053, 2020.
- [5] S. S. Fetisov, V. S. Zubko, S. Y. Zanegin, A. A. Nosov, and V. S. Vysotsky, "Optimization and cold test of a triaxial 2g hts power cable with high current capacity," *IEEE transactions on applied superconductivity*, vol. 31, no. 5, pp. 1–4, 2021.
- [6] S. S. Fetisov, V. V. Zubko, S. Y. Zanegin, A. A. Nosov, and V. S. Vysotsky, "Numerical simulation and cold test of a compact 2g hts power cable," *IEEE transactions on applied superconductivity*, vol. 28, no. 4, pp. 1–5, 2018.
- [7] S. Lee, V. Petrykin, A. Molodyk, S. Samoilenkov, A. Kaul, A. Vavilov, V. Vysotsky, and S. Fetisov, "Development and production of second generation high temperature superconducting tapes at superox and first tests of model cables," *Superconductor science technology*, vol. 27, no. 4, 2014.
- [8] X. Zhang, Z. Zhong, J. Geng, B. Shen, J. Ma, C. Li, H. Zhang, Q. Dong, and T. A. Coombs, "Study of critical current and  $n$ -values of 2g hts tapes: Their magnetic field-angular dependence," *Journal of Superconductivity and Novel Magnetism*, vol. 31, no. 12, pp. 3847–3854, 2018.
- [9] A. Stenvall, M. Siahraang, F. Grilli, and F. Sirois, "Computation of self-field hysteresis losses in conductors with helicoidal structure using a 2d finite element method," *Superconductor Science and Technology*, vol. 26, no. 4, p. 45011, 2013.
- [10] B. C. Robert, M. U. Fareed, and H. S. Ruiz, "How to choose the superconducting material law for the modelling of 2g-hts coils," *Materials*, vol. 12, no. 17, p. 2679, 2019.