

# A Data-Driven Methodology for Modeling Losses in HTS Power Systems

Roberto Oliveira<sup>1</sup>, João Murta-Pina<sup>1,2</sup>, Anabela Pronto<sup>1,2</sup>, Henrique Simas<sup>2</sup>, Miguel Teixeira<sup>2</sup>, Isabel Catarino<sup>2,3</sup>, João Rosas<sup>1,2</sup>, Masoud Ardestani<sup>2</sup>, Alfredo Álvarez<sup>4</sup>, Pilar Suarez<sup>4</sup>, Belén Rivera<sup>4</sup>, Belén Perez<sup>4</sup>

<sup>1</sup> Centre of Technologies and Systems (CTS),  
UNINOVA,  
Portugal

<sup>2</sup> NOVA School of Science and Technology,  
NOVA University of Lisbon  
(FCT NOVA),  
Portugal

<sup>3</sup> Laboratory for Instrumentation, Biomedical Engineering and Radiation Physics,  
LIBPhys-UNL,  
Portugal

<sup>4</sup> “Benito Mahedero” Group for Electrical Applications of Superconductors,  
University of Extremadura  
Spain

Corresponding author: [jmmp@fct.unl.pt](mailto:jmmp@fct.unl.pt)



**PRELIMINARY NOTE: Due to the pandemic and successive lockdowns it was not possible to advance this work to be adequate for an oral contribution. Therefore, the authors would like to ask to be changed for a poster presentation.**

# A Data-Driven Methodology for Modeling Losses in HTS Power Systems



This work was supported by project **tLOSS** (*Transforming Losses Calculation in High Temperature Superconducting Power Systems*), funded by FEDER (Programa Operacional Regional de Lisboa) and Portuguese national funds, with reference PTDC/EEI-EEE/32508/2017\_LISBOA-01-0145-FEDER-032508; and by FCT Fundação para a Ciência e a Tecnologia (CTS multiannual funding) under the framework of project UIDB/00066/2020



# Abstract

Cryogenics accounts for a significant part of the costs of superconducting-based power devices, even when using High-Temperature Superconducting (HTS) materials, that may often operate in liquid nitrogen, thus allow reducing cooling costs when comparing to operation at lower temperatures. Adequate ratings of the cryogenic systems are mandatory for the economy of HTS-based technologies, and those are related to losses in the superconducting materials, which must be predicted in the design stage.

Calculation of losses in the design of HTS devices requires the use of complex, computational-intensive numerical modelling tools, applied in different formulations/state variables, with different accuracy and requirements. Typically, just a section of the system is represented, often reducing dimensionality, to decrease the required computations. This is due to nonlinear resistivity of HTS (current-field-temperature dependent), and extreme aspect ratios, where characteristic dimensions range from micrometers of HTS tapes' thickness to hundreds of meters of, e.g., cables length.

Those numerical tools thus require huge computation times which make their application often unfeasible in the design of large-scale devices (as changing parameters, e.g., number of turns in windings, would require running whole new simulations) or in the integration into grid simulation software (to assess the performance of the devices in realistic operating conditions and their interaction with other grid elements). Besides these limitations, the calculation of losses often only addresses pure AC regimes, but grid currents are harmonically polluted.

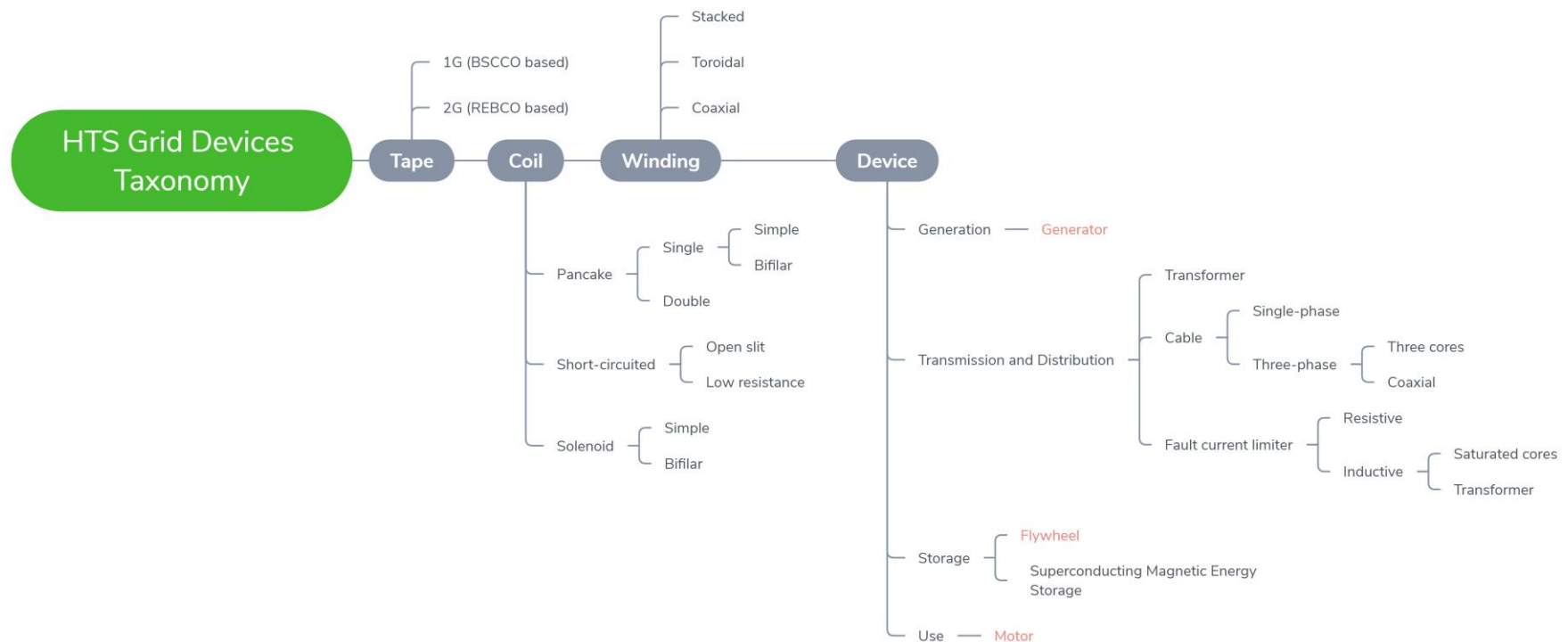
This work proposes a hierarchical, data-driven approach for modeling losses in HTS power systems. The problem is split into several levels, from HTS tapes to the whole device, where higher levels receive inputs from lower ones. By mixing empiric, equation-based models with black-box modelling, namely artificial neural networks, the computation times required to the preliminary evaluation of losses is reduced unprecedentedly.

Simulations and experimental results are used to assess the methodology, with distinct tapes, coils, windings and active materials, and the learning ability of the latter, as well as its precision and applicability in the design of HTS power devices, are discussed.

# Taxonomy of applications

A taxonomy of HTS applications, with increased complexity, underlies the proposed concept. An example of such (evolving) taxonomy is shown in the figure.

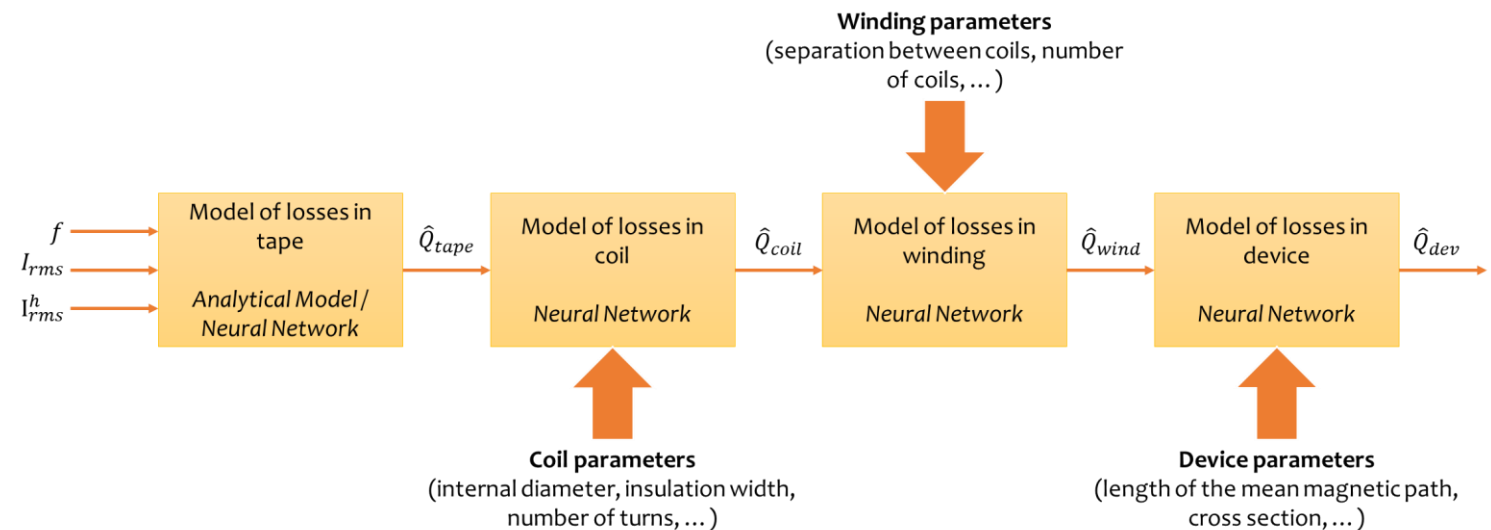
Electromechanical devices, as motors, generators, and flywheels, are not addressed by the proposed methodology, which envisages static devices.



# Modeling workflow

The prediction of losses in each element of the taxonomy (tape, coil, winding) is an input to the next level, together with the corresponding parameters. In this workflow, we have:

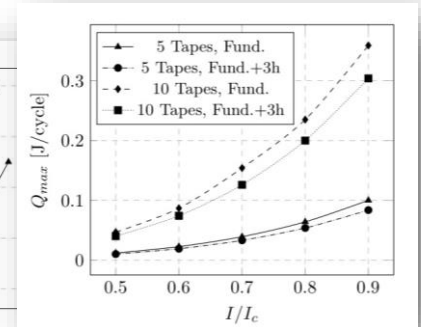
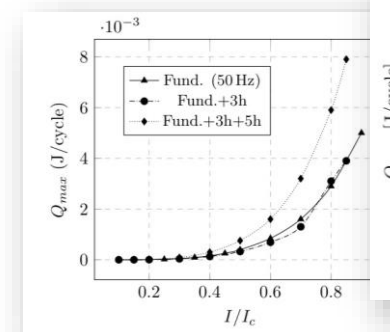
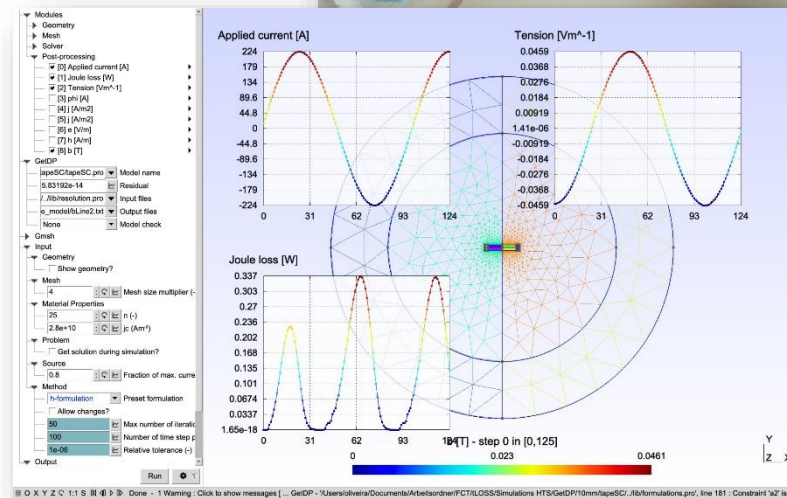
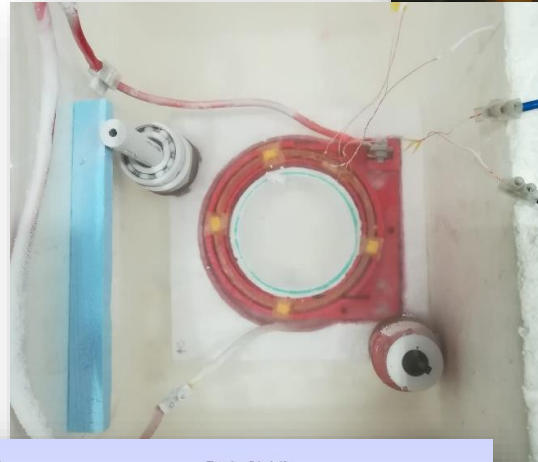
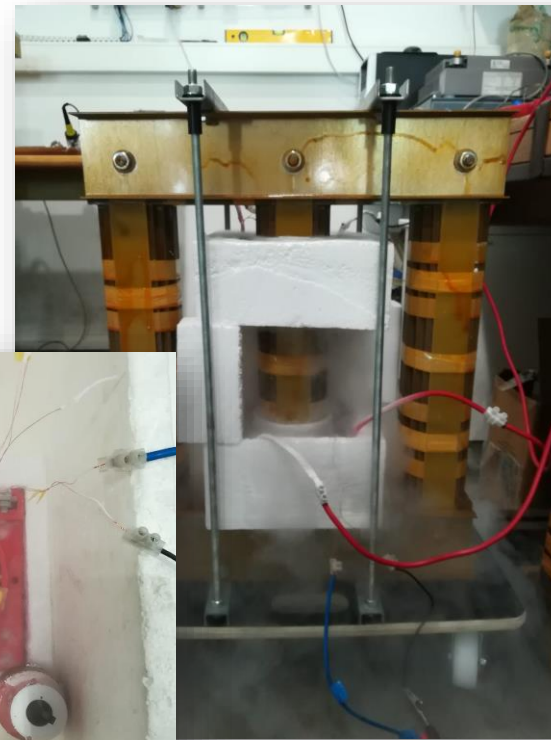
- $f$ : fundamental frequency
- $I_{rms}$ : rms fundamental component
- $I_{rms}^h$ : vector with rms harmonic components
- $\hat{Q}_{tape}, \hat{Q}_{coil}, \hat{Q}_{wind}, \hat{Q}_{dev}$ : **estimation or parametrization** of losses in a tape sample, coil, winding and device.



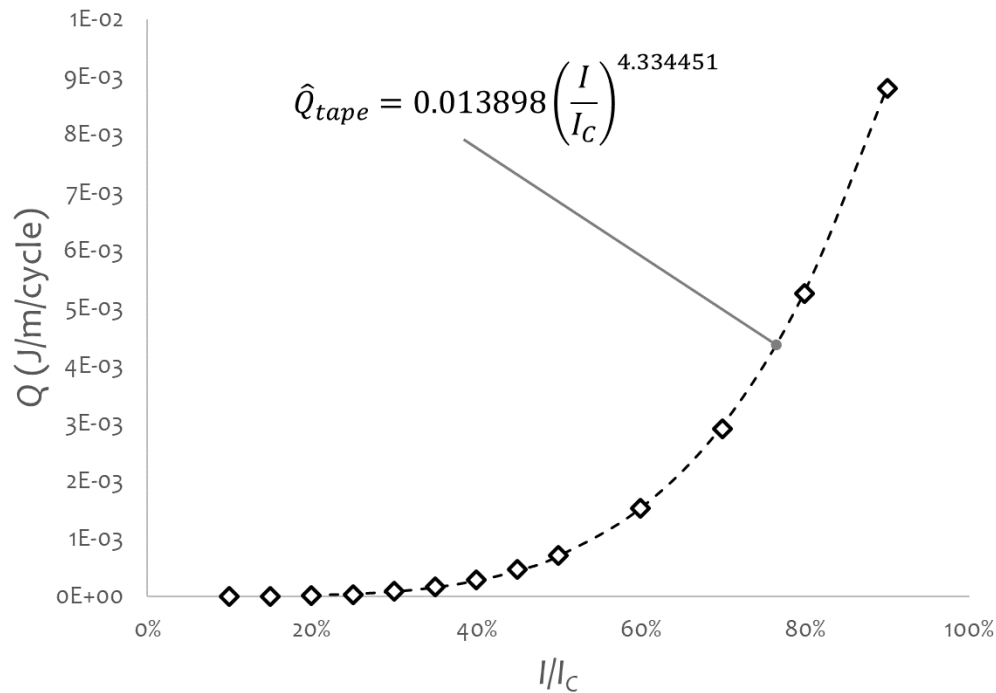
# Data gathering

Simulations and experiments allow generating data that is used in the modelling process, in each element.

The availability of large amounts of data, as diverse as possible, is fundamental for the viability of a general procedure.

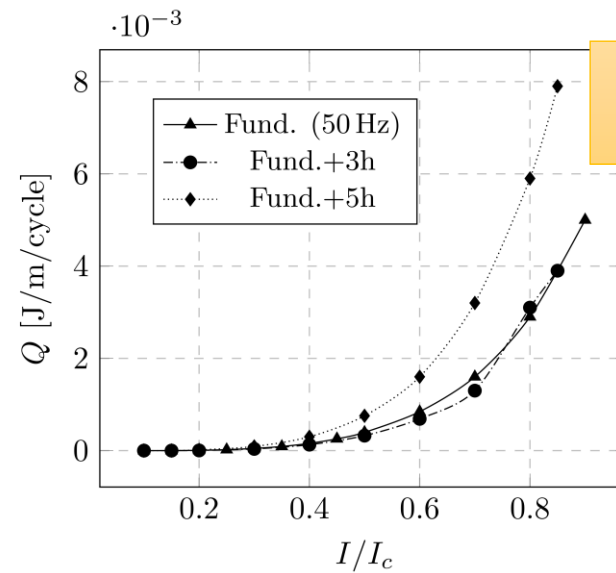


# Data-driven modelling examples



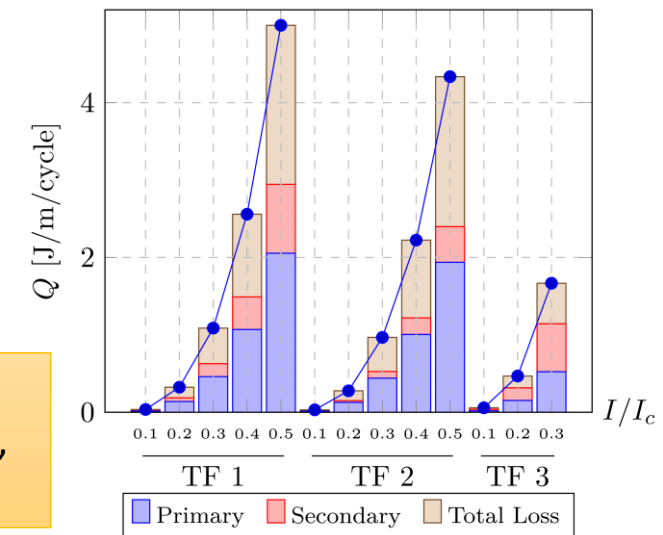
Analytical:

Losses in a tape, at 50 Hz, modelled as  $\hat{Q}_{tape} = a \left(\frac{I}{I_c}\right)^b$



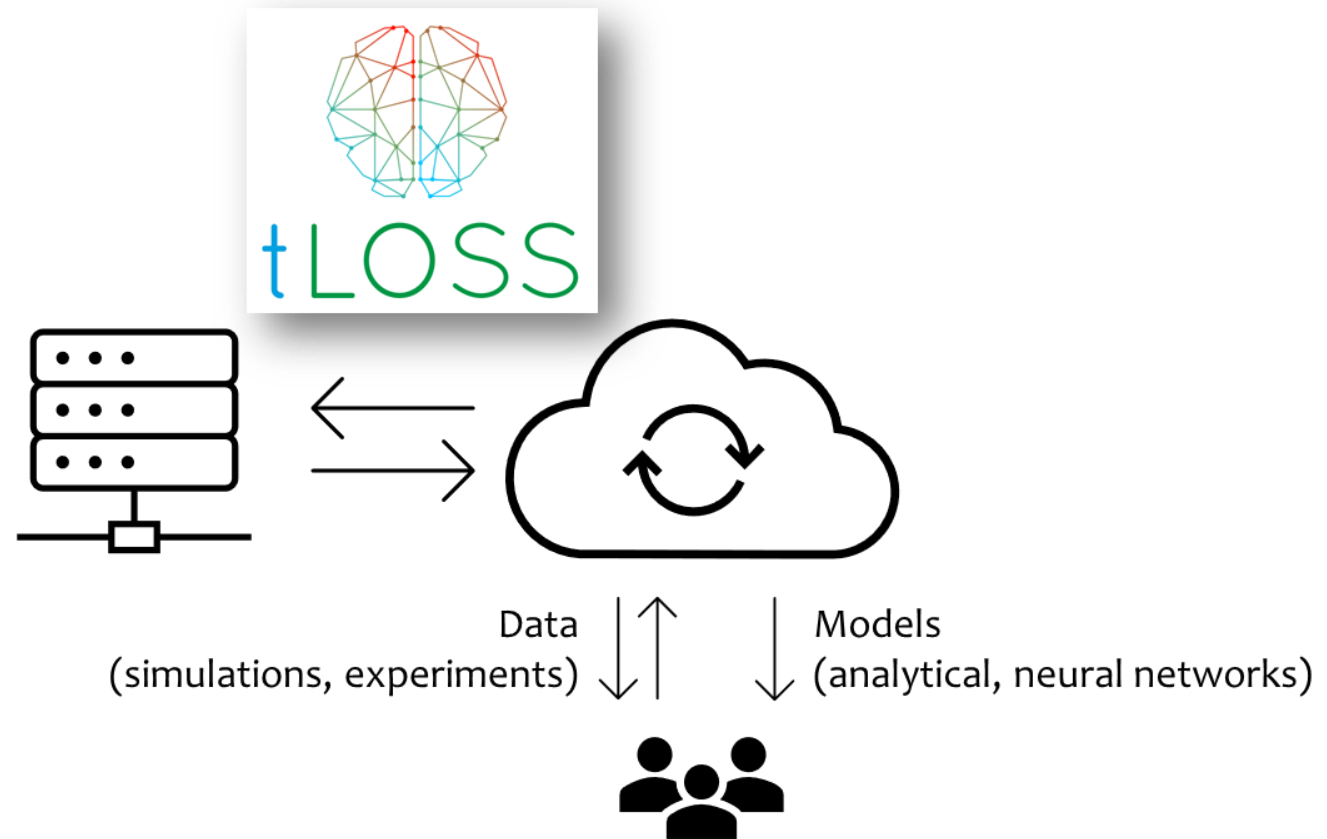
Neural networks:  
Losses in a tape, at 50 Hz, with harmonics

Neural networks:  
Losses in in different transformers (TF1, TF2 and TF3), at 50 Hz



# Machine learning collaborative platform

To boost the amount of data that can be used to build models, a web platform (called tLOSS) is being developed. It will allow researchers to upload/download datasets and obtain models of losses.



# Conclusion, on-going and future work



- A data-driven based methodology and ecosystem is being developed under the national project tLOSS (Transforming Losses Calculation in High Temperature Superconducting Power Systems).
- It envisages a data-driven, collaborative paradigm to accelerate the design of HTS grid devices, concerning the calculation of losses and corresponding cryogenic requirements.
- The modelling workflow allows changing one parameters of the design (e.g., the number of turns of coils) and calculating losses immediately, without having to run whole new numerical simulations.
- The success of the paradigm, i.e., the generalization ability, requires the availability of larges amount of data, to train neural networks, but also to build analytical models, which are generated by researchers worldwide. Thus, a collaborative platform is being developed within the project.
- Concerning devices, the project is focused on grid-frequency and high-frequency HTS transformers and fault current limiters of inductive (transformer) type. Several datasets are being generated within the project by simulations and experiments.
- Neural networks have been able to extract patterns of losses, but the generalization ability of the paradigm is still to demonstrate at the higher levels of the workflow (although first results are promising).