Innovative Electro-Thermal Modeling of Quench in REBCO Roebel Cables

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Abstract – An innovative 'quasi-3D' electro-thermal model is developed in the COMSOL Multiphysics environment to analyze the effect of quench in HTS Roebel cables. The model is based on a reduced dimensionality approach, under the assumption of a negligible thickness of the individual REBCO tape. While the tapes are meshed in an identical 1D pattern, the non-continuous electrical and thermal contacts among them are accounted for as a sources in the corresponding thermal and electrical equations. The Normal Zone Propagation Velocity is computed and the Minimum Quench Energy is studied and analyzed for different cable configurations.

Thermal Model

- **Only one tape is discretized** and a **set of equations** is solved for an array of temperatures **[T_1, …, T_{Nt}]** representing the temperatures of the N_t tapes.
- The thermal equation can be written for the ***i*-th** tape as

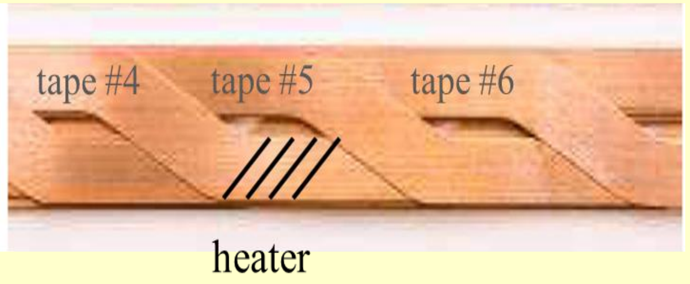
$$\rho C p(T_i(x,t))\frac{\partial T_i(x,t)}{\partial t} - \frac{\partial}{\partial x}\left(k(T_i(x,t))\frac{\partial T_i(x,t)}{\partial x}\right) = \sigma_i\left(T_i(x,t), V_i(x,t)\right)\left(\frac{\partial V_i(x,t)}{\partial x}\right)^2 + \sum_j Q^J_{i,j}(x,t) + \sum_j Q^c_{i,j}(x,t) + Q^h_i(x,t)$$

Joule power due to the current exchange between the tapes *i*-th and *j*-th in contact:

thermal conduction between the tape *i*-th and *j*-th in contact

$$Q^c_{i,j} = \sum_j f_{i,j}(x)\frac{T_i - T_j}{R^c_{th}\, t}$$

heater thermal disturbance

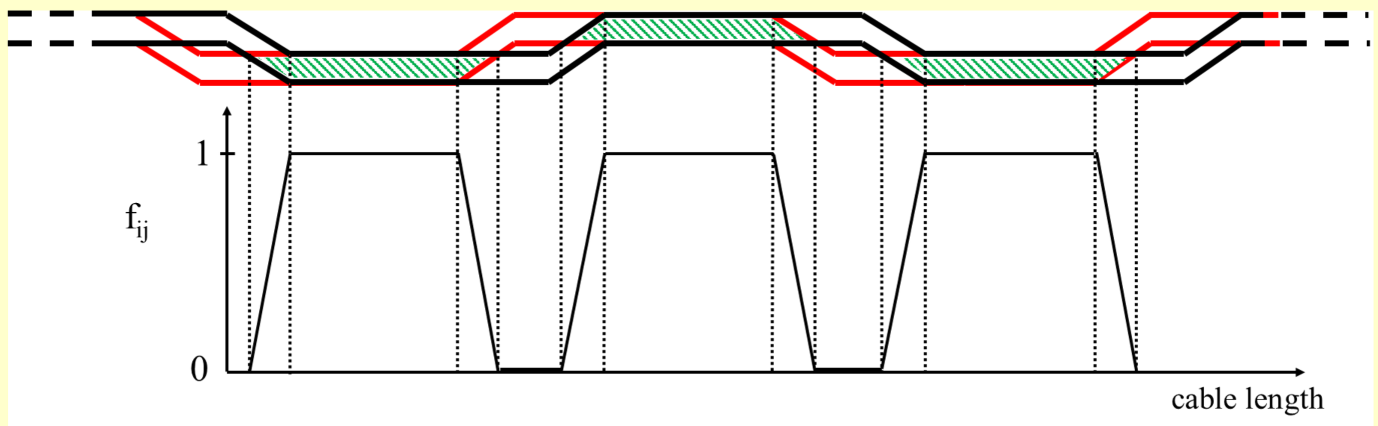


Electrical Model

- A set of equations solved for an array of electric potential representing the voltages **[V_1 , …, V_{Nt}]** of all the tapes
- The **current density continuity** condition is written for the ***i*-th** tape as

$$\frac{\partial}{\partial x}\left(-\sigma_i\left(T_i(x,t), V_i(x,t)\right)\frac{\partial V_i(x,t)}{\partial x}\right) = \sum_j f_{i,j}(x)\frac{V_j(x,t) - V_i(x,t)}{R^c_{el}}$$

- **f_{ij}** takes into account the **contact area** between the *i*-th and the *j*-th tape..

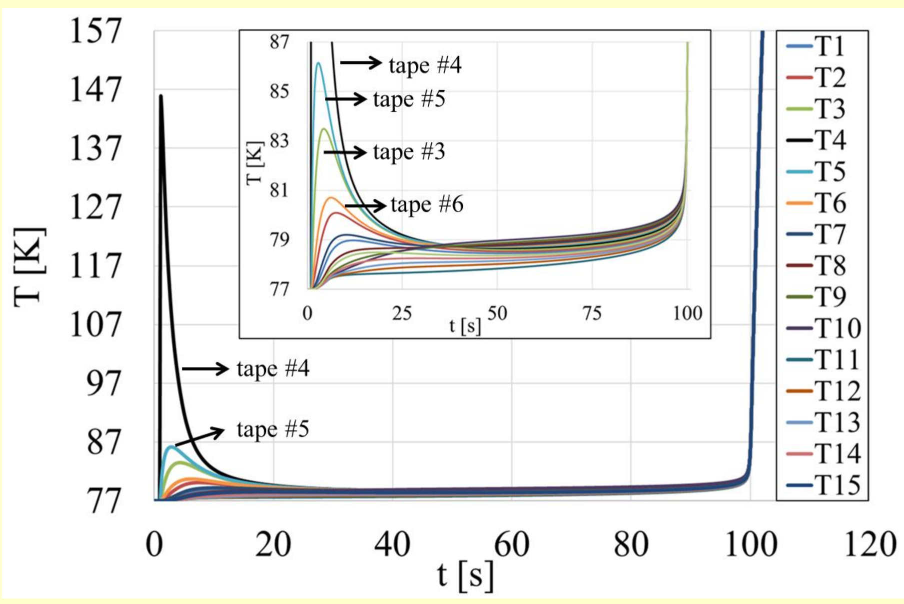


The function is equal to one if the two tapes overlap while zero if they are not in contact

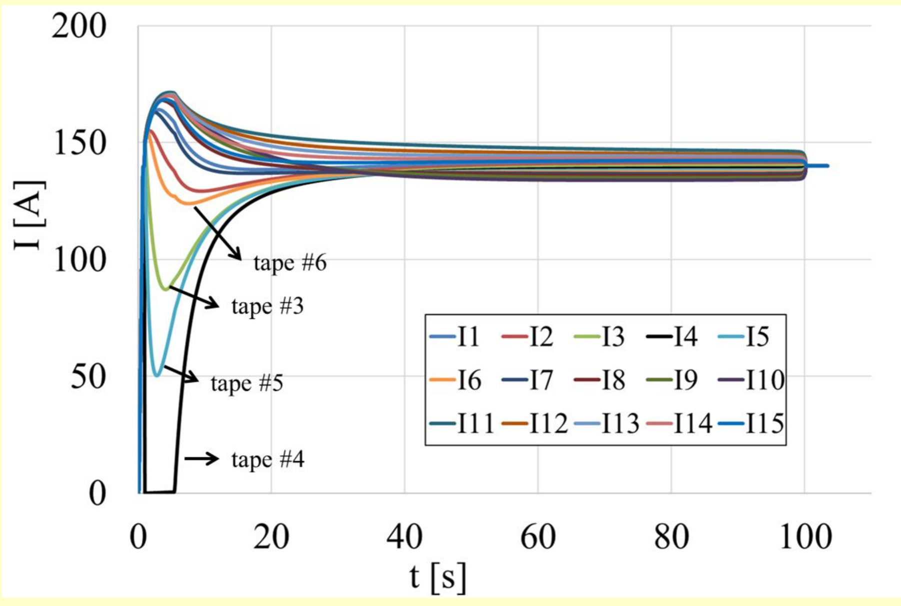
Quench Analysis

- One terminal of each tape is energized with a transport current of **140 A** and an initial temperature of **77 K** is imposed. The quench is initialized by a **triangular pulse** starting at t = 0.95 s for 1 s with a peak of power equal to 3.50*10^9 W/m^3 by means of a **3 cm heater** located in the middle of the **tape #4.**

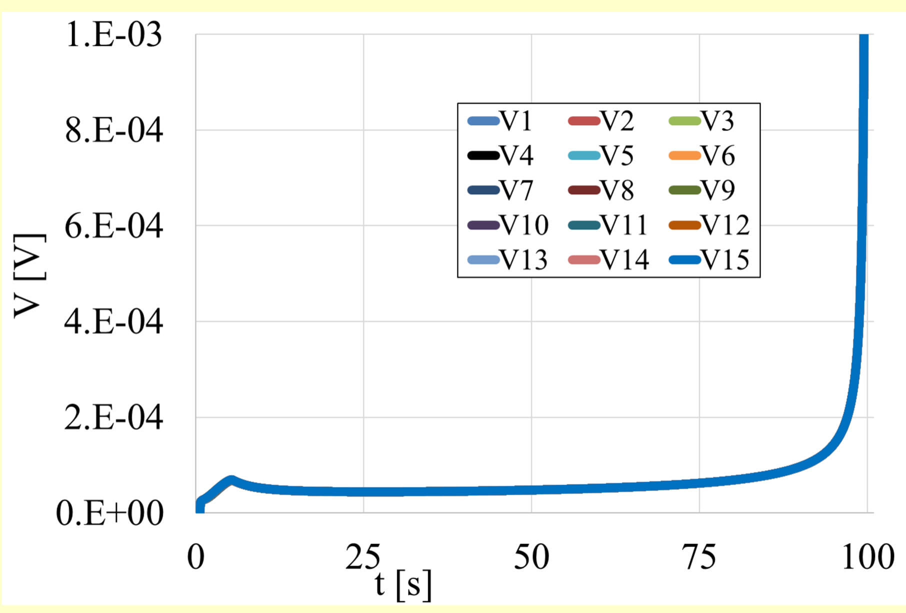
- The **temperature evolution** in a point located in the middle of the cable is shown for all the tapes.



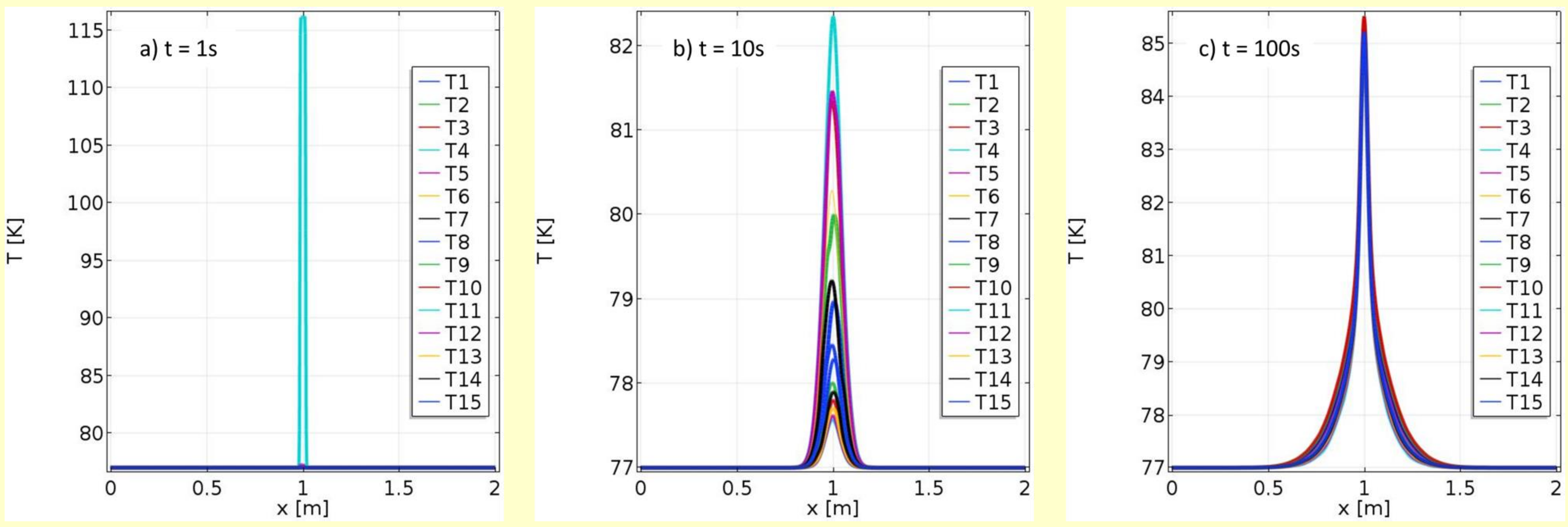
- The **current** on the heated tape decreases to **zero redistributing towards the other tapes**



- The **voltages at the terminals of the tapes** show a local peak of 100 μV during the heater pulse

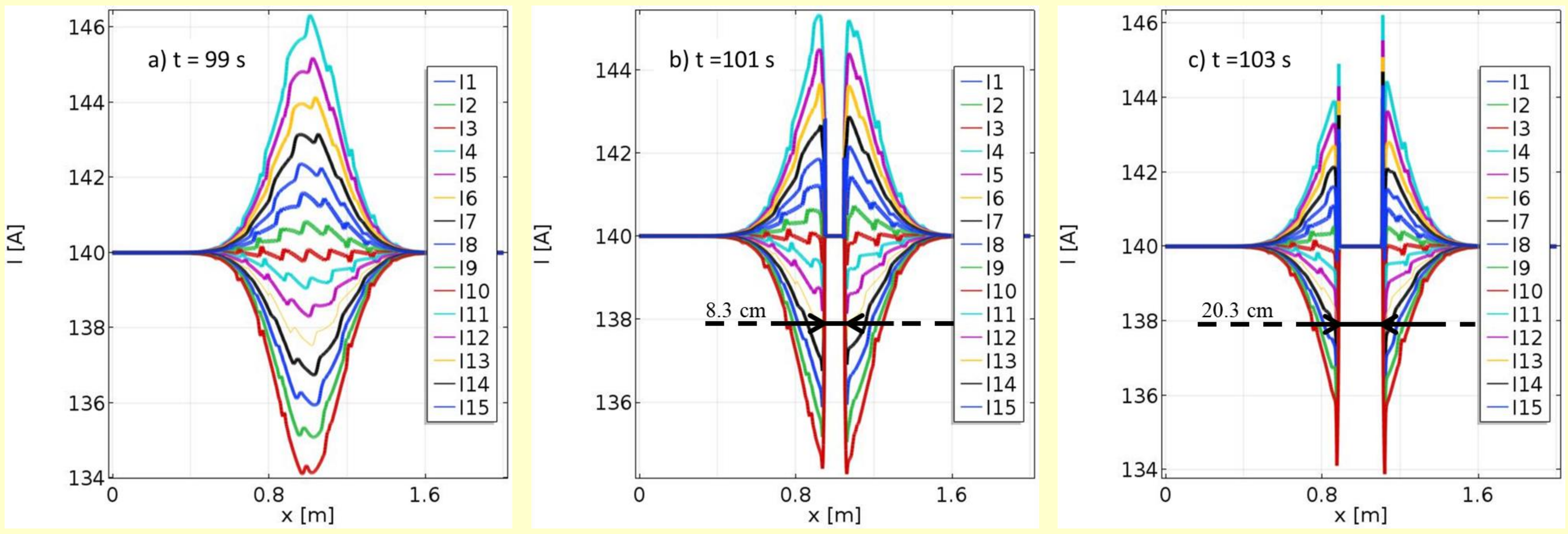


- The **temperature of the tapes** along the cable. The temperature of the **tape #4** rise up due to the heater pulse



After few seconds the temperature redistributes and at **100 s** the tapes show the same temperature profile determining the quench of the cable.

- The **current** on the heated tape decrease to zero **redistributing towards the other tapes**

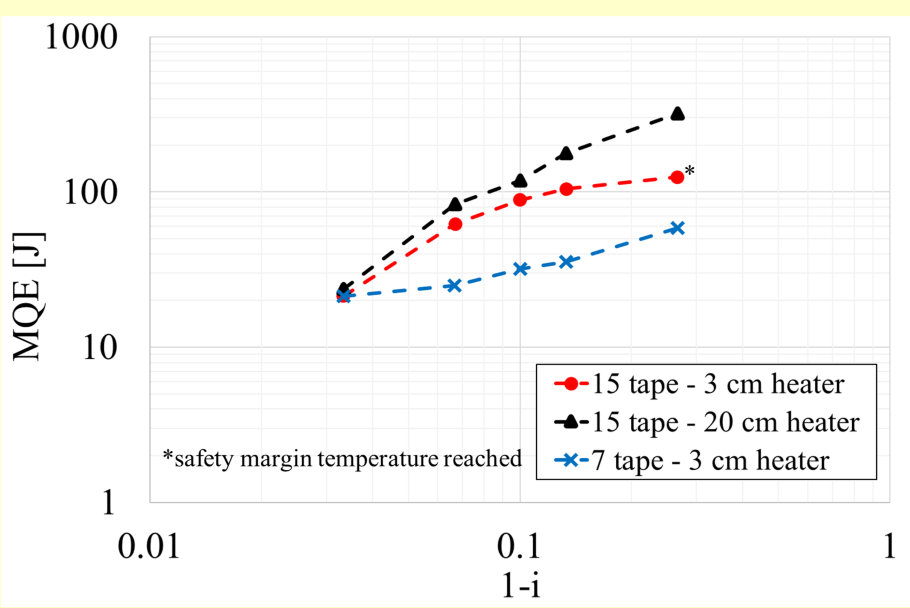


NZPV 6 cm/s

In the central zone, the tapes are at the **normal state** and carry the same current value. The current distribution shows the quench initiation and propagation along the cable.

Minimum Quench Energy

- At low current, the **3 cm heater** is not able to quench the cable, a **20 heater** is introduced.
- To analyze the impact on the MQE of the number of tapes, the MQE is also computed for a Roebel cable composed by **7 tapes**.



Conclusion

- An innovative approach for the analysis of quench and thermal stability of **HTS Roebel cable** is developed in the frame of a **quasi-3D electro-thermal FEM model.**
- The low normal zone velocity in a range of **6 cm/s** increases the **quench detection time** to values of hundreds of seconds, influencing the design of safety **protection systems** for the Roebel devices.
- The direct consequence of the current sharing between tapes is the effect on the MQE of the number of tapes: **the 15-tapes cable shows MQE values higher more than a factor 2.5 with respect to the 7-tape cable.**