Context of the research activity

The adoption of DC cables using High Temperature Superconductors (HTS), such as rare-earth (BSCCO or YBCO) tapes or MgB2 wires, is attractive for the DC transmission of high power at high voltage (HVDC) on very long distances [1], connecting for instance the EUMENA regions [2] or within megalopolis [3]. The actual TRL of the HVDC HTS cables, preventing their strong penetration in the electric grids, is 5, according to [1], but it should grow to 9 in the next 10 years [1] by means of a dedicated R&D. One point that is actually weak, in the direction of increasing the stability, safety and reliability of such cables, is their numerical modeling, which needs and integrated thermal-hydraulic and electric approach. In the cable, the superconducting (SC) part, suitably stabilized, is actively cooled by N2 or He, and inserted into concentric cryogenic envelopes, which are shielded and insulated from the external ambient according to different alternative designs. Some modeling effort has been already done, for the pure thermal problem, by means of the lumped-parameters Volume Element Method (VEM), borrowed from the electronic device cooling field [4], [5]. A first coupling of the VEM to an electric model has been performed in [6], with some validation against experimental data. The coolant thermal-hydraulic transients in such model is reduced, however, to simple enthalpy balances, which are unsuited to deal with off-normal operating conditions. A 1D thermal model in the radial direction of the cable is coupled to a 1D transport model for the coolant in the axial direction in [7], where, however, the electric modeling is missing. A dedicated model for the coolant has been developed in [8], but it is currently only steady state.

The problem of the coupled thermal-hydraulic and electric modeling and analysis of HTS-HVSC cables presents many analogies to that of the modeling of SC conductors for fusion applications, field in which the proponent group developed, in the past 20 years, the state-of-the-art code for the analysis of thermal-hydraulic transients in SC magnets [9], as well as contributed to the development of a powerful numerical tool for the coupled electrical and thermal-hydraulic analysis of fusion SC conductors [10].

References

The present proposal is the development of a flexible tool for the analysis of normal and off-normal operating conditions for HVDC HTS cables. The model should be able to describe the following aspects that could be relevant in different operating conditions:

- The thermal-hydraulic transients in any of the different coolant paths that are currently envisaged in the most-advanced HVDC HTS cable layouts (see, for instance, the review in [1]), with the possibility to accounts for different coolants (He and N2, for instance) that could be present at the same time in different regions of the cable

- The transient heat-conduction equation in any of the “thermal” (i.e., solid) component of the cable, cooled by the coolants. The solid components will be suitably coupled to the other fluid and solid components that have, spotty or along the entire cable length, a thermal contact, by means of conductive, convective and/or radiative thermal resistances.

- The current distribution (or, in case of faults, re-distribution) among the current-carrying elements, together with the transient losses whenever present. The model will take into account the interaction between the different strands or tapes of the SC in different and complex 3D layouts. Suitable numerical techniques will be used to minimize the computational effort as well as memory usage.

- The connection to the sub-stations for the fluid pumping.

The model should be implemented in a flexible object-oriented environment, where different cable layouts could be assembled starting from base components, with their reciprocal coupling, using a user-friendly input/output interface. The resulting code should follow a rigorous V&V approach. A detailed solution and code verification should be performed by suitable numerical convergence analysis and manufactured solutions checks.

A detailed benchmark against results from other models, mainly VEM-based, will be performed to check the capability of the code to reproduce published results, when the same cable layout is modeled. After the first positive benchmarks, a specific comparison to the results obtained, in a selected number of test-cases, by the numerical tool developed at RSE [2] will be carried out. The aim will be to provide support to the research activity which RSE has been developed in the past few years on this topic, and give a contribution in the assessment of the credibility of their simulation results.
The verification of the new numerical tool against experimental data available from literature will be also performed, whenever possible. The code will be finally applied to a test case, identified together with the RSE colleagues, which could be relevant for the application of that technology in Northern Italy.

References


Skills and competencies for the development of the activity

Know-how in the field of thermal-fluid-dynamics, heat transfer, electro-dynamics and computational methods (finite elements, finite volumes).