Potential and Limits of Numerical Modeling for Supporting the Development of HTS Devices

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Abstract - The development of HTS devices has made significant progresses over the last few years. Prototypes are now close to commercial products, or even already commercially available, as in the case of superconducting fault current limiters. Although the cost of 2G HTS wires still makes devices expensive, steady progresses in materials science and in manufacturing processes brings them to closer to the market every year. In parallel to materials improvements, it is possible to further decrease the cost of devices by minimizing the quantity of HTS material used in a given application. This is not an obvious exercise though, as HTS materials are highly nonlinear and presents strong anisotropic field dependence. In most cases, only numerical methods allow relating power dissipation in HTS parts with their geometrical arrangement within the device.

In a general sense, numerical modelling in engineering is a mature discipline. Techniques such as finite elements and others are well known and documented in the literature. However, each engineering application has its own specificities, which we can take advantage of in order to simplify the problem and reduce its computational size. This is of tremendous importance in a context of device optimization, where hundreds or even thousands of parametric simulations are often required. This is also the reason why we find dozens of variants of the established numerical methods in the literature.

Combined to this variety of applications, the materials used in devices introduce nonlinearities that significantly affect the numerical behaviour of the problem, some times to the point where the mathematical theory behind the numerical method must be revisited. This is particularly true in the case of superconducting materials, where the disappearance of the resistivity at low current leads to singular behaviour of the electromagnetic fields (moving current fronts). In practice, this does not mean classical methods cannot handle the problem, but rather than blindly applying classical methods is by far sub-optimal and may lead to computation times that are much longer than required.

This presentation will start by briefly reviewing the current numerical techniques and modelling approaches commonly used to solve problems involving HTS materials, in particular AC loss and quench problems. These problems usually represent a portion of HTS device. Different questions will be addressed, namely: 1) Is it always necessary to simulate the whole device? 2) Are 2-D simulations sufficient for most cases, and when are 3-D simulations necessary? 3) What level of accuracy can be obtained, and how accurate does it really need to be as compared to experimental results? After reviewing the most common models and numerical methods, their limits will be outlined, in order to identify the working paths towards numerical methods that are specifically tailored for problems involving superconducting materials. In particular, we will discuss the issue of necessary degrees of freedom and adaptive finite element methods that allow placing the unknowns where they are really needed. It will be shown that there is still a significant potential for making these simulations faster and therefore developing fast optimization tools that would significantly speed up HTS devices development.

Finally, the need for a systematic benchmarking of the various models and methods will be exposed. Existing benchmarks will be presented, and attendees will be invited to contribute in developing new benchmarks that are representative of the state of the art of HTS device engineering. These benchmarks will greatly help in focusing the R&D effort of the numerical modelling community towards the most relevant numerical approaches.

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