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Modeling and simulation of runaway electrons: spatiotemporal effects in dynamic scenarios

A summary of recent progress on modeling and simulation of runaway electrons (RE) at Oak Ridge National Laboratory is presented including new results on the following problems: (i) Role of magnetic confinement, spatiotemporal transport of impurities, and electric and magnetic fields dynamics in the efficiency of impurity-based dissipation of RE. (ii) 3D spatiotemporal effects on the production rate of RE in dynamic scenarios. (iii) Polarization of synchrotron emission (SE). We discuss improvements of physics models and algorithms in the Kinetic Orbit Runaway electron (RE) Code KORC, the SE synthetic diagnostic, and the Backward-Monte-Carlo (BMC) method. Following are further details on the content and main goals of the presentation.

(i) RE dissipation by impurity injection
For this problem KORC has been upgraded with Monte-Carlo operators describing collisions involving partially ionized impurities, and by incorporating time-dependent experimentally reconstructed electric and magnetic fields. Also, line integrated electron density data is used to
construct spatiotemporal models of electron and partially-ionized impurity transport. Simulations involving high-Z impurity injection show that RE losses to the wall are the primary dissipation mechanism and not collisional slowing down. The induced toroidal electric field can actually lead to an increase of the RE energy before loss of confinement. The assessment of the effectiveness of impurity-based RE mitigation is a complex problem involving the competition of different physics mechanisms with potentially very different times scales. In particular, if as in the simulations presented, the time scale of the deconfinement due to the magnetic field evolution is faster than the time scale of the stopping power of the impurity, then the RE might hit and damage the plasma facing components of the tokamak before they can be significantly slowed down.

(ii) Production rate of RE in dynamic scenarios
Going beyond our previous work that limited attention to the computation of the production rate of RE in 2D with a given momentum and pitch angle, we extended the BMC method to account for radial transport. The numerical implementation of this 3D extension uses hierarchical sparse-grid interpolation methods and adaptive refinement techniques. Another important extension of the BMC that will be discussed is the computation of the RE production rate in time dependent scenarios incorporating models for the temperature and electric field evolution during the thermal quench.

(iii) Polarization of synchrotron emission.
The accurate modeling and simulation of SE by RE is critical because it can be used as an experimental diagnostic to infer RE parameters including energy and pitch angle distribution. Although the majority of studies have focused on the total intensity, the polarization of SE can provide valuable information specially regarding the pitch angle distribution. Motivated by this, we present a study of the polarization of SE emitted by RE. In particular, the Stokes parameters describing the statistical polarization state of an ensemble of RE are computed taking into account full-orbit effects and the geometry of the emission. The effects of linear polarization filters on SE synthetic camera images are also discussed.

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