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An Efficient Algorithm for the Wall Electric Field Diffusion Problem During Fast Current Quenches

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During fast current quenches in tokamak discharges the toroidal electric field at the plasma surface E_1 is an important boundary condition as it affects both the rate of the current quench and production of prompt or secondary runaway electrons. The surface boundary condition is influenced by thickness Δ and resistivity η of the vessel wall. If the characteristic skin time of the wall $\tau_{\rm skin} \sim \Delta^2 \mu_0 / \eta$ is much shorter than the decay time $\tau_{\rm p}$ of the plasma current $I_{\rm p}$, then all field quantities within the wall may be assumed to be uniform. Hence, the surface field is given by $E_1(t) = \eta I_{\rm wall}(t) / (2\pi a \Delta)$, in which the wall current is dictated by

$$\frac{dI_{\rm wall}}{dt} + \frac{I_{\rm wall}}{\tau_{\rm wall}} = -\frac{dI_{\rm p}}{dt} \ , \tag{1}$$

with $\tau_{\rm wall} \sim \mu_0 a \Delta / \eta$ being the characteristic time for external flux decay, and a the plasma minor radius. This boundary condition, involving the plasma current at each time step in the plasma current density evolution equation, was used in the KIP code, a (1-D) straight-cylinder plasma model for study of killer pellet shutdown scenarios with runaways in ITER [1].

However , the realistic situation is that $\tau_{\rm skin} \geq \tau_{\rm p}$ and thus the problem of diffusion of the fields into the wall must be solved self-consistently with the plasma evolution making the fully soaked in wall model, Eq. (1), inaccurate. The new approach described here involves three coupled integro-differential equations for $I_{\rm wall}(t)$ and the electric fields on the inner and outer wall surfaces: $E_1(t)$ and $E_2(t)$, respectively. The equations are reduced to two coupled Volterra-type integral equations relating $I_{\rm wall}(t)$ and $E_1(t)$ to the plasma current $I_{\rm p}(t)$ which replace Eq. (1). In this way the essential skin effect during the fast current quench is captured. The numerical algorithm uses a stepwise procedure [2] which allows one to express each discretized variable in terms of earlier values, and thus avoid iterations. Initial results will be presented and compared with previous killer pellet shutdown solutions.

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