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 $\Delta$ and resistivity $\eta$ of the vessel wall. If the characteristic skin time of the wall $\tau_{\text{skin}} \sim \Delta^2 \mu_0 / \eta$ is much shorter than the decay time $\tau_p$ of the plasma current $I_p$, then all field quantities within the wall may be assumed to be uniform. Hence, the surface field is given by $E_1(t) = \eta I_{\text{wall}}(t) / (2\pi a\Delta)$, in which the wall current is dictated by

$$\frac{dI_{\text{wall}}}{dt} + \frac{I_{\text{wall}}}{\tau_{\text{wall}}} = -\frac{dI_p}{dt},$$

(1)

with $\tau_{\text{wall}} \sim \mu_0 a\Delta / \eta$ 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 $\tau_{\text{skin}} \geq \tau_p$ 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 $I_{\text{wall}}(t)$ 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 $I_{\text{wall}}(t)$ and $E_1(t)$ to the plasma current $I_p(t)$ 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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