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Advances in Modeling of Nonlinear Effects in LHCD Experiments

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The concept of lower hybrid current drive (LHCD) in fusion reactors has been recently supported by the experimental evidence that lower hybrid wave power can penetrate at reactor-relevant plasma density. The control of plasma-wave nonlinear interactions occurring at the plasma edge allowed to overcome the density limit observed in previous LHCD experiments. Suitable antenna designs, optimised spectra and operating conditions for efficient current drive in fusion reactors should be based on an accurate modeling of the nonlinear effects. The main nonlinear effect involved in LHCD experiments is the parametric decay of the launched 'pump'waves into LH sidebands. The latter emerge from the thermal noise and are amplified by parametric instabilities (PI) involving ion-acoustic quasi-modes. We propose, here, a full-wave analysis of the nonlinear interactions, considering full LH spectra. We include the effects of the collisions and introduce an accurate modeling of the LH waves produced by the thermal noise. The new modeling significantly improves the standard approach to treat PI in inhomogeneous plasmas, which is based on the eikonal approximation and is limited to 4-wave interactions in collisionless plasmas. We derived from the Maxwell-Boltzmann system, utilising the perturbation theory, the coupled nonlinear equations for the electric field in the high frequency (LH waves) and low frequency (ion-acoustic quasi-modes) ranges. Numerical solutions have been obtained by an iterative method. The frequency spectra of the LH waves calculated for typical LH experimental scenarios confirmed the broadening effect measured by the RF probes. The new model also confirms the result of the standard PI theory that the broadening of the LH frequency spectra is reduced by increasing the density gradient and the electron temperature. In addition, we have found that the nonlinear effects are reduced by increasing the mass/charge ratio of the plasma ions. This suggests a possible, beneficial effect of the lithization, considering that single ionization of Li atoms is expected in the peripheral plasma region where PI occur. The relevant results are discussed and compared with the measured RF spectra in LHCD experiments performed in the FTU tokamak.

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