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Observation of efficient lower hybrid current drive at reactor-level densities on Alcator C-Mod

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In achieving a steady-state tokamak reactor operation, efficient off-axis current drive is essential for developing non-inductive advanced operation scenarios. Lower hybrid current drive (LHCD) has been recognized as the most efficient reactor-relevant actuator, but has appeared to suffer from the "LH density limit" problem- an anomalous loss of efficiency at a density approaching the accessibility limit.

On C-Mod, this limit [1] was observed above a line-averaged density of $\bar{n}_e \approx 1\text{x}10^{20}$ m^{-3}. In the experiments showing this limit, however, the plasma current was set low (< 1 MA) with an aim of maximizing the non-inductive current fraction. As a result, these high Greenwald fraction plasmas ($\bar{n}_e/n_G > 0.2$) had a broad scrape-off-layer (SOL) profile with a high level of blobby turbulence [2].

Studies on C-Mod have shown that parasitic wave interactions in the edge/SOL region may account for the density limit behavior [3-5]. For example, the density for onset of parametric decay instabilities (PDIs) was found to increase with plasma current, suggesting that Greenwald fraction – and associated density shoulders in the SOL – is an important control parameter.

In the most recent C-Mod experiments, the operating plasma current was raised up to 1.4 MA in order to minimize the SOL width and its turbulence level. PDI onset was delayed to $\bar{n}_e \approx 1.4\text{x}10^{20}$ m^{-3} i.e., up to near the accessibility limit. At this density (with $\bar{n}_e/n_G$=0.15), the injected LH power (600 kW) produced a loop voltage drop (ΔV = 0.2 V) consistent with engineering efficiencies found at low density. The LH frequency spectrum measurement indicates that the parasitic edge interactions are minimized. Concurrently, the non-thermal bremsstrahlung emission rate was increased by more than two orders of magnitude compared to the lower current cases that exhibited the "density limit".

The new experimental results indicate that efficient current drive at a reactor density can be attained with proper management of the edge/SOL plasma in a diverted configuration. They also support a proposal to place LH launchers at the high-field-side of the tokamak in a double null configuration [6,7]. In this case, the HFS SOL becomes disconnected from the LFS SOL; density shoulders and blobby transport phenomena are absent at this location. Based on the C-Mod observations, this means that parasitic edge/SOL wave interactions may be avoided on the first pass even at high Greenwald fraction, thus enabling efficient current drive in reactor grade plasmas.

References

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