Towards fully non-inductive operation in NSTX-U

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The start-up, ramp-up, and sustainment of a tokamak plasma utilizing little to no induction from a central solenoid is a major challenge in magnetic fusion. Because of the scientific and operational challenges, the problem is best solved by employing an iterative loop between experiment and simulation where validation plays a critical role in the improvement of modeling and in the projection to new experiments. On NSTX-U, high harmonic fast waves (HHFW) and NBI are available and can be combined to ramp the plasma current non-inductively. This work discusses time-dependent simulations and challenges in optimizing the non-inductive fraction in the early ramp-up phase. It is shown that only a combination of RF and NBI can bridge the phase between startup plasma (either ohmic or non-solenoidal) and ramp-up. In fact, the NBI is lost for shine through in the low density, start-up plasma and cannot be used to drive current in the early phase of the discharge. HHFW prepares a target plasma where NBI can be injected with minimal losses. Current profile control is critical in order to attain the desired target and avoid the peaking of profiles at start-up and ramp-up that are conducive to ideal MHD instabilities.

An interesting synergy is observed between Electron Cyclotron waves and HHFW, depending on the phasing of the antenna. It is shown that the addition of EC wave heating can significantly increase the effectiveness of the RF power and relax the requirements on the total level of power that must be coupled to the start-up plasma. With 1 MW of EC power, the total power that needs to be coupled to the plasma to drive 300 kA of direct fast wave current is reduced from 4 MW to 1.5 MW. This work describes and revisits these simulations in light of the first experimental campaign on NSTX-U with emphasis on the limitations in our modeling capabilities.

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