Modeling of fully non-inductive ramp-up towards development of advanced scenarios in NSTX-U

F.M. Poli, C.E. Kessel, N. Bertelli, G. Taylor

Princeton Plasma Physics Laboratory, Princeton, NJ, 08543-0541, USA

Future Nuclear Science facilities based on the Spherical Tokamak design (ST-FNSF) are projected to rely on Neutral Beam Injection (NBI) to drive about 50% of the plasma current, with the remainder provided by the self-generated bootstrap current. In addition, NBI is also envisioned to provide heating and current drive for non-inductive current ramp-up. In order to assess non-inductive advanced scenarios in ST-FNSF, the National Spherical Torus eXperiment (NSTX-U) is undergoing an upgrade to allow a doubling of the toroidal field from 0.55T and 1s duration to 1T and 6s duration, with 2MA of current for 5s at full magnetic field [1]. A second Neutral Beam system will add three sources with tangency radius of 110-130 cm, providing stronger off-axis current drive (CD) capability. In order to begin extensive discharge scenario modelling, a model of NSTX-U has been built in the free-boundary transport code TSC, which includes the solenoid coils, the poloidal field coils and the passive conducting structures. Time-dependent simulations evolve self-consistently the kinetic profiles and the heating and current drive profiles in order to develop fully non-inductive ramp-up. High Harmonics Fast Waves (HHFW) heating and current drive is applied shortly after the solenoid assisted startup to ramp-up the current and prepare a target plasma where NBI can be used with minimal power/particle losses. Calculations indicate that the power shine-thru can be significant even in plasmas that have been pre-heated with RF to central temperatures of about 800eV. It is expected that the first 500ms of the discharge will have to rely on the dominant use of HHFW and EC heating to prepare optimal target plasmas that are suitable for heating and fuelling by NBI, with minimal shine-thru and orbit losses. 5.1MW of NBI power generates 200kA of NBCD and can ramp the total plasma current up to almost 500kA non-inductively in 2.5s, with the remaining 300kA provided by the bootstrap current. Simulations to define plasma parameters, like the density waveform, that improve the coupling of HHFW are in progress. In addition, the use of EC heating after the startup is being explored to heat the plasma in the early ramp-up phase to improve the HHFW coupling and efficiency. Time-dependent simulations are ongoing to identify an adequate range of density and temperature for optimal EC absorption. It is projected that 5s are needed to ramp-up the current non-inductively to 1MA with 4MW of HHFW and with up to 15MW of NBI, with plasma parameters and shape optimized for maximum absorption and current drive. We will discuss how the phasing of the various sources in time and their energy affect the profile evolution and the access to the advanced target scenarios in NSTX-U, including long pulse operation at 0.75T and 900kA current (not fully non-inductive) and 100% non-inductive current drive at full field and 1MA current. These simulations will provide a reference operational space for non-inductive ramp-up experiments during the first two years of operation of NSTX-U (2015-2016), as well as guidance for the EC accessibility and use for optimization of the ramp-up phase in later non-solenoidal startup experiments.

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[1] Menard J. E. et al, Nucl. Fusion **52** (2012) 083015