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

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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 additional flux available in the new ohmic coil allowing the sustainment of 2MA of current for 5s at full magnetic field [1]. A second Neutral Beam system will add three sources with tangency radius of 110cm, 120cm, 130 cm respectively, providing stronger off-axis current drive (CD) capability. The second beamline is designed to provide 100% non-inductive current for discharges with up to 1.3MA and will extend the operational space available to NSTX-U by enhancing current drive efficiency by an estimated 40% [1]. Extensive simulations have been previously undertaken to define the operational space for fully non-inductive plasmas in NSTX-U [2]. Scenarios were defined over fully relaxed equilibria, extrapolating from experimental NSTX density and temperature profiles. However, a systematic study of the ramp-up phase has not been undertaken so far and this is the focus of this work. 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 [3]. 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 in support of access to advanced scenarios in NSTX-U.

Figure 1 shows the time traces of power, current and plasma parameters for a TSC simulation of a NSTX-U discharge with 0.75T magnetic field and a 500kA target current. Although having about half the target current at the selected field, this case is used as a reference for assessing the RF and NB accessibility and power levels in the first part of the ramp-up phase. Here, High Harmonics Fast Waves (HHFW) heating and current drive is applied shortly after the solenoid assisted startup, at 7.5ms, to ramp-up the current and to raise the electron temperature, in order to prepare target plasmas where NBI can be used with minimal power/particle losses. The HHFW injected power is progressively increased to 4MW and then reduced to zero after 600ms and replaced by NBI. In the case shown in the figure, the simulation uses three sources at 80keV on the new beamline, each delivering 1.7MW of power, with the first source being turned-on at 400ms, and the other two at 550ms and 700ms respectively. Calculations indicate that the power shine-thru can be significant in the ramp-up phase, even in plasmas that have been pre-heated with RF to central temperatures of about 800eV. By using the source at 110cm first, shine-thru losses are reduced from 30% to 9% at the time when the beam is turned-on and drop 75% within 100ms. It should be noted that the beam deposition and efficiency depend on plasma parameters like the density and the pedestal temperature, as well as on the outer gap between the plasma and the limiter, which is not optimized in this simulation. 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 neutral beam injection with minimal shine-thru and orbit losses. In the case shown in Fig.1, 5.1MW of NBI power generates 200kA of NBCD and can ramp-up the total plasma current up to almost 500kA non-inductively in 2.5s, with the remaining 300kA provided by the bootstrap current. For comparison, the same beamline source energy at lower tangency radius can drive only 30% of the current delivered by the new beamline. 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 and improve the HHFW coupling and efficiency. Accessibility conditions for EC injection at 28GHz are satisfied only at the low densities in the early ramp-up phase, typically within the first 100-150ms of discharge [4]. Time-dependent simulations are ongoing to identify an adequate range of density and temperature for optimal EC absorption.

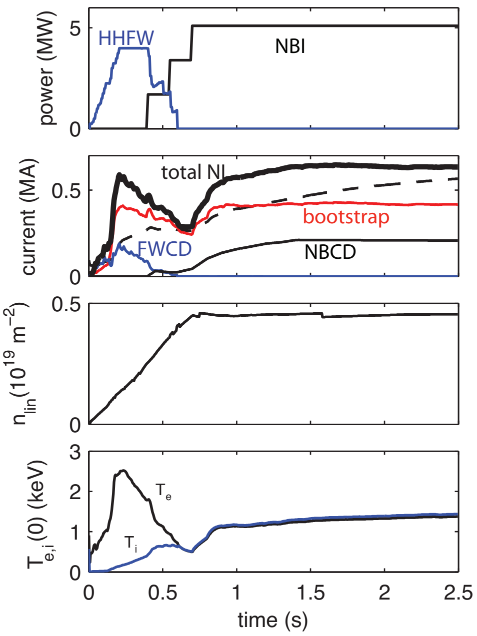

Figure 1. time traces from a TSC simulation of non-inductive ramp-up in NSTX-U, for 0.5T field.

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. It is likely that NSTX-U will have to rely on the new beamline during the first 3s of the discharge, to take advantage of the increased current drive efficiency and better beam confinement, and on the old beamline and sources at 65keV to 85keV in the second part of the ramp-up phase. We will discuss how the phasing of the various sources in time and their energy affect the profile evolution in the ramp-up phase and the access to the advanced target scenarios in NSTX-U, as envisaged in [1,2]. These include 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 non-solenoidal startup experiments.

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