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Advances in the Steady-State Hybrid Regime in DIII-D –A Fully-Noninductive, ELM-Suppressed Scenario for ITER

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A new regime with beta, collisionality and plasma shape relevant to the ITER steady-state mission has been attained in DIII-D using the fully noninductive hybrid scenario, including complete ELM suppression over a wide q_95 window (between 5.9 and 7.1) and with little confinement degradation using resonant magnetic perturbation (RMP) coils. Furthermore, high-beta hybrid plasmas have been integrated with an Argon-based radiative divertor to advance divertor heat flux dissipation towards reactor relevance. Fully noninductive hybrids with simultaneous high beta (β_N≤3.1) and high confinement (H_98y2≤1.4) in the ITER similar shape have achieved zero surface loop voltage for up to two current relaxation times using efficient central current drive from ECCD and NBCD. This steady-state regime has been successfully integrated with ELM suppression by applying an odd parity n=3 RMP, which has only a minor impact on the pedestal pressure (˜15%) and H_98y2 (˜10%). The odd parity RMP couples well to the high-q_95 ITER steady-state case discussed here, whereas the even parity RMP couples better to the low-q_95 ITER baseline scenario. The achieved β_N (=3.1) equals the no-wall limit while remaining below the ideal with-wall limit (=4.1). Central ECCD is found to be effective in suppressing Alfven eigenmodes (AE) and although the thermal transport increases during ECCD, this is mostly offset by the improved fast ion transport from AE suppression. Scaling these DIII-D hybrids to ITER' s major radius and magnetic field while keeping the dimensionless parameters fixed except ρ* yields a 9 MA plasma with 500 MW of fusion power and a required current drive power of 130 MW; this gives Q_fus ≈ 4, close to the desired value of Q_fus = 5. In additional experiments that integrated the hybrid scenario with a radiating divertor, the combination of Argon seeding and strong Deuterium puffing more than doubles the plasma radiative power, up to 55% of the input power, with less than 10% increase in Z_eff and less than 5% reduction in H_98y2. IR camera measurements find that the peak heat flux in the upper, outer divertor falls by a factor of 2 (from 4.6 to 2.3 MW/m2) for the Argon-based radiative divertor.
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