White paper on power-efficient current drive and current profile control

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The fusion program needs to develop power-efficient current drive and current profile control. Conventional RF and neutral beam current drive are very power-inefficient, requiring as much as 1000 times greater than the minimum power to sustain the driven current against Ohmic dissipation[1,2], ($P_{Ohm} / P_{CD} = 10^{-3}$) leading to an unacceptably high recirculating power fraction in a fusion reactor.[3] Lack of profile control causes disruptions,[4] a major weakness of the tokamak configuration. Efficient current drive and profile control would allow operation at the highest beta without the high-bootstrap-current constraint.

Presently the tokamak has three coil sets and a toroidal vacuum chamber that are interlinked. The coil sets are the transformer solenoid, the toroidal field coil and the equilibrium coil. The transformer is used for current drive on present tokamaks and works very well since the plasma current is almost purely toroidal. However, since it is only used for startup in a reactor and other current drive methods must be developed, the transformer can be eliminated and indeed recent ARIES reactor studies[5] do not have this coil. The solenoid free startup method developed on HIT-II using CHI has been successful on NSTX[6] and the first DEMO will probably not have the transformer coil set. Of the remaining two coils only the equilibrium coils are fundamental for toroidal confinement and stable equilibria have been produced transiently that have good confinement at temperatures in the kilovolt range using very little[7] or no[8,9,10,11,12,13] externally produced toroidal field. However, the benefits of the large external toroidal field are considerable. It lowers the amount of current drive required because it allows large β-poloidal and large bootstrap current. It greatly increases MHD stability, allowing a broad range of MHD-stable current profiles. Therefore, the near-term burning plasma experiment, ITER, has the external toroidal field coil. However, if efficient steady-state current drive with sufficient current profile control can be developed, future burning plasma experiments will not need this coil. Elimination of the toroidal field coil allows a simple vacuum vessel, further reducing operational and maintenance complexity, which may be necessary for economically competitive fusion power.[14]

In summary, a high priority should be given to developing high power-efficiency current drive and current profile control.

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