Plasma Initiation and Startup in DIII-D Simulating The ITER Scenario

by
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for
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Plasma Startup in ITER Must Address Several Issues

- Plasma rampup while limiting on outer wall bumper limiters
- Operation near n=0 vertical stability limit (places constraints on maximum $\ell_j$)
- Initiation at relatively low toroidal electric field (~0.3 V/m)
- $q_{\text{min}} > 1$ for advanced inductive and advanced tokamak scenarios

DIII-D HAS STARTED EXPERIMENTS AND MODEL VALIDATION SIMULATING THE ITER STARTUP
DIII-D Has Simulated the ITER Baseline Startup Scenario

- **l_i (1.6)**
  - ITER design limit

- **q95 (12.8)**
  - Constant q95 Baseline Scenario

- **T_e0 (1.8)**
  - Gapout (cm)

- **V_p (15)**
  - Diverted

- **I_p (1.0)**
  - Disruption n/ncrit = -0.91

- **Time (ms)**
  - t=100ms
  - t=800ms

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DIII-D has simulated the ITER Baseline Startup Scenario and helped develop an improved ITER Startup.
$\ell_i$ Feedback Enables Operation Below the Vertical Stability Limit

- Usefulness for optimizing current profile in ITER
- $dI_p/dt$ is used as the actuator
- Real time EFT calculates $\ell_i$, PCS compares to target $\ell_i$ and produces error signal
- Baseline discharges are near $n=0$ stability limit and sometimes exhibit a VDE
Plasma Formation in DIII-D is Near the Inner Wall, But Rapidly Limits on the Outer Wall (< 1s on ITER Time Scale)

- $I_p$ always initiates near the inner wall ($V_{loop}/R$ is maximum)
- ITER startup is "planned" to be further outboard

**Graphs:**
- Graph 1: $R(m)$ vs. $t_{DIII-D}(s)$
  - Single filament fit
  - EFIT(jtvs)
- Graph 2: $I_p(A)$ vs. $t_{DIII-D}(s)$

**Diagram:**
- Large bore startup scenario
- RECH resonance (2nd Harmonic)

**Text:**
- DIII-D scaled to ITER using resistive current time (1:50)
Reduced VLOOP Startup Was Achieved in the ITER Scenario

Initial experiments achieved startup on the outer wall at reduced voltage.
Reduced $V_{\text{LOOP}}$ Startup was Achieved in the ITER Scenario
ECH Allows Initiation at A Higher Neutral Pressure

- Initial experiments achieved startup on the outer wall at reduced voltage.
- Higher prefill with ECH may provide more flexibility in startup.

### Graphs

- **Reduced $V_{\text{LOOP}}$ vs. Time (ms)**
  - Normal DIII-D
  - ITER design value (0.3 V/m)

- **Heat Power ($P_{\text{Heat}}$) vs. Time (ms)**
  - $P_{\text{ECH}}$
  - $P_{\text{Ohmic}}$

- **Current ($I_p$) vs. Time (ms)**
  - Normal DIII-D

- **Pressure ($P_{D_2}$) vs. Time (ms)**
  - Normal DIII-D

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Modeling Predicts Vertical Stability (n=0) And Coil Currents are Near Limits During the Ip Ramp

- CORSICA simulation models ITER baseline scenario
  - Scenario 2 “small bore baseline startup
  - Maximum \( i(3) = 1.15 \)
- Good control during rampup
- But...
  - poloidal field coils are near current limits
  - Vertical growth rate, \( \gamma \), is near control limit

- Inner Coils in vertical control circuit (VS2) can improve stability
Corsica is Being Benchmarked Using the DIII-D Current Ramp Phase

- Corsica modeling predicts approximate onset time for sawteeth ($q_0 \sim 1$)

- Corsica predicts $l_i$ higher than ITER design values. Both $l_i$ formulations are included:
  - $l_i(1)$ used in DIII-D
  - $l_i(3)$ is ITER $l_i$ approximation
Summary

- DIII-D has simulated the ITER small bore baseline outer wall startup scenario
  - Measured $l_i$ is above the ITER design limit.
- A new large bore startup scenario was developed for ITER
  - Lower $l_i$ and higher $q_{\text{min}}$
- Real time feedback control of $l_i$ has been demonstrated
  - Allows control of the current profile (important for AT scenarios)
- Breakdown in DIII-D always occurs near the inside wall
  - Occurs at or near maximum $E_{\phi}$
  - ITER breakdown is assumed to occur further outboard
- ECH and low voltage startup experiments have started
  - Can provide better simulation of ITER startup
- CORSICA benchmarking of DIII-D experiments will allow more accurate predictions of ITER startup
  - ITER coil current and vertical stability are near limits
- Continuing work in 2008 will extend these initial results