EUROfusion

PULSE DESIGN SIMULATOR FOR JT-60SA

E. Joffrin 1), F. Artaud 1), M. Mattei 2), D. Frattolillo 2) 5), W. Bin 3), C. Boulbe 4), L. E. Di Grazia 5), G. Falchetto 1), B. Faugeras 4), G. Giruzzi 1), M. Iafrati 6), A. Mele 7), M. Schneider 8)

1) CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France.
2) Università di Napoli Federico II, Consorzio, via Claudio 21, 80125, Napoli Italia
3) Consiglio Nazionale delle Ricerche (ISTP-CNR), via R. Cozzi 53, 20125 Milano, Italia
4) Université Côte d'Azur, CNRS, INRIA Castor, LJAD, Parc Valrose, 06108 Nice Cedex 2, France
5) CREATE Consorzio, via Claudio 21, 80125, Napoli Italia
6) ENEA - C.R. Frascati - Via Enrico Fermi, 45 00044 Frascati (Roma)
7) École Polytechnique Fédérale de Lausanne Rt Cantonale, 1015 Ecublens (VD) Switzerland
8) ITER-Organisation, Route de Vinon sur Verdon, 13115 St Paul Lez Durance, France

Objective of the PDS

Tool for scientists to assist the development of their experimental/operation scenario before proposing or implementing an experiment on the machine.

- Light tool: accessible with a « reasonable » CPU time.
- Capable of simulating a discharge from start of ramp-up to end of ramp-down, including X-point formation, heating, ramp-down, etc …
- Includes the machine operational constraints (current limits, forces, voltage limits, …
- Friendly interface

The present simulator was developed in a pragamatic way with modellers, control engineers and operation specialists. The same principle is used for the WEST and ITER PDS.

What the pulse design simulator does not do

- The simulator is not aiming at describing transport (like ASTRA; CRONOS, etc). It uses light formulation for « reproducing » plasma kinetics and reduced models.
- It is not a high fidelity model for plasma discharges: does not contain disruption models nor sophisticated edge or fast particle or transport models models for example.

Pulse design simulator structure

The simulator is built on the coupling of three main components:

1. The plasma kinetic simulation from METIS [1]
2. A free boundary equilibrium (FBE) code CREATE_NL[2] or NICE [3] (used in “direct mode”)
3. The Simulink© controllers.

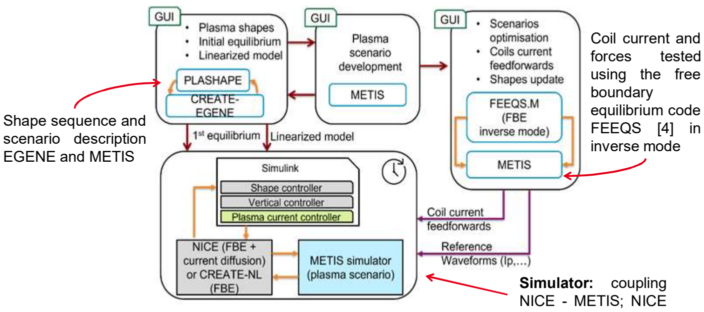

Figure 1: Pulse simulator structure

Two possible modes of operation:

1. Weak coupling (faster and more stable but only I_p, β_P & l_i exchanged) [5]
2. Strong coupling (slower and less stable: P' and FF' exchanged), but not stable due to the challenging coupling of the Grad-Shafranov equation with the current diffusion equation.

New numerical coupling between NICE and METIS [6]

Provides a cleaner mathematical solution between the Grad Shafranov and the current diffusion equations. The current diffusion is solved in NICE and coupled to METIS.

Sawtooth mechanism implemented to prevent excessive peaking of the current profile

Controller design

Magnetic controllers designed from linearized models using CREATE-L [7] and CREATE-NL+ [8] codes. These models describe the dynamic behaviour of the plasma, the active control circuits, and the currents flowing in the surrounding conductive structures in the neighbourhood of a given equilibrium point.

The output of the code includes plasma current, currents in the active coils, plasma to wall gaps [9], as well as the poloidal flux and fields on specified control points to control the plasma shape in the iso-flux control mode (see figures below)

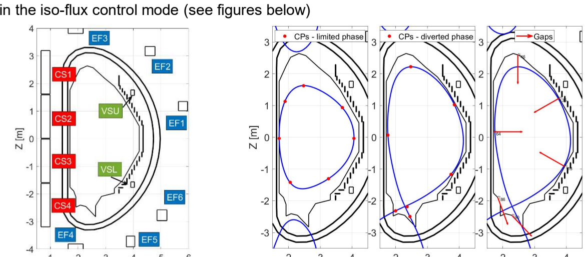

Figure 2a (left): JT-60SA poloidal cross-section with the poloidal coils – Figure 2b, 2c and 2d: Example of Control Points (CPs) on which to compute poloidal flux and fields for the limited plasma phase, and diverted plasma phase, and controlled gaps.

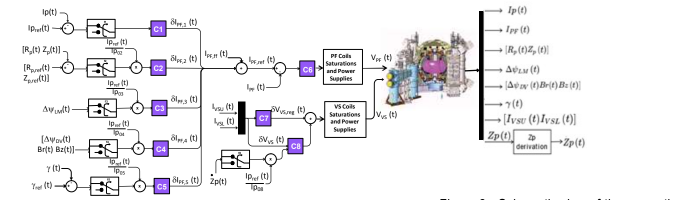

Figure 3 - Schematic view of the magnetic control architecture [10], [11], [12].

C1: Plasma Current Controller (SISO, PI)
C2: Centroïd controller radial and vertical position (SISO)
C3: Plasma shape controller, used for limiter plasmas
C4: Plasma isoflux shape controller for early diverted phase [13].
C5: Plasma gap controller
C6: PF Current Controller guarantees PF currents circuits track the references $I_{PF,ref}$ which is the sum of the nominal feedforward currents and the requests generated by controllers (C1-C5).
C7: Regularization control action to regulate the VS current to zero.
C8: Vertical Stabilization control for highly elongated plasma [14]

Simulator results and outlook

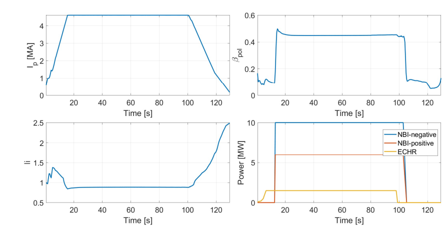

Figure 4 (above): Relevant global quantities for METIS simulation of the 4.6MA scenario: plasma current, poloidal beta, internal inductance and auxiliary power. The plasma composition is deuterium and carbon/oxygen as impurities.

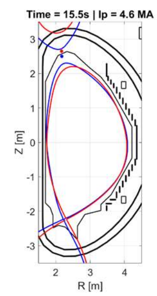

Figure 5 (above): Example of equilibrium modification for the 4.6MA scenario. The initial equilibrium (obtained using FEEQS current) is corrected to move the non-active upper X-point outside the chamber.

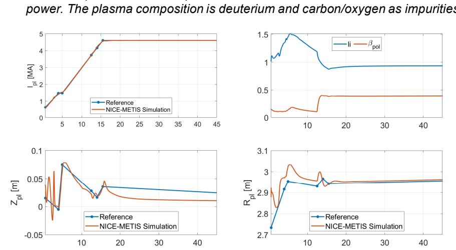

Figure 6 (left): Evolution of plasma current, internal inductance, beta poloidal, radial and vertical plasma centroid position during NICE-METIS simulation for the 4.6MA scenario

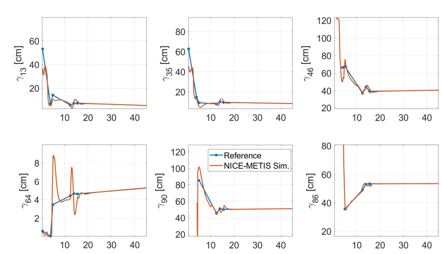

Figure 7 (left): Gap control during NICE-METIS simulation for the 4.6MA scenario

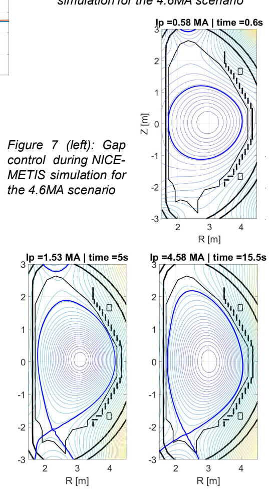

Figure 8a, 8b and 8c (above) - Relevant plasma shapes during NICE-METIS simulation for the 4.6MA scenario.

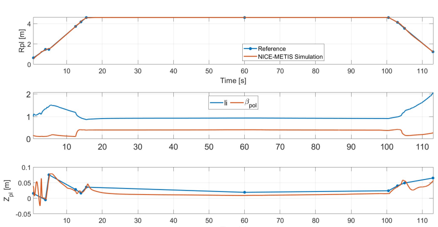

Figure 9 (left): Simulation of the 4.6MA/2.25T scenario with the pulse design simulator with Ip (top), b, internal inductance (middle) and vertical position (bottom).

- The pulse design simulator (PDS) and its controllers are ready for use by dedicated expert
- The controllers used in the simulator have been designed in an ad hoc way, but the simulator use those developed during JT-60SA operation and tested in the first phase of operation of the machine (OP1) [15]
- At this stage tuning the controllers parameters still requires the help of a control engineer specialist.
- The simulator runs on the EUROfusion Gateway and a user manual has been produced.
- The CPU time has not yet been fully optimized but this is the task of future work with the expert users

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