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The architecture and test-bed of the T-15MD tokamak plasma control system

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Currently, National Research Center "Kurchatov Institute" is working on the tokamak T-15 modernization. Plasma parameters (current, position, the shape of plasma cord, electron density, and energy content) on the T-15MD tokamak are controlled by an electromagnetic system, dynamic gas injection, and a complex of additional plasma heating systems (neutral beam injection, ion-cyclotron, low-hybrid resonance, and microwave). The individual components of the Power Control System (PSCS) and Plasma Control System (PCS) are distributed over distances of up to 300 m, and their interaction must be coordinated and synchronized with an accuracy of tens of microseconds.

A key feature of the developed T-15MD PCS is its ability to rapidly design, test, and deploy real-time shot scenario algorithms with the distribution of computing power between subsystems.

The electromagnetic PCS architecture consists of two levels:

1. High application-specific level: model development and linear approximation, calculation of the experiment scenario, controllers design and experiment simulation (Matlab Simulink RT / Linux RT).

2. Process control level: real-time control of plasma parameters (National Instruments (NI) hardware running LabVIEW RT operating system and ported CS-PF regulator as dll from Simulink).

In the Hardware-in-the-Loop (HIL) simulation mode (Fig. 1) communication between the levels (1) and (2) is realized by the reflective memory (RFM) "star"topology network and the middleware S-function package within Simulink RT / Linux RT environment that performs the role of Middleware. The electromagnetic PCS Simulink model structure shows in Fig.2.

At the moment, the electromagnetic PCS shown in Fig. 3 is implemented. The total data transfer latency in the PCS control cycle does not exceed 1.1 ms, which fits into the required maximum latency of the 3.3 ms.

The proposed architecture will allow performing tests and configuration of the PCS before plasma shots, which increases the efficiency of the experiments while reducing costs. In the future, the plan is to use Simulink RT on PCS DAQ Server to perform real-time calculations of plasma equilibrium reconstruction in the magnetic control loop, implementing PCS data exchange in the RFM network. It is planned to develop infrastructure for simplified integration and testing of third-party control algorithms and plasma-physical codes. Plasma equilibrium reconstruction code deployment on a high-performance server integrated in real-time with the EMD and the PCS controllers in the operational configuration. Interoperability is provided by the Skiner PTP adapter (data transfer with the exact timestamp binding) and RFM. The achievements and advantages of PCS architecture:

1) Development of regulators, codes, and models in the Simulink and DINA environment:

- Currently, Linux OS used with function ported from Simulink;

2) Adding the HFC PS control system after the T-15MD tokamak physical start-up will be performed as a simple upgrade without changing the hardware architecture and software.

3) The use of RFM network and the implemented decomposition of the hardware kit allow to quickly and cost-effectively switch from operational configuration to HIL test-bed (Fig. 4) and expanding PCS functionality.

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