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Real-time control for long ohmic alternate current discharges

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HIGHLIGHTS

- 40 Alternate plasma current (AC) semi-cycles without loss of ionization, more than 1 s of operation.
- AC discharges automatic control: feedback loops, time-windows control strategy, goal oriented time-windows and exception handling.
- Energy deposition and Carbon radiation evolution during the AC discharges.

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ABSTRACT

The ISTTOK tokamak has a long tradition on alternate plasma current (AC) discharges, but the old control system was limiting and lacked full system integration. In order to improve the AC discharges performance the ISTTOK fast control system was updated. This control system developed on site based on the Advanced Telecommunications Computing Architecture (ATCA) standard now integrates the information gathered by all the tokamak real-time diagnostics to produce an accurate observation of the plasma parameters. The real-time actuators were also integrated, allowing a Multiple Input Multiple Output (MIMO) control environment with several synchronization strategies available.

The control system software was developed in C++ on top of a Linux system with the Multi-threaded Application Real-Time executor (MARTe) Framework to synchronize the real-time code execution under a 100μs control cycle. In addition, to simplify the discharge programming, a visual Human–Machine Interface (HMI) was also developed using the BaseLib2 libraries included in the MARTe Framework.

This paper presents the ISTTOK control system and the optimizations that extended the AC current discharges duration to more than 1 s, corresponding to 40 semi-cycles without apparent degradation of the plasma parameters. This upgrade allows ISTTOK to be used as a low-cost material testing facility with long time exposures to nuclear fusion relevant plasmas, comparable (in duration) with medium size tokamaks.

1. Introduction

Alternate Current (AC) plasma discharges [1,2] is one of the ISTTOK tokamak ongoing research topics. The fast control system was recently upgraded [7] with new hardware based on the Advanced Telecommunications Computing Architecture (ATCA) standard [3–6] to improve the AC discharges stability and reliability.

The ATCA hardware crate is composed by: (i) an adapted Commercial Off-The-Shelf (COTS) motherboard equipped with an Intel® Q8200 chip (4 cores running at 2.33 GHz), and (ii) two acquisition boards with 32 analog-to-digital converters (ADCs) each. This system also contains a four serial ports board connected to the main control board via the motherboard PCI connection, the serial ports communicates with the power supplies at a rate of 921.6 kbit/s.

The real-time control system runs on a configured version of Linux GENTOO with several kernel features disabled in order to optimize it for real-time operation. The control system was programmed in C++ on top of the Multi-threaded Application Real-Time executor (MARTe) Framework which synchronizes the code execution. Thanks to these features the system runs with a control cycle of 100 μs with low jitter assured by the correct configuration of the MARTe framework.

Multi-cycle AC discharges require different type of control strategies throughout the discharge. In order to improve the plasma

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control quality, a multiple input multiple output (MIMO) system was developed, including all ISTTOK real-time diagnostics and actuators. As a part of this upgrade, a new ohmic power supply (PS) was also commissioned to improve the plasma current control. This power supply is described with more detail in Section 3. After the control system commissioning the AC discharges duration increased from about 250 ms, with 10 AC cycles without constant plasma parameters (old system), to more than 1 s with 40 complete AC cycles with no dwell time in the plasma current inversion phase.

To extend the AC discharges duration, several synchronization and active feedback strategies were developed. A visual Human-Machine Interface (HMI) was also developed in order to simplify the more complex control structure [8]. This interface provides the necessary tools for the machine operator to program more complex synchronization strategies. The system is controlled using the time-windows paradigm where the user defines the control mode for each time-window and for each actuator. The HMI uses the BaseLib2 libraries from the Multi-threaded Application Real-Time executor (MARTe) framework [9–11] to generate an HyperText Makeup Language (HTML) and Javascript based interface that runs outside the MARTe real-time thread and in a different processor core to avoid degradation of the system real-time characteristics.

Several studies were performed after the control system was commissioned to access the long term performance characteristics of the AC discharges in terms of impurity content and power deposition. The results from these studies are included in the results chapter.

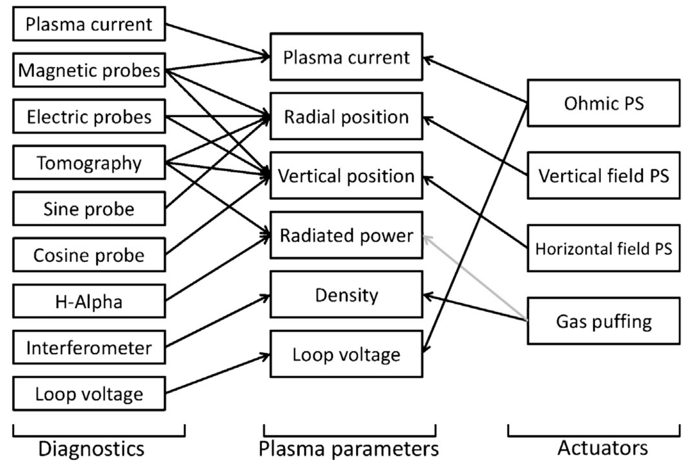

Fig. 1. ISTTOK diagnostics contribution to the measured quantities and actuators main contribution in the plasma parameters.

2. Diagnostics

The available real-time diagnostics are acquired by two ATCA acquisition boards and were integrated into the plasma control system in order to produce a Multiple Input Multiple Output (MIMO) system. The developed control system has the redundancy advantage and also allows the machine operator to select each diagnostic contribution when establishing an observer measurement. In Fig. 1

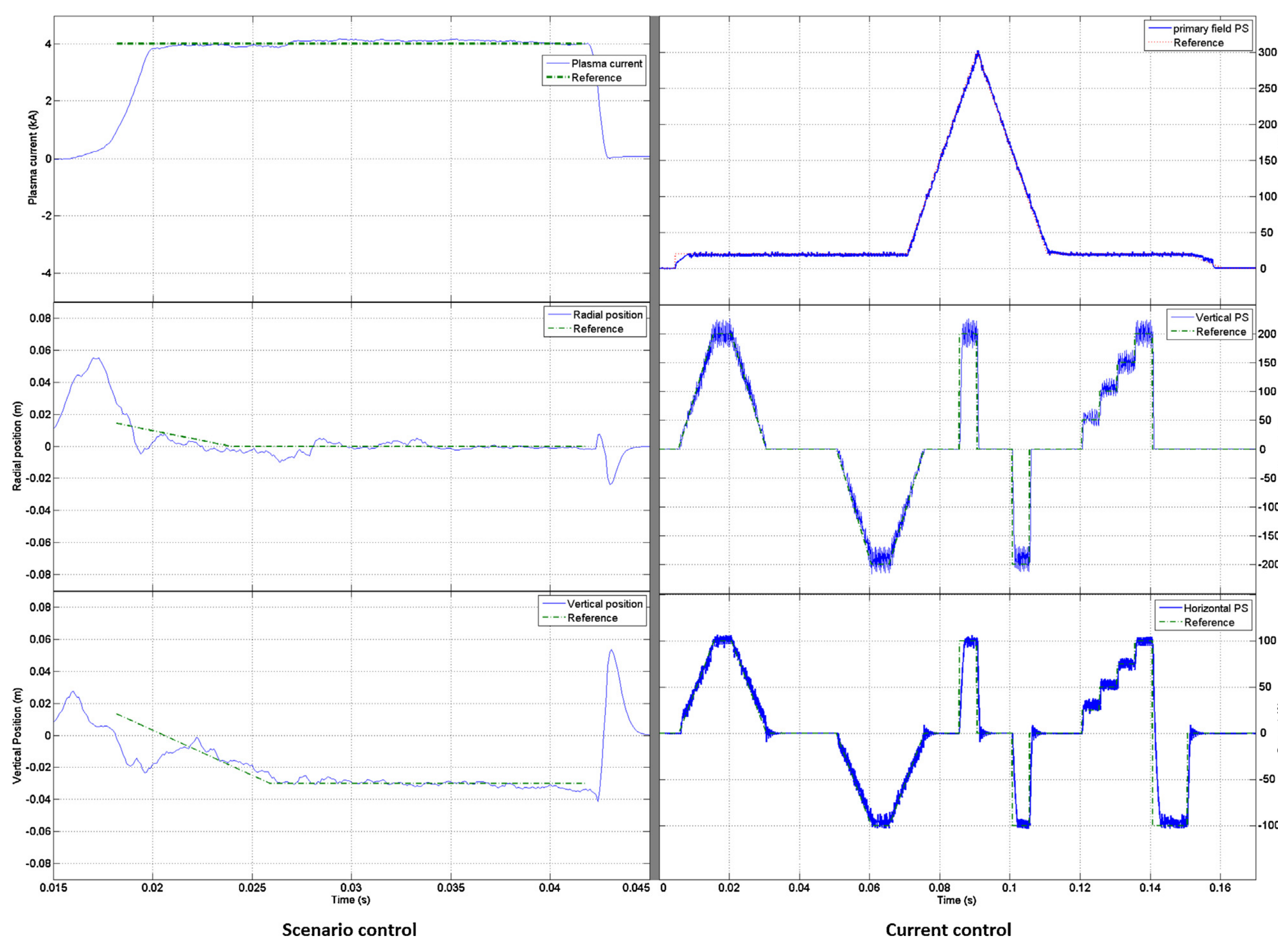

Fig. 2. Differences in reference following between scenario control and current control. In the left and from top to bottom are: plasma position, radial position and the vertical position. In the right and from top to bottom are: magnetizing field PS current, vertical field current and horizontal field current.