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The design and implementation of a new plasma control system

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For present tokamaks and future fusion reactors, the control of plasma initiation, shaping, heating, stabilization, and safe termination of discharges is required. In order to integrate various control functions and meet the requirements of safe and steady-state operation of the device, the design and implementation of the plasma control system (PCS) infrastructure have been completed.

A dual redundant cluster structure is adopted for system scalability and reliability concern. Non-real-time applications and real-time control processes are deployed separately on host and real-time nodes. Master and slave clusters, configured with same hardware and operating parameters, can run synchronously and be switched within a control cycle when one of them works abnormally. Besides, a heartbeat network is designed among PCS and external input/output systems, such as distributed real-time data acquisition systems and actuator command receiver subsystems. Any abnormal heartbeat will trigger the event handling of PCS to ensure the system reliability.

A component-based distributed real-time control framework is designed as the software architecture. The core framework provides communication, XML configuration, data management, etc. While various application components can be expanded like Lego blocks building to realize plasma operation functions, such as user login, parameter configuration, task deployment, execution workflow and health management, etc. By adopting data encryption, user permission hierarchical authentication, and parameter legality check, the new PCS ensures the security of input data. During operation, the health component can collect system hardware and software operation status for the local interlocking, while the plasma transient status is also detected and handled in real-time by the off-normal event handling component to ensure the safety and reliability of the system. The real-time performance of the new PCS infrastructure is guaranteed by developing high-speed real-time data distribution service based on real-time network and shared memory technology, and utilizing multi process parallel technology to achieve multi task distributed deployment across CPUs. The statistical results indicated that the fastest control cycle was less than 50 microseconds. To support steady-state operation, the real-time parameter parsing, state machine real-time operation scheduling, and data segmental storage technology is adopted in the new PCS. And over 50 hours continuously running has been verified using historical experimental data.

The integration of the main control algorithms of EAST in the infrastructure was achieved using a visualization software development platform PCS-SDP. And then, the correctness of control and the reliability of the system were fully validated by utilizing historical data simulation, model-based simulation through the plasma control simulation verification platform PCSVP, and experimental piggyback running. Finally, the prototype system was successfully put into operation in EAST experiments in August 2023. In nearly 300 discharge shots, the system ran without any failures and achieved stable plasma current, shape and density control. The plasma current control error is less than 1%, and the shape control accuracy reaches millimeter level.

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