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An overview of control system for the ITER electron cyclotron system

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ABSTRACT

The ITER electron cyclotron (EC) system having capability of up to 26 MW generated power at 170 GHz is being procured by 5 domestic agencies via 10 procurement arrangements. This implies diverse types of equipment and complex interface management. It also places a challenge on control system architecture to entertain the constraints of procurement slicing and meeting the overall functional requirement. The envisioned architecture is to use the local control units (supplied with each procurement) and a supervisory plant controller (by ITER). This offers a reliable control configuration for such delicate and complex EC plant system. The control system is envisioned to monitor the whole plant and perform automated tasks that are today performed via direct human intervention. For example, the automated gyrotron conditioning and active control of the EC plant to respond to requests from the plasma control system (PCS). This later aspect requires rapid shut down of the gyrotrons and power supplies, deviation of the actuators to direct the power from an equatorial to upper launcher and then restart of the power generation for rapid stabilization of the magneto hydrodynamic (MHD) instabilities that occur in high performance plasma operation. The plant controller will be designed for optimized performance with the PCS and the feedback control system used to actively control the power (with modulation capability up to 5 kHz) and launching direction for MHD stabilization.

1. Introduction

The ITER EC system operating at 170 GHz is designed to inject 20 MW CW power [1]. The major components of EC H&CD system are comprised of up to 26 gyrotrons, corresponding 13 High Voltage Power Supplies (HVDC) and 24 transmission lines (typical length of 160 m) [2,4] and launchers (1 equatorial and 4 upper).

The EC system is one of the three envisioned heating systems providing $\geq$ 73 MW for plasma heating and current drive applications. The ITER machine and so the EC system also require automated operation with minimum number of operators. The requirement for control on the EC system is very complex and needs to perform various functions in different time scales and tight coupling with plasma properties. This is a very delicate and crucial part of the EC system and the key aspect is how the EC H&CD system interfaces are established from instrumentation and control point of view within the system and with the plasma control system. A concept for the instrumentation and control (I&C) is being established to meet the functional requirement of the EC system complying with many restrictions and guidelines. This paper provides a brief overview of the EC system components and its organization, then describes the standards for instrumentation and control (I&C) at the ITER organization, the conceptual design of the EC instrumentation and control and proposed concept being envisioned for the EC system.

2. EC system and operation requirement

The current configuration of the electron cyclotron system allows 12 power supplies to feed 24 gyrotron units to generate

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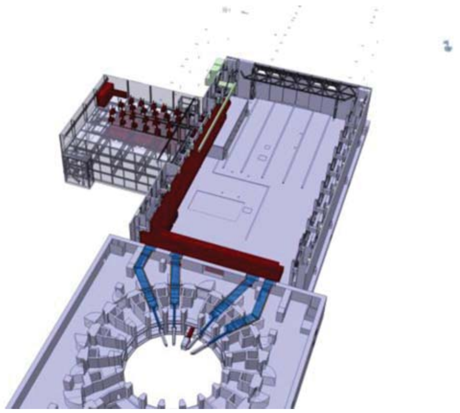

Fig. 1. Overview of EC system at ITER.

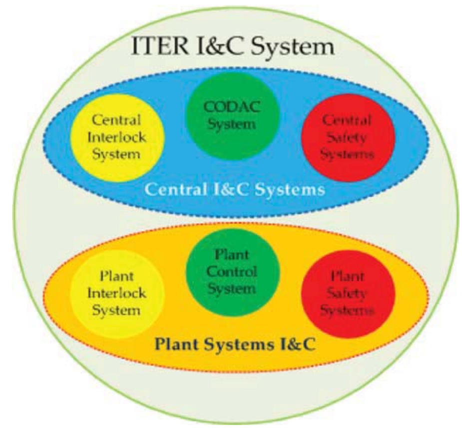

Fig. 2. ITER instrumentation and control components and its organization.

the 24 MW of EC power, which is then transmitted via 160 m corrugated low loss circular waveguide to two types of launching antennas (or launchers). In the present configuration one main HVDC power supply shall be used to power 2 gyrotrons [3]. A picture of the EC system at the ITER is shown in Fig. 1. Numerous ancillaries such as the auxiliary power supplies associated with the super conducting magnet, collector coil, cathode heater, vacuum pump, etc. all of which are controlled via I&C system is not visible in Fig. 1. The transmission line also includes components that play active role in EC system operation like the polarisers, the mitre bends with power and other diagnostics, isolation valves, RF switches to direct the microwave power to the different launchers. The launcher uses a steering mirror assembly to steer the RF beams to required plasma position in the ITER tokamak.

The ITER is mainly built by in-kind procurements and so the EC system also with different procurement arrangements. All the mentioned components above are grouped in the different procurement packages and contributed to ITER by the five parties (domestic agencies) as described in Table 1. Normally the control system is a single system designed, built and installed by the organization assembling the whole EC system, but the ITER in-kind procurement strategy divides the control system in accordance with the procurement packages.

The EC system shall be used primarily for initial breakdown, auxiliary heating in H mode, on & off axis current drive and the control of MHD instabilities by localised current drive. Hence it is required in almost every experiment in the ITER and throughout nearly the entire plasma pulse. Starting with the initial plasma breakdown, the plasma control system (PCS) will direct the turn on and power level of the EC power required initiating plasma breakdown, followed by plasma burn-through. Then the PCS will regulate the applied power and its deposition for the current ramp-up phase and L to H-mode transition. As needed the EC power will be distributed for controlling the temperature and current profiles and in the event of the MHD stabilization activity, the PCS system will redirect the power as needed to the relevant q-surface for stabilizing the MHD mode. The MHD control requires real time feedback system to track the instabilities and steer the EC power to the mode in question. Depending upon the plasma conditions, the EC power steered to act upon the instabilities and RF power is modulated up to 5 kHz with phase tuning in track of the feedback obtained from plasma control system.

Table 1
The In-kind procurement sharing of EC H&CD plant.

EC subsystem	Units	Contributor
Gyrotron (RF power source)	8 MW (8 units)	Europe
Gyrotron (RF power source)	8 MW (8 units)	Japan
Gyrotron (RF power source)	8 MW (8 units)	Russia
Gyrotron (RF power source)	2 MW (2 units)	India
HVDC power supply	2/3 of all the units	Europe
HVDC power supply	1/3 of all the units	India
Transmission line	24 sets	United States
Upper launcher	4 units	Europe
Eq. launcher	1 unit	Japan

To achieve all these functionalities, the EC system requires well interfaced and close coupled instrumentation and control system. The ITER and the domestic agencies (contributor parties) are working with the ITER organisation developed standards, to use combination of different types of controllers, sensors, interface scheme and data communication scheme to have unified control for EC system and its integration in the ITER operation.

3. ITER instrumentation and control

As mentioned above, the EC system is required to interface with the central instrumentation system of ITER and plasma control system. Apart from these, the control and data communication interface is required between the service provider system like water cooling, vacuum etc. and the EC system. The ITER organization has developed a set of standard to address the issues for interface and integration.

The instrumentation model of the ITER is made up two levels of hierarchy and three different tiers corresponding to dedicated type of function (Fig. 2). The control function communication between different system can be performed over CODAC networks made up of high performance data communication networks for deterministic data and the control command transfer while general purpose Ethernet network called plant operation network (PON) to communicate for slow time scale in asynchronous mode. The plant interlock system communicates with the central interlock system over the central interlock networks. The safety system provides occupational and environment protection. The coordination between the plant system and central safety system shall be carried over a dedicated physical separate central safety network [5].

A specific set of rules and guidelines are organised in plant control design handbook, which can be used while developing the plant system I&C model for easy integration and compatibility to the ITER environment. The standards have been framed and revised for hardware and software to be used for the plant instrumentation and control system [6].

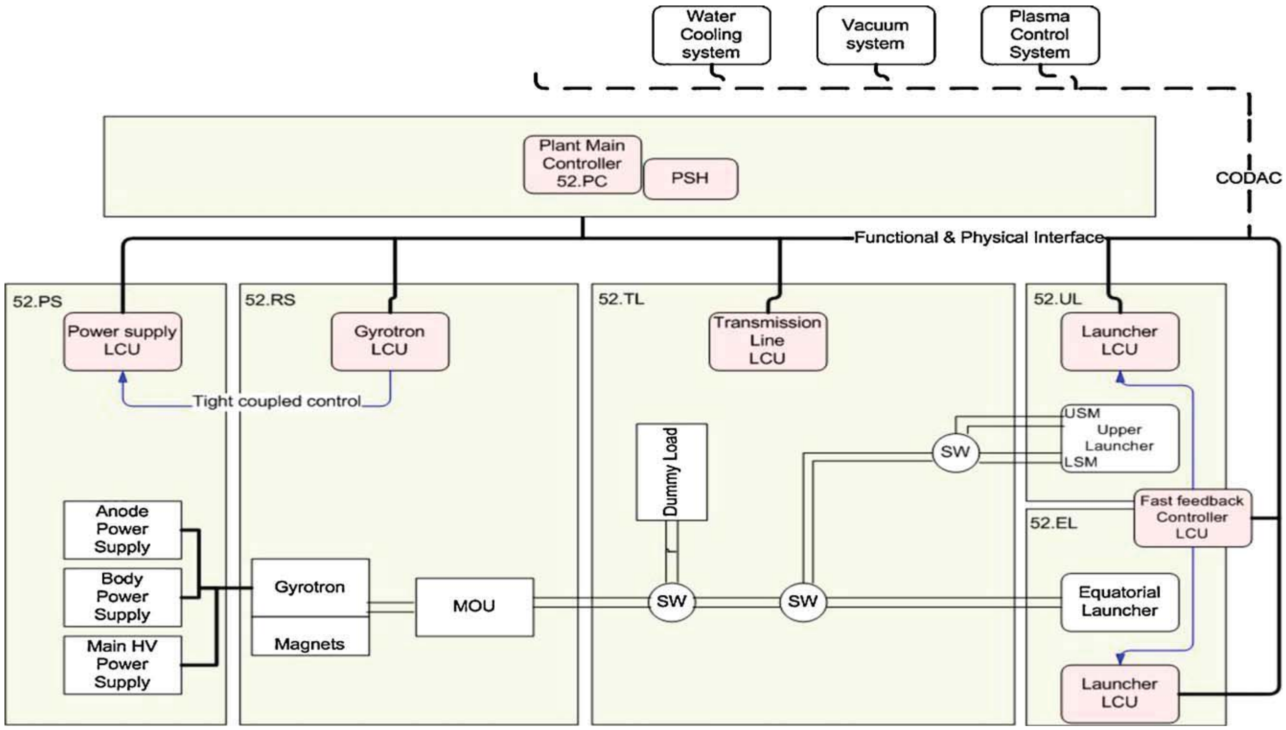

Fig. 3. Major I&C components for EC system.

4. Control system architecture

A conceptual signal list of EC system estimates around 5000 signals, which need to be processed for operation of the EC system. The functionality demands different time responses and scale of processing. The signal list covers the measurement and control of cooling water parameter to the control of DC high voltage (~55 kV). The envisioned architecture for the control system of the EC system will be modular to meet the control requirement of EC system over a wide physical range and procurement scope. A modular approach also facilitates processing of such huge amount of signals.

There shall be local control units associated with the subsystems. The local instrumentation control unit (LCU) provides an autonomous close loop control on steady state operating parameter of components like auxiliary power supplies, cooling system, and other services. The state and alarm are communicated to other subsystems to map and control the operation state.

In the terms of operation and control, the gyrotron with auxiliary power supplies and main power supplies form a complete RF source. The ITER operations need automatic configuration as well as fast feedback real time control. To survive on the real time feedback control loop, a minimum number of data interfaces are desired. A remote I/O based interface architecture is being proposed to handle the real time control of power supplies from gyrotron LCU. The concept facilitates almost independent development of the control logics at power supply and gyrotron ends. The structure allows gyrotron LCU to configure the operation point and sequence logic as per the gyrotron requirement. The sequence logic control which obviously required slow time response (not faster than 10 mS) shall be developed using Siemens S7 Programmable Logic Controller (PLC).

The ITER machine shall be a CW operation and requires the launchers control in very dynamic way. The logic for the operation of launchers need a feedback from plasma control system and the loop needs a relatively fast time response in order of 20 mS. The commands/feedbacks are translated in to the configuration chart by the main controller of EC system and shall establish a direct communication channel between launcher and gyrotron controllers with Plasma control system to participate in the fast feedback control function. ITER is working to establish the standard technology to use for high speed data communication.

The EC system main controller will serve as supervisory controller to provide control and operation co-ordination. As per the current schema, the main controller shall serve as a manager for the 24 units and provides the functional requirement to LCUs. It provides the operation mode to derive configuration parameters by local control units (LCU) for their components. Fig. 3 lists the schematics of EC H&CD control system functional diagram. The EC system main controller performs the supervisory control but the signal and command can flow in between the two LCU directly based on the configuration set by the main controller. The LCUs are interfaced in wide variety to perform the integrated action commanded by main controller. The LCUs shall be developed individually with constraints of standards and interface specifications provided by the ITER to meet long term cost for up gradation and spares. To perform internal communication between the local controller and EC subsystems CODAC networks will be used to maximum possibility. It provides a flexibility of testing the configuration and operation performance.

The EC system at ITER shall be required to operate on two prime modes as Dummy load operation mode and Tokamak injection mode. In the dummy load operation mode, the system coordinates the operation of a reduced set of RF sources to their dummy loads. This mode of operation is used for system calibration; commissioning and gyrotron daily start-up/conditioning. In the tokamak injection mode the system coordinates the EC system for the plasma heating and current drive applications. Efforts are being put to cover and develop a versatile instrumentation and control system to cope with all the operation requirements.

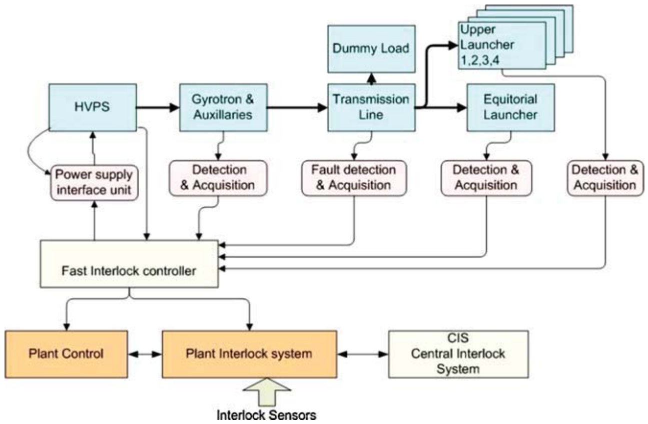

Fig. 4. A typical schema for fast interlock processing for EC system.

5. Interlock and safety system

The interlock system will be operated in hierarchy depending on criticality and time scale of operation. The conventional interlock signals with response time of few tens of milliseconds, the interlock actions are handled through the local interlock control units, typically made up of Siemens S7 PLC. The state of component is conveyed to over the plant interlock networks (PIN) to different subsystems and over the central interlock network to other plant systems. There are many industrial solutions are available to communicate between PLCs but the EC system shall adapt the IO recommended communication protocol to communicate the interlock events between subsystems. The topology needs a detailed analysis and prototype test to confirm the operation Fig. 4.

There are also fast action interlock signals, of which a good example is the interlock event when a gyrotron encounters an internal arc event. The main HVDC power supplies of gyrotron unit need to be shut off within 10 μS. All the detectors shall communicate with the fast interlock processor for the event. The fast interlock processor works as a central processor and provides triggers to corresponding power supplies to protect gyrotron tube against damage. The time of operation is crucial and so the direct interface between the sensors and the processor is desired. The signal will be coupled to the interlock processor over the fibre optic link. A definition of the standard communication protocol between subsystem components needed to communicate efficiently and reliably with minimum communication delay to participate in <10 μS interlock action. The signals are also required to record for the post event analysis. The fast interlock signal will be acquired on the event basis with the time stamping from the timing information conveyed over the Time Communication Network (TCN) with very high resolution rate in order of <1 μS. The fast interlock processor is envisioned to be based on application of FPGA technology. The standard FPGA boards shall be encouraged to be used over EC system.

The safety system shall provide occupational and environmental safety. The system requires high level of reliability. The sensors and controllers need be redundancy of operation to provide higher reliability of action. A task is on going on defining the safety function related to EC system to develop the Schema of architecture

6. Summary

The EC system at ITER is to be the largest EC system of world. This plant is being assembled by the ITER organization and the five international partners (Europe, India, Japan, Russia and US). The procurement method adds an additional challenge. The EC control system is designed with an architecture that is compatible with the procurement strategy and provides an efficient operation. A review of this architecture has been presented that demonstrates the feasibility and methodology in handling the numerous signals, interlocks and control sequences.

The whole control system is being developed in collaboration with the international partners to ensure compatibility in the installation and operation.

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