

Seminar

Institute for Plasma Research

Title: Development, Installation and Validation of Control System for operations of 1MW, 170GHz, 1000s Gyrotron System at ITER-INDIA Gyrotron Test Facility

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Abstract

ITER is an international experimental fusion reactor that is under construction in France to demonstrate the feasibility of Nuclear Fusion as an alternate energy source. ITER-India has to deliver two “Gyrotron based RF Source sets” for ITER-ECRH (Electron Cyclotron Resonance Heating) applications [1]. To support ITER deliverables and to understand complex Gyrotron operations, a MW class ITER-India Gyrotron Test Facility (IIGTF) has been developed and successfully commissioned [2]. This facility includes ITER relevant Test-Gyrotron (170GHz, 1MW, 1000s) procured from M/s Gycom Russia, and necessary sub-systems like High Voltage Power Supplies (HVPSs), Auxiliary Power Supplies, Control, Monitoring & Protection systems, RF diagnostic systems, Cooling & Vacuum Services etc. A modern, fast and reliable control system has been indigenously developed that supported the successful Gyrotron operation and site acceptance with demonstration of major operating parameters [2] [3] (1MW/1000s Operation, Reliability Test, Modulation Test etc.)

To operate the Gyrotron safely & reliably, its control, monitoring & protection system should be reliable & support customizations as per operational needs. Additionally, it should consider fail-safe design aspects, and be immune to the electromagnetic interference & ground noise that occurs during operations.

At IIGTF, the development of control system is carried out in two phases. In the phase-1, development is mainly done considering COTS solutions & some of the indigenously developed systems. In the phase-2, development is planned considering the ITER recommended hardware & software platforms. The phase-1 control system consists of three main COTS platforms: NITM cRIO, NITM PXIe and Siemens PLC for various functions. In addition, many custom hardware modules are developed to cater the critical measurement and protection requirement.

NI-cRIO system supports Fast HVPSs synchronized operation with Configurable pulse length & delay from 1us-1000s. NI-PXIe system is used for Real-Time Data acquisition of parameters with acquisition rate of ~1us for short pulse operations & ~1ms for long pulse operations. Slow protection with reaction time ~100ms is also implemented in NI-PXIe system. Siemens-PLC is used for slow monitoring & protection of cooling & auxiliary services with reaction time of ~500ms. FPGA based cRIO digital & Analog optical modules compatible with NI-cRIO system are developed for current monitoring & protections [4]. This cRIO module & COTS high speed optical modules are used for field signal optical interfaces. Critical fast protections (<10us) are implemented with combination of NI-cRIO system & FPGA based Centralized interlock module (CIM).

Some of the hardware & firmware are developed using opensource framework, that solve the problem of obsolescence which usually occur in the long-term projects. Critical field measurements like forward beam current, filament current, RF power & Frequency measurement are installed and tested. The LabVIEW based operator-HMI integrates all the sub-system operation in a pre-defined sequence and displays main operating parameters in RT. The WinCC application displays the cooling parameters & calorimetric measurements. Other software functions like programmable ramping of filament power supply, RF-Pulse re-application are programmed and tested.

The phase-1 control system is developed & qualified with successful Gyrotron testing & operations. The key parameters test result is shown in Figure1 and Figure2. The work demonstrates indigenously developed control, monitoring, and Interlock protection system capable of supporting 1 MW, 170 GHz gyrotron operation up to 1000 s pulse length. A unique architecture has been implemented enabling robust operation across different time scales. The developed Real-Time data acquisition system provides very important insight on gyrotron operational behaviour. The development of FPGA-based centralized interlock and optical interface modules enhancing system safety under high-energy operating conditions.

Development of LabVIEW-based operator interfaces and programmable functions (e.g., filament ramping, RF pulse re-application) improves operational flexibility and accuracy beyond standard implementations. Incorporating open-source hardware/firmware approaches addresses lifecycle challenges typical of long-duration fusion projects, improving maintainability and future scalability. The control system has been validated during full-power gyrotron operation, demonstrating immunity to electromagnetic interference and ground noise — a critical challenge in high-power RF facilities.

This paper presents the phase-1 Control system design, its development details and test results achieved during the successful commissioning of the Test Gyrotron at IIGTF. It also discusses the Gyrotron operational experience along with different issues and corresponding troubleshooting. Here the phase-2 development and further plans will also be introduced

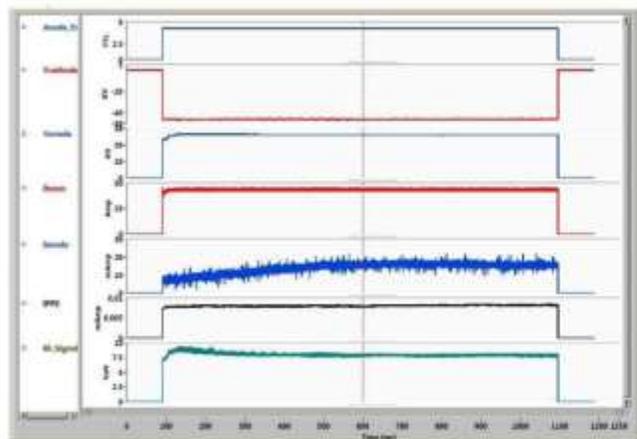


Figure1: Gyrotron operating parameters for a 1MW,1000s

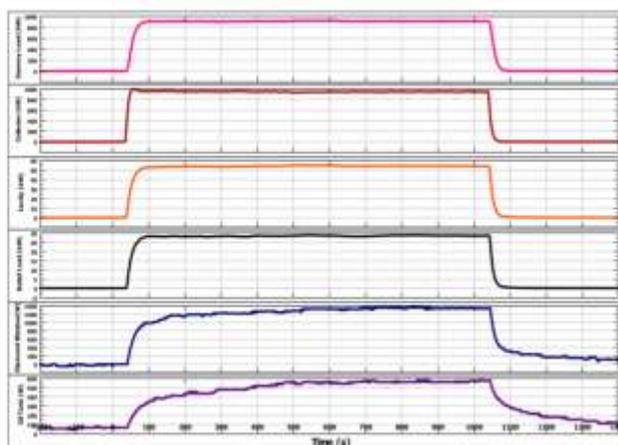


Figure2: Calorimetric Power measurements for 1MW, 1000

The Phase-1 control system hardware architecture have most of the component in compliance with ITER PCDH requirements while only software part need to be updated as per the ITER Plant system operational requirements. The Phase-1 development will serve as a validated platform that reduces technical risk for IN-DA to perform Phase-2 ITER deliverable. The Phase-1 will also support IN-DA for the development and deployment of ITER-recommended control systems to the ITER and performing gyrotron source delivery, Installation and commissioning at ITER site

References

- [1] S.L. Rao et al, Fusion Science & Technology, 65, 129-144 (2014), “Electron Cyclotron power sources system for ITER”
- [2] S.L. Rao et al, Commissioning of MW class Gyrotron Test Facility at ITER-India & Demonstration of ITER relevant RF performance (1MW for 1000 s at 170 GHz), EPJ Web of Conferences 313, 04002 (2024), EC22

[3] Vipal Rathod et al., EPJ Web of Conferences 203, 04013 (2019) EC20, “Developments towards 1MW Gyrotron Test Facility at ITER-India”

[4] Ronak V Shah et al, IEEE Transactions on Plasma Science, VOL. 48, NO. 6, JUNE 2020, “Design and Development of Fast Protection & Fast Monitoring Module compatible with NITM Compact RIO system for ITER-India Gyrotron Test Facility”
