DEVELOPMENT & VALIDATION OF CONTROL SYSTEM FOR OPERATION OF 170GHZ, 1MW, 1000S GYROTRON AT ITER-INDIA GYROTRON TEST FACILITY

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1. BACKGROUND & OVERVIEW

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. As a part of its in-kind contributions, ITER-India, the Indian Domestic Agency, has to deliver two “Gyrotron based RF Source sets” to ITER project for ECRH (Electron Cyclotron Resonance Heating) applications [1]. To support ITER deliverables and to understand and validate the complex Gyrotron integrated system operations, a MW class Gyrotron Test Facility has been developed and successfully commissioned at ITER-India (IIGTF) [2] [3]. This facility has been developed with all the necessary sub-systems like High Voltage Power Supplies (HVPSs), Auxiliary Power Supplies, Control, Monitoring & Protection systems, RF diagnostic systems, Cooling & Vacuum Services etc. The facility also includes an ITER relevant Test-Gyrotron (170GHz, 1MW, 1000s) that is procured from M/s Gycom Russia. To guarantee the stable gyrotron operation requires, very precise sub-system remote integrated operation, which demands a specialized control system. At ITER-India a modern, fast & reliable control system has been indigenously developed using which a successful gyrotron site acceptance testing was performed. The control system has successfully demonstrated the different modes of gyrotron operation & achieved key operating parameters (1MW/1000s CW Operation, 1KHz Modulation operation etc.). The control system has also implemented necessary protections to guarantee the gyrotron safety.

2. CONTROL SYSTEM REQUIREMENTS

The main objective of the Gyrotron control system is to ensure safe, reliable and operator friendly operations considering the required operational sequences, operational protection limits and operational data needs. Additionally, it should consider fail-safe design aspects, and be immune to the electromagnetic interference that occurs during operations. The table shows the main gyrotron control system functional and time critical requirements. Other than this the operator-HMIs should be user friendly, integrate sequential operation of all the sub-system from single HMI and should have various software checks to avoid human errors.

Sub-System/Functions	**Requirements**
High Voltage Power Supplies Control	Fas,t Real-Time (RT) Synchronized Control Loop time <1µs
Auxiliary Power Supplies Control	Control through serial protocol interface (RS-232, RS-485)
Real-Time Fast Data Acquisition	Data storing rate 1µs to 1ms
Slow Data acquisition	Data storing rate ~500ms
Event based acquisition	Data storing rate 1µs
Fast Protection	Detection & protection <10µs
Slow protection	Detection & protection <100ms

3. CONTROL SYSTEM DEVELOPMENT AND TEST RESULTS

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 indigenously developed systems. In the phase-2, the development is being planned considering the ITER recommended hardware & software platforms. The phase-1 control system was successfully developed, deployed and validated during the test gyrotron operations.

The phase-1 control system hardware architecture is shown in Fig.1. It has two main controllers, the fast & Slow controller. The fast controller implements all the critical gyrotron functions within the time scale of 1us to 100ms. It ensures the reliable control of all the sub-systems and protecting the gyrotron tube in case of any internal arcing and other critical faults. The Fast HVPSs synchronized operation with Configurable pulse length & delay from 1us-1000s is implemented in NI-cRIO FPGA system. RT Data acquisition of parameters with acquisition rate of

~1µs for <1s operations & ~1ms for 1s-1000s operations are implemented in NI-PXIe DAQ system. Also, slow protection with reaction time ~100ms is also implemented in NI-PXIe system. Critical fast protections (<10µs) are implemented with combination of NI-cRIO system & FPGA based Centralized interlock module (CIM).
The LabVIEW based operator-HMI shown in Fig.2 integrates all the sub-system operation in a pre-defined sequence and displays main operating parameters in RT.

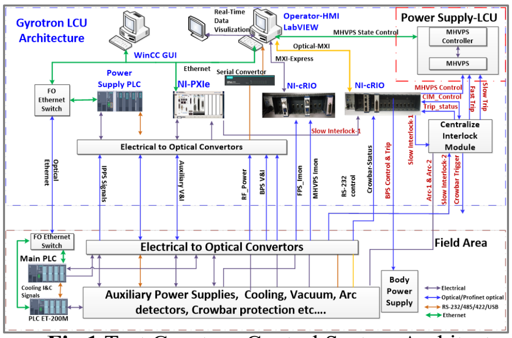

Fig.1 Test Gyrotron Control System Architecture

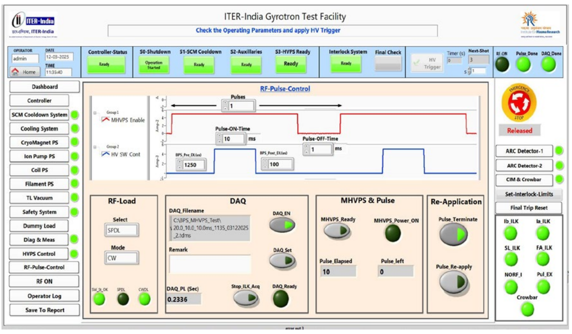

Fig.2 Gyrotron *Operator- HMI*

The slow controller implements all the health monitoring functions of gyrotron with time scales of >100ms. It performs measurement of cooling system, vacuum system & other auxiliary services and protect gyrotron in case of fault in these parameters. Siemens-PLC is used for slow monitoring & protection of cooling & auxiliary services with time of ~500ms. The WinCC application displays the cooling parameters & calorimetric measurements.

Custom FPGA based digital & Analog optical modules compatible with NI-cRIO system are developed for current monitoring, protections & field interface [4]. FPGA based Centralized Interlock Module (CIM) is developed and tested. Critical measurements like beam current, filament current, RF power & Frequency measurement are tested. Software functions like programmable ramping of filament power supply, RF-Pulse re-application are tested.

The phase-1 control system is developed & qualified in harsh (EMI/EMC) environment during the gyrotron operation. The achieved test results for a typical 1MW,1000 s shot is shown in Fig.2 and Fig.3 during the successful commissioning of the Test Gyrotron at IIGTF.

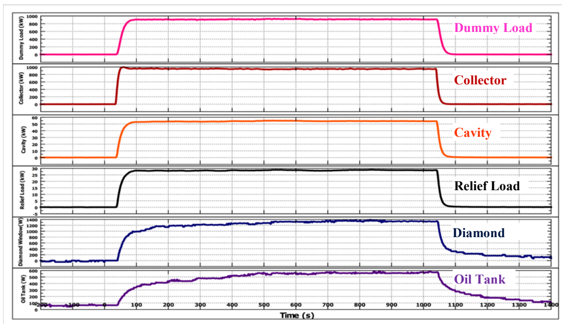

Fig.2 Calorimetric Power measurements for 1MW, 1000 s

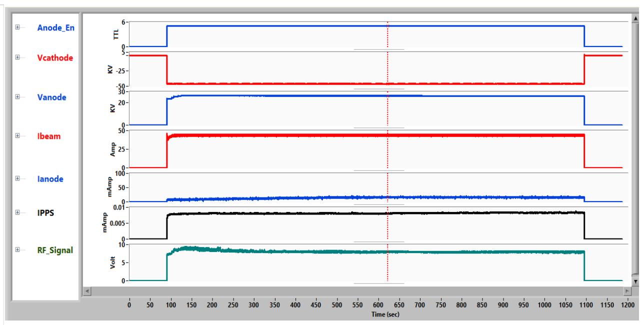

Fig.3 Gyrotron operating parameters for a 1MW,1000s

This paper presents the phase-1 Control system design, development and the performance results. It also discusses the Gyrotron operational experience along with different issues and corresponding troubleshooting. Further the future plans for phase-2 development would also be indicated.

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