10

उच्च तीव्रता वाले प्रोटॉन लिनॉक हेतु नियंत्रण प्रणाली का अभिकल्पन एवं विकास

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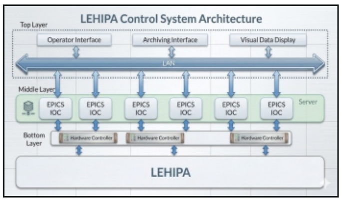

लेहिपा की नियंत्रण प्रणाली का वास्तुकला

सारांश

यह लेख भाभा परमाणु अनुसंधान केंद्र में भारत के त्वरक प्रचालित प्रणाली (एडीएस) कार्यक्रम के तहत निम्न ऊर्जा उच्च तीव्रता वाले प्रोटॉन त्वरक (एलईएचआईपीए) हेतु विकसित नियंत्रण प्रणाली के अभिकल्पन, वास्तुकला एवं प्रचालन अनुभव को प्रस्तुत करता है। ईपीआईसीएस-आधारित वितरित नियंत्रण प्रणाली त्वरक उप-प्रणालियों के विश्वसनीय प्रचालन, संरक्षण एवं निगरानी को समर्थ बनाती है। प्रमुख घटकों में एलएलआरएफ, समय प्रणाली, पर्यवेक्षी नियंत्रण, डाटा संग्रह और मशीन संरक्षण प्रणाली शामिल हैं। लेहिपा नियंत्रण प्रणाली के स्वदेशी विकास और एक दशक में त्वरक प्रचालन अनुभव प्रस्तुत किए गए हैं। लेख में आगामी अति-चालक मेहिपा चरण-1 त्वरक के लिए भविष्य की चुनौतियों एवं नियंत्रण आवश्यकताओं पर भी चर्चा की गई है।

10

Design and Development of Control System for High Intensity Proton LINACs

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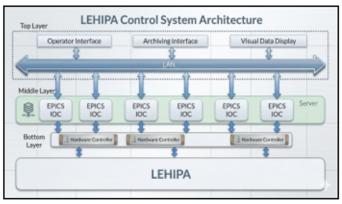

Control System Architecture of LEHIPA

ABSTRACT

This article presents the design, architecture, and operational experience of the control system developed for the Low Energy High Intensity Proton Accelerator (LEHIPA) under India's Accelerator Driven System (ADS) program at Bhabha Atomic Research Centre. The EPICS-based distributed control system enables reliable operation, protection, and monitoring of accelerator subsystems. Major components include LLRF, timing system, supervisory control, data archiving, and machine protection systems. Indigenous developments of the LEHIPA control system and accelerator operational experiences over a decade is presented. The article also discusses future challenges and control requirements for the upcoming superconducting MEHIPA Phase-1 accelerator.

KEYWORDS: *Control systems, Machine Protection System, EPICS*

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Introduction

Long term goal of the Indian nuclear program is to be self-reliant in nuclear fuel by utilizing vast thorium reserves of India. Accelerator Driven System (ADS) has emerged as one of the promising route for Thorium utilization. At the heart of the Accelerator Driven System lies High Intensity Proton Accelerator (HIPA) which delivers CW proton beam to carry out spallation reaction to generate external neutrons required for ADS [1].

Low Energy High Intensity Proton Accelerator (LEHIPA) is a flagship accelerator project of BARC. LEHIPA is the front end of the ADS program. LEHIPA accelerates proton beam to 20 MeV and is capable of delivering beam of 10 mA maximum. LEHIPA is commissioned in August 2023 in pulsed mode. Time of flight method is used for the final beam energy measurement in LEHIPA [2].

LEHIPA consists of many subsystems such as Ion Source, Vacuum System, Low Conductivity Water System, High Power Amplifiers, RF distribution and coupling system, Beam Diagnostics System to name a few. Reliable long term availability of proton beam at target depends on the fine balance of optimal operation of these subsystems.

Control System is one of the most important subsystem of the LEHIPA [3]. Control system ensures safe and efficient operation of the accelerator via proper signal, data and command exchange between various subsystems and with the operator running the machine. To ensure safe and efficient operation of high power accelerator like LEHIPA control system must carry out following responsibilities:

- Maintaining stable electric filed in the cavity. (LLRF System)
- Ensure unified timing reference to synchronize various activities/events distributed in space for beam acceleration efficiently and safely. (Timing System)
- Data acquisition and presentation of field data to operators, users/experimenters and Implementation of operator actions on field devices.
- Generation of alarm for operator.
- Acquiring and presenting beam diagnostic data to operator.
- Protection and Interlock System
- Archiving of machine data during operation and retrieval of historic data.
- Operational logbook of accelerator operation.

Technical Specification of Control System

Details on typical hardware, software and signals that are used in the linac control system are as given in Table 1.

Table 1: Specifications of linac control system.

Sr. No.	Parameters	Values
1.	Type of control system	Distributed Control System (DCS)
2.	Software Platform	RTEMS, Linux, EPICS SCADA system
3.	Software Layers	3 Layers (Layer-1: Machine interface running on RTEMS, Layer-2: Middle layer Running on Linux/RTEMS, Layer-3: Operator interface running on Linux)
4.	Programming Language	C/C++, Qt C++ API
5.	Redundancy level	Machine protection System in layer-2
6.	Communication protocols	MODBUS over TCP/IP , EPICS Channel Access protocol
7.	Time Server	Centralized time server and event trigger
8.	Type of signals	Voltage signals, 4-20 mA and contacts
9.	No of signals	Approximately 5000
10.	Signal levels	variable analog signals max span -10 to +10 Volts , ADC /DAC 16 bit precision, optical signals (0-10 kHz, 0-100 kHz , 0 to 300 kHz)
11.	Response Time (min, max)	Control system - 50 milliseconds, fast interlock protection system-10 microseconds
12.	Control hardware (standard)	cPCI, VME and VME based Trombay PLC, standalone Modbus-based control modules
13.	Control hardware (custom made)	cPCI , VME
14.	PLC hardware	Trombay PLC

Control System Architecture

LEHIPA is a three layered distributed control system (Fig.1). Bottom most layer is the hardware that ensures the functional requirements of the accelerator. The top level is the presentation layer. In this layer operator interface and other graphical representation of the accelerator parameters and field data assist operators to operate the accelerator to deliver accelerated beam. In between top and bottom layer, Experimental Physics and Industrial Control System (EPICS) exists as the middle layer which acts the 'glue' between the operator interface and field hardware.

The middle layer, EPICS Input Output Controllers (IOC), acquire field data from the hardware controllers such as vacuum gauge controller, magnet power supply etc. and make that data available in the network so that every EPICS compliant system can get that data seamlessly. IOCs also receive the operator commands and soft interlock I/O signals and send them to the particular hardware controller to carry out the I/O operation in the field.

In LEHIPA all EPICS IO controllers are developed in house, using C programming language and are working satisfactorily for the last ten years.

Brief overview of control system

The control system of any high power accelerator and that of LEHIPA is a distributed control system as accelerator and its supporting subsystems are spread over a considerable area both inside the tunnel and in the ground level. Each subsystem has its own local control station/controller, often placed in the field. Control station/controller implements subsystem's data acquisition and control requirements. These subsystems are interconnected via a high speed redundant Local Area Network (LAN) to the control room servers and Operator Work Stations (OWS) as shown in the Fig.2. Each subsystem has three types of connection, LAN for data, command and slow interlocks, hard wired signal lines for the fast interlocks and timing signal for maintaining common uniform timing across all the components of the accelerator. All subsystems provide the required global control to the Integrated Control System (ICS) of LEHIPA to carry out LEHIPA operation by operator at control room in a cohesive manner.

The ICS is responsible to carry out communication with each of the Local Control Stations (LCS) of various subsystem and synchronize the various operations to start the accelerator, provide synchronization requirements for various subsystem during operation, tune the beam for required characteristics and shutdown the accelerator under normal condition and emergency condition. ICS also provides overall machine protection and interface with various subsystems to the operator in a homogeneous manner for comprehensive operations, troubleshooting and maintenance. Another important responsibility of ICS is to keep archiving data from different subsystems for future reference/provision of historical operational and event data. The front end of the ICS is operator Interface, which is the application that present the data, information and command panels to the operator. ICS presents important operational data to the wall mounted large displays. The control system works on Linux operating system and uses EPICS-based SCADA frame work for LCS and Qt-EPICS based GUI panels for operator workstation.

The timing pulses for the pulsed subsystems (like ion source, HV for klystrons, RF for cavities and data acquisition) is generated by the LEHIPA Timing System (LTS) using cPCI-based programmable timer cards.

Protection system

Protection system is the crucial aspect of the control system. It has two parts , Personnel Protection System (PPS) and Machine Protection System (MPS). PPS is used to protect human from any danger. Search and Secure system for LINAC tunnel is the part of personnel protection system, implemented using Trombay PLC.

The Machine Protection System (MPS) in LEHIPA is designed to protect the accelerator and its components from

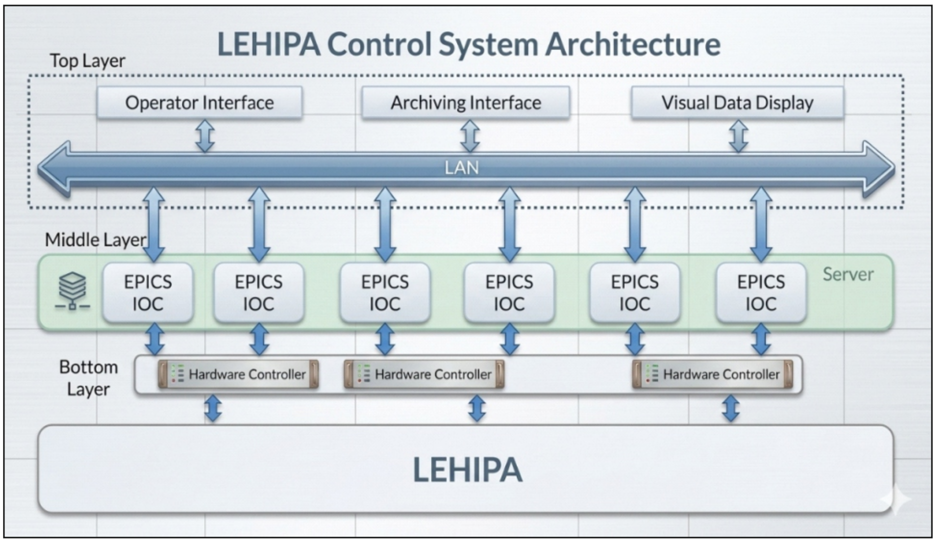

Fig.1: Control System Architecture

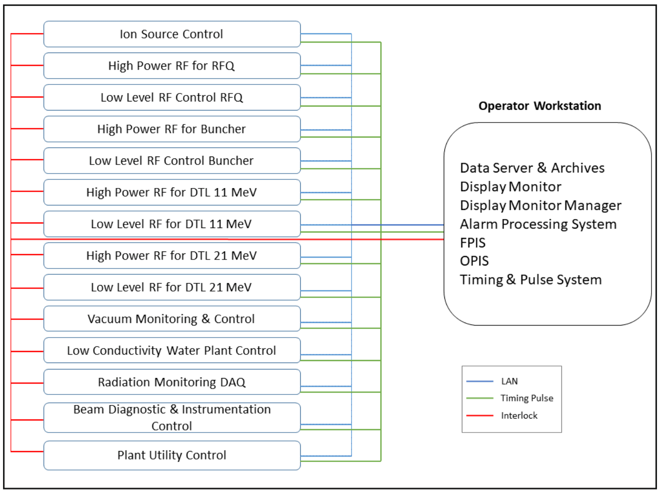

Fig.2: LEHIPA Control System.

damage during abnormal operating conditions. It continuously monitors parameters such as beam current, vacuum, RF systems, magnet status, and cooling systems. When a fault is detected, the MPS quickly generates an interlock signal to stop or inhibit the RF and beam. The system ensures safe and reliable operation of the accelerator by minimizing the risk of equipment failure and beam-induced damage. Fast response and high reliability are essential features of the LEHIPA MPS.

Control System of MEHIPA

The next stage of ADS program is 40 MeV MEHIPA Phase-1, planned to be commissioned in Vizag. MEHIPA Phase-1 is very similar to the LEHIPA till 10 MeV and design of the control system for that will be the refinement of the control system design of LEHIPA. Use of latest hardware platforms like MicroTCA and other emerging technologies will be explored for achieving better performance and reliability.

However, MEHIPA is different from LEHIPA in a significant way: from 10 MeV to 40 MeV it will have superconducting accelerating structures which brings new challenges for their very high quality factor. LLRF system needs to be designed considering the low bandwidth of the superconducting cavities requiring sophisticated algorithms for feedback and feed-forward control. Also due to the presence of cryogenics subsystem, requirement of machine protection system for MEHIPA phase-1 will be significantly more challenging than the LEHIPA. Quench protection system will be an important additional control requirement for the superconducting cavities to protect the cavities from becoming normal conducting one and completely dissipating the stored energy. Compensation of cavity de-tuning due to various factors will also be a significant challenge of the MEHIPA control system and will be addressed by a resonance control system.

In the design of MEHIPA control system, integration of emerging new areas of technology such as machine learning and artificial intelligence are also in consideration.

Currently, IADD is carrying out the design of the MEHIPA phase-1 control system incorporating the learning from the decade-long experience of round the clock operation of the LEHIPA control system.

Conclusion

LEHIPA control system is working satisfactorily round the clock as per design requirements. It was designed as modular and scalable system and this helped to expand the control system organically as the LEHIPA commissioning was taking place starting with the RFQ commissioning in the year 2017 to full beam acceleration through DTL in 2023. A wealth of operational knowledge and experience gathered during LEHIPA operation is guiding the design of upgraded LEHIPA control system. Challenges arising out of superconducting cavities is being taken care in the design of MEHIPA control and machine protection system.

References

[1] P. Singh et al, “Accelerator development in India for ADS programme,” Pramana 68, 331 (2007). https://doi.org/10.1007/s12043-007-0038-0

[2] U. D. Malshe. Low Energy High Intensity Proton Accelerator (LEHIPA). (pp- 48-53). BARC Newsletter October 2023.

[3] Singh, S. K., Basu, A., Bharade, S., Rosily, S., Kewlani, H. M., Tayade, L., Parate, P., & Mathad, D. N. (2015). Distributed Control System for LEHIPA; Proceedings of the Indian Particle Accelerator Conference (InPAC) - 2015, TIFR, Mumbai.