18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR03

CONTROL SYSTEM FOR 6 MeV LINEAR ACCELERATOR AT LINAC PROJECT PINSTECH

N. U. Saqib†, M. Ajmal, A. Majid*, D. A. Nawaz‡, F. Sher§, A. Tanvir
LINAC Project, PINSTECH, Islamabad, Pakistan

Abstract

At LINAC Project PINSTECH, 6 MeV electron linear accelerator prototypes are being developed for medical as well as industrial purposes. Control system of the linear accelerators is a distributed control system mainly comprised of EPICS and PLCs. Graphical User Interface (GUI) are developed using Phoebus Control System Studio (CSS) and Siemens WinCC Advanced software. This paper focuses on design, development and implementation of accelerator control system for various subsystems such as RF, vacuum, cooling as well as safety subsystems. The current status of the control system and services is presented.

INTRODUCTION

Particle accelerators are complex machines that have been playing a major role in scientific innovations and discoveries. A particle accelerator is a device that uses electromagnetic waves, in the microwave range, to accelerate charged particles (electrons) to produce high energy charged particle or X-ray beams. In case of electron linear accelerators, electrons are generated from electron source such as electron gun (e-Gun) and are accelerated in a series of accelerating cavities by Radio Frequency (RF) waves, which are fed into the accelerating cavities by an RF source such as a klystron or a magnetron.

LINAC Project at PINSTECH aims at developing indigenous RF linear accelerators for medical and industrial applications. Along with ongoing progressive research and development, prototypes of medical linear accelerator (*Medical Linac*) for radiotherapy application and industrial linear accelerator (*Industrial Linac*) for Non-Destructive Testing (NDT) application are under development. Both of these accelerators are 6 MeV standing wave electron linear accelerators that produce high energy X-rays by striking high energy electron beam onto a tungsten target.

There are several subsystems that are required for operating a linear accelerator: an e-Gun system to produce and extract electrons, an RF system to accelerate the electrons produced by e-Gun, a good vacuum system to avoid arcing or breakdowns, a cooling system to maintain the temperatures of various devices at a desired point for stable operation. As particle accelerators grow more complex, so do the demands placed on their control systems. The complexity of the control system hardware and software reflects the complexity of the machine. Accelerator Controls and Electronics (ACE) Group of LINAC Project is responsible for controls, electronics and IT infrastructure for Medical and Industrial Linac prototypes. Figure 1 shows block diagram of the linear accelerator that contains main subsystems and their interfacing. All these systems need to be controlled and monitored by a sophisticated control system, which enables safe and smooth remote operation of the Linac from control room. Next subsections provide a brief description of Medical and Industrial Linac prototypes.

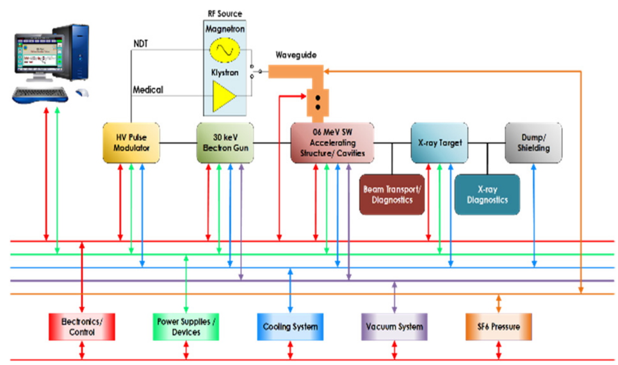

Figure 1: Block Diagram of Linac.

Medical Linac

A medical linear accelerator customizes high energy x-rays or electrons to conform to a tumor's shape and destroy cancer cells while sparing normal tissues. Cancer is a leading cause of death worldwide and its types such as breast, lung, liver, prostate, head and neck carcinoma are most commonly diagnosed in Pakistan. Increasing number of cancer patients has made demand of cancer treatment machines. Therefore, it was need of the time to build an indigenous medical linear accelerator to cope with soaring number of cancer patients in available financial resources. For this purpose, a Klystron based 6 MeV Medical Linac prototype is being developed at LINAC Project PINSTECH. Accelerating cavity was designed indigenously, fabricated and brazed locally. Initially, there was one vacuum port and vacuum didn't sustain to a good pressure, recently a second vacuum port is installed and RF conditioning is under process.

Industrial Linac

Out of several applications of industrial linear accelerators, one is radiography in for Non-Destructive Testing purposes, which provides a method for examination of internal structure and integrity of given specimen/material. Keeping this in view, an indigenous magnetron based 6 MeV Industrial NDT Linac prototype is in final stages at LINAC Project PINSTECH. Accelerating cavity was designed indigenously, fabricated and brazed for this purpose. Most of the parameters of both the linear accelerators are similar as shown in Table 1.

† najm.control@gmail.com
* aaminahmajid@gmail.com
‡ danishplcinc@gmail.com
§ falaksher@gmail.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR03

Table 1: Specifications of the Linac

Parameter	Value
Maximum Energy	6 MeV
Input Power	2.5 MW
Pulse Repetition Frequency	50 Hz
RF Pulse Width	4 µs

CONTROL SYSTEM DESIGN

Control system acts as brain of a linear accelerator. It allows smooth and safe operation of the Linac by providing remote control/monitoring of accelerator hardware as well as interlocked environment for safety and protection. Control system at our facility is EPICS and PLC based four layer architecture [1,2]: Graphical User Interface (GUI) layer consisting of Phoebus Control System Studio (CSS), Middleware layer consisting of EPICS, Front-end layer consisting of PLCs, instruments and controllers, and Accelerator Hardware layer consisting various physical phenomenon that need to be controlled and monitored by the control system. Next subsections describe various components of the control system of our facility [3].

Input/Output Controllers (IOC)

IOCs in our EPICS [4] based control system are soft IOCs deployed on CentOS 7 Linux Virtual Machine. IOCs communicate with various commercial-off-the-shelf instruments and controllers via interfaces like Ethernet, Serial (RS-232/422/485) and GPIB. They send commands and acquire signals from instruments and controllers. The IOCs deployed in our control system are organized in a hierarchical manner. First of all, in folders according to the subsystem they represent (RF, vacuum, cooling) and then according to the device they control (signal generator, delay generator, klystron modulator). For example, an IOC that controls signal generator which provides pilot signal to Klystron pre-amplifier is placed at ${HOME}/epics/ioc/RF/signalGenerator. EPICS support modules provide enhanced functionalities for IOC applications. Support modules currently installed and configure in our control system include Asyn, Stream Device, Modbus, Calc, s7nodave and Sequencer modules. Separate virtual machines are used for IOC development and IOC deployment. At system reboot, all IOCs are started from a bash script containing path to their startup script files.

Programmable Logic Controllers (PLC)

Siemens Simatic S7-300 and S7-1200 programmable logic controllers are installed, configured and programmed to interface field devices. Input/Output (I/O) modules include analog input, analog output, digital input, and digital output modules. Communication modules for Serial RS-232/422/485 interface are also installed for remote control & monitoring of commercial-off-the-shelf equipment. Interfacing between EPICS and Siemens PLCs is achieved via EPICS s7nodave support module that allows interfacing of Siemens Simatic S7 controllers with EPICS. PLCs act as front-end controllers in our system to interface with the accelerator hardware.

Operator Interfaces (OPI)

Operator interfaces (OPI) developed in Phoebus Control System Studio [5] are used to operate the linear accelerators from control room. Previously, OPIs were developed in Eclipse based Control System Studio, but later on, upgraded to Phoebus based Control System Studio. This transition provided more reliability and better features required by the control system. Several OPIs are designed according to the functionality they provide (Control, Monitoring, Trends). Also, specific equipment details OPIs are developed for various equipment such as Klystron Modulator, Oscilloscope etc. Example Phoebus OPIs are shown in Fig. 2.

For Industrial Linac, Human Machine Interface (HMI) screens are developed in Siemens WinCC Advanced and shown in Fig. 3.

Figure 2: Phoebus OPIs.

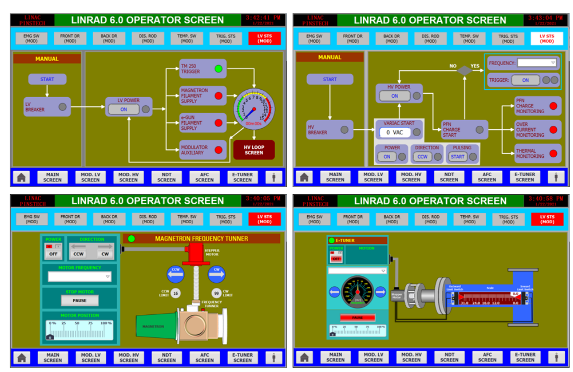

Figure 3: WinCC Advanced HMIs.

Services

An archiver system and an alarm system are necessary services of a control system. These services inform operators about events happening during linear accelerator operation and their history, as well as provide data analysis functionalities to scientists and engineers.

Archiver system saves process variables history in a database which is a necessary task for a control system. It provides lot of benefits such as detection of a system fault, detection and analysis of undesired behavior of the system and also provides data to scientists and engineers for research purposes. Best Ever Archiver Toolkit Yet

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR03

(BEAUTY) is used for data archiving in our system. It contains archive engine command-line tool, which is provided with configuration and settings from XML files. Archive engine then utilizes Channel Access protocol to access process variables contained in EPICS IOCs into MySQL relational database. Phoebus CSS Data Browser is used to display history trends for the operating personnel. Figure 4 shows architecture of the archiver system.

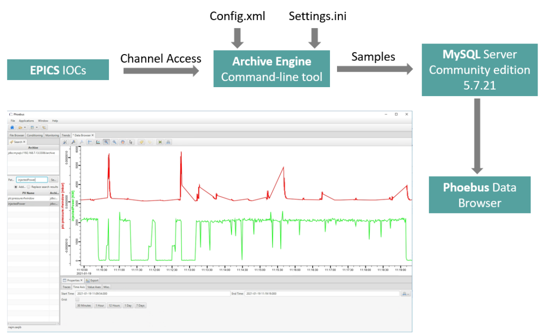

Figure 4: Archiver System Architecture.

Alarm system is a great tool for the operators to be notified about events happening during the operation of accelerator. Alarm system consists of Best Ever Alarm System Toolkit (BEAST) which contains alarm server. Configuration and settings are provided from XML files. Previously, alarm system consisted of RDB & JMS but after update to Apache Kafka, we have updated the alarm system accordingly. Alarm Panel, Alarm Tree and Annunciator provide a great alarm system. Figure 5 shows the alarm system architecture.

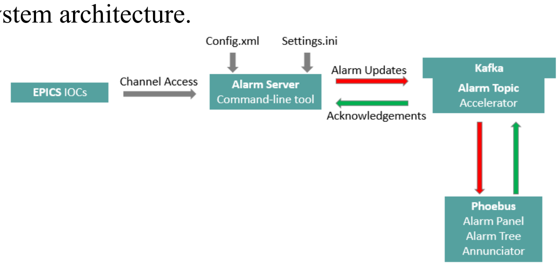

Figure 5: Alarm System Architecture.

Computing Infrastructure & Network

Network deployed at LINAC Project is an Ethernet based Local Area Network (LAN). The overall LAN is divided into two segments: Technical Network and Office Network. Both networks are isolated and contain independent IT infrastructure. Control system consisting of measurement and control devices including commercial-off-the-shelf equipment and related devices are connected to the Technical network while Office network consists of users related devices including scientists' and engineers' PCs, printers, scanners, test equipment etc. Dell EMC PowerEdge servers are configured and installed to provide reliable services for both the networks.

Technical Network contains all components related to control system consisting of servers, desktop computers and commercial-off-the-shelf equipment. This provide isolation for achieving security and reliability. Figure 6 shows various application/services provided by Dell EMC PowerEdge R630 virtualized server deployed in the Technical Network.

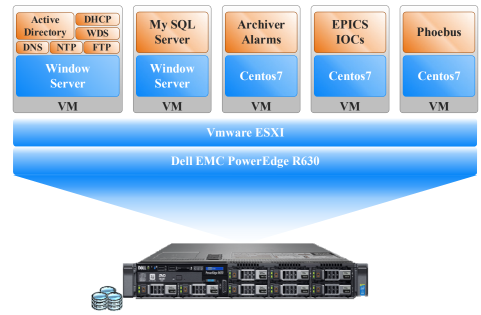

Figure 6: Technical Network Virtualization.

ACCELERATOR SUBSYSTEMS

This section describes various subsystems of linear accelerator and how their components are interfaced with the control system. Subsystems of Medical and Industrial Linacs that significantly differ from each other with respect to control system point of view are described separately in each subsystem's section.

RF System

Medical Linac RF system consists of Klystron as RF source, Scandinova Klystron Modulator as HV source for the Klystron, Stanford Research System Signal Generator as RF pilot signal provider to Klystron preamplifier, BNC Digital Delay Generator as trigger of the modulator, Rohde & Schwarz Oscilloscope as RF Power measurement device. All of these devices are interfaced with EPICS IOCs using Ethernet interfaces. Klystron modulator communicates via Modbus TCP protocol, Delay Generator via Telnet protocol and other instruments via Vxi-11 protocol. Figure 7 shows RF system interfacing with the control system. RF conditioning process is automated using EPICS Sequencer module to minimize human interaction requirement and make the process error prone and reliable.

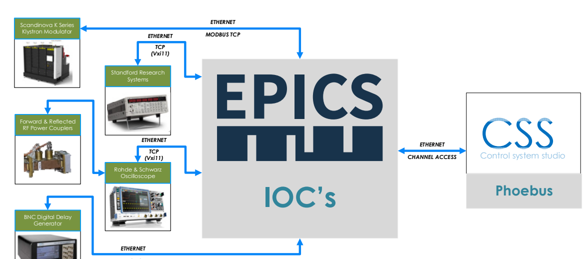

Figure 7: RF System of Medical Linac.

Industrial Linac RF system consists of S-band Magnetron as RF source, indigenously developed 48 kV/110 A HV Pulse Modulator as HV source for the Magnetron. Modulator control system consists of Siemens Simatic S7-1200 PLC CPU along with analog and digital input/output modules. EPICS communicates with S7-300 via s7nodave module and provides data to Control System Studio via

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR03

Channel Access Protocol. Figure 8 shows interfacing of RF system and Control system.

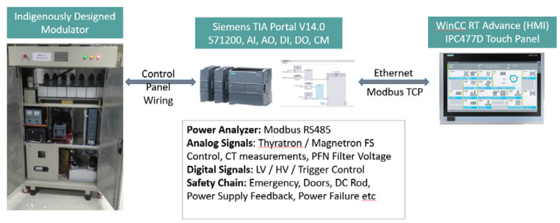

Figure 8: RF System of Industrial Linac.

Electron Gun System

Electron Gun system consists of indigenously developed high voltage pulse modulator to provide HV power to electron gun. Lambda ZUP Power Supply are installed to provide Low Voltage (LV) power to the electron gun filament.

Medical Linac EPICS IOC interfaces ZUP Power Supply via RS-422 and ramp up/ramp down of filament voltage, and conditioning of the filament is automated using EPICS Sequencer module.

Industrial Linac interfaces this supply via RS-422 PLC communication module and ramp up/ramp down of filament voltage, and conditioning of the filament is automated with PLC Ladder Logic programming. Figure 9 shows interfacing of e-Gun system and Control system.

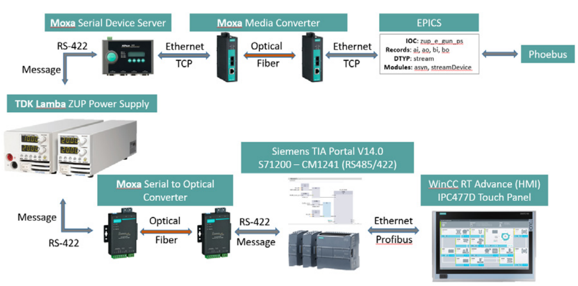

Figure 9: e-Gun System.

Vacuum System

Vacuum is monitored using IMG-300 gauge card of Agilent Technologies XGS-600 vacuum gauge controller. The controller is interfaced with EPICS via RS-232 interface and also with Siemens S7-300 PLC via analog input module. Figure 10 shows interfacing of Vacuum system and Control system.

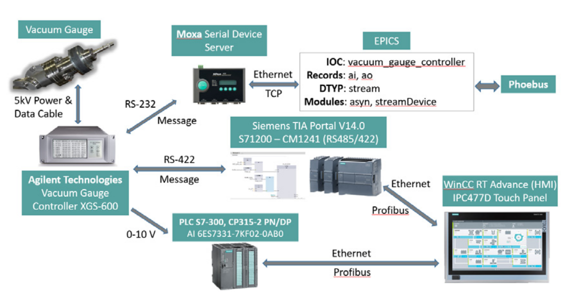

Figure 10: Vacuum System.

Cooling System

Chiller provides cooling to the Linac hardware. K-type thermocouples are used to monitor temperatures at various points along the accelerator. Phoenix temperature transducers are interfaced with S7-300 PLC via analog input module. EPICS communicates with S7-300 via s7nodave module and provides data to Control System Studio via Channel Access Protocol. Figure 11 shows interfacing of Cooling system and Control system.

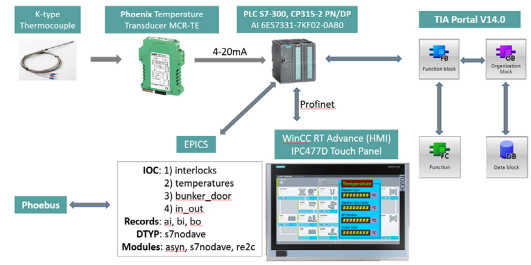

Figure 11: Cooling System.

EXPERIMENTAL SETUP

Accelerator Hall (Main Lab) situated at LINAC Project PINSTECH hosts both Medical Linac experimental setup and Industrial Linac prototype. These linacs are operated from Control Room that is adjacent to Accelerator Hall. Control Room contains six LED screens. We have also configured and installed CCTV system for surveillance. One LED screen is used for CCTV cameras installed at different locations and five screens are used for different operator interfaces. Figure 12 shows the experimental setup of Medical Linac, Fig. 13 shows the NDT Linac prototype and Fig. 14 shows the Control Room.

Figure 12: Medical LINAC Experimental Setup.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR03

Figure 13: NDT LINAC Prototype.

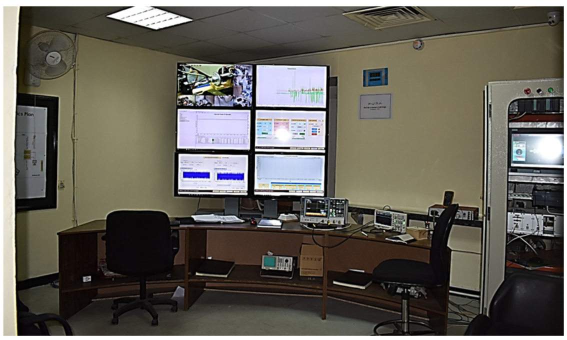

Figure 14: Control Room.

CONCLUSION

Accelerator control system provides smooth, safe and reliable operation of the linear accelerators at the facility. Control system is continuously upgraded according to requirements from operating personnel and other groups of the Project. Accelerator control system community recommended practices are being followed to develop a state-of-the-art control system which can be comparable with control systems of other facilities.

ACKNOWLEDGEMENTS

The authors thank all groups of the LINAC Project for their support. Also, we thank JACoW and ICALEPCS for providing literature that guides us towards right direction.

REFERENCES

[1] T. Wilksen *et al.*, "The Control System for the Linear Accelerator at the European XFEL: Status and First Experiences", in Proc. 16th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'17), Barcelona, Spain, Oct. 2017, pp. 1-5. doi:10.18429/JACoW-ICALEPCS2017-MOAPL01

[2] Y. B. Yan *et al.*, "The Control Systems of SXFEL and DCLS", in Proc. 16th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'17), Barcelona, Spain, Oct. 2017, pp. 525-530. doi:10.18429/JACoW-ICALEPCS2017-TUPHA058

[3] H. Kaji *et al.*, "Control System of SuperKEKB", presented at the 17th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper MOAPP01. doi:10.18429/JACoW-ICALEPCS2019-MOAPP01

[4] EPICS, https://www.epics-controls.org

[5] Control System Studio, https://controlsystemstudio.org