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DESIGN OF THE HALF CONTROL SYSTEM*

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Abstract

The Hefei Advanced Light Facility (HALF) is a 2.2 GeV 4th synchrotron radiation light source, which has been under construction in Hefei, China since June 2023. The HALF contains an injector and a 480-m diffraction limited storage ring, and 10 beamlines for Phase-I. The HALF control system is built on EPICS with integrated application and data platforms for the entire facility, which includes accelerator, beamlines, and utilities. The unified infrastructure and network architecture are designed to build the control system. The infrastructure provides resources for the EPICS development and operation through virtualization technology, and provides resources for the storage and process of experimental data through distributed storage and computing clusters. The network is divided into the control network and the dedicated high-speed data network by physical separation, the control network is subdivided into multiple subnets by VLAN technology. Through estimating the scale of the control system, the 10Gbps control backbone network and the data network that can be expanded to 100Gbps can fully meet the communication requirements of the control system. This paper reports the control system architecture design and the development work of some key technologies in details.

INTRODUCTION

The Hefei Advanced Light Facility (HALF) is a 2.2 GeV 4th synchrotron radiation light source, which has been under construction in Hefei, China since June 2023. The main parameters of the storage ring are listed in Table 1 [1].

Table 1: Main Parameters of the HALF Storage Ring

Parameter	Value
Beam Energy	2.2 GeV
Circumference	480 m
Emittance	86.3 pm·rad
Beam current	350 mA
Brightness	1.15×10^{21} phs/mm^2/mrad^2/0.1%BW/s
Injection	Full energy, Top-off
Lattice	6BA
Straight sections	20×5.3 m + 20×2.2 m
RF	500 MHz

As shown in Fig. 1, HALF is composed of a 2.2 GeV full energy linac, a transport line, a 480 m diffraction limited storage ring and 10 beamlines at phase-I.

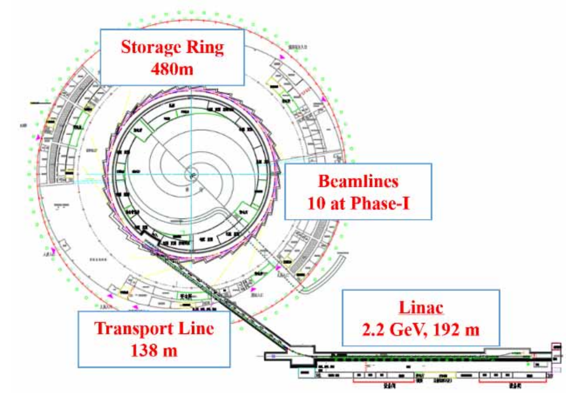

Figure 1: Layout of HALF.

The HALF control system serves as the platform for the commissioning and operation of the entire facility. It adopts a unified architecture to enable device control, process control, data acquisition and analysis for the accelerator, beamlines, and utilities, thereby addressing the issue of insufficient manpower. HALF is a user facility, and its availability is a primary requirement in design to ensure high-quality operations. With approximately 250,000 process variables (PVs), efficient development, deployment, and operation of the control system are required. Additionally, scalability, flexibility, and security must be considered. The users of HALF control system can be divided into accelerator physicists, operators, engineers, beamline staff, experiment station users, and facility managers. To meet their respective requirements, targeted design should be conducted, and corresponding user interfaces should be provided.

Considering the design requirements and development team's experience and foundation, EPICS7 [2] will be used as the software development platform. Server virtualization, VLAN, and commercial off-the-shelf (COTS) products will be utilized to complete the control system development within the constraints of human resources, budget, and time.

ARCHITECTURE

The HALF control system is a distributed control system based on EPICS7, which is divided into 3 layers: device control layer, middle layer, and presentation layer, as illustrated in Fig. 2. The device control layer is the basis of the HALF control system, and it controls the facility-wide devices from the accelerator, beamlines, and utilities, while providing equipment protection and timing. The middle layer provides basic IT services such as DNS, NTP, and data collection and processing. In the presentation layer,

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CSS [3] and/or PyDM [4] are used for human-machine interface development; Python is adopted to develop high level physics applications; Java is employed to develop web clients to enable data visualization and analysis.

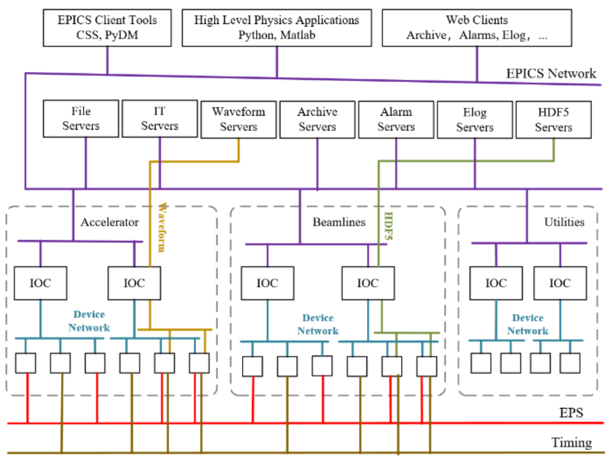

Figure 2: Architecture of the HALF control system.

COMPONENTS

The HALF control system is composed of multiple components, mainly including environment, device control, equipment protection, timing, network, database and application.

Environment

Based on the computing and storage hardware infrastructure, a server platform is established by means of virtualization technology to provide IT basic services and construct EPICS development and operating environment and experimental data management environment. The structure of the platform is shown in Fig. 3, which is divided into four parts: IT infrastructure, IT services, EPICS development and operating environment, and experimental data management environment.

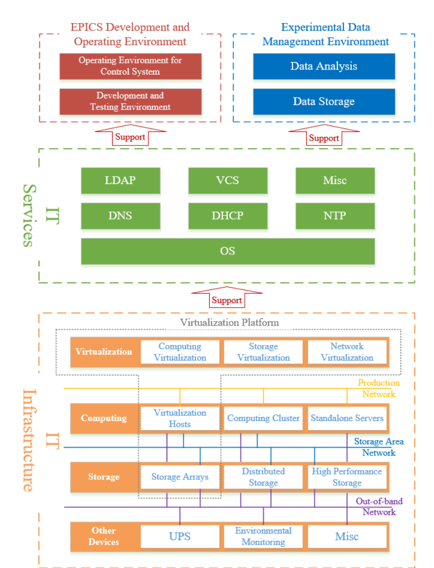

Figure 3: Structure diagram of the server platform.

Device Control

Device control is the foundation of the HALF control system, which implements tasks such as parameter setting and status reading back. The controlled devices include electron gun, power supply, vacuum gauge, stepper motor, timing device, beam diagnosis device, LLRF, and so on. According to the real-time requirements, device control is divided into two types: slow device control and fast device control, the structural diagram is shown in Fig. 4. For fast device control, IOC must be a physical controller with high-speed and low-latency performance. However, for slow devices such as power supply and vacuum gauge, they support Ethernet or serial communication. Serial communication can be converted to Ethernet communication through a serial device server. Therefore, a virtual machine (VM) can be used as IOC to utilize the benefits of server virtualization technology, such as high availability, fast deployment, and convenient management. In order to reduce network traffic, and enforce network security, VLAN is used to isolate the EPICS network and device network. VLAN divides the device network into multiple subnets for further isolation according to the types of controlled devices.

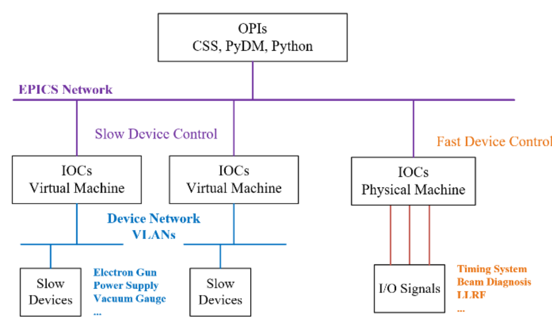

Figure 4: Structural diagram of the device control.

Equipment Protection System

The equipment protection system (EPS) establishes the interlocking protection logic to protect the key equipment from damage in the event of a fault. The EPS follows the design principles of independence, failure safety, reliability, real-time and flexibility. The controller adopts COTS products such as PLC, it processes each input signal in three ways: bypass, latch, and reset.

The HALF EPS is designed with a hierarchical structure and consists of two separate systems: the accelerator EPS and the beamline EPS. The accelerator EPS is composed of a main PLC and multiple salve PLCs. The interlocking response time within the PLC is less than 20 ms, while that between PLCs is less than 100 ms. The beamline EPS consists of 10 independent subsystem. The functions and interlocking logic of each subsystem are similar, and they are implemented using a PLC. When multiple experiment stations share a beamline, the interlocking logic must be carefully designed to consider the mutual relationships and operation mode between experiment stations. The interlocking response time of each subsystem is less than 100 ms.

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Timing System

The timing system provides trigger signals for the HALF injector, storage ring and beamlines, coordinates beam injection and measurement, and achieves filling of the storage ring bucket with any designated bunch pattern.

The timing system must meet the repeatability requirements of beam injection, with a repeat frequency adjustable between 1-10 Hz. The delay and pulse width of each signal can be adjusted independently, with a minimum step size of 10 ns (where the timing delay adjustment for the electron gun and injection system has a minimum step size of 10 ps). The signal jitter should be less than 30 ps. To ensure stable operation over a long time, the trigger signal drift caused by changes in fibre length should be minimized.

A prototype system is built using the event system hardware based on MTCA.4 manufactured by MRF Company, and the software is developed with EPICS general record. The hardware structure diagram and photo of the prototype system are shown in Fig. 5. Test results show that the jitter of trigger signal is about 20 ps, and the signal drift is controlled around 3 ps after delay compensation, both meet the design requirements of the HALF timing system [5].

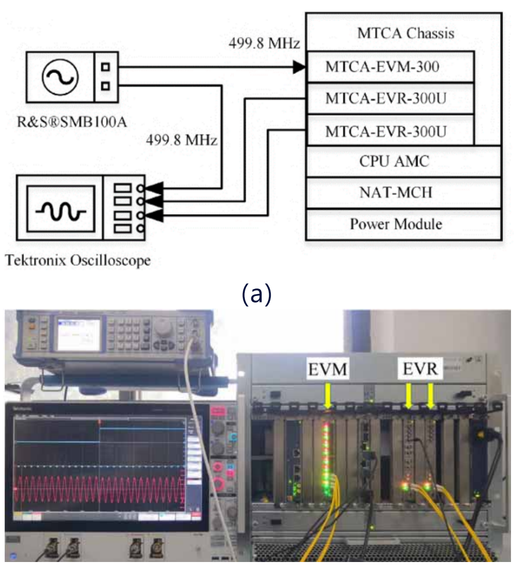

Figure 5: Hardware structure diagram of the timing prototype system (a) and its photo (b).

Network

The network system serves as the connection between the various components of HALF. It enables control data transmission between front-end devices, IOCs, OPIs, servers, and storage units on one hand, while also supporting high-speed data communication requirements such as accelerator waveforms and experimental data on the other. The network system is composed of communication network, network security system and network status monitoring system.

The communication network is divided into two distinct parts: the control network and the data network, which are physically isolated from each other. The control network is further divided into the EPICS network and the device network with VLAN, and the device network is subdivided into multiple VLAN subnets to achieve network isolation. By estimating the scale of the control system, the 10 Gbps control backbone network and the data network that can be expanded to 100 Gbps can adequately meet the communication requirements of the HALF control system.

The network security system plays a crucial role to ensure the reliable operation of HALF. It is designed by combining network security tools and management measures. The network security tools such as firewalls, antivirus, intrusion detection and prevention systems (IDS/IPS), virtual private networks (VPN) are deployed. The adopted management measures include account management, device access rules, and so on.

The network status monitoring system monitors the status of network devices, which can promptly discover issues such as network failures and degraded performance, thus enriching operation and maintenance methods, ultimately improving overall efficiency.

The network status monitoring system is developed with Zabbix [6]. It consists of a three-tier architecture, including the basic resource layer, data collection layer and application service layer, as shown in Fig. 6. The monitored objects serve as the data source for the system. The types of monitored devices include Ethernet devices, Linux PCs, VMware VMs, and VMware vSphere components. Zabbix collects metrics (e.g., basic information and current status data) from the monitored objects through protocols such as Zabbix agent, SNMP, SOAP, etc. The collected metrics are processed by the Zabbix server and then stored in the Zabbix database. Zabbix web is provided for easy access to Zabbix from anywhere and on any platform [7].

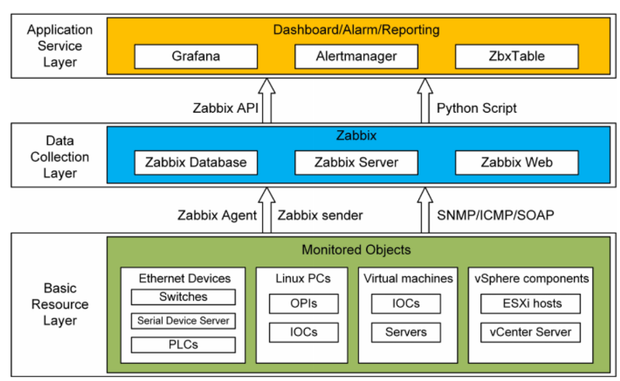

Figure 6: Architecture of the network status monitoring system.

Database and Application

The database and application system mainly include the data archiving system and the alarm system.

The software architecture of the HALF data archiving system is shown in Fig. 7. RDB Archive Engine [8] is used as the data acquisition engine and TimescaleDB [9] is used to store PV data. The web service layer includes historical data retrieval module and real-time data module, while the web application layer provides web-based data display, query and analysis services.

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According to the estimation based on the HALF scale, approximately 25,000 EPICS PVs will be stored in the database. In the EPICS PV data scenario of HALF, a fair database test platform is designed and built to evaluate the read-write performance of databases commonly employed in the particle accelerator field. The evaluated objects include EPICS Archiver Appliance and the five databases, i.e. MongoDB, HBase, InfluxDB, TimescaleDB, and Cassandra. The test results indicate that TimescaleDB has best read performance and second-best write performance. Furthermore, TimescaleDB supports continuous aggregation, which allows to summarize data at different levels of granularity and form materialized views. Materialized views can significantly improve query performance for long term data.

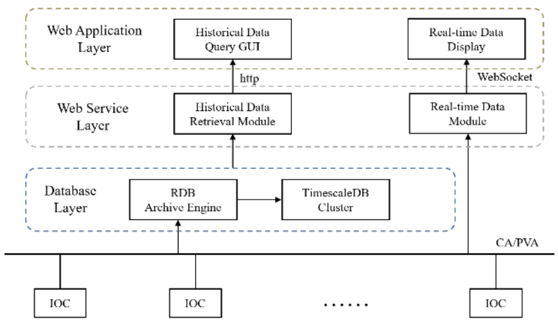

Figure 7: Architecture of the data archiving system.

The HALF alarm system is developed based on Phoebus/Alarms [10], and its architecture is shown in Fig. 8. The main work of our development is to expand the ways of alarm message distribution and enhance the methods of suppressing the alarm flood. In accordance with the requirements of HALF operation, three ways of alarm message distribution have been added, including WeChat, SMS and web-based GUI.

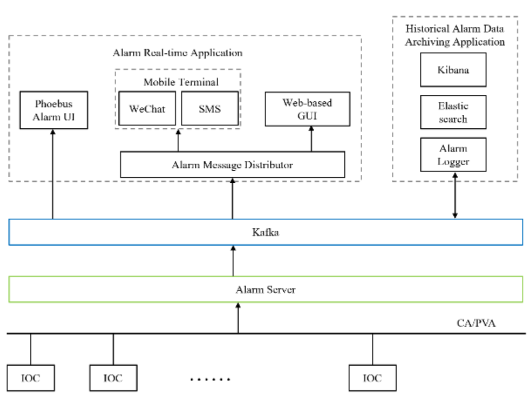

Figure 8: Architecture of the alarm system.

CONCLUSION

The HALF control system is built on EPICS with integrated application and data platforms for the entire facility, which includes accelerator, beamlines, and utilities. In order to save manpower and improve development efficiency, a unified architecture is adopted, incorporating server virtualization technology, VLAN technology and COTS products. Some R&D tasks have been started, such as timing system, network status monitoring system, data archiving system and alarm system.

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