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DESIGN AND IMPLEMENTATION OF SESAME'S STORAGE RING CONTROL SYSTEM

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Abstract

SESAME is a synchrotron light source located in Allan, Jordan. It is expected to become operational in late 2017. Storage ring is currently under commissioning. SESAME's control systems are based on EPICS used for developing both soft and hard IOCs. Control System Studio (CSS) is used to build the graphical user interfaces. PLCs are used in machine protection and personal safety systems. VME crates are used in timing and power supplies control systems. This paper presents progress made in design and development of the Storage ring's control systems including: vacuum, power supplies, RF, diagnostics, cooling, MPS, PSS and timing systems.

INTRODUCTION

SESAME consists of a 22 MeV Microtron, an 800 MeV Booster Synchrotron and a 2.5 GeV Storage Ring. The storage ring is composed of 16 cells; each cell consists of a bending section and a straight section.

EPICS base version R3.14.12 is used in control system implementation. EPICS Input/ output Controllers (IOCs) are running as servers. A custom build of CSS based on V.3.16 is used to implement graphical user interfaces. Scientific Linux version 6.4 is used as a main operating system in development and administration platform. A Git version control is used to track development and documentation. Siemens S7 PLC controllers are used for the Machine Protection System (MPS). Allen Bradley PLC controller is used for the Personal Safety System (PSS). VME crates are used in the Timing and Power Supplies systems. All clients, servers, and controllers are connected to an isolated machine network. Twelve virtual servers are reserved to run the IOCs, archive system, alarm system and Git repositories.

The storage ring's control system is divided into several subsystems: vacuum, power supplies, RF, diagnostics, cooling, MPS, PSS and timing. Each control subsystem consists of one or more clients, servers, and controllers.

DESIGN AND IMPLEMENTATION

Vacuum

The vacuum subsystem for the Storage Ring consists of 106 ion pumps, 27 vacuum gauges, 16 gate valves, 32 ion pump controller, 8 vacuum gauge controllers, and one PLC. Ion pumps are connected to a quad ion pump controllers, where each controller is connected to the control network through Ethernet communication port. Gauge controllers have RS232 serial communication ports. Four serial terminal servers are used to connect the gauge controllers to the control network. Gate valves and gauge controllers' set points are connected to the PLC which is used for machine protection system.

Vacuum control system consists of CSS Operator Interfaces (OPIs), One EPICS IOC is running on a virtual server with Linux-x86 platform to control all vacuum subsystem devices. Stream device and S7PLC EPICS support modules are used in the IOC. Table 1 shows a summary of the devices used in the vacuum subsystem.

Table 1: Vacuum Subsystem Devices

Device	Qty.	Manufacturer
Ion pump Controller	32	Gamma Vacuum - QPC
Ion Pump	106	Gamma Vacuum
Gauge Controller	8	Agilent - XGS600
IMG Gauge	27	Agilent
Serial terminal server	4	3onedata
PLC	1	Siemens – S7 300

Power Supplies

The power supply subsystem for the Storage Ring consists of DC power supplies and pulsed power supplies. DC power supplies consist of 141 power supplies selected from EEI [1], TDK-lambda [2] and PSI [3]. For the quadrupoles and sextupoles, commercial off-the-shelf units from TDK-Lamda were selected. These power supplies are controlled by an analogue voltage. The dipole power supply was chosen from an existing design by EEI, Italy, in operation at Medaustron, Austria. The power supply is controlled digitally via an RS422 link. Finally, the corrector power supplies were supplied by PSI (Paul Scherrer Institute). Power supply controller (PSC) is used from PSI. The PSC reads the measurement from the current transducer and generates the voltage reference to be sent to the voltage source in order to produce an accurate current. The regulation loop is implemented in the digital domain but the voltage reference can be either analogue or digital. This requires a high precision current transducer and ADC for the reading of the current and a DAC to generate an analogue voltage reference.

Power supplies' control system consists of CSS OPIs (clients), EPICS IOCs, (gateways or servers), power supply controllers (PSCs), and a timing system. EPICS IOCs are running on Linux based PowerPC platforms hosted inside 1U VME crates. Gateways relay commands from the clients to the PSCs, and report back process variables. Each gateway controls up to 16 PSCs. There are a total of 6 gateways controlling a total of 93 PSCs. Gateways communicate with clients over a Gigabit Ethernet network, and communicate with PSCs over

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point-to-point optical fibre links. An event-based timing system serves as the timing reference for the entire control network. An event generator distributes trigger and synchronisation events to the gateways. The gateways relay trigger events to the PSCs to synchronize waveform sequencing across all power supplies [4]. Figure 1 shows the DC power supplies control architecture.

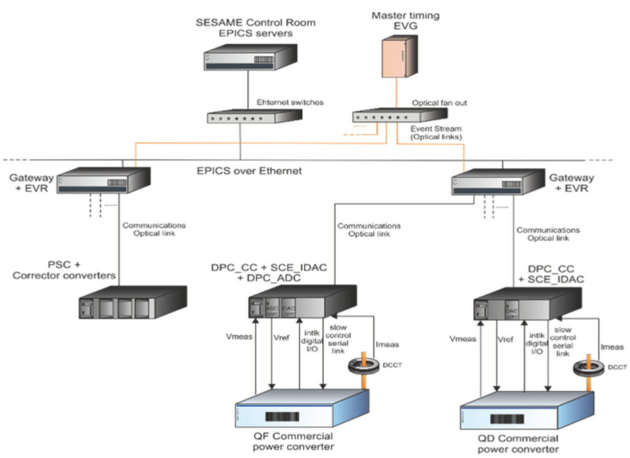

Figure 1: Power supplies control architecture.

Pulsed power supplies are DC power supplies connected to a separate pulsed triggering mechanism. They consist of one power supply for the injection septum and one power supply for the injection kicker. Each of the mentioned power supplies is connected directly to the control network over TCP/IP. A single EPICS IOC server running on a Linux-x86 platform is used to control the pulsed power supplies.

A summary of the power supplies used is shown in Table 2.

Table 2: SR Power Supplies Subsystem Devices

Device	Qty.	Manufacturer
Bending magnet PS	1	EEI
Quadrupole PS	64	TDK-lambda
Sextupole PS	4	TDK-lambda
Corrector PS	64	PSI
Skew Quad PS	8	TDK-lambda
PSC	93	PSI
Gateway	6	IOXOS Technologies
Injection Septum PS	1	Delta-SM400
Injection Kicker PS	1	FUG-HCP35

Radio Frequency (RF)

The RF subsystem for the Storage Ring consists of four RF cavities and four cooling racks from ELETTRA, four Solid States Amplifiers (SSA) from SOLEIL & SIGMAPHI, two Digital Low Level Electronics (D-LLRF) from DIMTEL, one signal generator, one motion controller and one PLC. The four RF cavities have been contributed from Italy. Each cavity is connected to a cooling rack which has a process controller (Siemens SIPART DR24) to manage the thermal process automatically. The four DR24 controllers are connected to the RF PLC through a PROFIBUS communication to monitor all the signals from the cooling racks. Solid states amplifiers consists of combining 165 basic amplifiers, each providing up to 600 W RF power, 80 kW in total. Five controllers are used for the SSA, each controller monitors module-temperature and current for four groups (8 modules) and the forward and reflected power of each group, a sixth controller is used to monitor the SSA total forward and reflected power and the water flow [5]. SSA controllers are connected to the control network through SNMP communication. Two units of D-LLRF are used to control the four storage ring cavities. Each unit has up to 9 Input signals and 2 drive outputs. Additional slow inputs are used for monitoring vacuum and tuner positions. Communication with the motion control system, consisting of two axes Galil controller and two motor drives, is done by direct Ethernet connection. One main signal generator is used to generate the RF frequency which is 499.67 MHz. It is connected to the control network through Ethernet. One main Siemens S7 PLC is used to manage the interlocks to the RF system in addition to a fast interlock chain connected to the D-LLRF.

RF control system consists of CSS OPIs, One EPICS IOC communicates with the 4 SSAs and the signal generator running on a virtual Linux server, Two EPICS hard IOCs running on the D-LLRF boards with Linux-x86 platform and one EPICS IOC communicates with the PLC which is responsible for the cooling racks and the machine protection. Stream device and S7PLC EPICS support modules are used in the IOCs. Table 3 shows a summary of the devices used in the RF subsystem.

Table 3: RF Subsystem Devices

Device	Qty.	Manufacturer
Cavity	4	ELETTRA
Cooling Racks	4	ELETTRA
SSA	4	SOLEIL & SIGMAPHI
D-LLRF	2	DIMTEL
Signal Generator	1	Work Microwave
Motion Controller	1	Galil
PLC	1	Siemens – S7 300

Diagnostics

The diagnostics subsystem for the Storage Ring consists of 64 Beam Position Monitors (BPMs), three florescent screens, one Fast Current Transformer (FCT), one Direct Current Transformer (DCCT), two scrappers, two shakers, one Beam Loss Monitor (BLM), one Synchrotron Radiation Monitor (SRM), one motion controller and three externally triggered digital cameras.

Each four BMPs are connected to one Libera Brilliance Plus controller. One Florescent screens and two scrappers are controlled through stepper motors which are connected to one Galil motion controller. Two pneumatic actuated florescent screens are controlled using Siemens S7 PLC. The FCT signal is connected to oscilloscopes. DCCT is connected to Digital Voltmeter (DVM) which is

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controlled through Ethernet in order to read the current remotely. Shaker consists of two power amplifiers and RF switch to control the trigger for both amplifiers, and it is connected to Ethernet controller. SRM consists of Interferometer (double slits), copper mirror, optical components, digital triggered camera and three stepper motors connected to Galil controller in order to align the mirror. BLM consists of a detector and signal acquisition electronics (Libera BLM) which is connected to the network through Ethernet. Cameras are connected to the network, and they are externally triggered by the timing system.

Diagnostics control system consists of CSS OPIs, Three EPICS soft IOCs communicate with cameras, DVM, motion controller and PLC, 12 EPICS hard IOCs running on the Libera Brilliance Plus controllers. All IOCs are running on Linux-x86 platform. Stream device, S7PLC and Galil EPICS support modules are used in the IOCs. There are also dedicated EPICS drivers for the cameras and Libera Brilliance Plus controllers build by SESAME and Instrumentation Technology Company. Table 4 shows a summary of the devices used in the diagnostics subsystem.

Table 4: Diagnostics Subsystem Devices

Device	Qty.	Manufacturer
BPM	64	FMB, kyocera
Libera Brilliance Plus	12	Instrumentation Tech.
Florescent Screens	3	VAB
Scrappers	2	VAB
FCT	1	Bergoz
DCCT	1	Bergoz
Shaker	1	In-house
SRM	1	NA
BLM	1	Instrumentation Tech
Motion Controller	1	Galil
PLC	1	Siemens – S7 300

Cooling

The cooling subsystem for the Storage Ring consists of magnets cooling interlocks. Sixteen in-house designed security boxes are responsible of protecting the magnets in case of any flow or temperature interlocks happened. The storage ring magnets are divided into 16 cells, each cell has a bending section which consists of 9 magnets as follows: one bending magnet, two quadrupole focusing magnets, two quadrupoles de-focusing magnets, two sextupole focusing magnets and two sextupole de-focusing magnets. Each security box is responsible for one cell. The security box has 18 relays inside and 18 LEDs on the front panel to show the flow and temperature interlocks for the nine magnets as shown in Figure 2. All security boxes are connected in series to the magnets power supplies, so if any interlock occurs it will directly interlock the power supplies. Siemens S7-300 PLC is connected to the security boxes to monitor all the interlocks and to send a reset command signal to them.

Figure 2: Security Box.

Cooling control system consists of CSS OPIs and one EPICS IOC communicate with the PLC is running on a Linux-x86 virtual server. S7PLC EPICS support module is used in the IOCs Table 5 shows a summary of the devices used in the cooling subsystem.

Table 5: Vacuum Subsystem Devices

Device	Qty.	Manufacturer
Security Box	16	In-house
PLC	1	Siemens – S7 300

Machine Protection System (MPS)

The machine protection subsystem for the Storage Ring consists of three main Siemens S7-300 PLCs. Each PLC has a CPU module, communication module and signal modules. Each PLC is responsible to protect its connected subsystem as follows:

- Vacuum/Diagnostics PLC (CPU 314)
- Cooling/Power Supplies PLC (CPU 314)
- RF PLC (CPU 315-2dp)

The storage ring is divided into 16 cells, each 4 cells makes one quadrant. It is difficult to connect the subsystem's devices to the PLC modules in one place because that requires using very long cables which is not recommended. For that reason a PROFINET communication has been used between the CPU and the remote I/O modules which are distributed in the four storage ring quadrants racks as shown in Figure 3.

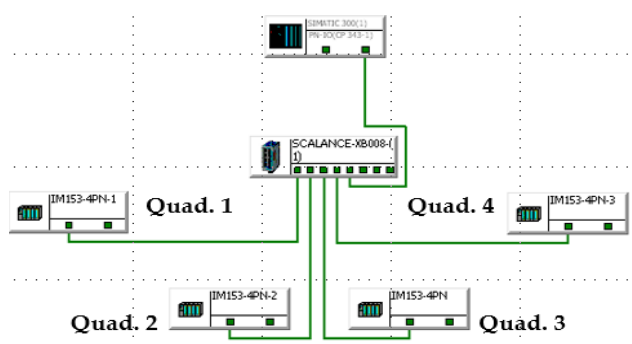

Figure 3: PLC PROFINET Layout.

Vacuum/Diagnostics PLC is connected to all gate valves in the storage ring and to all gauge controllers set points. If the vacuum gets bad in any cell in the storage ring, PLC will send a command to close all the valves and it will give an interlock command to the RF PLC which will kill the beam. Cooling/Power Supplies PLC is connected to all security boxes to monitor any flow or a

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temperature interlock related to the magnets. Magnets power supplies will switch off by hardware interlock connection. RF PLC is connected to the Solid States Amplifiers and to the D-LLRF units. If any interlock is detected in the SSAs or if the vacuum PLCs send any interlock, the RF PLC will send interlock signal to the D-LLRF units which will kill the beam.

MPS control system consists of CSS OPIs and one EPICS IOC communicate with the PLCs is running on a Linux-x86 virtual server. S7PLC EPICS support module is used in the IOCs

Personal Safety System (PSS)

The personal safety subsystem for the Storage Ring consists of a PLC based control system which provides an easy tool to implement the PSS sequences and procedures in a protected programming tool where all changes are recorded. PSS has been designed and selected to meet the requirements of SIL3. The safety PLC (Allen Bradley Guard -Logix L72s) monitors a set of conditions connected to its input modules and as result of the programmed logic safety PLC will send the permissions to allow the operation of the interlocked system as Microtron, Booster RF, Storage Ring RF, Injection from booster to Storage Ring and beam shutters, each system has some conditions to be verified, if one or more conditions lost, the PLC will disable the related system [6]. Figure 4 shows the layout of personal safety system PLCs.

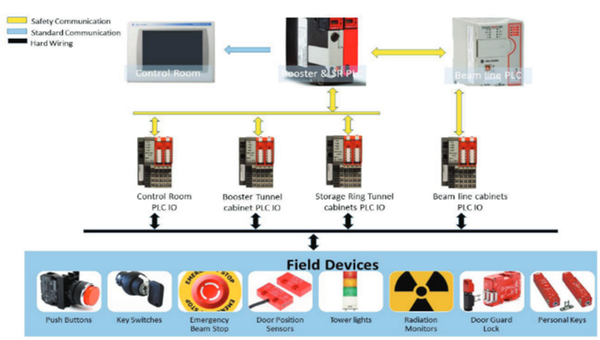

Figure 4: PSS Layout.

PSS control system consists of CSS OPIs, dedicated GUIs developed using Factory Talk software, and one EPICS IOC communicates with the Allen Bradley PLC is running on a Linux-x86 virtual server. Either IP EPICS support module is used in the IOC.

Timing System

The timing subsystem for the storage ring consists of one event generator, seven event receivers, one fan-out module and five splitter modules. All these modules are hosted in VME crates. The event generator and the event receiver cards are manufactured by Micro-Research Finland (MRF). The splitters are manufactured by Caen Italy. Event generator sends one event to the optical fan-out module which distributes the event to 6 event receivers installed in the power supplies gateways to trigger all the power supplies, and to one event receiver responsible for triggering cameras, Liberas, scopes, and pulsed power supplies. It also generates the machine clock. Splitters are used to split the event receiver triggers to the devices which are distributed in the storage ring quadrants. Figure 5 shows the layout of the timing system.

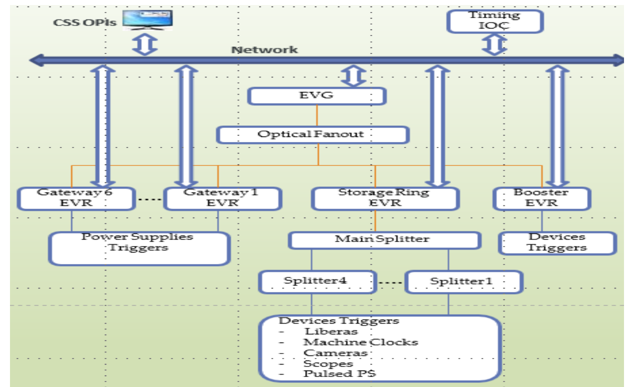

Figure 5: Timing System Layout.

Timing control system consists of CSS OPIs, one EPICS IOC communicates with the event generator and event receiver is running on a Linux-x86 virtual server. Evg and Evr EPICS support module which are developed at SESAME are used in the IOC. There are also 6 hard IOCs running on the power supplies gateways which communicate with 6 integrated event receivers.

CONCLUSION

EPICS is used to build the control systems at SESAME. Git version control is used to track development of the control systems. Twelve virtual servers are reserved to run the IOCs, archive system, alarm system and Git repositories. There are standards to be followed in building IOCs. CSS is used to build OPIs. Archiver and alarm handler are built using Beauty and Beast. Building the beamlines control system will follow similar strategy as in the storage ring.

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