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EQUIPMENT AND PERSONAL PROTECTION SYSTEMS FOR THE SIRIUS BEAMLINES *

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Abstract

The beamlines and front ends at Sirius, the Brazilian 4th generation synchrotron light source, require monitoring and protection systems for personal and equipment safety in general, due to the high beam power dissipated along the beamline, vacuum safety, secure radiation levels, use of robots, special gases, cryogenic systems, and other highly sensitive and costly equipment throughout the facility. Two distinct programable logic controllers (PLC) were then deployed to create the Equipment Protection System (EPS) and the Personal Protection System (PPS). This work presents an overview of the EPS/PPS - requirements, architecture, design and deployment details, and commissioning results for the first set of beamlines.

INTRODUCTION

The personal protection system (PPS) and equipment protection systems (EPS) are individual per beamline and are implemented in general by two programmable logic controllers (PLCs). The PPS central process unit (CPU) is the Siemens's safety model 1516F-3 and the EPS CPU is Siemens's standard model 1516-3. Both systems use distributed I/Os with Profinet communication with the CPU. The main Graphical User Interface (GUI) is implemented by a Human Machine Interface (HMI) common to other PLC based subsystems and the Input/Output Controller (IOC) [1] is used to allow communication via OPC Unified Architecture (OPC UA) [2, 3] between the PLCs and the Experimental and Industrial Control System (EPICS) [1].

This article is divided into three parts: The first part is about the EPS, the second part is about the PPS and the third is about common subjects related to EPS and PPS.

EPS

Basic Principles

The principles of EPS are low response time, use of positive logic, distributed I/O modules, and simplified detection of the protection logic triggers. The protection logics are very similar among the beamlines, the main protection logics are related to vacuum, temperature, position, and power loss. The program is modularized by hutches, the interface data and functions with the sensors and components form an object's library. The interface with other systems happens through galvanic isolated signals, then the EPS logic and the other system logic actuate together.

There are three checklists for commissioning the EPS: I/Os signals validation, HMI validation, and protection logic validation.

Protection Logics

The protection logic related to vacuum, temperature, position, and blackout fail are following. These protection logics are triggered by an EPS reading or an interface signal with other systems.

Vacuum protection. The vacuum protection system is divided into fast vacuum protection, slow vacuum protection, and low vacuum protection.

Fast vacuum protection is treated individually by the following VAT's devices: Controller VF-2, cold cathode gauge and shutter valve [4]. The shutter valve is installed in the front-end (FE) and the gauge is installed in the vacuum path between FE and the first optical hutch. These devices aim to protect the storage ring (SR) from a high-speed shock wave that could come from the beamline. A detailed description of tests and validation of this matter can be consulted in the article [5].

Slow vacuum protection is used in ultra-high vacuum (UHV) regions, it consists in isolate vacuum paths and interlocks the valve opening in case of high pressure detected. Ionic pump and cold cathode gauge controllers diagnose high pressure through digital signals. Intended to keep the beam on SR, the FE's protection system is triggered if the ionic pump and the cold cathode gauge detect high pressure. Disconnecting the cold cathode gauge connector, it reads a very low pressure, which could indicate a safe condition to FE's protection system even if the ionic pump is turned off. To avoid this unsafe condition, the gate valves opening is allowed only if all ionic pumps before FE's shutter are detecting pressure below the limit, and all cables are connected.

Low vacuum regions are usually situated in experimental stations, with pressures between 1000 *mBar* and $1x10^{-7}$ *mBar*. The protection logics are specific for each region.

From FE's shutter, if a high pressure is detected on a vacuum path by any sensor, the protection logic is triggered closing and interlock the opening of all the gate valves in UHV downstream to the shutter where the trigger occurred. The valves opening logic between shutters are sequential, from downstream shutter to upstream shutter.

Some vacuum paths are specified as critical paths. On these critical paths, due to a fast actuating needed by the

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valves, valve's close commands and shutters' close commands are sent simultaneously. The critical paths are usually presented in vacuum paths close to experimental stations' windows.

High temperature protection. The protection against high temperature is made through temperature measurement right on device structure and water flow measurement. The most used temperature sensors are PT100, PT1000, and thermocouple type K. For PT100 and PT1000, it's preferentially connected using the four wires connection. The water flow sensors are manufactured by SMC [6], model series PF3W, and uses the Kármán vortex measurement method. If the temperature read by EPS is higher than the limit or water flow is lower than the limit, the upstream shutter is closed and interlocked.

Position protection. This protection system is present usually on beam visualization devices, monochromators, and devices next to robots' workstations. The position protection ensures that the beam does not focus on parts not prepared for beam. On other devices, it also guarantees that collisions do not happen. The most used sensors are inductive or optical barrier types. In case some sensor detects an unsafe position, the upstream shutter is closed and interlocked, or the unsafe device has its motion interrupted and interlocked.

Power outage protection. This protection logic is triggered in case of fail on EPS' power supply 24 VDC. The power supply consists of the use beamline's UPS circuit, two voltage sources 24 VDC, a redundancy module, a buffer, fuses, and selectivity modules. The following Fig. 1 exposes a connection diagram of these devices.

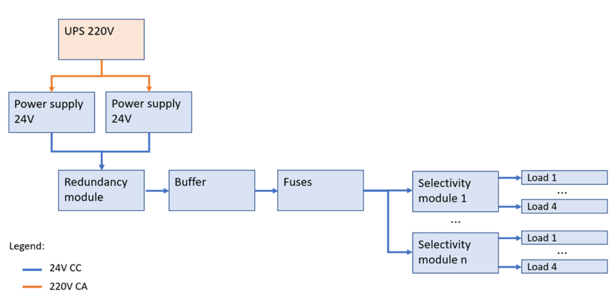

Figure 1: EPS and PPS's 24 VDC connection diagram.

The power supply failure occurs due to a beamline UPS device fail, 24 VDC power supply distribution device fail or by pressing the electricity emergency button. In case of pressed electricity emergency button, because of safe conditions defined together with Sirius' safety group, all the components of the beamline are shutdown, including ionic pumps, turbopumps, and mechanical pumps. This protection logic's priority is to keep beamline vacuum paths in a safe condition before EPS shutdown, this safe condition is guaranteed closing all the valves.

A power outage failure diagnostic is made through state signals available by the voltage sources, redundancy modules, buffers, and selectivity modules. The buffer generates a delay on the shutdown between 200 ms and 10 s, which is enough time to execute the protection logic.

Software Structure

EPS' program was separated into: Protection logic, devices' objects, other systems interface, and communication. Figure 2 represents the software structure scheme.

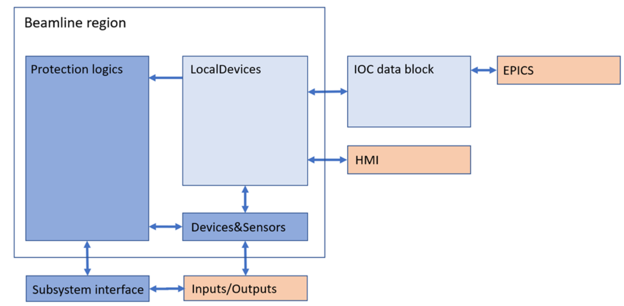

Figure 2: Scheme containing function blocks (dark blue), data blocks (light blue) and external interfaces (orange).

Objects. The objects in EPS are a set of variables and functions that allow actuating on devices, generate alarms, set settings, and collect information. As the connected signals are like each other in all beamlines, the set of object types, like gate valves, digital sensors, analog sensors, and among others, creates a library. In EPS, the objects' variables are contained in a data block called LocalDevices, and the functions of each device are contained in a function block called Devices&Sensors.

The creation of objects and the use of the library favors standardization and decreases developing time because it provides a simpler programming interface, the diagnostics variables that are used in protection logics, alarms, and devices' data accessed through HMI and EPICS communication.

By using this patterned structure of the devices, was developed a script that generates the files of IOC's settings, and the code in SCL programming language that moves LocalDevices' data blocks to EPICS' interface communication data block.

Interlock. In the functions' interface inside Devices&Sensors, there are inputs dedicated to interlock. These inputs work with positive logic and the interlock function is executed independently the others inputs' state.

Vacuum protection logic. The slow vacuum protection logic owns a patterned structure. The first part of the code generates diagnostic flags that indicates if the regions before or after the shutter are with a good vacuum. For that, each vacuum path has a logic AND or OR among the vacuum gauges depending on the path's location. Posteriorly, the generated flags of the regions before or after the shutter are used below in each valve's logic, which could trigger the device's interlocks inputs.

Commissioning

To execute the beamlines EPS' commissioning three tests was developed: signals checklist, protection logics tests, and HMI tests. The signals checklist verifies if the signal's tag on the PLC matches physically to the device and if the signal behaves as specified in the tag's

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description. The protection logic tests consist in emulating in PLC all fail conditions in the beamline that triggers one of the protection logics and watch the resulting signals and components' states. In HMI all the visual indicators and commands are verified.

After these three tests validation, the hutch can operate from the equipment protection system point of view. The software division mentioned in Software structure by hutches allowed a faster availability of hutches to commissioning with the beam.

PPS

Basic Principles

The PPS consists of an automation system designed to allow facilities to operate at the appropriate security levels, determined by personal risk analysis. The solutions applied are based on engineering good practices, Brazilian and international technical standards, acquired experiences over the years in the first Brazilian synchrotron light source and from the other countries synchrotron light sources, and using certificated security components commercially available.

Protection Logics

From risk analysis in the beamlines and previous experience, four main protection logics are highlighted.

Search. The search procedure is monitored by PPS, performed by one person, and consists in a visual inspection of the hutch or a beamline's region and pressing the search buttons, to guarantee that there is nobody inside the risk region.

The search procedure must be executed by a trained and enabled person. Beyond these administrative requirements, is in development an enabling system of the search that uses an RFID card. This system will be responsible for generating a data logging containing data about the performer of the search: The date, time, and local that the search has been done. Besides, the system can set an expiration time to each RFID card.

As an improvement, light curtains were installed on the region of the hutch's door and are used to verify if more than one person goes into the hutch during the procedure. In case of interruption on the curtain's beam before all the buttons being pressed, the search process is interrupted and must be restarted. After the procedure's finalization, the light curtain inside the hutch keeps monitoring and is used as an additional emergency signal, in this case, the shutter is closed, the beamline goes to fail state and the doors are unlocked.

Security locks. On the hutches' doors were installed security locks from different manufactures to offer diversity and redundancy. One of the locks counts with an electromagnetic lock and the other with a mechanical lock, so that exists a position monitoring and a lock that generates a force maintaining the door in a safe position.

Enabling keys. Each beamline count with a set of keys monitored by PPS. Being one for each hutch, a general enabling key used by the radiological protection group, and a key for reset. The chicanes own monitored keys by PPS and use the trapped key system.

Emergency buttons. The types of emergency buttons were reduced to only two buttons, being the personal protection emergency button and the electrical emergency button. The personal protection buttons are distributed over the beamline and monitored by PPS to react in case of pressing, immediately closing the shutters and disabling other systems that could exist in the beamlines, like robots.

Software Structure

The PPS's program is separated into some logical parts: safety protection logic, non-safety protection logic, data blocks to create an interface between safety and non-safety logic, and data blocks used for communication. Figure 3 represents the software structure scheme.

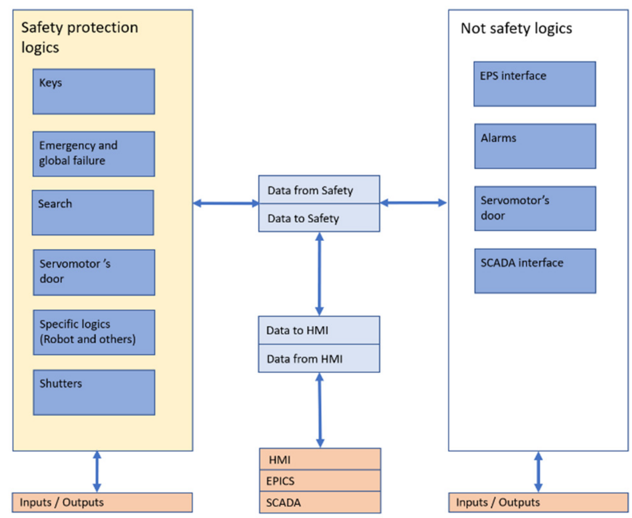

Figure 3: Scheme containing the main function blocks (dark blue), data blocks (light blue) and external interfaces (orange) to the PPS.

The search and shutter function blocks are equal functions for all the regions that need these functionalities.

The HMI, EPICS, and SCADA communication data blocks were separated from the safety data for security.

Initial Tests of the Protection Logics

To validate the PPS's logic before using the program in the beamline were developed a simulation software by tables using a virtual controller through an API from S7-PLCSIM Advanced and an application based on SimTableApplication, made available by Siemens [7].

The program inputs consist of tables with initial beamline conditions, inputs with changed values in an interval of time, and the expected states to the outputs. By executing the program, the generated outputs by the virtual controller are compared with the expected states and are generated a report indicating the comparison result.

Commissioning

To execute the beamlines PPS's commissioning, initial tests of hardware operation are made (indicator lights, buttons, safety locks, and others), following is a checklist

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simulating in the beamline all the conditions of each protection logic and possible human fails during the safety procedures. This inspection is made before the beginning of the beamline operation and is repeated periodically by the radiological protection group.

COMMON TOPICS

Interface with MPS

The interface between the SR machine protection system (MPS) and PPS is made to guarantee the FE Gamma shutter closed during the injection and to provide a redundancy in case of gamma shutter closing failure.

The interface between MPS and EPS is made to verify if there is beam in FE, provide, and receive vacuum status and allow or not beam in the beamline.

Although is necessary the exchange of signals between the beamline's protection and MPS, the beam availability on SR was considered and preserved on the maximum to a beamline fail does not affect all the other beamlines through the SR.

Interface with EPICS

To allow the integration of the EPS and PPS with EPICS to use Epics Process Variables (PVs) in control interfaces and Archiver [8], an IOC was created.

The EPICS is a standard tool used in beamline control systems and that's the reason to make the EPS and PPS data available in EPICS.

In EPS, the PVs are used principally to actuate a device remotely and inform the diagnostic related to interlock logics, limits, and status flags with or without reset from the read values and analyzed by the sensors and components. In PPS, the PVs are mainly used to inform the status and actuate the shutters, inform the radiological protection keys status, emergency or fail in the beamline and give commands to reset.

Human Machine Interface

The HMIs are installed in the beamlines' user's room and provides the PLC based systems GUIs. A more high-level view of the Sirius' facilities is shown in the SCADA system in development [9]. Other screens can be developed in EPICS by other teams using the available PVs.

EPS and PPS. The HMIs' screens of the beamline are divided per subsystem; therefore, PPS and EPS screens are separated. In EPS and PPS screens the information is divided in an initial screen by hutch of the beamline. The screen consists of an installation map, the main signals of diagnostic and operation. Some examples of EPS and PPS screens are shown in Fig. 4 and Fig. 5 following.

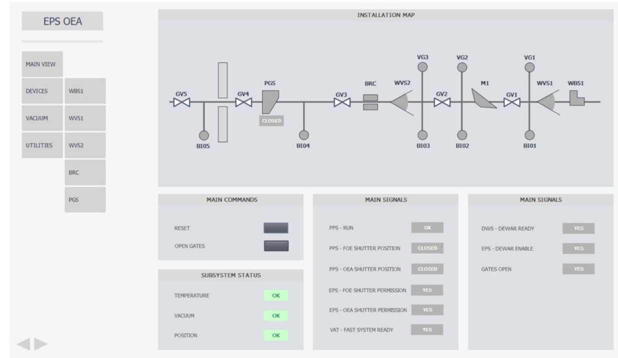

Figure 4: The main screen of EPS HMI of a hutch from a beamline representing a P&ID simplified diagram with components status, protection logics status, reset button, and the main interface signals between EPS and PPS.

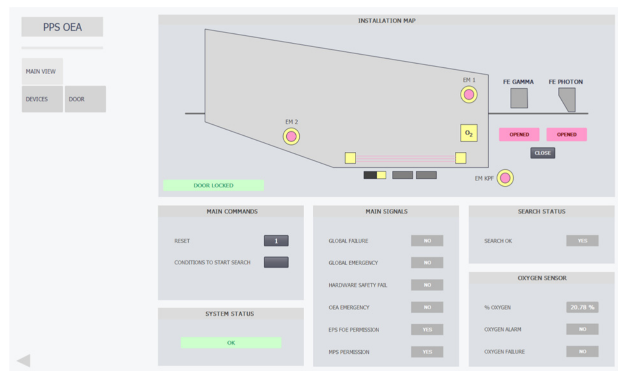

Figure 5: The main screen of PPS HMI showing FE's shutter status and components status inside the hutch, main diagnostic internal signals, interface signals with EPS, reset button, oxygen, and search status.

Alarms. An alarms table in Fig. 6 concentrates EPS and PPS alarms. The different types of alarms are encoded by colours: Red indicates that the alarm is active, and the beamline cannot operate, that is, the beam is no longer enabled to get to the sample. Yellow indicates a warning, that is a condition that requires attention, but does not prevent the beamline operation. Green indicates that fail or warning was active, but the problem is solved.

This table has two types of visualization called normal and buffer. On normal mode, the status of the alarm's status is shown in real-time, and on buffer mode all the historic of the alarm activation, deactivation, and acknowledgment are present. The buffer data can be cleared by using the button "clear" on the screen, this button has restricted access by password.

To make a more efficient visualization a filter was created that allows filtering the alarms shown in the table per hutch and subsystem. This filter uses as input the alarm description text that owns at beginning of the text the subsystem and the origin hutch.

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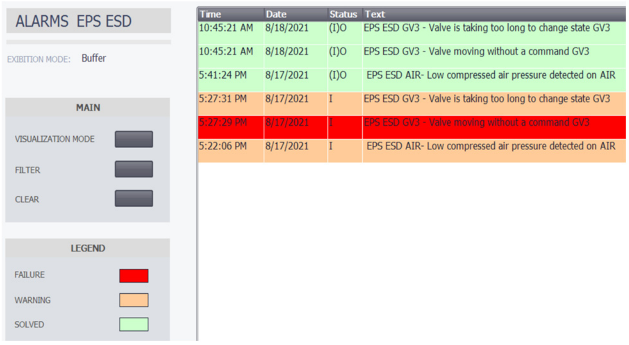

Figure 6: Sequence of alarms registered when there was a lack of compressed air on D hutch from beamline Carnauba.

For example, analyzing the alarms in Fig. 6 is possible to conclude that probably the lack of air made the valves move to a position different from that EPS was commanding, it caused a failure on the beamline, and that the insufficient pressure did not close the valve completely. It's also observed when the pressure was back to normal and when the valve moved to a close position. Only using Archiver [8], this analysis of causes and effects could consume a time considerably higher.

Sirius Improvements and UVX

In UVX, EPS and PPS worked differently than was projected to Sirius. The principal characteristics in UVX were: There was only one CPU per beamline from manufacturer Pepperl Fuchs [10] for both systems EPS and PPS, personal safety logics were executed using safety relays, distributed I/Os with ASI communication, and the interface with the user was made through panels with pushbuttons and a graphic interface developed by LNLS called Superinter to generation and verification of alarms communicated by RS232. In this system, no analog sensors were reading, only digitals because of the used hardware characteristics.

The main improvements in Sirius are related to infrastructure, software structure, communication, user interfaces, EPICS communication, and alarms diagnostics.

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