EQUIPMENT AND MACHINE PROTECTION SYSTEMS FOR THE FERMI@Elettra FEL FACILITY*

F. Giacuzzo, L. Battistello, L. Fröhlich, G. Gaio, M. Lonza, G. Scalamera, G. Strangolino, D. Vittor, Sincrotrone Trieste, Trieste, Italy.

Abstract

FERMI@Elettra is a Free Electron Laser (FEL) based on a 1.5 GeV linac presently under commissioning in Trieste, Italy [1]. Three PLC-based systems communicating to each other assure the protection of machine devices and equipment. The first is the interlock system for the linac RF plants; the second is dedicated to the protection of vacuum devices and magnets; the third is in charge of protecting various machine components from radiation damage. They all make use of a distributed architecture based on fieldbus technology and communicate with the control system via Ethernet interfaces and dedicated Tango device servers. A complete set of tools including graphical panels, logging and archiving systems are used to monitor the systems from the control room.

INTRODUCTION

The protection systems are based on Siemens S7 PLCs with an extensive use of Profibus to connect several distributed I/O peripherals and LCD operator panels. The communication between systems is realized either by means of Profibus or digital I/O signals, while Ethernet-TCP/IP is employed to interface to the FERMI@Elettra control system [2] using the Send/Receive protocol and dedicated Tango servers.

In all, the protection systems make use of five 315-2DP and 16 IM151 CPUs, 30 operator panels and 31 Profibus nodes. The systems manage in total about 1900 digital inputs, 500 digital outputs and 250 analog inputs.

LINAC RF PLANTS INTERLOCK SYSTEM

As shown in Fig. 1 each RF modulator is equipped with one PLC (CPU_MU), which guarantees the required performance in terms of reaction time. The goal is to allow no more than one linac shot after an interlock alarm is detected; given that the linac maximum repetition frequency is 50Hz, the protection action must be accomplished in less than 20 ms. This has also been achieved with an accurate design of the software architecture and a thorough programming. It has been necessary, for example, to avoid pre-compiled functions in favour of very primitive home-made functions and, whenever possible, to make extensive use of "jump" instructions. With a Siemens IM151 CPU controlling about 18 digital I/Os and eight analog inputs, the maximum reaction time is 12 ms.

Each RF plant has one touch-screen operator panel manufactured by UNIoP. A number of synoptic panels display the modulator interlock states and the analog input values, such as temperatures and klystron focalization currents, and allow the operator to set the corresponding interlock values.

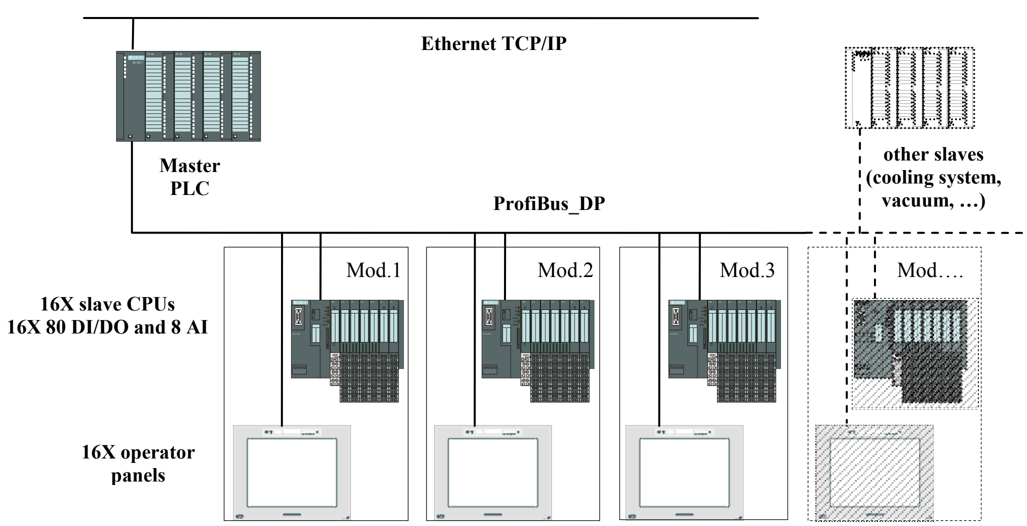

Figure 1: Block diagram of the linac RF plants interlock system.

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An example of panel representing the logics of the signals that enable the various RF plant subsystems is shown in Fig. 2.

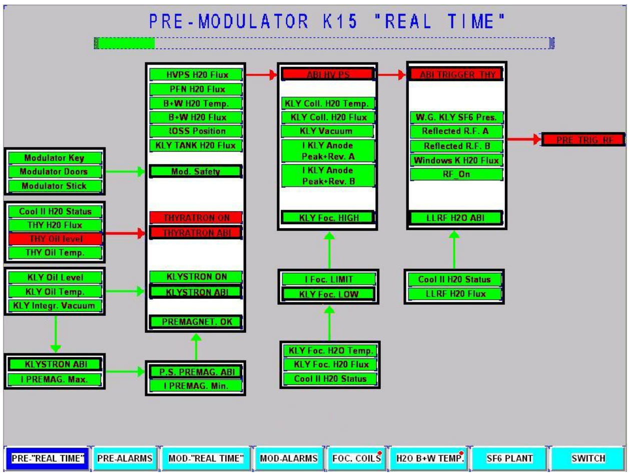

Figure 2: A page of the RF interlock operator panel.

All the CPU_MUs and the operator panels are connected through Profibus to a “Master PLC” configured as Profibus master, which does the following:

- Distribute to the CPU_MUs some common interlock alarms related for example to the general water cooling system, which don’t need a short reaction time;
- Collect all the data from the CPU_MUs and send them through Ethernet to the Tango server; the same data are also sent to the local operator panels.
- Receive control commands from the Tango server and send them to the proper CPU_MU.

With this architecture the interlock system of each RF plant is independent from each other. If one of them fails the others can continue working. Within some functional limitations the systems can also work without the “master PLC”.

During the first period of the machine commissioning, we suffered from a few interruptions of the communication between the master and slaves probably due to electromagnetic noise from klystron modulators. The problem has been solved by modifying the default DP Profibus profile; in particular, we have increased from one to ten the number of connection attempts from master to slave.

MAGNETS AND VACUUM INTERLOCK

The interlock for the protection of the accelerator electromagnets switches off the power supply in case of alarm from the cooling system of the corresponding magnet. Depending on the magnet type, alarms can be generated by flux-meters and thermo-switches. For safety reasons a lamp driven by the interlock system in placed on the magnets with potentially dangerous voltages. Moreover, the interlock system is also used to safely inhibit the power supplies in case of personnel access in the tunnel.

The purpose of the vacuum interlock is to avoid the propagation of possible leaks along the vacuum chamber. In the accelerator the PLC receives vacuum alarms from ion pump and vacuum gauge controllers by means of voltage-free contacts; the alarm thresholds (set points) are set on the controllers. In the machine front-end, instead, also analogic signals are acquired from temperature sensors, turbo-ionic pumps and vacuum gauges.

According to the coded protection logics, the PLC closes at least two valves in order to isolate the segment of vacuum chamber where an anomalous pressure increase has been detected; at the same time the PLC disables the electron beam to avoid damages of the valves. The vacuum valves can be remotely controlled (status reading and open/close command) either by using the local operator panels (Fig. 3) or via the Ethernet TCP/IP interface.

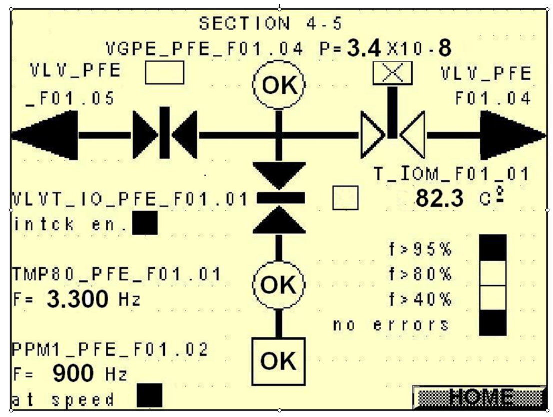

Figure 3: An operator panel display dedicated to the frontend vacuum interlock system.

MACHINE PROTECTION SYSTEM

The Machine Protection System (MPS) protects the FEL undulators from the deposition of excessive radiation doses caused, for example, by bad alignment of the electron beam. Several diagnostics are used to detect radiation, including ionization chambers, charge loss monitors and Cherenkov fibres [3]. The block diagram of the MPS is shown in Fig. 4.

In order to guarantee the required reaction time, a specific PLC has been dedicated to the MPS. It directly receives the alarm signals from the ionization chambers electronics. The analog signals generated by charge loss monitors and Cherenkov fibres are acquired by a VME system running Linux and the Xenomai real-time extension [4], which performs the signal processing and generates the alarms. The connection of the VME system with the PLC is realized by means of digital outputs and a heart-beat signal that synchronizes the communication.

Other signals not needing a fast response are collected by the PLC via Profibus from the interlock system.

In case of alarm, the PLC closes a shutter that stops the laser of the photo-injector, thus switching off the electron beam. The measured reaction time is less than 10 ms, so only one shot could eventually be fired after the alarm is received.

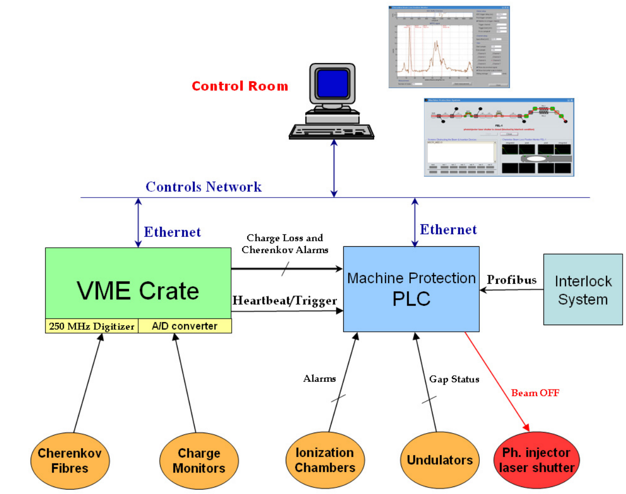

Figure 4: Block diagram of the Machine Protection System.

Since incorrectly inserted multi-screens hit by the electron beam can cause the release of huge radiation fields, the screens position is detected by means of micro-switches and the beam is disabled when they are moving. When a given screen arrives in the final position, the beam is automatically enabled only if that screen can be safely hit by electrons.

The reading of the undulators gap status (open/closed) is used to stop the beam only if the alarm is coming from a location were the undulator gap is closed. Moreover, the state of the bending magnets power supplies are used to determine the real path of the electron beam, so that only screens that can actually be reached by the electron beam are taken into account. A future upgrade of the system will provide analog readings of the bending currents.

In order to allow machine operations in the presence of anomalous situations during the machine commissioning, a feature has been implemented to selectively "bypass" some alarms. This possibility is only permitted to expert people.

The PLC cycle is synchronized with the linac trigger (up to 50Hz). At each linac shot the PLC compile a portion of a Data Block (DB) containing all the alarm states and adds to it a time stamp. When the DB is fully compiled with 50 shots, it is sent via Ethernet to a Tango server which stores it into a database. With this feature every event detected by the MPS is recorded and made available for analysis.

THE SUPERVISION SYSTEMS

Supervision applications run in the FERMI@Elettra control systems and are developed using the Tango framework. The interlock systems communicate with the control system through Ethernet links and dedicated Tango servers, which acquire alarms and send commands.

At every cycle each PLC compiles a DB with the data acquired from the field, both digital (true/false) and analog (floating point) values. If the PLC detects the variation of at least one of the values with respect to the previous cycle, it adds a time-stamp and sends out the DB via the Ethernet port. This is called "Real-Time DB".

In order to detect and memorize fast events that normally could be lost, a second DB called "Alarm DB" similar to the first one, latches the active alarms until an acknowledge command is received via the external interface. Also the Alarm DB is sent on variation.

A Tango Device Server for each PLC is in charge of receiving the DBs and saving them into a MySQL database. A second level of Tango servers communicating with the first level has been developed to extract data from the DBs and export every single value as a meaningful Tango attribute. The servers also receive commands from Tango client applications and forward them to the PLCs.

A number of graphical interfaces have been developed using Matlab and QTango, a C/C++ graphical library for the Tango control system. They display the status of the systems and warn operators of interlock alarms. Fig. 5 is an example of a synoptic panel representing the status of the vacuum interlock.

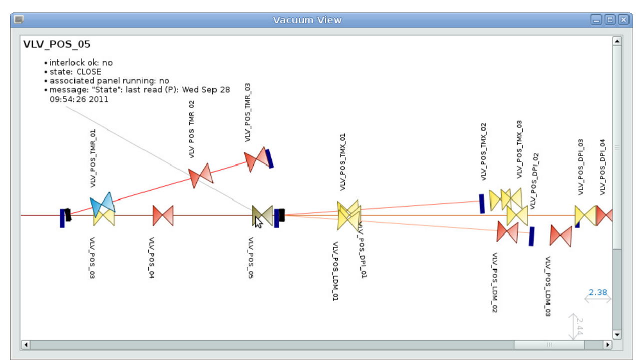

Figure 5: Synoptic panel of the vacuum interlock system.

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