MANAGEMENT OF THE FERMI CONTROL SYSTEM INFRASTRUCTURE*

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Abstract

Efficiency, flexibility and simplicity of management have been some of the design guidelines of the control system for the FERMI Free Electron Laser. Out-of-band system monitoring devices, remotely operated power distribution units and remote management interfaces have been integrated into the TANGO control system, leading to an effective control of the infrastructure. The Open Source tool Nagios has been deployed to monitor the functionality of the control system computers and the status of the application software for an easy and automatic identification and report of troubles.

INTRODUCTION

FERMI is a 4^{th} generation light source, based on a linear accelerator, designed to operate two FEL undulator chains covering the wavelength range from about 100 nm to 4 nm. The machine, more than three hundred meters long, develops on two levels. The linac accelerator tunnel and the undulator hall are underground, whereas the service galleries are overground and the experimental hall includes both.

The control system infrastructure has been designed to span all over those levels and be capillary available. Whenever possible, the network equipments and the field computers have been protected against possible radiation damage by keeping them away from the linac tunnel and undulator hall.

CONTROL SYSTEM INFRASTRUCTURE

Control System Network

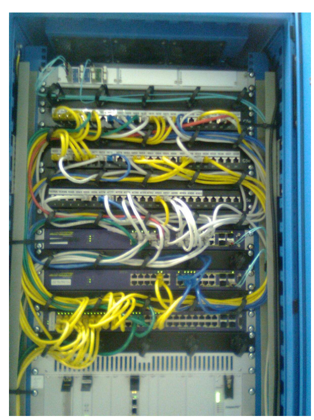
The FERMI control system is based on a distributed architecture which develops on a three-layer star-topology network. Two high performance, enterprise level, Black Diamond 8810 routing switches, manufactured by Extreme Networks, have been installed as the star center in a high-availability configuration. Designed to host up to ten blades, the BD8810 has 800 Gb/s total switching capacity.

Optical Multi-mode class 3 (OM3) and class 4 (OM4) fiber optic cables [1][2], capable of 10 Gb/s (10GbE) network speed over the plant distances, connect the star center, the first and second layer peripheral switches, installed into the controls and diagnostics racks. At the time of writing no active device has been installed into the intermediate level, and feed-through patches have been installed between the incoming and outgoing fiber optic cables. The three layer topology remains valid and can be easily activated to improve the flexibility: three concentration racks, one in each service gallery, have been arranged in advance to possibly move some advanced routing capability towards the periphery. Also, the physical data paths between the middle aggregation layer and the star center could possibly benefit of incoming 40GbE technology. Although currently deployed using GbE transceivers, all these links can easily be upgraded to 10GbE, or even more, if needed. The network architecture is depicted in Fig. 1.

Category 5e, 6 or 6a shielded Ethernet cables connect the controlled devices to the peripheral switches, making use of structured cabling to reach the accelerator tunnels. Peripheral switches are mostly 1GbE, but certain applications that don't require high per-point bandwidth have been served using 100 Mb/s 24 ports Ethernet switches, though featuring 1GbE uplinks.

Figure 2 shows the typical network hardware setup of a control system rack, counting a total of 96 Ethernet ports, equipped with:

- the fiber optic cable termination box;
- the patch-panels for the structured cabling reaching the tunnels;
- two 24 ports peripheral switches;
- one 48 ports peripheral switch.



(a) Front

(b) Rear

Figure 2: Network hardware inside a peripheral rack.

A total amount of 13 wireless access points, in service to the control system network, have been installed in the accelerator tunnels as well as in the service galleries and experimental hall.

Ethernet technology is also used as a *fieldbus* to aggregate Ethernet enabled devices into a local subnet that

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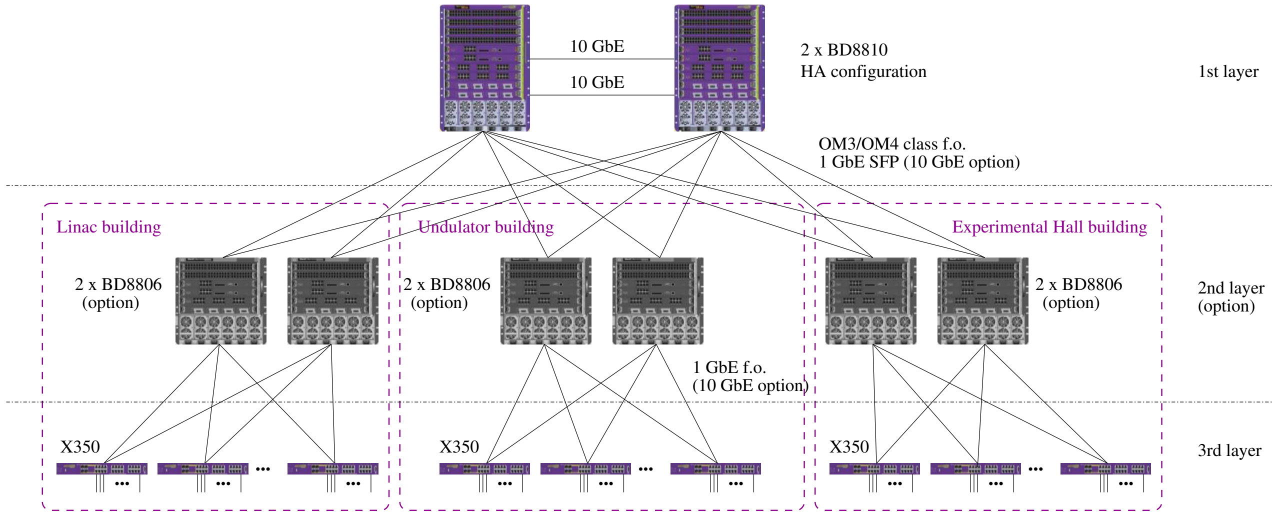

Figure 1: Controls network layout. Local network segments not shown.

doesn't need to be routed, in order to connect them to a dedicated field computer.

At the time of writing more than 110 peripheral switches, Summit X350 and X150 manufactured by Extreme Networks, are installed in the 65 racks that host the control system and diagnostics devices, distributed along the FERMI buildings. A grand total of about 1800 devices are connected to the control system network.

Front-end Computers

Currently, 64 VME based Equipment Controllers (EC) [3] featuring the Emerson MVME7100 PowerPC Single Board Computer (SBC) running GNU/Linux with Adeos/Xenomai real-time extensions are installed. This hard real-time platform has been used to interface all the standard controlled devices and to run the real-time acquisitions and control loops. Depending on the use, all four GbE interfaces availabile in the CPU have often been configured for the control, the real-time and the local network subnets.

Intel-based rack-mount servers have been used when required by proprietary software or computing power, for instance CCD acquisition [4], or PCI based hardware interfaces. To exploit all the processing power and overcome possible bandwidth limits, up to eight GbE interfaces have been used. Moreover, 10GbE adapters have been installed in the servers running the large image acquisition systems for the experimental stations [5].

IN-BAND SYSTEM MONITORING

A TANGO device server has been developed to monitor some fundamental operating system parameters in the control system computers. It can be configured to monitor:

- the total, used and free memory;
- the overall number of processes and threads;
- the overall system load;
- the memory footprint and system load of selected processes.

Some additional information such as system uptime and running kernel version are also exported by the device server. These parameters can be effectively used by the alarm system TANGO device server [6] and compared to predefined thresholds to alert the control room operators and/or control engineers of possible problems or malfunctions.

POWER DISTRIBUTION UNITS

All the racks containing control system devices, such as field computers, Programmable Logic Controllers (PLC), etc., have been equipped with intelligent Power Distribution Units (PDU). A number of racks belonging to additional accelerator subsystems, such as power supplies, vacuum, radio frequency modulators, host one or more PDU. The PDU core functionalities, switching on/off and monitoring the current absorption of the utilizer, are remotely availabile by means of an Ethernet interface. Furthermore, a large number of PDUs have been installed in the linac tunnel and the undulator hallbelow the accelerator girders, and used to power most of the electronic devices installed near the machine. In case of a device malfunctioning, when in-band recovery is no more effective, a complete device restart can be carried out by power cycling it from remote, without the need to access the tunnels. The overall grand total number of PDUs in service is more than 190.

Three Commercial Off The Shelf (COTS) models, selected from the catalog of two manufacturers, have been adopted and are described below.

Raritan PX8

The Raritan PX8 is a 1U 19" PDU featuring one IEC-60309 200-250 V 16 A input plug and eight

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IEC-60320 C13 outlets. It provides configurable users and groups with privilege control, access lists, host filtering, mains line voltage and current readback, overall unit apparent power, per-outlet complete control including actual current absorption, maximum peak current, active power, apparent power and power factor measurement. Advanced features, such as user defined timed sequences for outlet power on/off are also availabile.

Currently 40 PX8 PDUs are used in the control system racks and 28 in the power supply racks.

Apc AP792x

Two models have been selected from the APC product catalog. The AP7921 model is a 1U 19", similar to the PX8, with one IEC-60320 C19 200-250 V 16 A input plug and eight IEC-60320 C13 outlets, but overall current absorption measurement only. The AP7922 is a 2U 19" device, featuring one IEC-60309 200-250 V 32 A input plug and sixteen IEC-60320 C13 outlets.

About 65 AP7921 PDUs have been installed along the linac tunnel and undulator hall. The AP7922 PDUs have been used inside the racks hosting many small devices, such as the ones for the vacuum system, linac modulators, stepper motor controllers, etc. The total amount of AP7922 installed sums up to more than 60.

Integration Into The Control System

A TANGO device server has been developed for both the PX8 and AP792x PDU; the TANGO device server talks to the device through the Simple Network Management Protocol (SNMP) using the manufacturer Management Information Base [7] (MIB) file. The basic functionalities, such as powering on and off an outlet and reading the overall and per-outlet current absorption have been integrated into the TANGO control system. A graphical user interface, shown in Fig. 3, is availabile on the control system workstations.

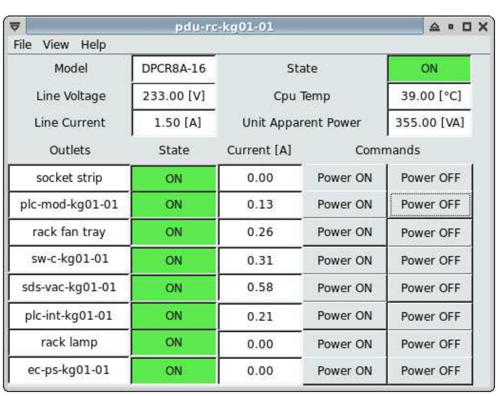

Figure 3: PDU graphical user interface.

OUT-OF-BAND REMOTE SYSTEM MANAGEMENT

Whenever needed, existing technologies have been adopted to monitor and/or to give remote access to the consoles of the control system computers. These are mainly serial lines for the VME computers and Intelligent Platform Management Interfaces (IPMI) devices for Intel-based servers. In the former case, serial to Ethernet converters, both wired and wireless, have been used to allow remote access to VME board consoles for monitoring or debugging purposes. In the latter the IPMI interface have been directly connected to a dedicated Virtual Local Area Network (VLAN) in the control system network.

Chassis Monitor Module

All the VME crates host an embedded controller, named Chassis Monitor Module (CMM), that controls and monitors the operating status of the chassis itself. Operating time, power supply output voltages, system temperatures, cooling fans rotational speed, are key parameters to perform some preventive maintenance. The CMM also allows for out-of-band VME system reset and complete crate power on/off. A TANGO device server integrates the CMM functionalities into the control system. The CMM is accessed via SNMP using the MIB provided by the manufacturer. The device is easily controlled by the operators using a dedicated graphical interface, shown in Fig. 4.

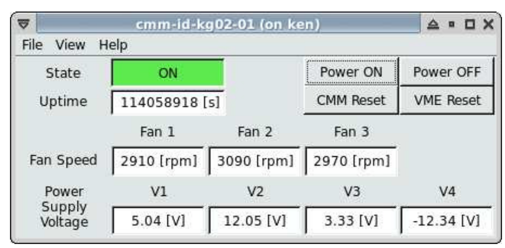

Figure 4: CMM graphical user interface.

Network Switches Management

The control system Ethernet switches have a management IP address on a dedicated VLAN. The management of these devices is made availabile by several tools and tecniques. Alongside the nice manufacturer proprietary graphical user interface, a really effective command line interface (CLI) is available through an encrypted channel access (ssh). The SNMP protocol is also supported. Using it, and the manufacturer MIB file, a TANGO device server has been developed to read some of the information availabile from the switch diagnostics. The following operating parameters are availabile:

- cooling fans rotating speed;
- temperatures;
- power supply status.

NAGIOS

Since the beginning, Nagios [8], an Open Source software package widely used to monitor IT infrastructures, has been introduced as a key tool to check the status of FERMI control system. It has been chosen for its flexibility, proven reliability and easy customization. The status of the whole infrastructure can be checked at a glance using the comprehensive web page, the add-ons availabile for the most popular web browsers and lots of additional applications.

The Nagios software runs on a dedicated virtual host which serves both FERMI and Elettra accelerators. Running Nagios requires little computing power and resources. It currently checks more than 300 hosts for reachability and a total amount of about 1000 services for availability. The most critical parameters are:

- available disk space;
- time and date synchronization;
- hardware or software RAID status;
- database replication.

The control function is performed through the *nrpe* utility [9], which directly runs on the monitored host, or using remote ssh connections from the system where Nagios is running. This second approach is preferred when checks are rare and the installation of software on remote system should be kept at minimum.

Plugins distributed with Nagios as well as home-made scripts written in Bash or Python are used. Many scripts use TANGO functions and tools to control the status and working parameters of a few critical accelerator components, adding redundancy for some key parameters already monitored by the control system alarm system. A screenshot of the NAGIOS summary page is shown in Fig. 5.

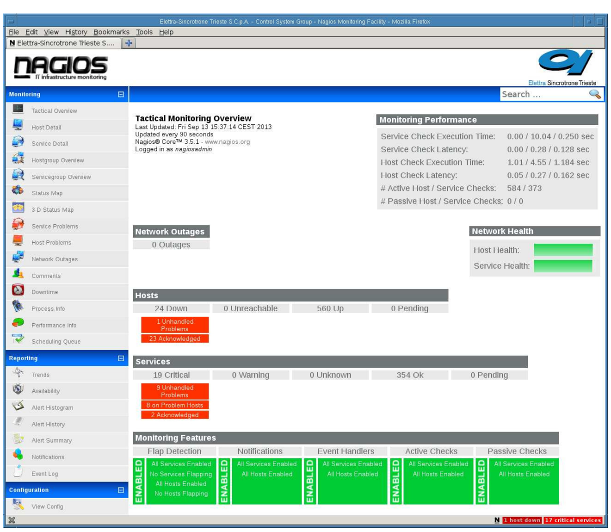

Figure 5: NAGIOS graphical user interface.

Warnings and critical states are notified via mail to the system administrator, to the people on call and to the responsible of specific subsystems. In some rare and very specific cases an asynchronous alert notice could be sent as a Short Message Service (SMS).

Because of the heterogeneity of the installations, particular care has been taken to tune the checks performed by Nagios on the systems in order to avoid issuing spurious alarms. Anyhow, from time to time the configuration should be reviewed to match the needs of the newly added parameters or to adapt to a changed mode of operation.

Up to now, thanks to this alert system, many potential problems have been notified well in advance and solved before leading to malfunctioning or even unavailability of the control system.

CONCLUSIONS

The described technologies have been widely adopted in the FERMI control system infrastructure. A well balanced mix of COTS products and technologies and in-house developed solutions have been deployed. Both in-band and out-of-band techniques have been exploited to be effective and maximize the control system availability and uptime.

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