ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA043

FIVE YEARS OF OPERATIONS FOR THE MAGNET POWER SUPPLIES OF FERMI

R. Visintini, Elettra Sincrotrone Trieste, Trieste, Italy

Abstract

FERMI, the FEL light source in Trieste, Italy, started its regular operation with external users in 2011. The construction of the facility began in 2008 and the commissioning of the complete system – LINAC, Undulators' chains (FEL-1 and FEL-2), photon front-end – started in 2010. On December 13, 2010 the first lasing occurred. From the Photo-injector to the electron Main Beam Dump (MBD), there are more than 400 magnets and coils, including those mounted on the accelerating sections of the LINAC and on the Undulators. With few exceptions, each magnet power supply energizes a single magnet/coil: there are about 400 magnet power supplies spanning from few tens of watt up to 42 kW. The power supplies types range from custom-made ones, to COTS (Commercial Off The Shelf), to in-house design (these accounting to 88% of the total). Almost all magnet power supplies are in use since mid-2010. During 5 years of operations, the reliability of the magnet power supplies proved to be extremely high: the downtime of FERMI operations due to magnet power supplies is very low.

INTRODUCTION

FERMI is the FEL source in operation for external users since 2011 [1] in the Elettra Research Center, in Trieste (Italy). FERMI is located extremely close to Elettra Storage Ring (SR) building: great care in planning and special low-vibration techniques were adopted not to interfere with the Users' activities on the Elettra's beamlines. FERMI is the long straight construction close to the circular Elettra SR building in Fig. 1.

Figure 1: Aerial view of FERMI and Elettra.

The civil works, carried out in about 4 years, ended in September 2010 but co-occupancy allowed the installation of the machine in parallel with the construction of the buildings and plants [2]. The commissioning started in September 2009 with the photoinjector and gun, and completed – excluding the experimental beamlines – in late 2010. The first seeded X-Ray lasing occurred on December 13, 2010 [3].

MAGNETS AND POWER SUPPLIES

The first magnet power supplies energized the gun solenoids and the injector spectrometer, starting in 2009. During 2010, about 400 more power supplies (PS) enter into operation on air- and iron-core magnets.

Design Strategies

In designing the magnet-PS combinations, we had multiple goals:

- Optimize the number of different PS for energizing the various types of magnets required by the particle physics design, taking in account the re-use of some magnets from the former LINAC to SR Transfer Line (TL) of Elettra.
- Standardize as much as possible the interface to the remote control and interlock (MPS – Machine Protection System).
- Make accurate estimations of the "contemporary factors", to define the actual power absorbed from the mains.
- Make realistic estimations of the dissipated power for the correct dimensioning of the HVAC (Heating Ventilation Air Conditioning) and water plants.

We achieved these goals through a close collaboration among the particle physics experts and the designers of the magnets, the PS, the control system, and the conventional plants. More details can be find in [4].

Power Supplies Types

The about 400 magnets and coils of FERMI belong to 37 different types, and, with few exceptions, they are individually energized. Following the optimization, the number of different PS types is 17: custom made, commercial ones (COTS – Commercial Off The Shelf) while the majority derives from an in-house design [5], as shown in Table 1.

Table 1: Types of Power Supplies

Type	# of Types	# of PS	Output [V/A]
Custom	2	4	25 – 55 / 750
COTS	12	31	15 -100 / 60 – 500
In-House	3	370	±12 - ±20 / ±5 - ±20
TOTAL	17	405	

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Custom PS energize the dipoles of the two electron beam dumps (6 magnets in total). These are large magnets from the former LINAC to SR TL and the required power level forced the adoption of a custom solution [6].

COTS PS, from various manufacturers, energize the 8% of magnets. Being FERMI, as other FELs, a "single-pass" machine, the stability requirements on the output current of the PS are "relaxed" (compared to those of a SR), allowing this solution.

The in-house solution is an evolution of a successful design of small, single card, bipolar PS for the Elettra new injector [7]. Trajectory feedback loops make use of small (<500 W) bipolar (4-quadrant) PS, that have to be matched to the corrector magnets. The remote control has also influence on the PS design, due to the integration with e-beam diagnostics systems. We therefore decided to develop two new families of PS, digitally controlled and regulated. They are named A2605 and A2620 (in short A26xx), whose main parameters are reported in Table 2.

Table 2: A2605 and A2620 Power Supplies

Type	A2605	A2620	Unit
Output Current	±5	±20	A
Output Voltage	±12	±20	V
DC/DC efficiency (full load)	>90	95	%
Switching frequency	104		kHz
Bandwidth-3dB (2Ω load)	1.5		kHz
Output Current Resolution	16		Bit
Accuracy	0.1	0.05	%
Long Term Stability (8 hrs)	±50	±25	ppm
Max Ripple	50		ppm
Cooling	forced air cooling		

Figure 2 shows three racks of PS. The large white ones are COTS while the red and blue ones are the A26xx.

Figure 2: PS racks in a FERMI Service Gallery.

Inside the racks, there are also ancillary devices like Ethernet switches and ETH/RS232 converters for interfacing the PS to the Control System, AC power distribution units and bulk DC supplies for the A26xx, as well as fan units for cooling.

OPERATION EXPERIENCES

We completed the startup of all power supplies in 2010 and the major number of issues occurred during this and the following year of operations. One possible classification of issues is the following:

1. Startup and commissioning of systems.
2. Regulation (adaptation to real loads).
3. Communication with Control and MPS.
4. Hardware failures.

Startup and Commissioning

At the early stages of the startup, all system – including the conventional ones – are under commissioning. This may lead to unexpected results from tests. As an example, the top plot in Fig. 3, is the output current stability result from a COTS PS, over 24 hours at a 300 A set value. The anomalous behavior is easily explained looking at the other plot in Fig. 3: the air conditioning system was also under commissioning and caused fluctuations in the room temperature, affecting our tests.

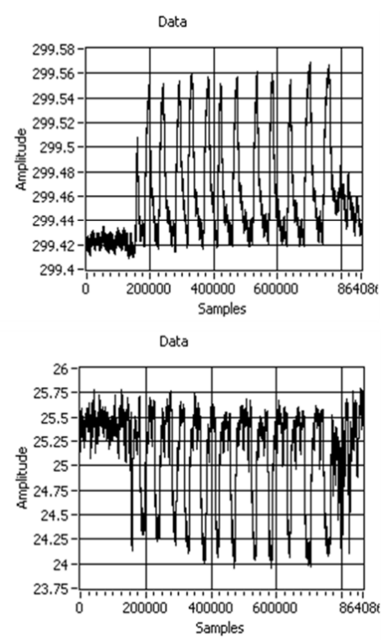

Figure 3: effect of room temperature on the stability test of PS over 24 hours (Top output current [A], bottom room temperature [ºC]).

Regulation

The power supplies have to be "tuned" to their loads, i.e. the regulation parameters must take in consideration the inductance of the magnets. Using COTS, in some cases, the standard regulation matches a resistive load.

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This brings to oscillations on the output when connected to a magnet. Figure 4 shows the output current (AC component) of a 30 V / 110 A commercial PS on its real load, before adapting the regulation parameters. The DC set is 100 A and the oscillation is ~10 A_{pk-pk} (green trace 4 is the readout from the current transducer, the orange trace A is the same signal converted into ampere)

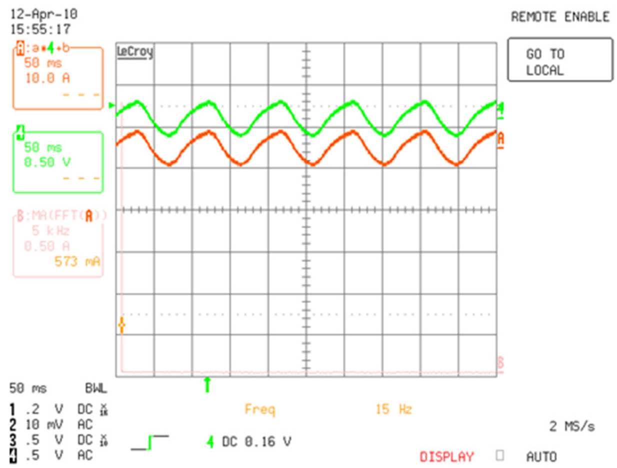

Figure 4: output current oscillation (DC set is 100 A), on a 30 V – 110 A COTS PS, before adjusting the regulation.

In the specific case, the manufacturer authorized us to modify, according to his recommendations, the regulation loop without warranty infringement, solving the issue on all PS from the company.

Communication

In FERMI, the common interface to the Control system is Ethernet (ETH) with TPC/IP. This type of interface is an option from many COTS products (others require an external ETH/RS232 unit), not a standard. During the first year of operation (2010 – April 2011), some bugs were discovered and definitively fixed in the ETH interface of a commercial PS and of the A26xx.

Hardware Failures

Besides very few (~20) cases – 3 failures on the custom PS, 3 on COTS and about 15 on in-house PS – almost all hardware issues occurred in 5 years involved ancillary systems (see Fig. 5). In particular, the most frequent failures concern the fan units under the A26xx crates (which lead to "over temperature" fault indications on the PS themselves) and the "Bulk" AC/DC power supplies for the A2620 units. The redundant installation of the "Bulk" PS (N+1 units) avoids downtime on FERMI when they fail and their "hot-swappable" feature allows quick replacement of the broken units without affecting the operation. According to the statistics on FERMI users' operations, the uptime in 2014 was 86.1% [8]. Considering the downtime over 4 years (2011 – 2014), the portion due to the power supplies is less than 1 % (excluding 2010, the first year of commissioning) with about 6500 hours/year of operations and 400 installed units.

Figure 5: ancillary devices (bottom to top). Bulk AC/DC PS, Ethernet switch, fan unit, A2620 crate.

CONCLUSIONS

The validity of the adopted solutions for the magnet PS of FERMI has been proved by the extremely reduced downtime caused by failures on the PS themselves over more than 5 years of continuous operation.

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