DAΦNE POWER SUPPLY SYSTEM: 5 YEARS OF EXPERIENCE AND STATISTICS

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Abstract

The Power Supply (PS) System of the DAΦNE Accelerator Complex consists of about 500 PS ranging from 10 A to 3000 A and from 250 VA to 1.5 MVA. All these PS are running almost continuously since 1997. This paper, after a brief description of the entire system, reports a lot of statistics concerning about 5 years of operation, describing the main problems the different kinds of PS have been affected by, their causes and remedies. The time distribution of faults and their grouping by fault type, PS producer, etc., are reported in the form of plots and graphs.

1 INTRODUCTION

DAΦNE is an Accelerator Complex [1] consisting of:

- e^+- e^- Linac
- ≈ 180 m of Transfer Lines (T.L.)
- e^+- e^- Accumulator/Damping Ring (A.D.)
- two Storage Rings (S.R.)

The PS in the DAΦNE Accelerators are used to supply different kinds of magnets working at room temperature. The global set-up, comprehensive of T.L., A.D. and S.R., of PS is listed in Table 1.

According to the design specifications the main characteristics are:

- Three phase, 50 Hz mains voltage (V) 380±10%
- (SR Bending Dipoles) (kV) 20
- Room Temperature (°C) 0÷40
- Current Setting & Contr.Rng.(-100%) 0÷100 % f.s.
- Normal Operating Range (100%) 70÷100 % f.s.
- Current Setting Resolution $5÷20*10^{-5}$
- Current Readout Resolution $5÷20*10^{-5}$
- Residual Current Ripple $10÷20*10^{-5}$

Different typologies of PS have been adopted according to the PS output current and power rates and to the specific experience of the builder as listed below.

- SCR's Graetz Bridge Converter with Active Filtering [HAZEMEYER, OCEM]
- SCR's Graetz Bridge Converter with Transistor Output Bank [DANFYSIK, EUTRON]
- Diode's Graetz Bridge Converter with Transistor Output Bank [DANFYSIK]
- Series Double Resonant Switching Converter [OCEM]
- Zero Voltage Switching Converter [DANFYSIK]
- Hard Switching Converter [INVERPOWER]
- Bipolar Linear Converter [DANFYSIK, HAZEMEYER, INVERPOWER, FUG]
- Bipolar Switching Converter with 4 quadrant output chopper [INVERPOWER]

The analysis of faults and events covers 5 years of PS operation.

Table 1: PS characteristics

PS	N.	I_{max}(A)	V_{max}(V)
Bending Dipoles	24	100÷750	25÷1250
Dipole Back Legs	16	±10	±20
Pulsed Dipoles	3	650	1300
Wiggler Central Poles	2	750	1250
Wiggler End Poles	8	750	120
Injection Septa	8	2300	8÷50
H/V Steering	102	±10 ÷ ±215	±10 ÷ ±25
"C" Steerings	16	±215	±25
"Lambertson" Steer.	16	±215	±6
Rectang. & Square Steer.	64	±10	±20
Splitter magnets	8	750	80
Quadrupoles	143	100÷585	25÷80
Sextupoles	34	336	25÷30
Skew Quad.Currectors	16	280	40
Solenoidal magnets	4	120	10
Octupoles	6	120	20
Solenoids for experiment	2	3000	6÷10

Data have been collected in a DataBase from Control System Log-Files and Operators' Log-Books where date and type of events have been recorded since 1997. The analysis has been limited to the equipment (4 builders) installed since the beginning of the commissioning. Data are not related to builder names for privacy. MATLAB software has been used for statistics.

2 STRUCTURE OF DATABASE

The DataBase consists of 535 events (Section 3) concerning PS operation. Daily events have been collected on a suitable Time Base (TB, 14 days), to give a statistical meaning to the data. With such a grouping, 119 TB have been obtained. They are depicted in Fig.1 in steps of 30 days. A smooth curve, averaging the values over four TB (2 months), has been added. The histogram clearly points out the high first-life death rate during the operation initial period. In Nov-'98, the KLOE detector was rolled in the IP1 interaction region of the S.R. After four months of machine shut-down, the graph shows a high increase of faults and the same holds for the short (1 week) time periods of shut-down for maintenance. Maintenance, necessary for long term good operation, seems in contrast with the tendency of PS to work their best with a continuous operating cycle.

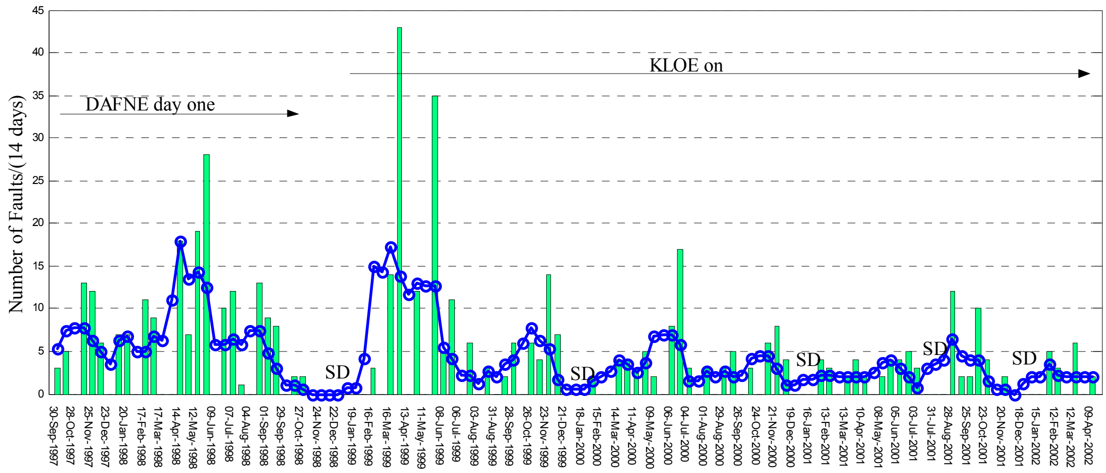

Fig.1: Faults Time Distribution

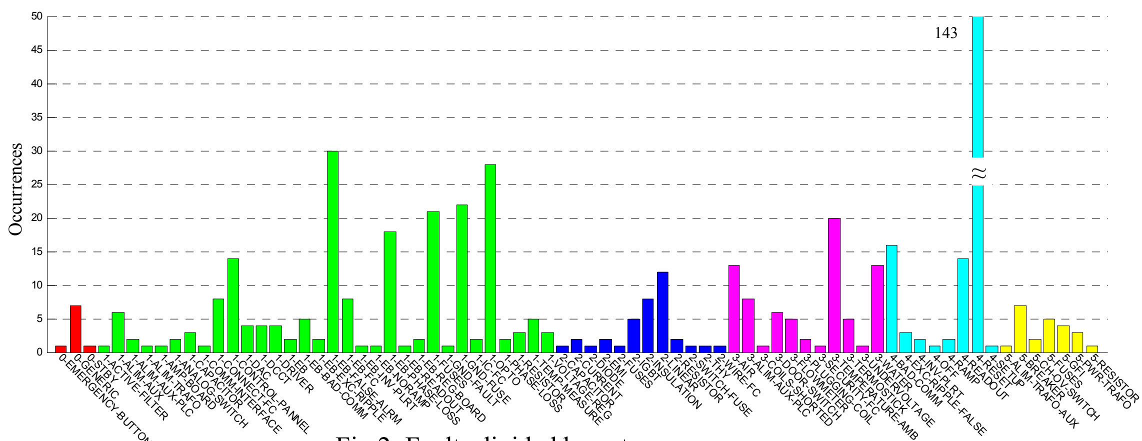

Fig.2: Faults divided by category

The average value of faults is:

$$F_{AV} = 4.47\, faults / TB \qquad (1)$$

In the last two years F_{AV} was about 2.5 and rarely exceeded 5.

3 FAULTS CATEGORIES

To point out the critical elements of the system, faults have been divided in categories [3] as follows:

0) Generic: No significant faults.
1) Electronic: Faults concerning logic electronic elements (DAC, Optocouplers, etc.)
2) Power Electronic: Faults concerning power electronic components (IGBT, power Fuses, etc.)
3) External: Faults caused by external events (Cooling Water, Ambient Temperature, etc.)
4) Control System: Faults caused by bad interaction with network elements (Readout, Reset, etc.)
5) Electric: Faults concerning typically AC elements (Breakers, AC-Fuses, etc.)

As shown in Fig.2, faults (1), are particularly significant, even if concentrated in the first years of operation. Main troubles concerned optocouplers used in communication interfaces, electronic boards utilised for phase-loss detection, and fuses whose current rate was too stringent. Power electronic elements appear to be quite reliable. Linear components, the ones most thermally stressed, showed a higher fault rate. Also ventilation (Fans) and water cooling (water leakage) played an important role as causes of faults [2]. High external room temperature have caused the shutting down of the PS for self protection. Today, almost all PS rooms are air-conditioned and temperature is not a source of fault anymore. About Control System Interaction, troubles have been found for some PS that go to zero current without any reason (4_RESET). This is not serious problem because of a fast reset procedure.

A reliability graph for any PS builder is shown in Fig.3. Three bars are presented: the first shows the total number of events occurred to each PS builder; the second relates to faults with no external events; the third shows a reliability index calculated as number of faults divided by total number of PS of the same builder.

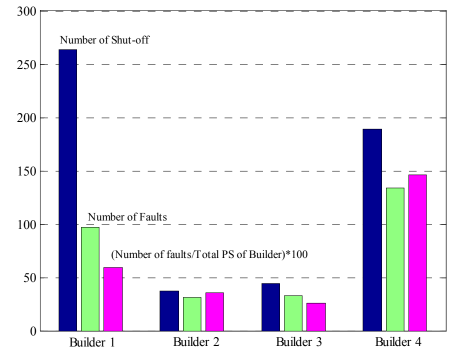

Fig.3: Builders Faults

4 STATISTICS

Some statistics calculations have been done to determine the behaviour of the PS system and foresee its behaviour. To weight the contribution of external causes, the number of Total Faults has been plotted versus the PS Faults excluding external causes for each TB (Fig.4).

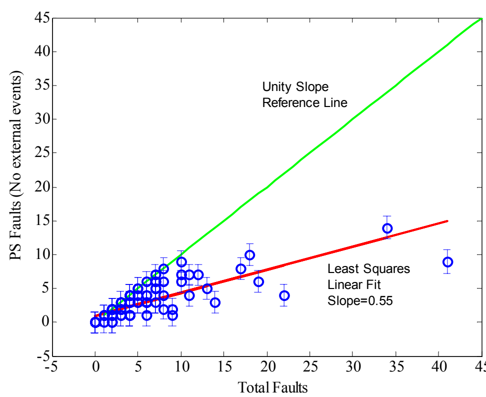

Fig.4: PS Faults (no ext.) vs. Total Faults

The unity slope line represents the equality between Total Faults and PS Faults. The dotted line is the least-squares interpolation of the scattered plot. The slope of this line can be taken as an incidence reference number of external faults. The percentile incidence of external faults can be evaluated as:

$$Ex_{\%} = \frac{1-0.55}{1} \cdot 100 = 45\% \qquad (2)$$

To evaluate the statistical behaviour of the system, the number of faults in TB has been taken as chance variable (c.v.). Occurrences of c.v. have been summed and divided by total number (119) of measurements, obtaining the probability. Thus Cumulative Probability and Probability Density plots have been derived and are shown in Fig.5. The behaviour of the system seems to be well described by Poisson distribution (dotted line). X^2 (Chi-square) goodness-of-fit test has been executed yielding Eq.(3), that, from probability tables, assures 5% statistical goodness-of-fit.

$$\chi^2 = \frac{1}{d} \cdot \sum_{k=1}^{n} \frac{(measure_k - n \cdot p_{fit,k})^2}{n \cdot p_{fit,k}} = 1.2 \qquad (3)$$

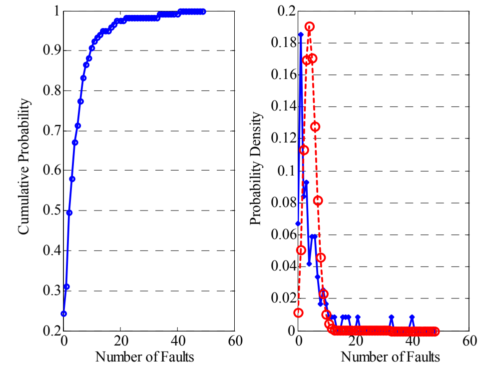

Fig.5: Cumulative and Density of Probability plots

Also an 8 months analysis of PS sensitivity to mains Voltage Dips has been done. Fig.6 shows the number of PS faults for each of the 19 recorded events. Tunings have been done on most sensitive PS to reduce the effects of Voltage Dips.

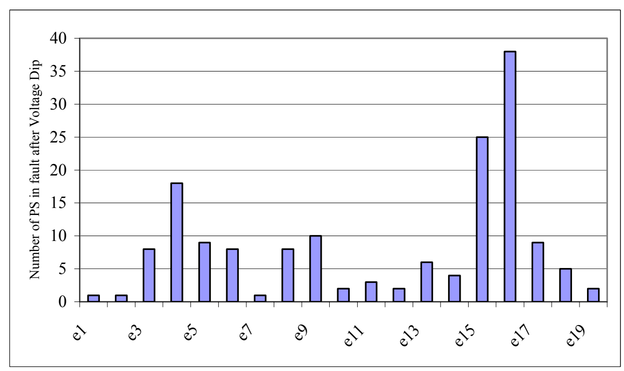

Fig.6: Voltage Dips sensitivity

5 CONCLUSIONS

PS system of DAΦNE Accelerators has been analysed showing at present a high reliability after few years of running. All PS used at LNF have fully met specifications after an initial period of tuning. The analysis points out some critical points that are currently being optimised and will be useful for future PS specifications.

6 ACKNOWELDGEMENTS

Authors whish to thank all the DAΦNE team with special attention the technicians B.Bolli, S.Ceravolo, F.Iungo, F.Sardone, for their kindness in helping to build up the database and their skill in operating the PS system.

7 REFERENCES

[1] R. Ricci, C. Sanelli, A. Stecchi: “DAΦNE Magnet Power Supply System”, EPAC’98.
[2] L. Pellegrino: “The DAΦNE Water Cooling System”, EPAC’98.
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