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THE SUPPLY OF THE 148 MW PULSED POWER TO THE CERN SPS AND THE ASSOCIATED MAINS VOLTAGE STABILIZATION AND FILTERING

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The magnet system of the CERN 400 GeV accelerator is the largest pulsed load in operation on the European 400 kV network. This paper describes briefly the network configuration and the nature of the load. The reactive power compensator used to contain the voltage fluctuations and harmonic distorsions within 0.6%, and the precautions taken by CERN to reduce reactive power and to avoid instabilities are studied in more details. The use of a second compensator for operating the accelerator at higher energy is discussed.

Network configuration

The CERN 400 GeV synchrotron, now in its third year of operation, is the largest pulsed load on the European 400 kV network. The power swing reachs 230 MW for a 400 GeV cycle, with a typical repetition rate of 6 pulses/min.

It was agreed at the beginning of the project to power directly this new machine from the 400 kV network of EDF (Electricité de France), without any form of intermediate storage - i.e. M-G sets - providing that steps are taken to fully compensate the reactive power of the pulse and to have a load substantially harmonic free. The short circuit capacity - 9 GVA - of the 400 kV Genissiat substation, on which CERN is connected, is high enough to keep at a low level the transmission-angle changes and the system frequency disturbance induced by the pulse. At Genissiat three other 400 kV lines achieve a satisfactory distribution of the pulse energy throughout the general network; thus relative power fluctuations in the nearest hydro-electric groups are less than 2.5%.

The basic supply connection is given on fig. 1. At CERN three 90 MVA transformers reduce the supply voltage to 18 kV and feed three independant networks. The first network - SPS pulsed network - feeds all the pulsed rectifiers for the accelerator. The second transformer feeds all the steady load on the site. The third network - North area pulsed network - is intended to pulse the beams in the North experimental area and the accelerator at energies higher than 400 GeV. A large reactive compensator plus filter are associated to each pulsed network; a 23 MVAR filter is connected on the stable network.

Pulsed load characteristics

The main source of pulsed load in the CERN-SPS laboratory is the power supply of the 744 bending magnets and of the quadrupole lenses installed in the synchrotron ring. The magnet convertor plant is based on 12-phase rectifiers, using watercooled thyristors. The convertor plant is subdivided into 14 stations installed in 6 service buildings around the 7 km circumference of the ring and connected in series, via the magnets, in order to optimise voltage symmetry and delay line mode characteristics (cf : fig. 2). Two other similar stations supply the quadrupoles. DC ratings of each station are 2120 V peak, 3120 A rms. The DC voltage and DC current of the bending magnets for a single flat top 400 GeV cycle are shown on fig. 3.

The total pulsed active power P_m and reactive power Q_m for such a cycle are shown on fig. 4. It was found by stability studies of the generation/transmission system that a transition time of 60 msec at Rise/Flat top and 120 msec at Flat top/Decay gave the optimal reduction of disturbances for generators in close electrical proximity to CERN.

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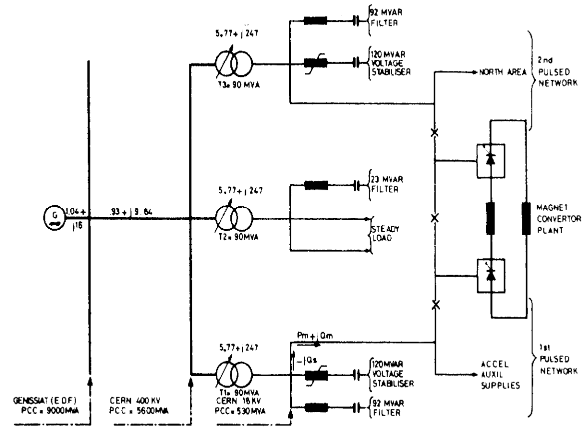

fig. 1 - Network configuration

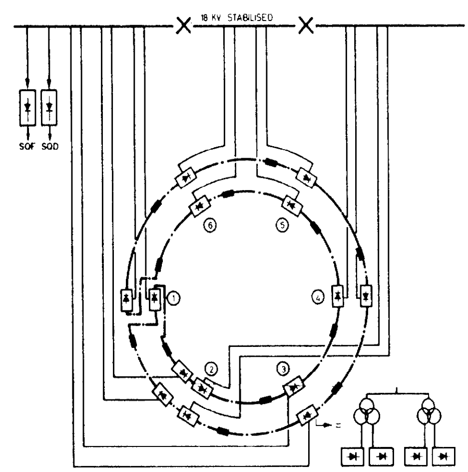

fig. 2 - Magnet convertor plant

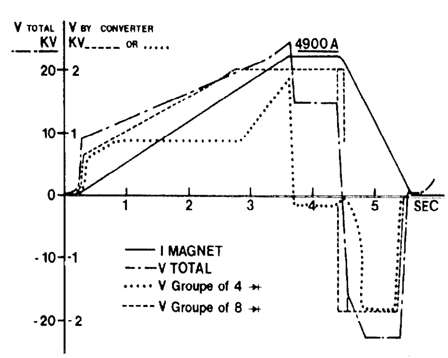

fig. 3 - 400 GeV cycle : DC voltage and current

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AC voltage stabilization and filtering

The voltage fluctuations are generated mainly by the cyclic flow of reactive power through the impedance of the network. Exceptionnal care was taken in designing the converter plant to reduce this inductive current to a minimum : (i) choice of transformers for the rectifiers with a low short-circuit voltage ratio (4%); (ii) use of a 18 kV filter dissociating the input 400 kV transformer from the commutation process of the rectifiers; (iii) use of a very sophisticated system for the control of the firing angle of the rectifiers, together with three programs for controlling the voltage of each third of the main rectifiers to ensure that 2/3 of the rectifiers are either fully conducting or fully inverting at maximum current; the last 1/3 being used for regulation (cf : fig. 3). Nevertheless the reactive power taken from the network by the rectifiers at the end of the rise of a 400 GeV cycle reaches 70 Mvar;at the same moment the active power reaches 140MW (cf. fig. 4). Without compensation of reactive power, the direct application of the pulsed load values $P_m(t)$ and Q_m (t) would produce a cyclic voltage fluctuation of 2% on the 400 kV, and 20% on the 18 kV busbars at CERN for a 400 GeV cycle. This was unacceptable. Mathematical studies of the pulse-induced voltage fluctuation in different parts of the network have shown that a complete stabilization of the 18 kV voltage complies with the fluctuation tolerances of 0.25% at Genissiat and 0.5% at the 400 kV CERN substation. This is achieved by the reactive power compensator and its associated filter. A first-order approximation of the reactive power Q_s produced by the reactive power compensator to maintain constant the 18 kV voltage is given by :

$$Q_s = Q_m + \frac{P_m^2}{2\,P_{cc}} + K\,P_m \quad (K = 0.028)$$

where Q_m and P_m are, respectively, the reactive and active power of the load, P_{cc} the short circuit level at the 18 kV busbars ($\sim$ 530 MVA), and K the resistance reactance ratio of the impedance up to the 18 kV busbars. A typical cycle for Q_s is shown on fig. 4 (bottom curve). Fig. 5 shows the corresponding voltage fluctuation and transmission angle change at Genissiat and at the CERN substation. The large phase fluctuation at 18 kV level (15°) has made necessary the division of the 18 kV network into pulsed and non pulsed section.

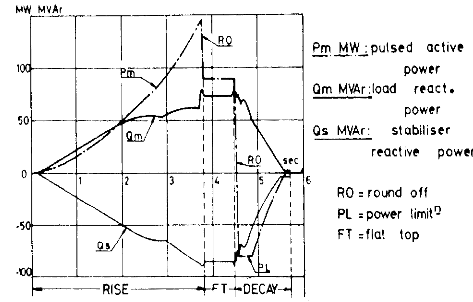


fig. 4 - 400 GeV cycle : power requirement

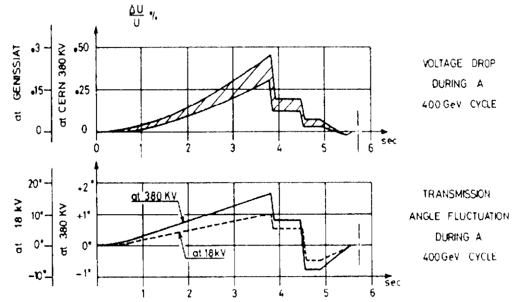
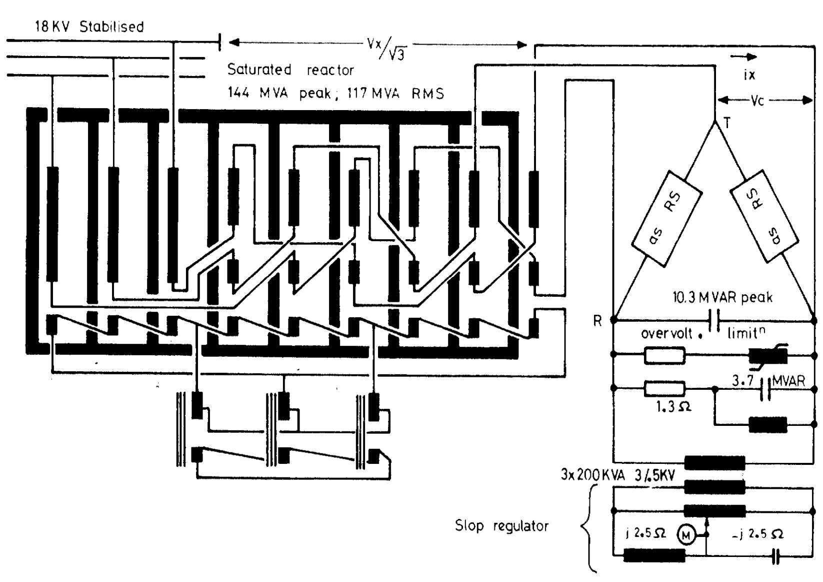
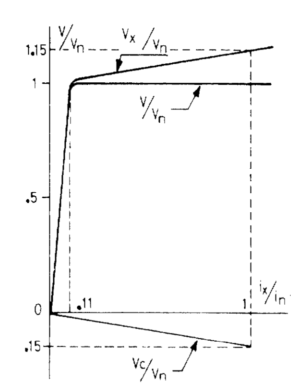


fig. 5 - Voltage and transmission angle fluctuation

Stabilization of the voltage at the 18 kV busbars is achieved by a saturated reactor, with a linear voltage current characteristic above the saturation knee; the required constant voltage current characteristic is obtained by adding to the reactor a series connected capacitor bank tuned at 50 Hz with the residual slope reactance. The schematic diagram is shown in fig. 6. The overvoltage limiting circuits and the damping circuits protect the series-capacitors against the transient overvoltages during switching on, and increase the response time ($\simeq$ 10 msec). The coupling of the windings allows for a complete elimination of all harmonics below the 17th, and improves the linearity of the characteristic. The deviation of linearity is $\pm$ 0.3% for line currents between 11% and 100% of the rated current.

Three regulators complete this compensator. The most important one maintains the pulsed reactive power of the reactor within a preset band, by operating the on-load tap changer of the input 400 kV transformer.

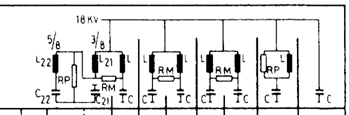




Reactor characteristic

fig. 6 - Schematic diagram of saturated reactor

The second one maintains at zero the slope of the characteristic, by compensating the temperature drift of the series capacitors. For that an electronic regulator measures the mean value over one cycle of the capacitance and operates in case of deviation the cursor of an autotransformer connected accross the series capacitors and feeding a balanced load (half capacitive, half inductive in mid position) equal to $\pm$ 4% of the series capacitors. The last one maintains constant the temperature of the reactor to avoid a drift of the saturation voltage with temperature. 2% deviations of the knee voltage were recorded between warm and cold state without regulation. With these 3 regulators absolute voltage of 18.1 kV $\pm$ 0.3% is maintained when the reactor performs within its limits (90 Mvar pulse).
The filter (cf. fig. 7) has three tasks : to balance the reactive power of the reactor; to decouple the rectifier stations from each other, in order to prevent the voltage distorsion caused by the harmonics of one station from affecting the operation accuracy of the other stations; and to decouple the rectifier stations from the main supply transformer, so that the high reactance of this transformer is not included in the commutation process and does not increase the comsumption of reactive power. The reduction of the distortion on the 400 kV voltage to a negligible value is achieved by this filter, which supplies 92.1 Mvar. The 18 kV voltage distorsions with and without filter are given on fig. 8; the distorsions of the 400 kV are ten times smaller.
The filter is equipped with 2 additional circuits tuned to 100 Hz and 150 Hz, to avoid instability of the rectifiers at full load when irregular harmonics are present; these circuits re-introduce at these frequencies the commutation impedance seen by the rectifiers to the corresponding value without filter. This impedance is plotted as a function of frequency on fig. 9. To prevent the filter from resonating at one of its natural oscillation frequencies, as a result of periodic perturbations induced by the load, a certain damping at these frequencies is provided. Damping resistors are built at a location producing minimum losses at 50 Hz. The 2nd and 3rd harmonic filters are strongly damped to provide a 20 msec damping time constant at the two first natural frequencies of the filter ($\sim$ 92 Hz and 120 Hz).



Tuning fréqu.	HZ	50	100	150	250	350	550	650	850	HF
Harmonic curr! (max.)	A		ε	20	70	50	300	210	60	60
C	µF	517	103	96	85	43	99	70	190	190
L	mH	19.6	12	12	4.7	4.7	.84	.84	.18	
RM or RP	Ω	30	48		500		100		1.8	
React. power	MVA	11	6	11	9	4.5	10	7.3	19.3	19.3

fig. 7 - Filter components

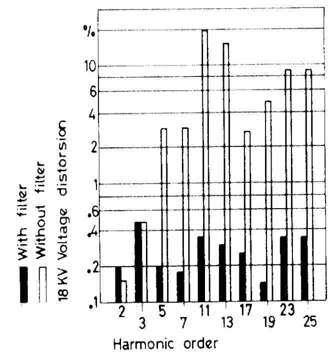


fig. 8 - Filter attenuation

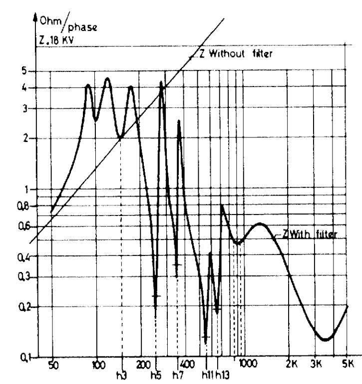


fig. 9 - Filter impedance

The second reactive power compensator

Owing to the good performances of the first compensator, an identical compensator was installed in 1978 to complete the second pulsed network, which is intended for three tasks : i) pulsing the rectifiers of the ejected primary and secondary beams in the North experimental area to save energy. The reduction in operational cost is expected to balance the investment for the 2nd compensator after two years of pulsed operation at full load (30 MW); ii) supplying the accelerator pulsed network in case of breakdown of its compensator or input transformer; iii) increasing the energy of the SPS above 400 GeV, as the first compensator is fully loaded at 400 GeV (90 Mvar pulse). The requirements for a 500 GeV cycle are compared below with those for 400 GeV.

		400 GeV	500 GeV
Peak DC current	A	4900	7800
Peak active power	MW	148	246
Active power swing	MW	230	320
Reactive power swing	Mvar	70	140

Above 400 GeV, by sharing the pulsed load in equal parts on the two networks, both compensators can operate correctly within their rated limits. 500 Gev cycle were performed successfully in december 1978. Nethertheless owing to severe stresses on the thyristors of power supplies, it is not intended to use this cycle in normal operation. The maximum operational

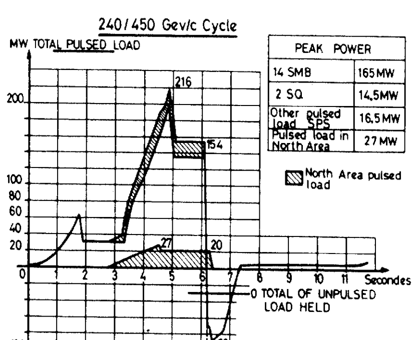


fig. 10 - 240/450 GeV/c Cycle

energy will be restricted to about 450 GeV. Fig. 10 shows a typical 450 GeV cycle foreseen for 1979, with the superposed pulse of the North area.

With their 540 MVA installed power these two compensators are the largest static compensating equipment presently known.