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The New Servo-Spill Power Converter of the CERN SPS Machine

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Abstract

The so-called servo-spill system of the SPS machine requires a very specific power converter to be used as the power actuator of the system. Due to this particular function, the main performance required, for this power converter, is an unusual large signal current bandwidth of up to 1.5 kHz. The procurement is based on a similar industrial product using switch mode technology. This paper describes the main power part as well as the control approach chosen to fulfil the specific requirements of this power converter. Final operational results are also presented.

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The New Servo-Spill Power Converter of the CERN SPS Machine

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1. Introduction

The flux of particles, which are extracted during the slow resonant extraction from the SPS, is controlled with the equipment called the servo-spill feedback system, which acts on the horizontal tune. This is achieved by modulating the current in a servo quadrupole that, together with the power converter, represents the power actuator of the overall closed loop system. Due to a change of the quadrupole magnets, the existing linear power amplifier was no longer suitable to feed this new load. Therefore, a new power converter was required.

2. Main Requirements for the Power Converter

In order to fulfil the new requirements [1] of the overall closed loop system, the following main characteristics of the replacement power converter are :

current amplitude range	: 0 to 200 A
voltage amplitude range	: ±200 V
maximum peak-to-peak output current ripple	: 20 mA
di / dt range	: 0 to 11 kA/s
large signal current bandwidth	: 1.5 kHz.

One of the fundamental parameters is the large signal current bandwidth required for the dynamics of the system. Therefore, the maximum voltage amplitude range of the power converter shall only limit the current amplitude limitation, over the whole bandwidth, i.e. the full output voltage swing is required at any frequency within the large signal bandwidth. The load, made up of four quadrupole magnets connected in series, has the following characteristics: $L \approx 18mH \quad R \approx 74m\Omega$.

3. Power Converter Topology

The relatively small output power requirement, combined with the large signal bandwidth, makes this power converter a very good candidate for applying switch-mode technology. However, the very short delay imposed for the system replacement did not allow any time for specific studies using, for example, soft commutation. Therefore a simple industrial approach became compulsory. This, based on our market knowledge, led us to invite a company having similar products in their current production range, but based on hard-switching technology. As this power converter is a key element of the SPS power converter complex, this same argument applies also for reasons of the very high reliability requirement.

Based on the above-criteria as well as for economic reasons, the OCEM Company has been selected to produce the required power converter. The proposed topology is given in Fig. 1.

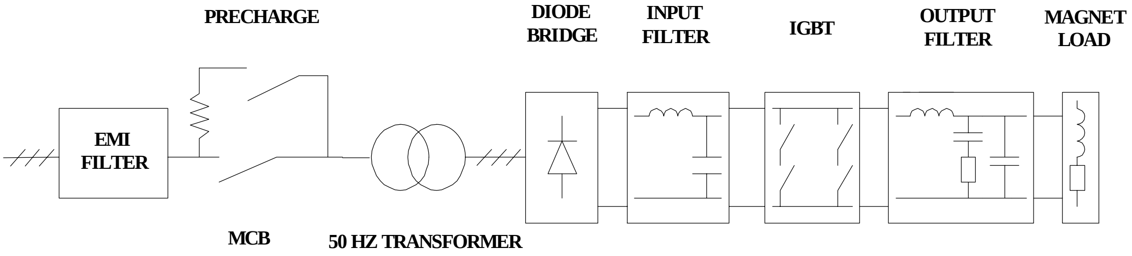

Fig. 1 - Power Part

4. 50 Hz Input Stage

A pre-charge circuit is used in parallel with the main circuit-breaker to prevent current inrush and over-voltage on the filter capacitor at switch on.

Insulation and adaptation to the load voltage requirements are achieved by a 40 kVA 50 Hz transformer feeding the unregulated d.c. voltage source.

The LC type input filter (40 Hz) is rated to give a maximum 300 Hz current ripple not exceeding 10% of the d.c. current. The capacitor rated voltage takes into account the energy exchange between the magnet and the input filter capacitor. Due to the relatively small inductance of the load (18 mH), this leads to 130 V of over-voltage that has to be added to the capacitor voltage rating. It can still easily been taken into account with electrolytic type capacitors. Therefore, capacitor protection using a brake chopper is not necessary.

5. IGBT Bridge

The adjustment of the output voltage is obtained by controlling a full bridge of IGBT's, with a PWM command at 16 kHz switching frequency. (Fig. 2).

It should be noted that the specification does not require the use of a full four-quadrant topology. However, in order to profit from the experience gained on similar converters, it as been decided to use the complete full bridge assembly, which includes also the low-pass filter capacitor. The latter is mounted very near to the power switches to reduce stray inductance that generates over-voltage at turn-off of the switches.

A lightly damped LC type output filter is necessary to reduce the maximum load current ripple to the specified value (20 mA).

A Semikron ® hybrid double driver has been used for each half-bridge. It is mounted near the bridge and fed from the electronics, by means of an optical links. The insulation level and the protection features, like short-circuit protection and the top/bottom drive interlock have been the determining elements of this choice.

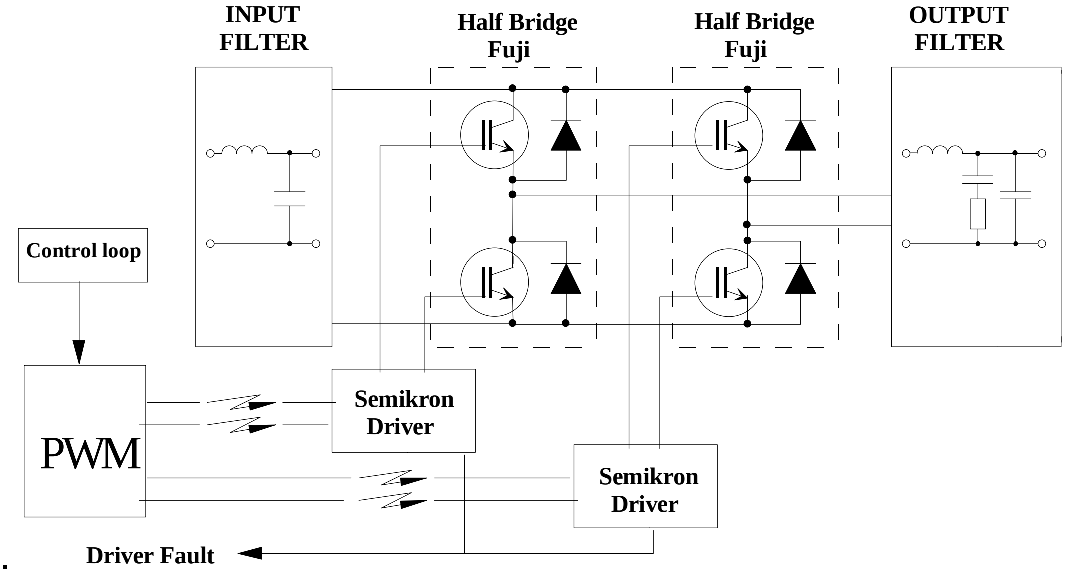

Fig. 2 - Full IGBT Bridge

6. Output Filter

As the specified ripple performance is not very difficult to meet, a critically damped L2C output filter would have been sufficient. However, due to full output voltage swing required up to 1.5 kHz, the power rating of the damping resistor would be of the order of a kW. The solution to reduce the power dissipation, is to reduce the damping resistor and to achieve the necessary damping by mean of partial state feedback [3]. This improves also the attenuation of the filter in the region of the switching frequency that is the main source of perturbation. A reduction of the global cost, and to a lesser extent the volume, is also appreciated.

To achieve electronic damping, it is important that the resonance frequency of the filter is placed within the bandwidth of the system. The final compromise, taking into account the switching frequency, the bandwidth of the open-loop system and the specified closed loop current bandwidth, led to the choice of a lightly damped filter at 4.5 kHz. The reason for keeping some damping is to avoid a higher resonant frequency (100 kHz) due to the stray inductance in the capacitor branch.

7. Control Loop

The control strategy consists in taking care of the resonant filter and providing the necessary current bandwidth. Complementary rejection of 50-300 Hz is not necessary to meet the ripple requirement, as there is no space in the available frequency range to implement the classical voltage loop that would improve rejection.

The block-diagram of the control loop is given in Fig. 3. The active damping is achieved by the inner loop where by controlling the capacitor current via the partial state feedback (k), the damping parameter is adjusted. The results of the active damping can be seen in the Bode plot of Fig. 4

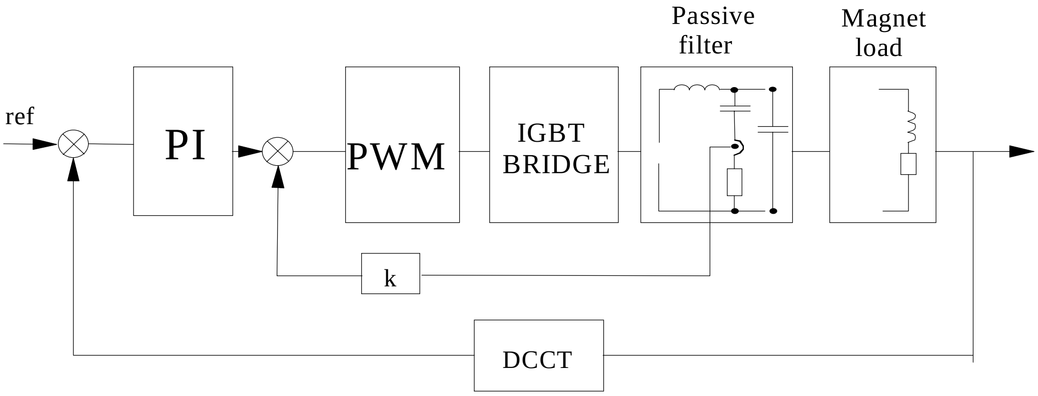

Fig. 3 - Block diagram for the control system

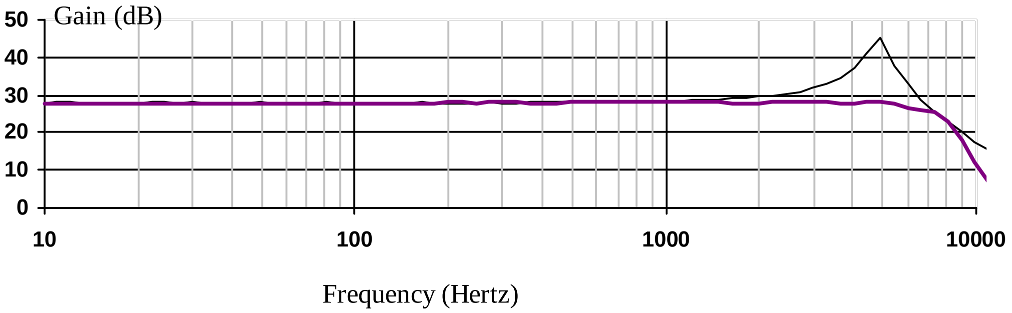

Fig. 4 - Frequency response of the passive filter before and after active damping

8. Current Loop

Due to the fact that the power converter is used in a closed-loop system, the main difficulty is the tracking criteria over the required bandwidth. The requirement is achieved by means of a simple PI corrector, which provides adjustment of the bandwidth and insures the very-low-frequency rejection not covered by the input filter. The closed-loop performance can be deduced from the Bode plot of Fig. 5. This result is identical for small and full amplitude excitations.

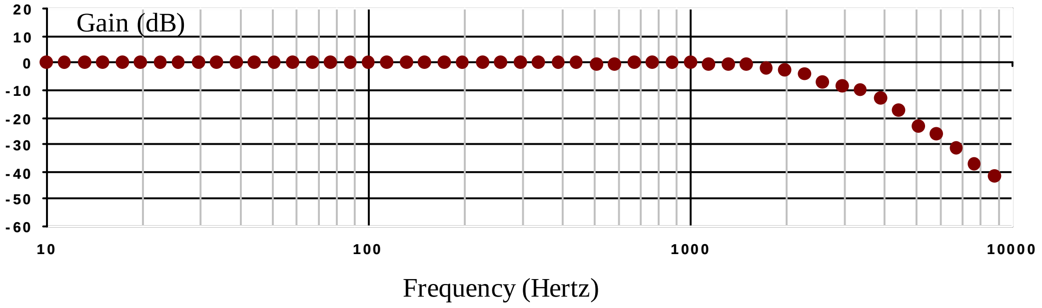

Fig. 5 - Frequency response of the closed current loop

9. Experimental Results

The large amplitude dynamic response can be evaluated from Fig. 6. This shows the output voltage of the power converter responding to a current reference excitation of 2 A peak-to-peak at 1.5 kHz. The full output-voltage swing requirement at the maximum bandwidth is clearly demonstrated.

The large amplitude step response of Fig. 7 shows that the large signal dynamic behaviour is in compliance with the results of the Bode plot of Fig. 5.

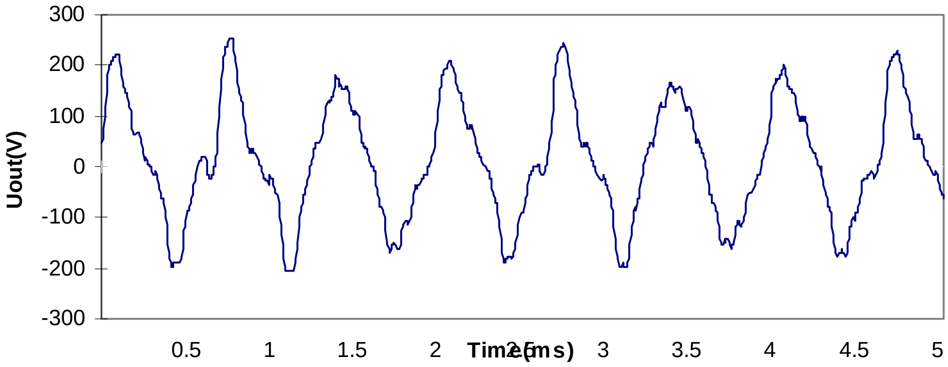

Fig. 6 - Full range output-voltage

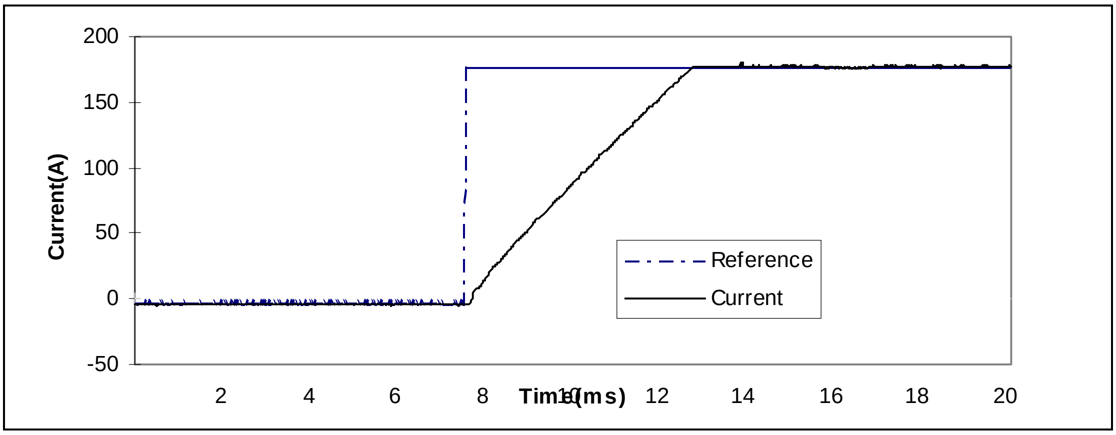

Fig. 7 – Step response

10. Electro-Magnetic Compatibility

The input EMI filter as been tested on previous similar equipment and results showed that the limit values for conducted EMI are according to IEC recommendations. The radiated noise, as well as conducted output noise, has not yet been measured. However, since the unit is in operation, no sign of this type of problem has been observed in the close environment. Nevertheless, a proper evaluation will be performed in a near future.

11. Conclusions

The new servo-spill power converter, based on switch-mode technology, is in service in the SPS since the start-up of March 98. The level of performance of the over-all process has been reached rapidly after fine adjustment of the spill parameters. After having cured some problems of spurious tripping, it proves to operate with a very good reliability.

As compared with the old unit providing the same function, it is clear that the space used as well as the efficiency gained is very important. The chosen topology has also fully proven that the equivalent performance to a linear power amplifier system could be reached.

12. References

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