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CONSIDERATIONS ABOUT A DYNAMIC RIPPLE FILTER FOR THE PS-BOOSTER MAIN POWER CONVERTER

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1. GENERAL REMARKS

The converter voltage ripple consists fundamentally of harmonics with a frequency of (p.n) Hz [n=1,2,...] for a p pulse rectifier. However, in practice, untypical ripple components of n·50 Hz are also induced due to:

- the fluctuation and assymetry of thyristor-rectifier firing angle;
- the unbalance among the three phases of the ac mains;
- the difference among the phase impedances of the rectifier transformer.

Therefore, while it is recommended to adopt a multipulse rectifier in consideration of the fundamental voltage ripple, one must nevertheless take also into account the untypical lower frequency ripple components.

The passive low-pass filter and the possible tuned filters at the output of the power converter are usually designed to reduce the fundamental ripple.

2. THE MAIN PS-BOOSTER POWER CONVERTER

The CERN PS-Booster main power converter system has 5 identical 12 pulse rectifiers as shown in Fig.1 [1].

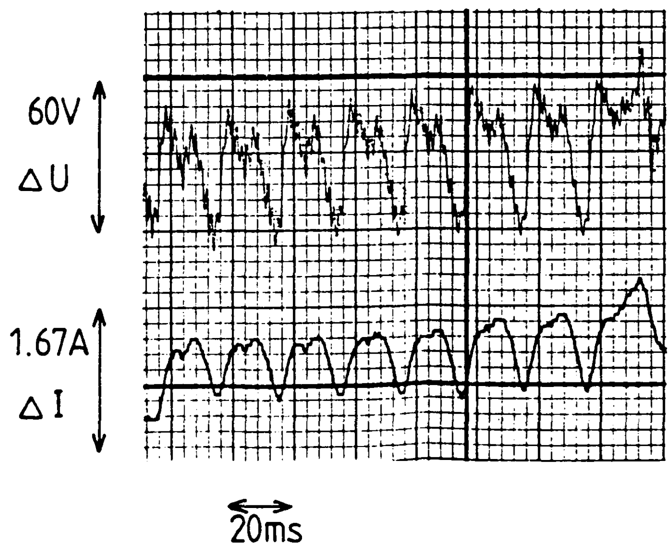

Figure 1 : PS-Booster main power converter system

The passive filter consists of a low-pass section with f_0=45 Hz and of resonance circuits tuned at 600 and 1200 Hz.

Fig.2 shows the difference signals ΔU and ΔI between reference and real voltage and current. These waveforms include the servoloop error signal as well as the ripple components. It appears clearly from these signals that residual 50 Hz and 100 Hz ripple components are present.

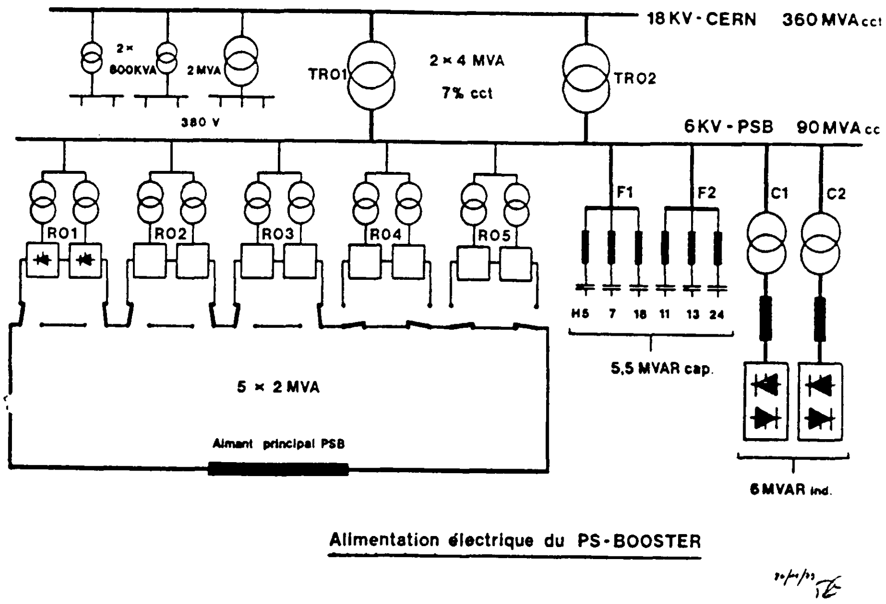

Figure 2 : Difference signals ΔU and ΔI (during acceleration)

3. DYNAMIC FILTER DESIGN

The general operating principle of the dynamic ripple filter is illustrated by the schematic circuit diagram of the converter shown in Fig.3.

In order to reduce the magnet voltage ripple, the latter is detected and amplified before being injected with appropriate phase into the primary of the reactor-transformer, whose secondary is connected in series between power converter output and magnet load[2,3].

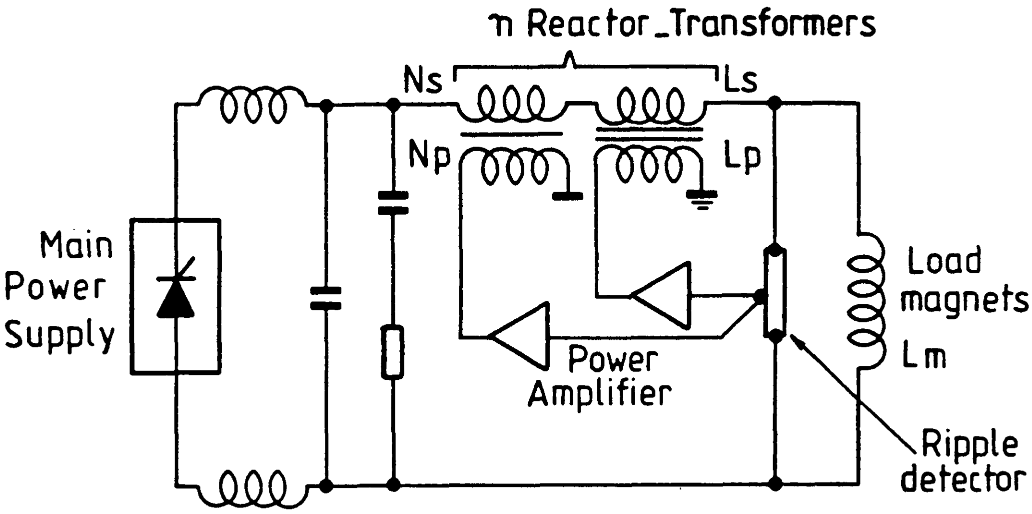

Figure 3 : Schematic converter circuit diagram

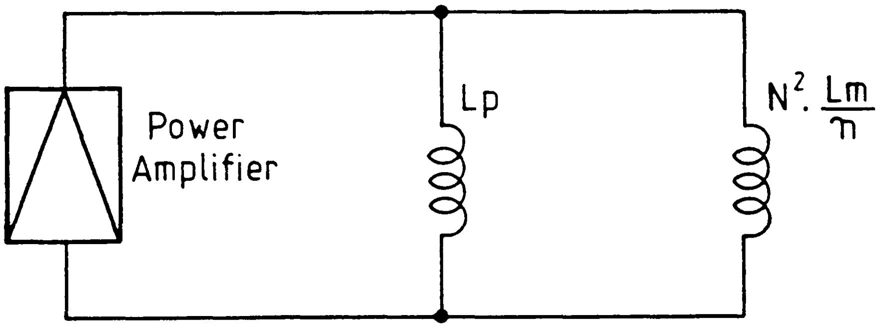

Fig.4 Equivalent circuit of dynamic filter.

Fig.4 represents the equivalent dynamic filter circuit as seen from the power amplifier; Lp is the primary inductance of the reactor-transformer, Lm is the total inductance of the main magnets (Lm=0.185 H), N=Np/Ns is the turns ratio of the reactor-transformer and n is the number of reactor-transformers and power amplifier assemblies.

The output power of a single amplifier Pa is

$$Pa= Pm+Pp= [1+N^2 (Lm/Lp)/n]\ Pt/n$$

where Pm is the effective ripple power referred to the primary of the reactor-transformer, Pp is the exciting power of the primary of the reactor-transformer and Pt is the total ripple power of the magnet voltage.

The total power of n amplifiers employed to reduce the ripple is given by

$$Pat=n\cdot Pa= [1+(Lm/Ls)/n]\ Pt$$

where $Ls=Lp/N^2$ is the secondary inductance of the reactor-transformer.

In the case where (Lm/Ls)/n is >>1 the required amplifier power is (Lm/Ls)/n times the ripple power Pt.

If on the other hand (Lm/Ls)/n is close to 1, the amplifier power needed is only twice the ripple power Pt. This means however that the secondary inductance of the reactor-transformer is the same as that of the main magnets, i.e. the total load of the main power converter is twice as large.

From Fig.2 we can derive the ripple power Pt as follows:

Pt= 30V x 0.4A =12 W (near 50 Hz and 100 Hz).

We assume 15W of ripple power including 20% margin and consider several cases:

i) (Lm/Ls)/n=100

nLs=1.85mH
N=1
nLp=1.85mH
Required power of amplifier nPa= 15W x 100= 1.5kW

n=1
Ls=Lp=1.85 mH
Pa=1.5kW (35V x 45A)
n=2

Ls=Lp=0.93mH
Pa=0.75kW x 2 (35V x 22A)

ii) (Lm/Ls)/n=200

nLs=0.93mH
N=1
nLp=0.93mH
nPa=15W x 200= 3kW

n=2
Ls=Lp=0.46mH
Pa=1.5kW x 2 (35V x 45A)

iii) (Lm/Ls)/n=500

nLs=0.4mH
N=1
nLp=0.4mH
nPa=15W x 500= 7.5kW

n=4
Ls=Lp=0.1mH
Pa=1.88kW x 4 (35V x 54A)

The author suggests the second example, i.e.:

n=2
Lp=Ls= 0.46 mH
Pa= 1.5 kW x 2 (35 V x 45 A)

4. DYNAMIC FILTER COMPONENTS

4.1 Power amplifier

A class B audio power amplifier system is suitable for this application. It consists of several water cooled high power modules and driver units and is made by push-pull circuits with two groups connected in parallel. Individual modules can rapidly be replaced in case of failure. A schematic diagram of the amplifier system is shown in Fig.5

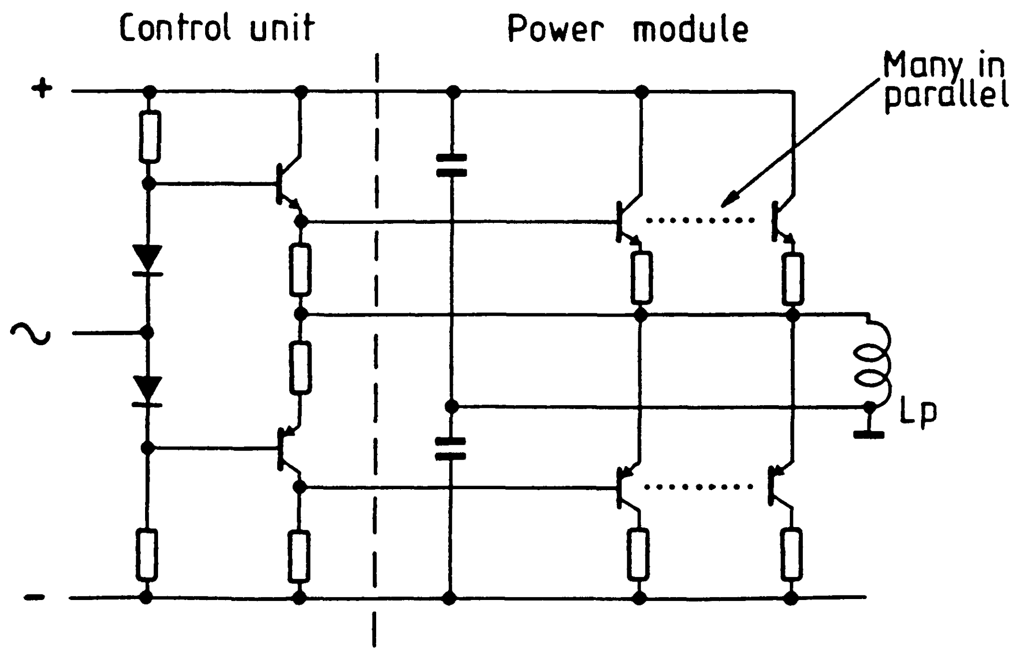

Fig.5 Schematic diagram of the amplifier system.

4.2 Reactor-transformer

Two reactor-transformers with a turns ratio of one and an inductance Ls=Lp= 0.46mH are required.

The main magnet current flows through the secondary winding; consequently it must be designed not to saturate at this current. The coupling factor between primary and secondary is required to be high for good efficiency. The insulating voltage between primary and secondary corresponds to that of the main magnet circuit (>2kV).

4.3 Ripple detector

In order to avoid earth loops by multi-grounding in the main power circuit, an isolation amplifier is used to read the ripple signal from the voltage devider. This signal does not only include the voltage ripple but also the converter output voltage waveform; it must therefore be subtracted from the output of an "equalizer function module" to obtain the the true voltage ripple signal.

The "equalizer" has to be designed to realize the transfer function between the converter voltage reference function and the output of the passive filter.

Modern filter theory would help to make an "equalizer module" in order to eliminate the converter voltage component in the ripple detector signal.

ACKNOLEDGEMENTS

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