Low Cost Concepts to Reduce the Voltage Ripple of the DC Power supply

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Abstract

If the gain of current feedback is low, the short term stability of magnet power supply will be affected by a soft power line. Typically, the step-change and the imbalance of the three phase power line cause the most serious voltage ripple. Usually, the voltage feedback with a coupling transformer is considered to reduce the voltage ripple. However, for the high current power supply, the space and cooling problem of the coupling transformer become inconvenient. In this paper, we suggest to use the toroidal core with the compensation winding, working like a DCCT, as the coupling transformer. Then, a high speed detector of the AC line level is developed. It restricts the voltage ripple passing to the coupling transformer. These methods have the advantage of small size, low power consumption and low cost.

I. Introduction

The beam life time of SRRC is expected to be more than ten hours[1]. The power supplies for the dipoles and the four families of the quadrupole should perform 50 ppm stability to keep the beam stored. All of these power supplies are made by the Canadian company INVERPOWER. They are SCR control type with the 12 pulse technology without the passbank current regulation (figure 1). The main ripple is 720Hz. This firing ripple passes a passive 20 Hz LC filter to the load magnet. The magnets connected in series have a time constant about one second. The 720Hz ripple in current is less than one ppm. However, there is a broad spectrum of the current ripple from 20Hz to 360Hz in the range of 10ppm. The amplitudes are not fixed. It depends on the AC line.

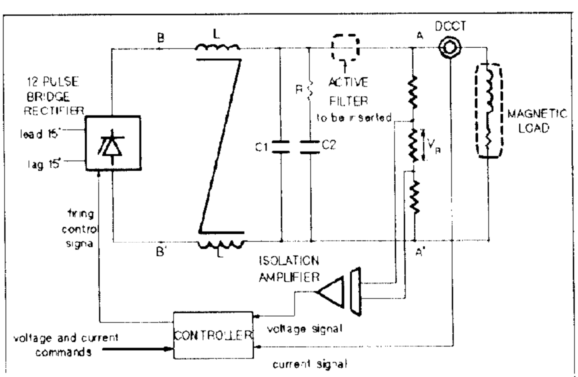

Figure 1: The block diagram of the power supply.

II. Soft AC line

The AC line power provided by the monopoly, Taiwan power company, performs quite poor quality. Even in the high-tech area of the Science-Based Industrial Park, where SRRC locates, many companies always complain about the soft line. Typically, we have the three phase imbalance about 0.5~1.0% around the hours. The step-changes occurs from hours to hours with a amplitude more than one percent. The impact of the higher value is unfortunately observed quite intensive[2]. This instability excites the current spectrum from 20Hz to 360Hz. The 20Hz one has a broad band structure which is raised by the passive low pass LC filter. The time variation ripple from 60Hz to 360Hz depend on the imbalance as well as the higher harmonics from the line. The fixed ripple from 60Hz to 360Hz has closed relation to the character deviation of the SCR's and the input step-down transformer of the power supply.

Since the load parameters don't change, the voltage loop on the firing is moved from AA' to BB' (fig. 1). If we set the voltage gain (all band) higher, the 20Hz ripple decreased, but the 360Hz ripple increased. Hence, we insert a low pass filter to drop the gain at 360Hz region. The DC gain of the voltage loop is extended to 20 times higher. The 20Hz ripple disappeared, but the ripple from 60Hz to 360Hz still remains.

The field penetrating into the vacuum chamber is reduced by the eddy current of the chamber, which has a bandwidth around 20Hz[2]. Therefore, we don't worry about the ripple higher than 60Hz in the range of 10ppm, if they are stationary. The concern is on the impact of the line instability, which excites higher value of the oscillation.

III. Active Filter

The idea to insert a transformer between the output terminals and the load magnet is not new. Many companies deliver their power supply with build-in active filter. In our case, we have to live with the space we have, don't change the construction, if it is possible.

We find a place right besides the DCCT. A strip wound toroidal core with double windings is inserted side by side to DCCT (figure 2). One of the windings is driven by the voltage feedback circuit. The other provides a constant current determined by the internal micro-processor to compensate the flux generated by the average DC output

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current. This arrangement allows the maximum feedback voltage but minimum size of the toroidal core.

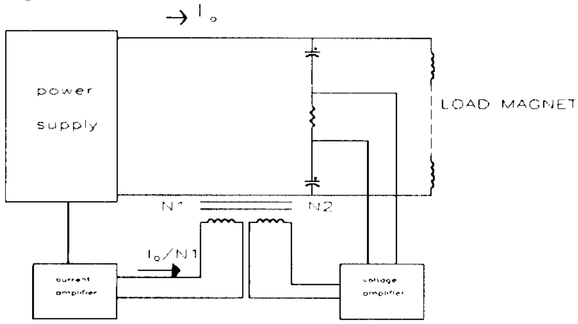

Figure 2: The active filter.

The cross section A of the toroidal core is decided by the following formula:

$$A = \sum_i \frac{\sqrt{2}\, V^i_{rms}}{2\pi f_i B_{max}}, \qquad ...(1)$$

where V^i_{max} is the maximum rms voltage ripple of the f_i component to be removed and B_{max} is the saturation flux density of the core. The output voltage ripple of 60Hz (main component) is about 0.3Vrms. We need a cross section of 10 cm^2 for the toroidal core with one Tesla saturation flux density. Since the transformer can be treated as open at the load side, the feedback amplifier needs the output voltage swing

$$V_{cc} = \frac{1}{2} N V_{p-p} \qquad ...(2)$$

and the maximum output current is

$$I = \frac{\ell V_{cc}}{2\pi f_{min} \mu A N}, \qquad ...(3)$$

where N is the winding number and ℓ is the circumference of the core.

In our application, we set N=20, Vcc= 15V and I = 0.3A. The strip wound core is made of the material VITROPERM from the German company VAC with the strip thickness of 20μm. The response is flat to 300kHz.

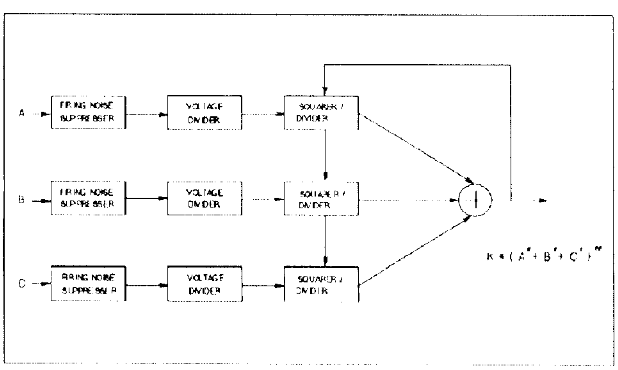

Figure 3: The AC level detector.

IV. AC level detector

The maximum rating of the active filter mentioned in the last section is limited by the cross section of the core and the amplifier. We have to restrict the voltage ripple passed to the active filter. Therefore, a fast AC detector is developed to pick up the signal of the line change, the imbalance and the higher harmonics (figure 3).

The detector is consists of three rms to DC converter. The detector output is

$$V_{out} = k\left(A^2+B^2+C^2\right)^{\frac{1}{2}} = \sqrt{\frac{3}{2}}\, k\, V_{AC}$$

$$A = V_{AC}\sin(\omega t)$$

$$B = V_{AC}\sin\left(\omega t + \frac{2}{3}\pi\right)$$

$$C = V_{AC}\sin\left(\omega t + \frac{4}{3}\pi\right) \qquad ...(4)$$

where A,B,C are the three phase line voltage and k is a scaling constant. The accuracy of the detector is better than 0.1% with a carefully calibration. Comparing with the 12 pules peak detector in our original design, it contains unwanted 720Hz ripple to be filtered. We compare these two detectors on the line with the integration over one line cycle to eliminate the harmonics of 60Hz. The RMS detector has the same behavior but is faster. Figure 4 shows the step response of the power supply with and without the feedforward.

All power supplies for the transport line and storage ring locate in the core area of the storage ring. They share the common 1.5 MW step-down transformer. Hence, only one AC level detector is sufficient to distribute the AC information to those power supplies. To avoid the grounding loop, the signal is transmitted by a voltage to frequency converter and received by isolated frequency to voltage converter.

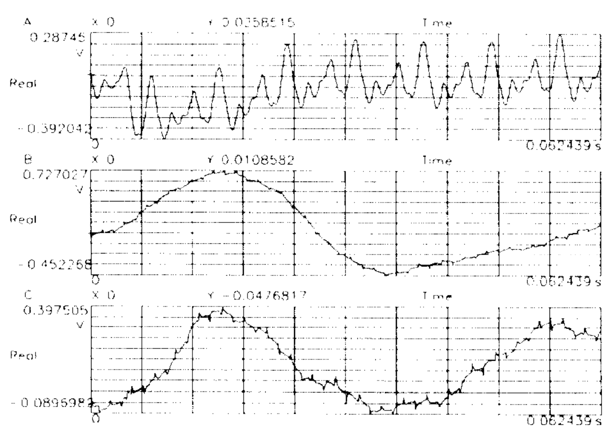

Figure 4: The step response. (a) FFW signal (FS: 7V),
(b) Current without FFW (FS: 250A=1KV),
(c) Current with FFW (FS: 250A=1KV).

V. AC Current Feedback

The detector of the three phase AC level mentioned in the last section can be also applied on the AC input current. For a constant current source, we have following power relation

$$I_{DC}^2 \cdot R + P_{loss} = \left(\overline{V_{AC}} + \Delta V_{AC}\right) \cdot \left(\overline{I_{AC}} + \Delta I_{AC}\right) , \qquad ...(5)$$

where P_{loss} is the power loss of the power supply. If we neglect the high order term, the AC input current is proportional to the AC voltage

$$\Delta I_{AC} = -\Delta V_{AC} \cdot \frac{\overline{I_{AC}}}{\overline{V_{AC}}} . \qquad ...(6)$$

This information of the AC current contains not only the AC line input but also the characters of the step-down transformer and the SCR's. The harmonics of output current at 60Hz and 120Hz are reduced by the factor of ten.

VI. Conclusion

The DC power supply of the SCR control type without the passbank current regulation is sensitive to the line change. The sub-harmonics of the line is the most harmful part of the ripple. If we compare the passbank current regulation. There are economical ways to reduce the voltage ripple. We developed the DCCT like active filter, which is compact and easy to mount. The information of the three phase AC line (voltage and current) is helpful to reject the line variation. We use the feedforward of the AC voltage to suppress the transient excitation. On the other hand, we reduce the harmonics with the feedback of the AC current. Hence, the size of the active filter can be very small.

One AC level detector (voltage) is sufficient to serve many power supplies in the group. In this case, it is also economic to use DSP type of the AC level detector, which can calculate the higher harmonic and compensate the phase shift due to the firing angle respectively for each power supply.

VI. References

[1] SRRC Design Handbook, Synchrotron Radiation Research Center, Taiwan, 1990.

[2] SRRC Status Report, (SRRC, April 1993).