UPDATE OF MAIN MAGNET POWER SUPPLIES AT PF-AR

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Abstract

A power supply for the bending magnets of the Photon Factory - Advanced Ring was updated in 2007, followed by the installation of a filter to minimize distortion on the AC supply line. A power supply for the main quadrupole focusing magnets was updated in 2009. This paper reports on these new magnet power supplies and the higher harmonic filter.

INTRODUCTION

In 1983, an 8 GeV accumulation ring (AR) was commissioned as a booster injector for a TRISTAN main ring. In 2001, this ring was converted to a synchrotron radiation dedicated machine and was named the Photon Factory - Advanced Ring (PF-AR). Since then, various maintenance tasks have been performed on this old machine. Recently we were able to replace the main magnet power supplies. This paper reports on the performance of the new power supplies.

BENDING MAGNET POWER SUPPLY

Design and fabrication

The current requirement of the bending magnet in PF-AR at 6.5 GeV operation is 1394 A. The load is 56 bending magnets which are connected in series. The circuit constant of the load is 1.05 H and 0.73 Ω. We therefore specified that the rating of the new bending magnet power supply is 1500 A and 1200 V.

A new power supply was fabricated at the Fuchu Works of the Toshiba Mitsubishi-electric Industrial Systems Corporation. The basic design is almost same as that of the J-PARC main ring. The main cubicle is 7.8 m long and the total weight is 12.7 tons. It consists of two converters, an over-voltage protection circuit, DC reactors, a hybrid filter and a cubicle with control-modules. One point earth is realized. Fig. 1 shows the principal circuit.

The converters are composed of IEGT bridges in a series-parallel connection (ref. 1). It works under three pulsed PWM. The IEGT switches three times symmetrically in the peak part of the alternating voltage. The operation has a merit that the power factor is always unity. As the basic ripple frequency is three times that of a conventional thyristor converter, the passive filter is compact compared to the conventional type. The IEGTs of the converters are triggered from VME modules through optical fibers. The converters act as a role of pre-regulator.

The fine regulation of the output current is performed in the hybrid filter, which is connected in parallel with the load and has two functions. First, it decreases the ripple-current to the side of the load by chopping the ripple voltage waveform. The second function is to maintain the load current to match with the setting current by adjusting the branch current through the hybrid filter. The current setting is performed through ACTNET from the central control room.

The bending power supply has two DCCTs which located in the positive-side line and the negative-side line. The negative-side DCCT is used as feedback for current stabilization. The positive-side DCCT is used as a current monitor to judge the malfunction of the feedback DCCT. If the output difference between the two DCCTs exceeds a threshold, an alarm is sent to the central computer, indicating the possibility of a ground fault. The problem which is peculiar to the PF-AR is in the feed line of aluminium bus bars. We have experienced some ground faults in the past. We had much cumbersome work to specify the point of ground fault. Moreover, the arrangement of the two DCCTs is beneficial in that it can measure the common mode current ripple as well as the normal-mode current ripple.

The outdoor power-receiving equipment consists of a cubicle and two transformers. The cubicle receives three-phase 6600 V power from the PF-AR substation. The cubicle has a VCB that opens the 6600 V lines in an emergency case under an interlock system of the over-voltage protection, under-voltage protection and the earth leakage protection. The two transformers were specially designed to correspond to the IEGT bridges and have a ratio of 500 V to 6600V.

Commissioning

Under 6.5 GeV operation conditions, the AC electric voltage and current of the old bending power supply were 6600 V and 269 A, while those of the new power supply are 6600 V and 115 A. This is because the new power supply operates with a power factor of 1. The high harmonics of the current distortion on the AC line were measured up to the 40th harmonic of the line frequency. We expect harmonic components above the 40th to decrease monotonically. The effective harmonic current was 14.7A in the old bending power supply, while that of the new one was 10.1 A. It seemed that some improvement had been made to the distortion of AC line power system.

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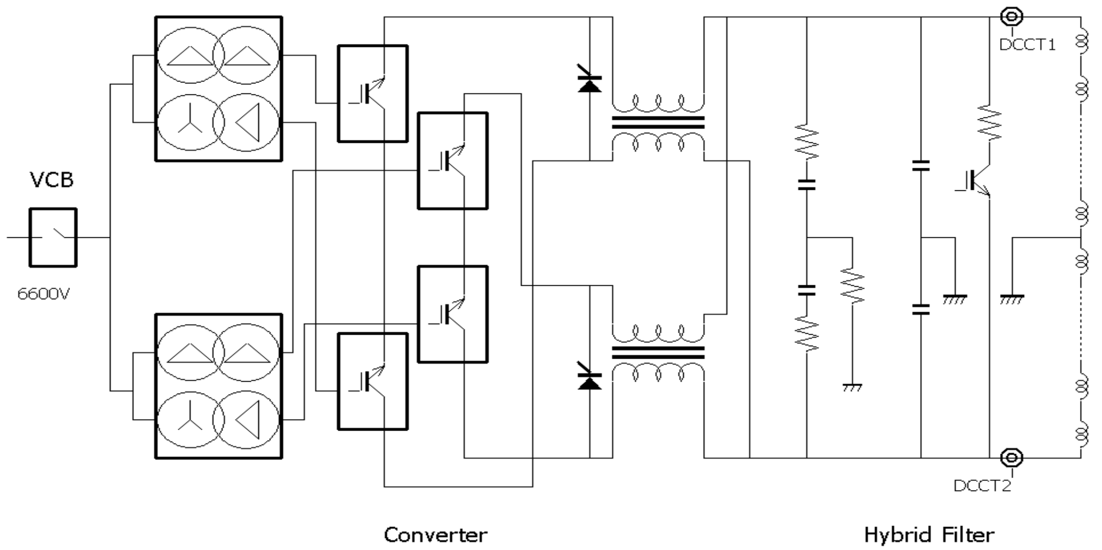

Figure 1: Principal circuit of the bending magnet power supply.

Higher harmonic current trouble

During the test commissioning, a trouble occurred. At that time, both KEKB and PF-AR had been stopped together. In the outdoor cubicle, a surge-suppressor was damaged. The insulator was broken and the oil inside was spraying around. The surge-suppressor had been installed in order to avoid a VCB closing surge.

We carefully installed a spare surge-suppressor. The bending power supply was operated at a low current. The current through the surge-suppressor was measured using an air-core Rogosky coil. Fig. 2 shows the spectrum of the current. The data shows that the higher harmonic components have a peak at around 6 kHz. The heat dissipated per resister due to harmonic current was calculated to be 119W. The rating of the resistor in the serge-suppressor was 20 W. Furthermore, the rise in surface temperature was measured using an infrared pyrometer. The loss of 120 W in one element was estimated. We confirmed the explanation that the higher harmonic current led to the extraordinary damage of the surge-suppressor. As a temporary solution, we had installed a new surge-suppressor with resistors of sufficient power tolerance.

The accident occurred during both the KEKB and PF-AR shutdown periods. We found that the filters and capacitors at the PF-AR power substation were not operating. It was one of the causes in the accident. The static capacitors are driven by monitoring the reactive power. The old power supply had produced considerable reactive power. Along with compensating the reactive power, the capacitors also compensate the harmonic current. However the new supply does not produce a reactive power, so the static capacitors do not operate and the harmonic current is not compensated.

We adopted the interlock condition that the static capacitors and filters of the 5th, 7th, 11th harmonics at AR substation must be in operation. The operation of the bending power supply was limited and required a procedure as follows. The interlock condition was cancelled after the 30 quadrupole power supplies were in operation, because the old quadrupole power supplies produced a considerable reactive power.

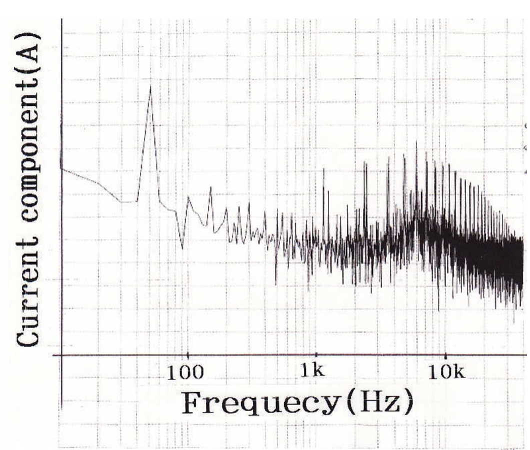

Figure 2: Fourier component of the current through the surge –suppressor in parallel with the VCB contactor.

We had measured the influence of the higher harmonic current distortion. The distortion seemed to remain in the first bank at the PF-AR substation. As the other bank is isolated by a 66 kV transformer, the influence of distortion on the first bank does not spread.

We conclude that this new power supply returns the higher frequency current to the AC side compared to the conventional type. The cause is not only three pulsed PWM, but also the high speed switching of IEGT. This led us to design the dedicated filter to eliminate the higher harmonic problem.

Higher harmonic filter

We manufactured a filter to solve the problem of higher harmonics generated on the AC supply line. The filter installed between the VCB and the transformers. Although we need a low-pass filter along the cable line, the real manufactured equipment has a high-pass filtering property. The reason is that the filter has been installed in the cable line in parallel, as shown in Fig. 3. The specification of the filter is an attenuation of 10 dB in the higher region above the 23rd harmonics.

The manufactured filter consists of two sub stages: an RLC high-pass filter and an RC filter. The RC filter acts as a surge suppressor. The former is installed in the delta connection among the lines. The latter is installed in the Y wiring and the neutral is grounded.

The new filter was installed in spring, 2008. A performance evaluation demonstrated that the attenuation of the higher harmonic satisfied the above specification. The filter consumes a reactive power of about 300 kVar. The total power factor is in the leading phase. The limited operation of the bending magnet power supply is relaxed under the condition that the static capacitors and filters of the 5th harmonics at the PF-AR substation are in operation.

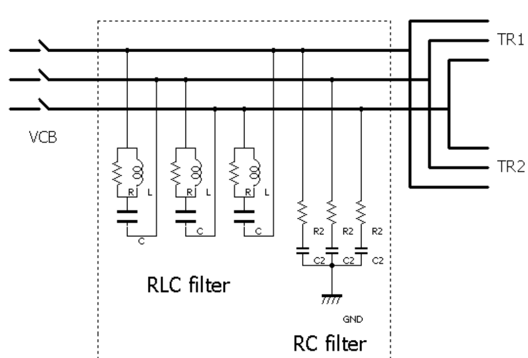

Figure 3: Filter for higher harmonic current.

QUADRUPOLE POWER SUPPLY

We updated the power supply for main focusing quadrupole (QF) in summer, 2009. The power supply consists of a thyristor pre-regulator and a transistor regulator. The load is 12 quadrupole magnets which are powered in series. The resistance and inductance of the load are 89 mΩ and 70 mH, respectively. The power supply is rated at 1340 A and 170 V. The specification for current stability is less than 50 ppm in 8 hours. The specification for current ripple is less than 5 ppm.

In the current regulation controller, the output current which is measured from a DCCT is compared with a current reference. The reference source is a 16 bit DAC with 9.5 V DC full-scale. The long-term variation of circuit elements is compensated up to 10 V using the double buffer method (ref. 2). The burden resistor of the DCCT, the DAC and the current-error amplifier are operating in a small box with temperature-regulated environment. Temperature regulation is accomplished by cooling the inside with a Peltier device or heating the inside. The temperature is maintained within ±0.1° at $25°C$. The error voltage between DAC and DCCT is sent to the transistor bank.

The interface board communicates with the central computers via ARCNET. The current pattern of acceleration, which is a collection of 16 bit digital data, is remotely set in a RAM from the central computers. In the acceleration, the data in the RAM is counted up according to the internal clock in the board, and the output of the DAC is used as a current reference of the power supply.

The status and faults-status signal are sent to an IOC module in a VME crate, which is connected to the computer system which utilizing EPICS.

In PF-AR, 28 power supplies for the 86 quadrupole magnets are in operation. The circuits were all of a similar design, though that for QF is the largest. We plan to update these old power supplies in the near future.

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