Improved the TPS Booster AC Magnet Power Supply Performance

Introduction

The primary goal of AC magnet power supply for the TPS Booster Ring is to increase the output electron beam energy from the linear accelerator from 150 MeV to 3 GeV and inject it into the storage ring. This energy increase is achieved through operating the booster ring AC magnet power supply (BACMPS) with a synchronized 3 Hz current ramping. This report provides an overview of the installation of the BACMPS system, the challenges encountered during commissioning, proposed improvements, and the development of an energy-saving mode.

BACMPS

The BACMPS system consists of a single bending magnet power supply (BMPS) and four quadrupole magnet power supply (QMPS) units to form the energy ramping structure for the booster ring. The bending magnets in the booster ring consist of 60 units of two different magnetic field lengths: 1.6 m (BR-BD) and 0.8 m (BR-BH). They are connected in series and powered by a single BMPS unit. The BMPS has the capacity to deliver currents as high as 1200 A within a voltage range of ± 1600 V. The internal topology of the BMPS, as shown in **Fig. 1**, includes an EMI filter, soft-start circuitry to mitigate input electromagnetic interference, components for DC-DC conversion, a dual full-bridge circuit, output filters, and control cabinet assemblies. Current feedback signals are provided by a direct current transformer (DCCT), and these signals are used with field programmable gate array (FPGA)-based proportional–integral (PI) compensation calculations and a 1 kHz PWM modulation signal to drive four intelligent SkiiP IGBT modules. Ethernet communication is used for AC and DC mode control, enabling adjustable 3 Hz sinusoidal current waveforms with a peak output current ranging from 0 to 1200 A.

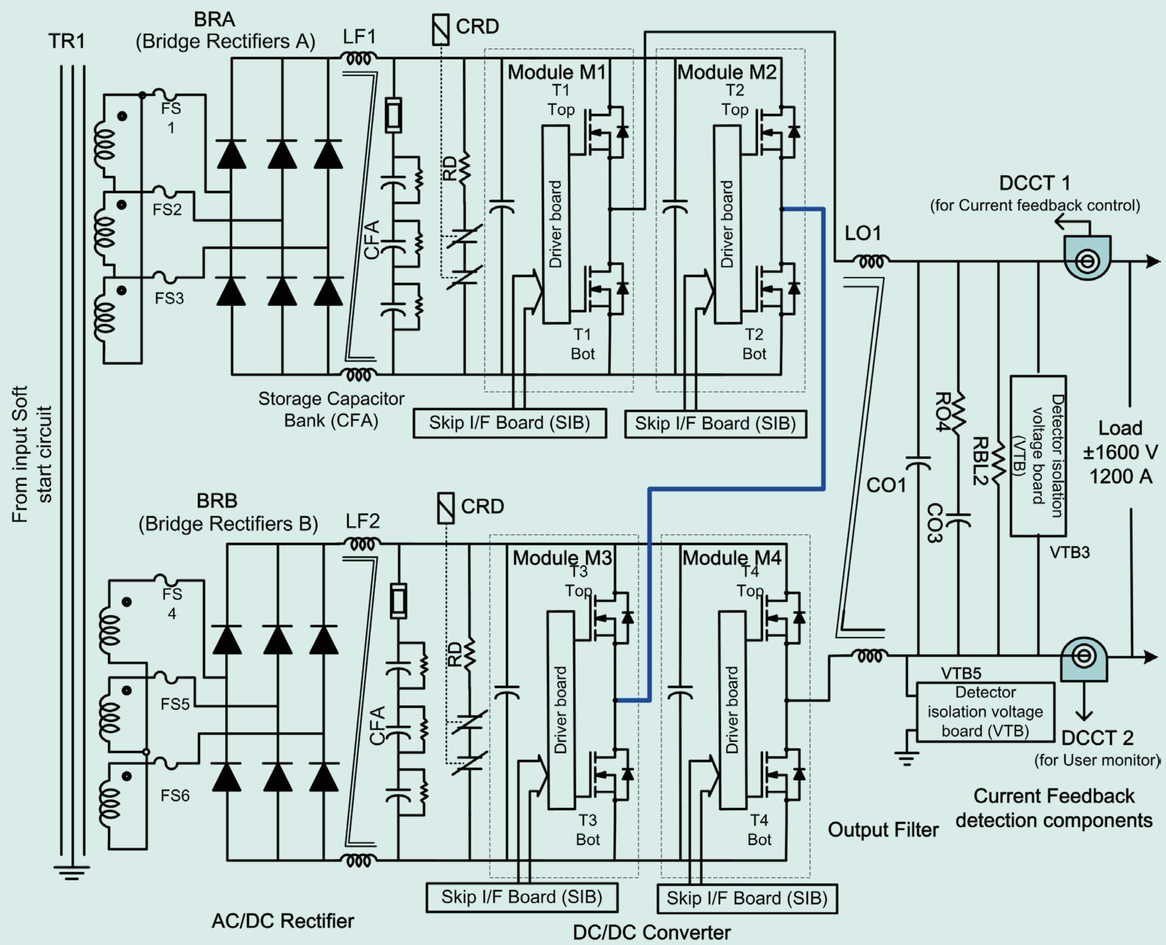

Fig. 1: System function diagram of the TPS BR BMPS.

The QMPS units have an internal topology similar to that of the BMPS but with a single full-bridge architecture and utilize a 40 kHz PWM modulation signal to modulate the output current. The capacity specification for the QMPS is 150 A/± 425 V.[1]

Installation and Cabling

All the installation requirements were satisfied during the installation of the BACMPS for the TPS booster ring. These requirements included provisions for cooling water, controller settings, cable specifications, and specifications for auxiliary interlock configurations. Careful cable routing strategies, particularly those involving crossover loops, were employed to minimize interference caused by the magnetic fields generated by the output current. This technique effectively reduced magnetic interference in the TPS area, ensuring compliance with high-energy output requirements and addressing challenges associated with high-current operations. A dedicated soundproof chamber was established to mitigate low-frequency noise generated during BMPS operation. These measures successfully reduced the low-frequency switching noise from 84 to 54 dB.

Commissioning Issues of BACMPS

Despite successful laboratory tests under purely resistive loads, the performance of the BACMPS during the initial TPS commissioning in 2014 did not meet expectations. The main challenges encountered were twofold. First, the effects of parasitic capacitance on the magnet load side resulted in the BACMPS generating common-mode high-frequency 1 kHz noise during AC mode operation. This noise led to poor current reproducibility at the injection point. Second, the distinct characteristics of the BMPS and QMPS output currents, including variations in phase delay angles and the lack of synchronous timing control in the FPGA controller, made it challenging to achieve synchronized waveforms for the BACMPS.

Effects of Parasitic Capacitance in the Booster Ring Bending Magnet

The effects of parasitic capacitance in the bending magnets of the booster ring, specifically between the SkiiP IGBT modules M1 and M4 (where the BMPS output terminals are considered a floating ground reference), pose unique challenges. Because the support girder of the bending magnet is grounded, the wire turns of the bending magnets and the girder form a capacitor, and 60 units of bending magnet in series create parasitic capacitance. **Figure 2**

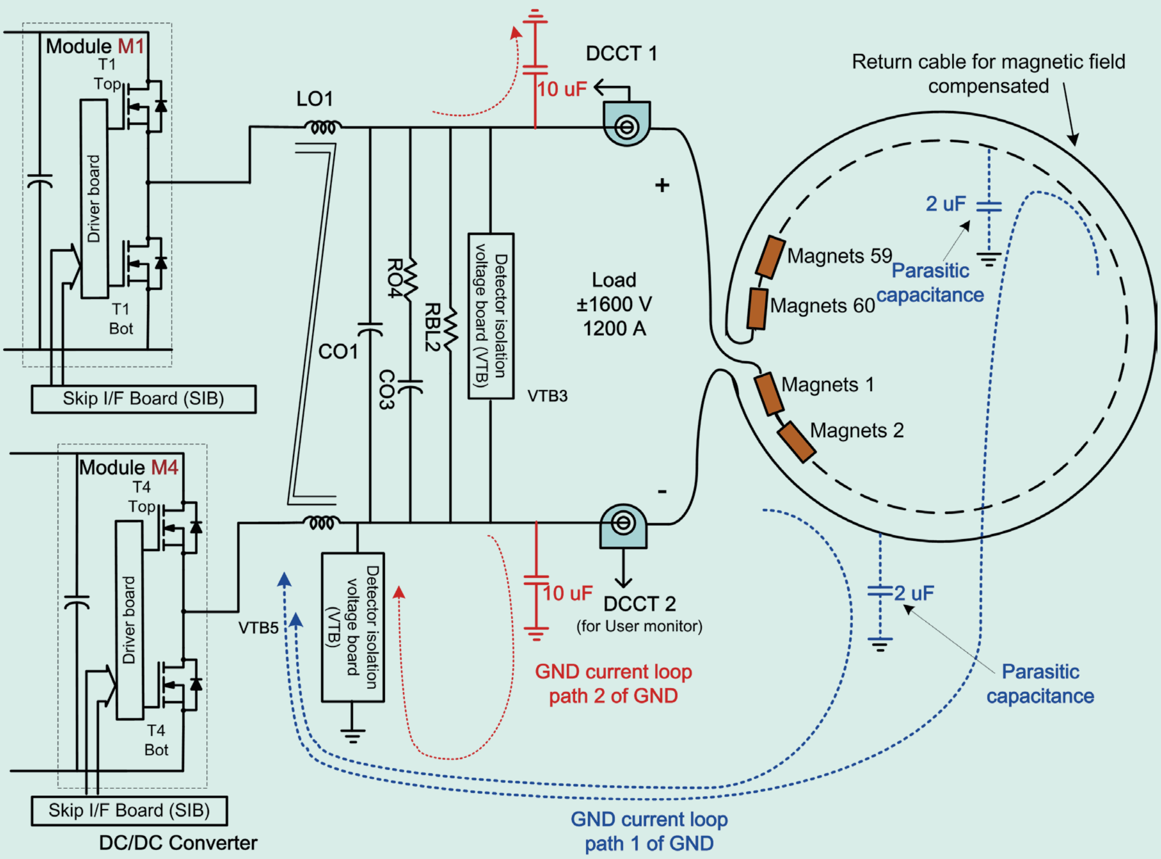

Fig. 2: Parasitic capacitance with the ground current path of the booster ring dipole magnet.

shows the equivalent circuit of the BMPS with the load of the booster ring magnet. From the BMPS output terminals to the bending magnets of the booster ring, a comparable 2 μF capacitance is established, as depicted in the blue current path in **Fig. 2**. During DC mode operation, a substantial amount of harmonic current is generated, as shown in **Fig. 3(a)**. At 2 kHz, the 80 mA harmonic current component clearly cannot meet the subsequent ramp tracking test requirements.

To address these challenges, a Y-type common-mode filter was designed and incorporated to absorb the noise generated by residual parasitic capacitance along the ground solder path. The capacitances of these capacitors are significantly greater than those of parasitic 2μF capacitors, as shown in the red trace in **Fig. 2**. This solution reduces the harmonic currents in the load current. The filter is installed before the DCCT to prevent harmonic current feedback into the control system. These improvements are shown in **Fig. 3(b)**, where the harmonic content in the 2 kHz output current is significantly reduced from the original 80 to 4.3 mA.[2]

However, the substantial harmonic currents generated by the BMPS are guided to the ground through the capacitive effects of the dipole magnet load. This energy returns to the system through the BMPS ground current protection detector. However, when the harmonic current exceeds the ground current detector's rated power, overload and damage occur.

Additionally, the rated power of the ground current detector was increased to enhance its tolerance of harmonic ground currents.

Control Card Synchronization Challenges

In **Fig. 4**, the high-precision analog differential signal modulation board on the COMMC card is shown. This component is primarily introduced due to the lack of external timing synchronization signals on the FPGA control card of BACMPS. While initial tests achieved a 3 Hz ramping operation, there were issues with the QMPS output current phase delay and waveform distortion, causing poor tracking of the BMPS output current by each QMPS in AC mode. This poor tracking highly impacting the current reproducibility at the injection point. To overcome these challenges, the BACMPS control card circuits were improved, which included a tarnsition from digital control modules to high-precision analog differential signal modulation boards. These boards allow external correction reference signals to adjust the phase and waveform of the BACMPS output current.[3]

Ramping Current Waveform of BACMPS

The power supply team successfully overcame numerous challenges during the operation of BACMPS. The BMPS and the QMPS energy were increased from 150 MeV to 3 GeV. The ramping current waveform of BACMPS is depicted in **Fig. 5**, highlighting the significant contributions of the instrumental control team. A stable and 3 Hz

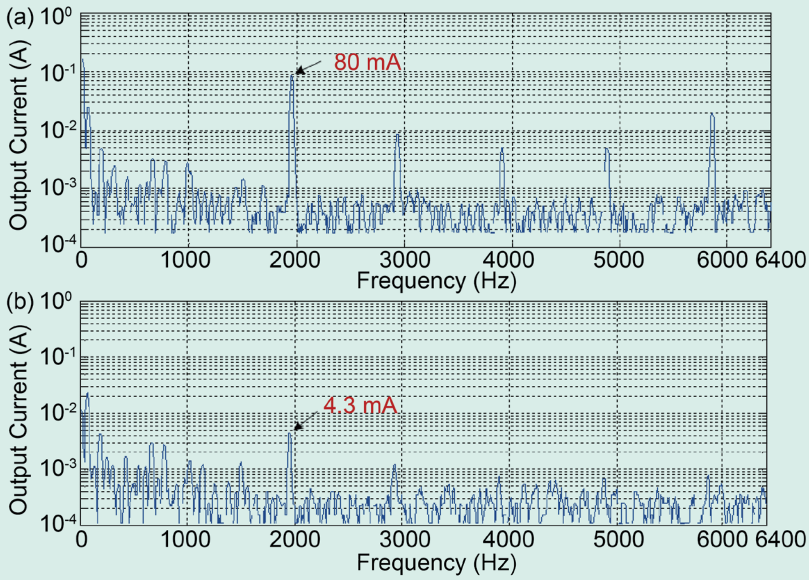

Fig. 3: (a) Leakage current spectrum of the booster ring parasitic capacitance. (b) Improved booster ring parasitic capacitance leakage current spectrum. [Reproduced from Ref. 2]

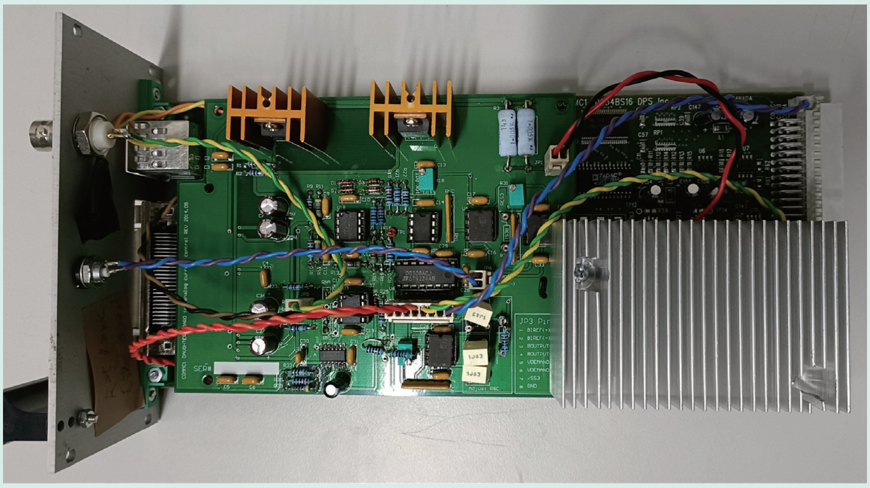

Fig. 4: High-precision analog differential signal modulation board on a COMMC card. [Photo courtesy of Bao-Sheng Wang]

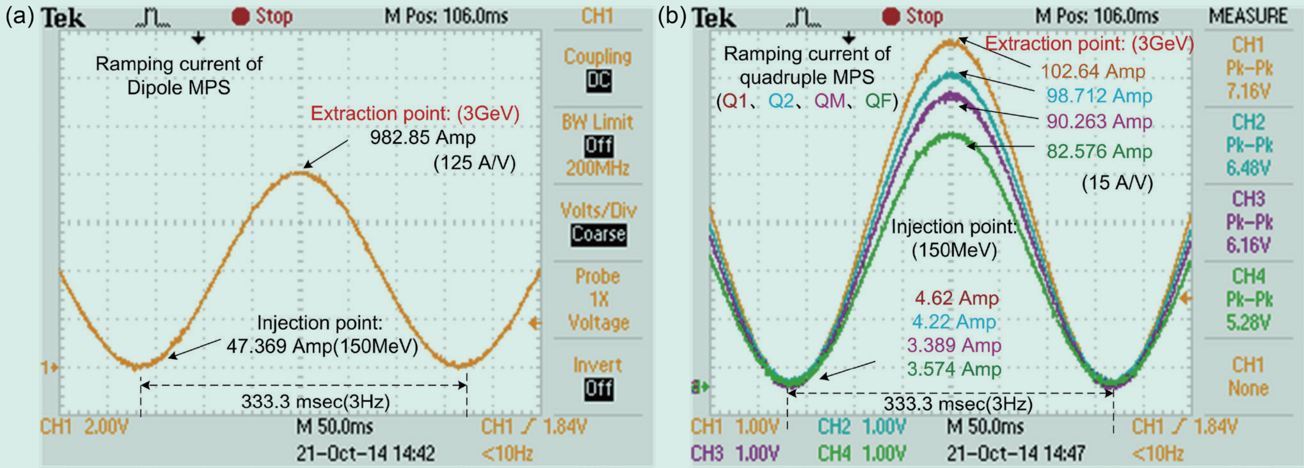

Fig. 5: Ramping current waveform of the BACMPS: (a) BMPS (b) QMPS. [Reproduced from Ref. 3]

sinusoidal current, with synchronized operation within the BACMPS, was achieved with precise timing control and current correction algorithms. This improvement in current reproducibility at the injection point to below 0.05% deviation between instances was instrumental in facilitating the injection of the electron beam from the booster ring into the storage ring, contributing to the experiments and work at the TPS facility.

Energy Saving Modes

In 2019, TPS implemented an energy-saving mode. In the BACMPS operating in the top-up mode, the current ramps up every 4 minutes, with the ramping current commencing 15 seconds prior. The injection duration depends on the injection efficiency and is typically within approximately 30 seconds. This initiative significantly reduces energy consumption and electricity costs.

In conclusion, the power supply and control groups have continually optimized the characteristics of BACMPS to increase the efficiency of TPS operations, from installation to the present, including testing, commissioning, and function to power-saving initiatives. (Reported by Bao-Sheng Wang)

References

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2. C.-Y. Liu, B.-S. Wang, Y.-S. Wong, Y.-C. Chien, K.-B. Liu, IPAC'**16**, THPMW016, 3573 (2016).
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The Automatic System for the TLS 07A1 Endstation

The **TLS** beamline **07A1** endstation was established to facilitate multiple uses with various modes. The mode switching capability was manually realized in the previous operation design, and it took considerable time to reinstall and realign dozens of devices as part of the mode switching process. Occasionally, urgent sample tests jumped into the experimental schedule and took much time to reconfigure the system if different methods were used. Thus, an automated process system design was proposed to reduce the time wasted in switching modes. This design includes different types of experimental device transformations and high-speed gas exchange. The automation process is now conducted. The operating time of the experimental equipment transformation is efficiently reduced from a couple of hours to two minutes, and the amount of required manpower is decreased as well. Moreover, the duration of the execution time of the gas exchange process is also reduced dramatically from 100 to five minutes.

When promoting the application of synchrotron radiation in industry, the ease of operation and efficiency of the experiments are often crucial factors. Noting that the **TLS 07A1** is an experimental station primarily designed to meet industrial needs, in the past, the system could not handle urgent order demands. Different tasks typically require the conversion of different