

NSLS-II STORAGE RING AUXILIARY DIPOLE POWER SUPPLY

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Abstract

The National Synchrotron Light Source II (NSLS-II) storage ring requires a high-current (400 A), high-voltage (1 kV) dipole power supply system to maintain stable beam in the Storage Ring. To reduce downtime of beam resulting from a failure of the dipole power supply, an Accelerator Improvement Project was undertaken to develop a redundant backup power supply system. This paper presents the design and implementation of an in-house developed auxiliary dipole power supply built to serve as a standby system for the main dipole power supply. The auxiliary system utilizes a modular architecture with N+2 redundancy and high-frequency switched-mode power converters with active power factor correction. This design eliminates large 60 Hz transformers, reducing the system footprint to 20% of the original installation while enabling hot-swappable servicing. A transfer switch ensures a rapid transition from primary to backup systems in under 20 minutes. To maintain stringent orbit stability, the system incorporates a custom DC EMI filter and a series-pass linear amplifier, achieving a measured current stability of better than 1 part in 10^5 (10 ppm). This paper presents results demonstrating the system's effectiveness in reducing recovery time and enhancing the overall reliability of NSLS-II beam operations.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) is one of the most advanced synchrotron light sources in the world. The facility enables scientists from academia and industry to tackle the most important challenges in quantum materials, energy storage and conversion, condensed matter and materials physics, chemistry, life sciences, and more by offering extremely bright light, ranging from infrared light to x-rays.

To create its intense ultrabright light, NSLS-II has an advanced particle accelerator complex that spins electrons around its half mile long ring at nearly the speed of light. NSLS-II's accelerators are comprised of many complex engineering systems. Running this intense, stable electron beam for 5000 hours every year, with no interruptions, requires constant attention to every integral component [1].

One of those systems that needs to operate reliably is the Dipole Power Supply System (DPSS). This system must meet the 5000 hours of operation requirement without any interruptions. Despite the high reliability of the primary system, a 2022 failure event resulted in over 20 hours of beam downtime, highlighting the necessity for secondary backup DPSS. To that end a decision was made to build an auxiliary DPSS capable of providing reliable power to

dipole magnets in case of failure of the main DPSS. After research and careful consideration of multiple different topologies, a compact modular solution was most viable when considering MTTR (Mean Time to Repair), performance and reliability are the main criteria.

PRIMARY NSLS-II STORAGE RING DPSS

Table 1 lists the important parameters from the original Dipole Power Supply System. The new DPSS has same or better performance rating.

Table 1: Dipole Power Supply System Requirements

Parameter	Specification	Unit
Output voltage	822	Volts
Output current	400	Amps
Accuracy	± 25	ppm
Ripple current	< 10	ppm



Figure 1: Primary Storage Ring DPSS

The Primary DPSS is divided into two banks positive bank and negative bank with center point grounded (Fig. 1). Each bank can provide 600Vdc-max at 400A maximum current making total DPSS output 1200Vmax at 400A. Each bank includes a large 3-phase 60Hz transformer for isolation and SCRs for rectification. A large capacitor bank is used for hold-up during AC line interruptions. Followed by parallel interleaved H-bridges, series pass regulator and LC filter. The H-bridge's effective switching frequency is 30kHz. The control cabinet provides accurate regulation to less than 10ppm.

AUXILIARY NSLS-II STORAGE RING DPSS

To support the rigorous operational demands of the NSLS-II, the dipole power supply system is engineered for both high capacity and extreme stability. The Auxiliary DPSS is designed with similar specifications in mind but with latest technology to achieve greater compactness. Like the primary system, Auxiliary DPSS features positive

and negative banks and employs high frequency Switch Mode Power Supplies (SMPS) to manage thermal output and energy consumption. Operating at high frequencies, minimizes size of passive components and allows for high efficiency across the full load range.

The power supply also features an active Power Factor Correction (PFC) with Power Factor (PF) of 0.99. This minimizes Total Harmonic Distortion (THD) reducing Electromagnetic Interference (EMI). Preliminary testing suggests that the power supplies' boost topology may provide robust AC line dip ride-through performance. By utilizing active feedback regulation rather than passive energy storage, the system maintains stability during input fluctuations.

Each bank in Auxiliary DPSS contains 12 individual 1U, rack mountable, liquid cooled power supplies (Figs. 2 and 4). Each supply can provide a maximum of 16.5kW. These power supplies are connected in series-parallel combination to achieve 300kW. The modular approach allows for N+2 redundancy in each bank, guaranteeing continuous operation even in the event of multiple failures. To reduce EMI input line filters are connected at input of each modular power supply. Commercial Off the Shelf (COTS) input line filters are connected at the input of each modular power supply.

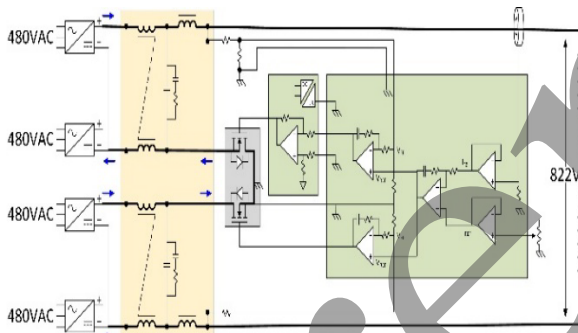


Figure 2: Dipole PS block diagram

The reduction in ripple is achieved via custom Low Pass Filter (LPF) and series pass regulator (Fig. 3). These are employed at both positive and negative power supply banks. These stages are critical for EMI and Electromagnetic Compatibility (EMC). The combination of the two chassis ensures low current ripple and less than 10ppm of stability.

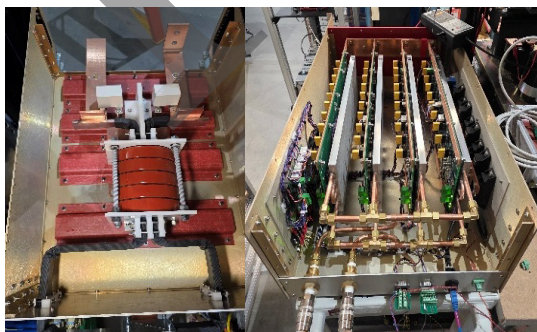


Figure 3: LPF (left) and series pass regulator (right)



Figure 4: Auxiliary DPSS and control racks

The precise control of the power supply is done by custom Power Supply Controller (PSC) Fig. 5. The PSC is meant to be a custom-made carrier chassis for the PicoZed SOM (System On Module). The PicoZed SOM features a Xilinx 7030 FPGA with an ARM processor. The PSC chassis is primarily split between two circuit boards. One board handling the digital GPIO, ADC data acquisition, 18- or 20-bit precision DAC output, as well as various TCP/IP and UDP packet data protocols for fast and slow data acquisition. The second board is primarily an analog board that precisely conditions a DCCT (DC Current Transformer) input and uses an analog PID control loop to allow for the highest possible precision and control.



Figure 5: Z-PSC including SOM

Transfer Switch

In the event of Primary DPSS failure, a custom transfer switch (Fig. 6) enables rapid transition to the Auxiliary DPSS. Designed by NSLS-II engineering team, this switch facilitates a full system transfer in less than 20 minutes.



Figure 6: DPSS transfer switch

The switch position can be visually inspected by opening the main enclosure door. For safety, an internal Lexan door is integrated into the Personnel Protection System (PPS) and interlocked if opened. The switch is operated by loosening the bolts and manually moving to its intended position. This capability allows maintenance personnel to safely troubleshoot and repair the decommissioned DPSS without interrupting operations.

AUXILIARY DPSS TEST RESULTS

Test bench was established to evaluate an initial set of four power supplies. These units were tested for ripple, AC dropout, over temperature, over voltage, over current, voltage linearity, and output stability. Both differential mode and common mode ripple were measured. The supplies were tested on resistive load with maximum current of 160A; through this test bench SMPS underwent full validation testing.

Following initial testing, all 24 power supplies were installed in the rack and moved to their final location. Validation of the full DPSS has shown promising results. The Auxiliary DPSS was first tested using electronic load at a maximum output of 120kW; at this power either full voltage or full current can be achieved but not both simultaneously. Following these successful tests, the Auxiliary DPSS was connected to all 60 dipole magnets. Top section of Fig.7 displays power supply output (shifted by -6V for clarity) and output of the series pass regulator. The frequency spectrum from DC to 10 kHz is displayed in the lower section. At lower frequencies the power supply output- after the LPF- is noisy; however, at frequencies above 100 Hz there is significant noise reduction. The series pass regulator exhibits minimum noise across the entire spectrum.

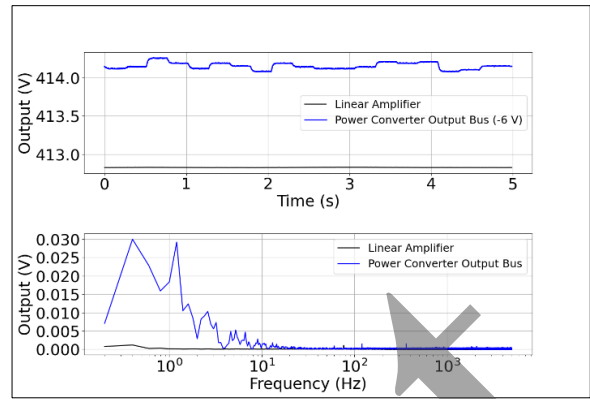


Figure 7: RMS noise positive bank

Lastly the power supply was tested with the beam in the storage ring (Fig. 8). Beam stability was compared against the Primary DPSS, and results indicated that the Auxiliary DPSS performed as effectively as the primary DPSS.

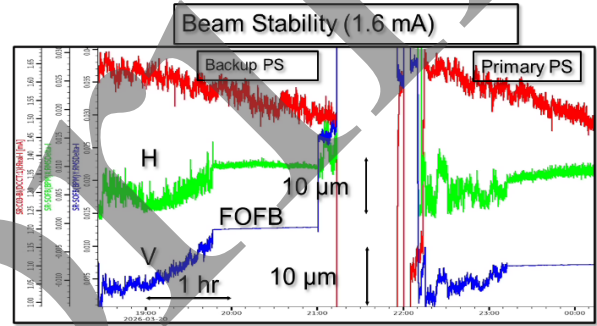


Figure 8: Auxiliary and primary DPSS comparison with beam.

CONCLUSION

Dipole magnets direct the electron beam around the accelerator, and a single power supply powers the 60 dipole magnets in the NSLS-II storage ring. The development and implementation of the Auxiliary DPSS provide the NSLS-II with a robust, high-stability power solution for its dipole magnets. By leveraging a modular architecture of twelve liquid-cooled SMPS units per bank, the system achieves the required 300 kW capacity with reliable N+2 redundancy. The integration of custom low-pass filters and series pass regulators ensures exceptional current stability and ripple reduction to less than 10 ppm, meeting the stringent precision requirements of the synchrotron.

Furthermore, the inclusion of a custom-engineered manual transfer switch ensures rapid switchover between the systems. Final validation with the storage ring beam confirms that the Auxiliary DPSS provides stability equivalent to the primary system. This successful integration ensures the NSLS-II maintains high operational availability.

REFERENCES

- [1] Brookhaven National Laboratory National Synchrotron Light Source II
<https://www.bnl.gov/nsls2/accelerator>