BOOSTER MAIN MAGNET POWER SUPPLY, PRESENT OPERATION AND POTENTIAL FUTURE UPGRADES

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Abstract

The Brookhaven Booster Main Magnet Power Supply (MMPS) is a 24 pulse thyristor control supply, rated at 5500 Amps, +/-2000 Volts, or 3000 Amps, +/-6000 Volts. The power supply is fed directly from the power utility and the peak magnet power is 18 MWatts. This peak power is seen directly at the incoming ac line. This power supply has been in operation for the last 18 years.

This paper will describe the present topology and operation of the power supply, the feedback control system and the different modes of operation of the power supply. Since the power supply has been in operation for the last 18 years, upgrading this power supply is essential. A new power supply topology has been studied where energy is stored in capacitor banks. DC to DC converters are used to convert the dc voltage stored in the capacitor banks to pulsed DC voltage into the magnet load. This enables the average incoming power from the ac line to be constant while the peak magnet power is pulsed to +/- 18 MWatts. Simulations and waveforms of this power supply will be presented.

PRESENT SYSTEM

The Booster MMPS consists of six pairs of thyristor controlled power supplies connected in series and implemented in two stations. Each pair is a 24 pulse controlled rectifier, rated at +/- 1000 volts DC. IAB and IIAB power supplies are rated for 5000 Amps DC, while the rest of the units are rated for 2800 Amps DC. There are bypass SCR's across every pair of rectifier modules. Module IAB is never placed into bypass mode. During RHIC (fast pulse) operation, the remaining power supplies come out of bypass during rectify and invert and are placed back in bypass between pulses. During NSRL cycles which require 2000VDC, IAB is always ON, IIAB comes out of bypass during rectify and invert, and placed back in bypass during dwell and flattop.

Table 1: Booster MMPS Ratings

Voltage DC max at 2800 amps DC max	+/- 6 kV
Voltage DC max at 5000 amps DC max	+/- 2 kV
Current DC max at +/-6000 V DC max	2800 A
Current DC max at +/-2000 V DC max	5000 A
Fundamental Ripple Frequency	1440 Hz
Magnet Resistance (R)	0.107 Ω
Magnet Inductance (L)	0.145 H
Nominal pulse repetition	4 sec
Nominal Flattop	1 sec
3600 KVA Transformer primary current rms	150 A

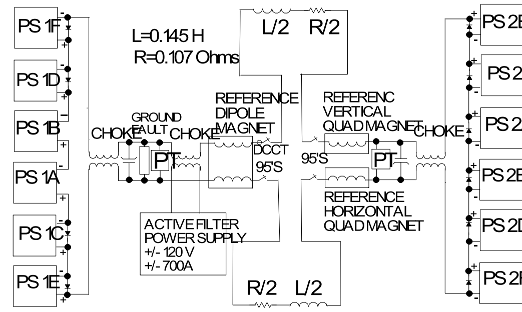

Figure1:.Block diagram of BMMPS.

All other modules are placed in bypass throughout the cycle. Table 1 shows some parameters for the Booster MMPS, while figure 1 shows a block diagram of the BMMPS. The Booster Ring consists of 50 quadrupole magnet and 37 dipole magnet connected in series. The total resistance R is 0.107Ω and a total inductance of 0.145H. Currently the Booster is being used for both NSRL and RHIC experiments. NSRL functions are usually Flattop function while RHIC functions are functions without flattop. For simulation purposes we will be using a super cycle which includes two RHIC pulses and one NSRL flattop function. During pulsing this super cycle, the total peak power is close to 15MW. The total energy in Kilowatt hours per super cycle was calculated to be 1.34KWH, for a super cycle length of 4 sec.

POTENTIAL FUTURE SYSTEM

One possible upgrade to the Booster MMPS is to take energy from a cap bank rather than taking energy directly from the power line. The basic building block for one station is shown in Figure 2. The proposed power supply is composed of two stations in series with half the load in series per station.

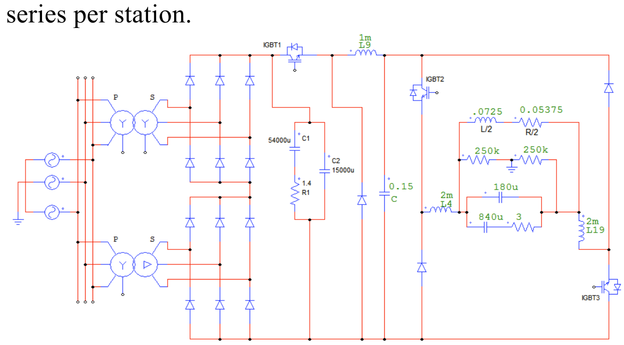

Figure 2: Block diagram of proposed topology per station.

From Figure 2, power is fed directly to a 12 pulse full wave bridge rectifier to charge a capacitor bank through a one quadrant buck converter. IGBT's that have separate control system are used to convert the capacitor bank voltage into pulsed DC voltage across the magnets. Since a total of two stations are required, the total energy stored per capacitor bank will be 1.2MJ. The required capacitance for the cap bank per station would be 0.15F at 4000VDC. If the switching frequencies of the IGBT's for both stations are in phase, the overall ripple at the magnet will be increased. This ripple can be reduced to a minimum if the switching frequencies of both stations are 180 degrees out of phase. The peak input power will be reduced since the magnet peak power is drawn from the capacitor bank and no power will be re-circulated back to the power distribution system, as it is done with the present system. Grounding is only done at one station as shown in Figure 2 above.

THE CONTROL SYSTEM

There are two separate control systems for the proposed upgrade of the BMMPS. One is used to charge the Capacitor bank while the input power is equal to the magnet dissipated power and the other is used to control the voltage across the magnet. See Figures 3 and 4.

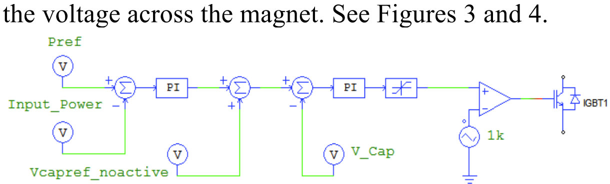

Figure 3: Control system used to charge the cap bank.

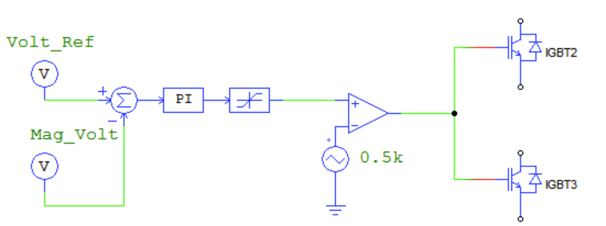

Figure 4: Control system used to control magnet voltage.

Figure 3 shows the control loop that was used in the simulation to charge the capacitor bank, while the input power is equal to the magnet dissipated power. This loop uses the input power, power reference (Pref), Capacitor voltage (Vcap) and the Vcapref_noacitve. Vcapref_noactive represents the capacitor bank C, voltage reference when only reactive power is drawn for a given magnet current cycle. An expression for Vcapref_noactive was derived and is shown below.

$$Vcapref\_noactive(t) \approx \sqrt{V_0^{\,2} - \frac{L}{C}[\mathrm{Im}(t)^2 - I_0^{\,2}]}$$

V is the initial capacitor bank charge voltage, 4000 volts. L is half of the Booster magnet inductance, which is equal to 0.0725 H. C is the capacitance of the capacitor bank per station, which is equal to 0.15F. Im(*t*) is the magnet current as a function of time and *I* is the magnet current during the time of the front porch which is equal to approximately 200 A. The second control loop, shown in Figure 4, is used to control the magnet voltage. This loop uses the voltage reference (Volt_Ref) and the actual magnet voltage (Mag_Volt), to drive IGBT2 and IGBT3. Since this is a current regulated power supply, an outer current loop must also be used, but was not implemented during the simulation.

SIMULATION RESULTS

After simulating the circuit in Figure 2 used for one station, the following results were obtained.

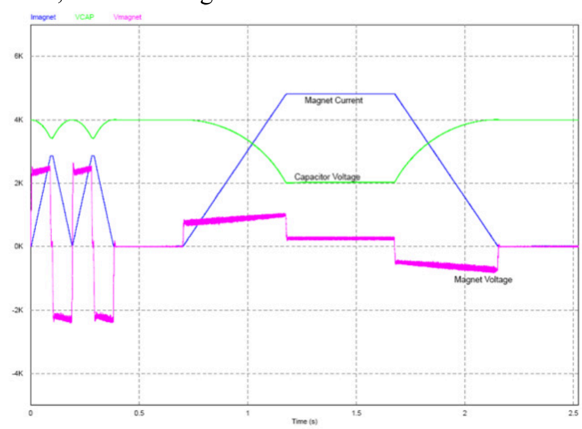

Figure 5: Magnet current, magnet voltage, capacitor bank voltage.

In this simulation the Capacitor bank was charge initially to 4000V. In this manner the magnet required voltage is always less than the capacitor bank voltage, see Figure 5. Figure 5 also, shows the magnet voltage magnet current, and capacitor bank voltage for a typical Booster Super Cycle. Note the super cycle length was 4 sec. Figure 6, shows the power drawn from the capacitor bank, the magnet power and the power drawn from the power line for one station only.

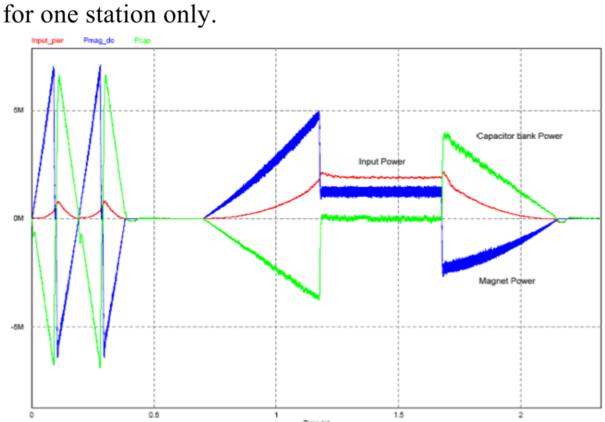

Figure 6: Capacitor bank power, magnet power and input power.

It should be noted that in such a system the power drawn from the AC line will be less, since the power that is not used will be re-circulated in the system to charge the capacitor bank. Referring to Figure 2, the energy will be drawn from the capacitor bank when IGBT2 and IGBT3 are turned on. Since the magnets acts as a source during negative voltage, the capacitor bank will be recharged. This can be seen in Figure 5. In the present operation of the Booster MMPS that power would have been redirected back to the power line. Figure 7, shows the input power and the power reference of the control system in Figure 3. Figure 7, shows some ringing on the input power, but is attributed to the fact that the simulation circuit was not optimized. Figure 8, shows the capacitor voltage, current and Vcapref_noactive.

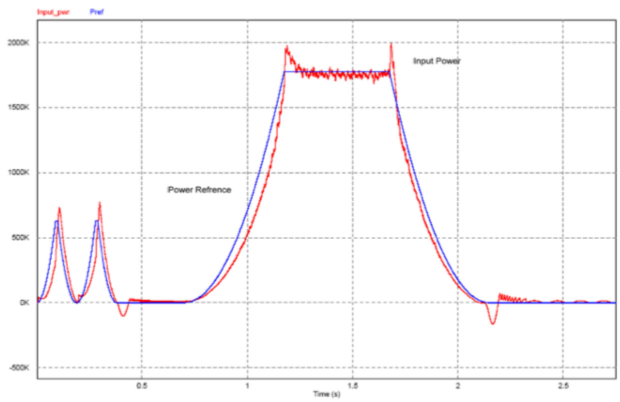

Figure 7: Power reference and input power.

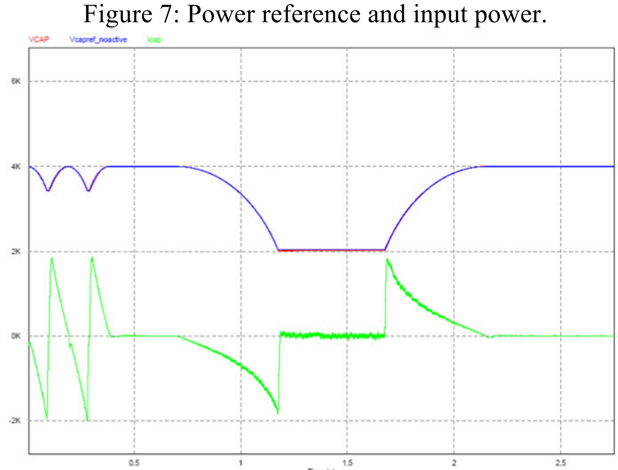

Figure 8: Capacitor voltage, current and Vcapref_ noactive

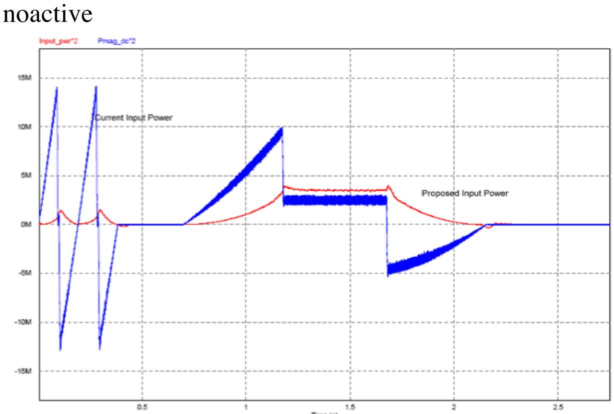

Figure 9: Total input power of existing power supply and total input power of proposed new BMMPS.

Notice that in Figure 9, the peak power is approximately 15MWatts for the current BMMPS system while the peak power for the proposed system is approximately 4MWatts. All magnet stored energy is used to charge the capacitor bank and not sent back out on the power line. The calculated kilowatt hours per super cycle for the current BMMPS it is approximately 1.34KWH, while the calculated kilowatt hours per super cycle for a capacitor bank storage system such as the one proposed would be approximately 0.63KWH, with a super cycle length of 4 sec. If 5 RHIC pulses are used only then the power dissipated is equal to 1.015KWH while the cap bank dissipates 0.096KWH for a 4 second super cycle.

CONCLUSION

Certainly installing this system would mean that the total power required for operation would be greatly reduced. In addition, we would also reduce the harmonics that are being sent out on the power line. The Booster Main Magnet Power Supply is already 20 years old. But there are several aspects that should be addressed before implementing such a system, average life and physical size of capacitor banks, life and availability of IGBT's. We also need to evaluate further the power devices IGCT's or IGBT's, which are currently available from the industry. A more modular approach for both the capacitor banks and the dc to dc converters may be a good solution. Another issue is to finalize the frequency at which the IGCT's or IGBT's would run, and therefore know in more detail the power supply voltage ripple in comparison with the present values. It should also be pointed out that CERN was in the process of commissioning a similar power converter, for their PS accelerator. We should discuss details with them to find out any potential problems during the commissioning of their system as well as potential problems after the system is operational for at least a year.

ACKNOWLEDGMENTS

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REFERENCES

[1] High Power Fast Ramping Power supplies, I. Marneris, E. Bajon, R. Bonati, T. Roser, J. Sandberg, N. Tsoupas, 2009 Particle Accelerator Conference.

[2] Simulations of the AGS MMPS Storing Energy in Capacitor Banks, 2007 Particle Accelerator Conference.

[3] F. Bordry, J.-P. Burnet, F. Voelker. Cern-ps main power converter renovation: How to provide and control the large flow of energy for a rapid cycling machine. Proceedings of 2005 Particle Accelerator Conference.

[4] Booster Main Magnet Power Supply Improvements for Nasa Space Radiation Laboratory at BNL, I. Marneris, K.A. Brown, J.W. Glenn, A. Mc Nerney, J. Morris, J.Sandberg, S.Savatteri. 2003 Particle Accelerator Conference