SIMULATIONS OF THE AGS MMPS STORING ENERGY IN CAPACITOR BANKS

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Abstract

The Brookhaven AGS Main Magnet Power Supply (MMPS) is a thyristor control supply rated at 5500 Amps, +/-9000 Volts. The peak magnet power is 50 MWatts. The power supply is fed from a motor/generator manufactured by Siemens. The generator is 3 phase 7500 Volts rated at 50 MVA. The peak power requirements come from the stored energy in the rotor of the motor/generator. The motor generator is about 45 years old, made by Siemens and it is not clear if companies will be manufacturing similar machines in the future. We are therefore investigating different ways of storing energy for future AGS MMPS operations. This paper will present simulations of a power supply where energy is stored in capacitor banks. Two dc to dc converters will be presented along with the control system of the power section. The switching elements will be IGCT's made by ABB. The simulation program used is called PSIM version 6.1. The average power from the local power authority into the power supply will be kept constant during the pulsing of the magnets at +/-50 MW. The reactive power will also be kept constant below 1.5 MVAR. Waveforms will be presented.

THE POWER SYSTEM

The proposed power supply is composed of two stations. Station I is composed of a 12 pulse full-wave bridge rectifier, charging a capacitor bank, through a one quadrant buck converter. In addition a two quadrant dc to dc converter is used to convert the capacitor bank voltage into pulsed dc voltage across the magnets. See Figure 2. Station II is identical to station I. Note station I is connected to half of the AGS magnets which are also connected in series with station II power supply. This power supply is also connected in series with the other half of the AGS magnets which are also connected in series with station I power supply see Figure 1.

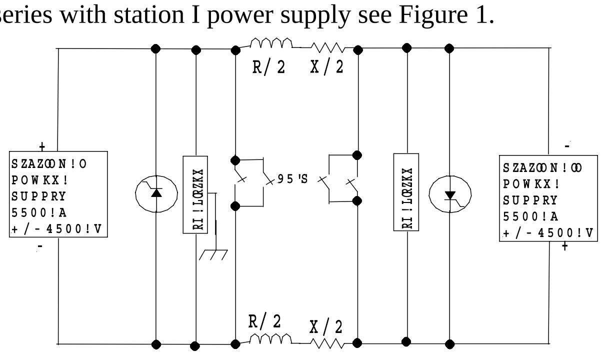

Figure 1: Station I, II block diagram

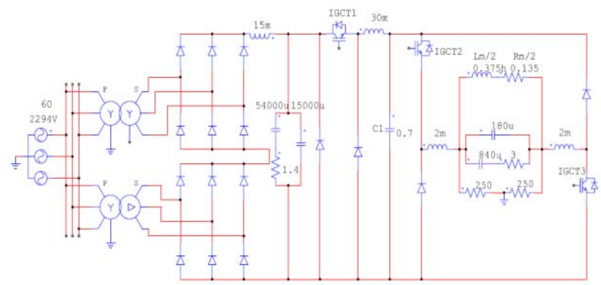

Figure 2: Simulation power supply topology

The energy of the capacitor bank C1 is 12.6 MJ. The maximum voltage is 6000 volts and the capacitance is 0.7 F. The frequency used to run the power electronics of both dc to dc converters for this simulation was 500 Hz. The reason is that ABB manufactures IGCT's with ratings similar to the ratings of our power electronics and they are being pulsed at around 500 Hz to 1 KHz. Station II could be pulsed at 500 Hz but delayed from station I by 180 degrees resulting in minimizing the magnet voltage ripple. The LC filter of the 12 pulse full wave bridge rectifier, has a 3 db point at 8 Hz. The LC filter of the 2 quadrant dc to dc converter has a 3 db point at 100 Hz. Both filters have not fully been optimized at this time.

THE CONTROL SYSTEM

There are two control systems used in the simulation. One which controls the buck converter power electronics IGCT1, and another used to control the magnet current using the power electronics of the two quadrant dc to dc converter IGCT2, IGCT3. The block diagram of the first control system is shown in Figure 3. There are two loops being used, the inner loop and the outer loop. The inner loop has a reference called Vcapref_noactive. This represents the capacitor bank C1 voltage reference when reactive power only is drawn from the capacitor bank C1, for a given magnet current cycle. This was calculated to be.

$$Vcapref\_noactive(t) \approx \sqrt{V_0^{\,2} - \frac{L}{C1}[\mathrm{Im}(t)^2 - I_0^{\,2}]}$$

V0, is the original capacitor bank voltage the capacitor is charged to, and in this case is 6000 volts. L is the magnet inductance, and is equal to half of the AGS inductance, which is 0.375 H. C1 is the capacitor bank value equal to 0.7 F. Im(t) is the magnet current as a function of time and I0 is the magnet current during the time of the front

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porch which is equal to around 300 A. VCap_actual in Figure 3, represents the actual voltage across the capacitor bank C1 during a magnet cycle. Pref is the average power losses reference, for a given super cycle of the magnet current. Pdraw is the average active power being drawn from the ac line for the same magnet cycle. Note that this loop, is the outer loop and it is slower than the inner loop. The time delay of this loop is 0.9 sec and the time delay of the inner loop is 0.1 sec. The objective of these two loops is to keep the average active power coming from the ac line constant, while the magnet current is being pulsed to about 25 MW peak power, and to keep the capacitor bank C1 charged to a voltage grater than the maximum magnet voltage for a given cycle.

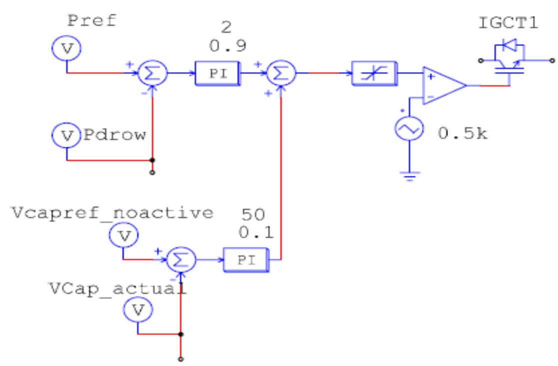

Figure 3: Buck converter control system

The second control system is used to control the magnet voltage and it is shown in Figure 4. In actuality a current loop should also be used as the outer loop, however for this simulation only the voltage loop was used. Verf represents the magnet voltage reference of station I for a given magnet current. Vmagnet represents the actual magnet voltage.

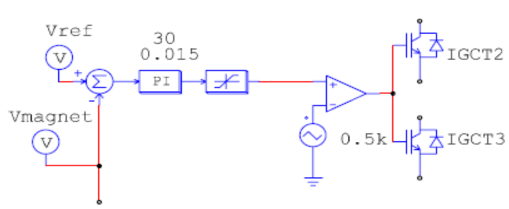

Figure 4: Two quadrant converter control system

It was calculated that, for a given magnet cycle, in order to keep the average in coming power constant, the capacitor bank voltage should follow the waveform of the following formula.

$$Vcap(t) \approx \sqrt{\frac{2}{C1}[Pam\times t+\frac{C1\times V_0^{\,2}-L\times[\mathrm{Im}(t)^2-I_0^{\,2}]}{2}-\int_0^t \mathrm{Im}(t)^2\times R\times dt]}$$

This waveform is shown in Figure 11. Note Vcap(t) from Figure 11 and VCAP from Figure 5 are the same, one was calculated the other was simulated. C1 is the capacitor bank capacitance, Pam is the average input power ,V0 is the cap bank peak voltage equal to 5750 volts, L is the load inductance equal to 0.375 H, R is the load resistance equal to 0.135 Ohms, Im(t) is the magnet current, I0 is the front porch current, equal to 300 Amps. This means that one could setup an independent loop to control the IGCT1 of the buck converter using as a voltage reference the above formula and voltage output the cap bank voltage. Doing this, the average incoming power should remain constant. This loop however was not simulated at this time.

SIMULATION RESULTS

The following results were observed after simulating the circuit of Figure 2. The magnet current, the magnet voltage and the capacitor bank voltage for a typical AGS cycle are shown in Figure 5. Figure 6 displays the capacitor bank C1 actual voltage (Vcap), the calculated Vcapref_noactive capacitor C1 voltage reference, for a given magnet current cycle, and the 12 pulse full wave bridge rectifier output voltage before the filter (Vps). Figure 7 displays the capacitor bank voltage and current. Figure 8 displays the calculated power reference (Pref), the active power draw from the line (WATTS-AC), and the reactive power draw from the line (VAR). Note that the active power draw fluctuations are not more than 100 KW. Also the reactive power is not more than 0.6 MVAR. Figure 9 displays the current provided by the 12 pulse rectifier into the cap bank (Isource), for the same magnet cycle. Figure 10 displays the peak magnet power and the average magnet power drawn from the ac line. Note that the peak magnet power is 20 MW, while the average input power remains constant around 2 MW.

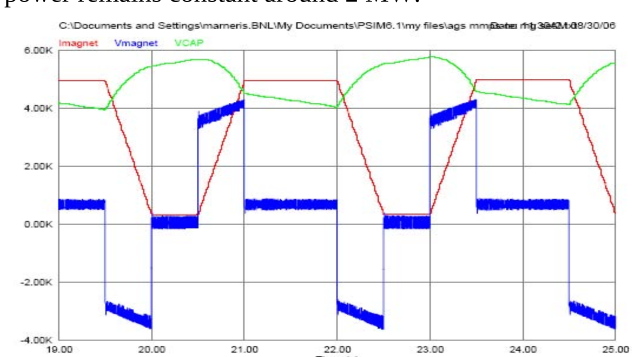

Figure 5: Magnet current, voltage and capacitor voltage

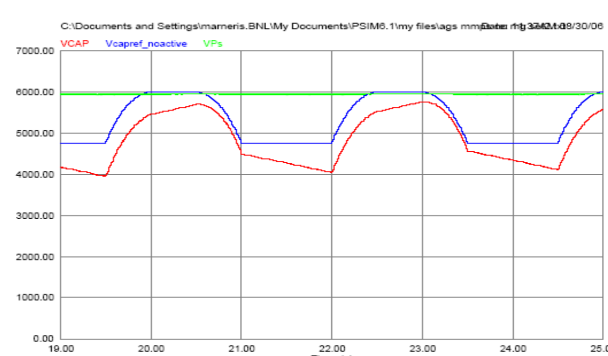

Figure 6: Capacitor and rectifier voltage waveforms

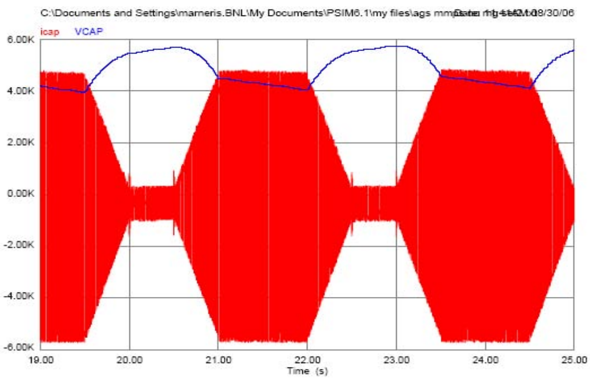

Figure 7: Capacitor voltage and current waveforms

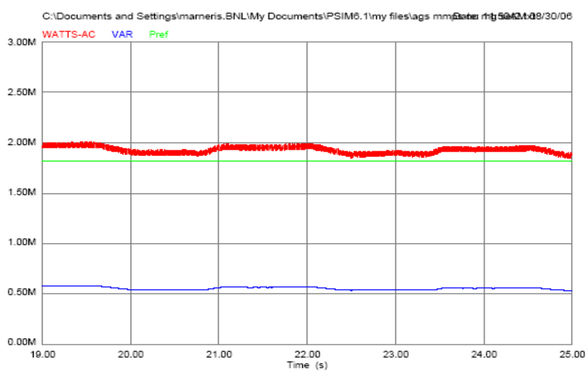

Figure 8:Real power, reactive and power reference

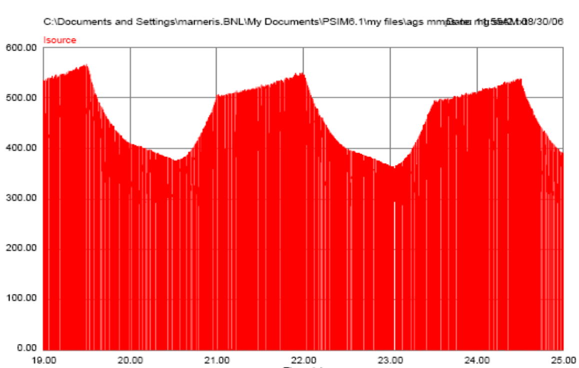

Figure 9:Rectifier dc current waveform

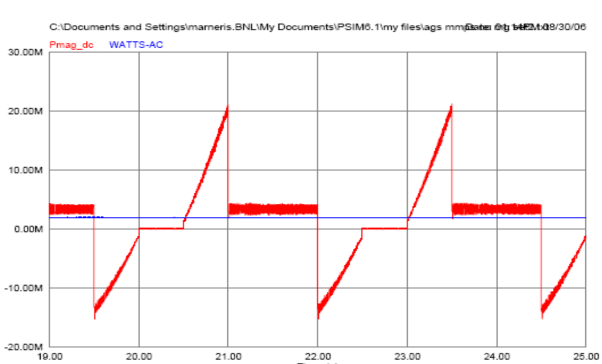

Figure 10:Average and pulsed power waveforms

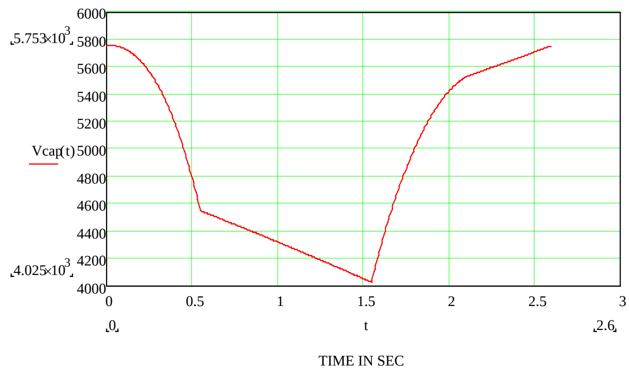

Figure 11: Calculated capacitor voltage waveform

CONCLUSION

It seems that based on the above simulation such a system may be possible, however we should address the following issues. We need to understand details of a 0.7 F, 12.6 MJ, 6000 V, 5000 A, capacitor bank and associated safety issues. 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 better 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. The 12 pulse rectifier should not be a problem. One needs a 6000 V, 800 A, dc rectifier.

It seems that we need to do a study with companies such as Siemens or ABB and understand better the complexity of the issues. We also need to understand in detail a cost estimate of such a system. We should be looking at these issues systematically, to be able to eventually have all the answers if we ever decide to take this approach.

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