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Commissioning of the new AGS MMPS transformers

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COMMISSIONING OF THE NEW AGS MMPS TRANSFORMERS

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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. During rectify and invert operation the P Bank power supplies are used. During the flattops the F Bank power supplies are used. The P Bank power supplies are fed from two 23 MVA transformers and the F Bank power supplies are fed from two 5.3 MVA transformers. The fundamental frequency of the F Bank power supplies is 1440 Hz, however the fundamental frequency of the P banks was 720 Hz. It was very important to reduce the ripple during rectify to improve polarized proton operations. For this reason and also because the original transformers were 45 years old we replaced these transformers with new ones and we made the fundamental frequency of both P and F banks 1440 Hz. This paper will highlight the major hurdles that were involved during the installation of the new transformers. It will present waveforms while running at different power levels up to 6MW full load. It will show the transition from the F-Bank power supplies to the P-Banks and also show the improvements in ripple made on the P-Bank power supplies.

DESCRIPTION OF THE NEW AGS MMPS TRANSFORMERS

Both F-Bank and P-Bank transformers are bi-filer winding transformer which were manufactured by Niagara transformers. The F-Bank transformers are rated at 5.3MVA/7500V on the primary and 1775A/431V on the secondary, while the P-Bank transformers are rated at 23MVA/7500V on the primary and 2288V/1451A on the secondary. The F-Bank transformer weighs approximately 76255 pounds including the type II mineral oil which has a volume of 3045 gallons. The P-Bank transformer weighs approximately 191460 pounds including the oil and contains approximately 7029 gallons of type II mineral oil. It should also be noted that the P-Bank transformers were not shipped with oil because they exceeded the Department of Transport weight limit and also would not be able to pass over the AGS ring due to the weight. The transformers are wound in an extended delta to a zig zag wye configuration. The primary windings are extended so that a phase shift of ±15°from the output of the Siemens generator can be obtained per transformer, see figure 1. The secondaries are zig zag wye to produce a phase shift of ±7.5° and ±22.5° from the primary. There are two secondary windings per transformer, Ua, Va, Wa, phase with Ub, Vb, Wb, connected to a module and Ua', Va', Wa', in phase with Ub', Vb', Wb' connected to another module. Figure 1 shows a vector diagram for an F-Bank transformer associated with modules 5 and 6. Here module 5 has a net phase shift of +7.5°, while module 6 has a net phase shift of -22.5° from the primary. The rest of the transformers have similar vector diagrams resulting in phase shifts per module from the primaries, shown in figure 2. Note that all transformer primaries are connected to the Siemens generator and rated at 7500V line to line.

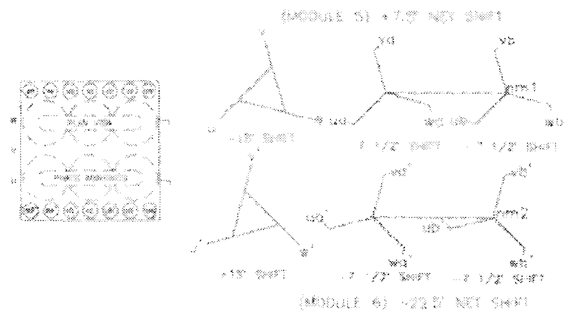

Figure 1. Station 1 F module 5 and 6 Transformer vector diagram

The P-Bank transformers have two tap settings, 50% and 100%. The F-Bank has four Tap setting, 50%, 80%, 90% and 100%. The normal operating tap settings for a polarize proton cycle is at 90% for the F-Bank and 100% for the P-Bank.

THEORY OF OPERATION

A 9MW Motor Generator manufactured by Siemens is used to supply power to the primary of the new AGS MMPS transformers as mentioned above. The thyristor controlled power supplies then pulse the main magnets up to 5MW peak electric power while the average incoming power to the motor is constant. The maximum power ever dissipated in the AGS magnets never exceeded 5MW. The AGS ring has a total inductance of 0.78 henries and a total resistance of 0.27ohms. The AGS MMPS is divided into two stations, each capable of delivering approximately +/-4500V and 5500A.

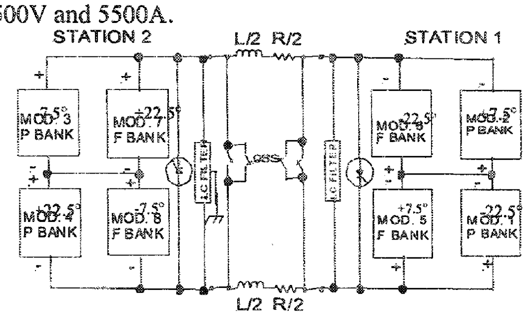

Figure 2. Block Diagram of the AGS MMPS

Figure 2 shows a block diagram of the AGS MMPS and how the two stations are connected to the AGS Ring. When the AGS MMPS is being pulsed, the F-Bank transformers and F-Bank modules are used at dwell and during the flat top while the P-Bank Transformers and P-Bank modules are used during rectify and invert only. A typical magnet current and voltage is shown in figure 3.

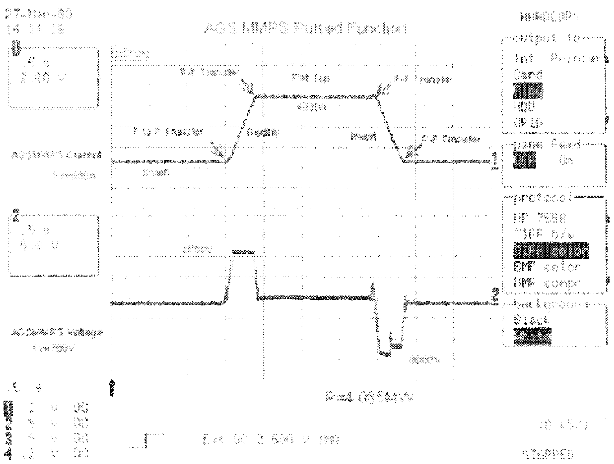

Figure 3. Voltage and Current waveforms of the AGS MMPS

The maximum rating of the ST1 and ST2 F-Banks is ±1900V at 5500A, while the maximum rating of ST1 and ST2 P-Banks is ±9000V at 5500A. The fundamental frequency of both F and P-Banks is 1440 Hz with the new transformer design. Note the P Bank used to be a 12 pulse rectifier with the old transformers.

IMPROVEMENTS MADE WITH THE NEW TRANSFORMERS

One of the reasons for the upgrade was to change the transformers because they were 45 years old and their reliability would degrade. Another fundamental reason was to improve the ripple during rectify to improve polarized proton operations. Using a spectrum analyzer, we were able to determine the peak voltage at various frequencies before and after installation of the new transformers. The results were measured after the passive filters for both station 1 and 2 from a polarized proton run cycle. The results can be seen in table 1. Comparing 720 Hz filtered magnet voltage from the old transformers to 1440 Hz filtered magnet voltage from the new transformers, there was an improvement by at least a factor of 10. Figure 4 shows the difference in ripple voltage before the passive filter, for the old 12 pulse P-Bank (720Hz) and the new 24 pulse P-Bank, (1440Hz). Comparing 720 Hz to 1440 Hz the ripple voltage before the filter was reduced by a factor of 2. Improvements were also made during the transfer from the F-Bank to the P-Bank by a factor of 1.5. Figure 5 displays station 1, 2 and the addition of station 1 plus 2 F-Bank to P-Bank transfers.

60HZ	*120HZ*	*360HZ*	*720HZ*	*1440HZ*
OLD	***OLD***	***OLD***	***OLD***	***OLD***
18.55 v-pk	28.94 v-pk	114.1 v-pk	171.3 v-pk	N/A
NEW	NEW	NEW	NEW	NEW
12.8 v-pk	15.6 v-pk	59.5 v-pk	14.6 v-pk	16.84 v-pk

Table 1. ST1+ST2 P-Bank ripple for Polarized Protons run cycle between the old and new transformers

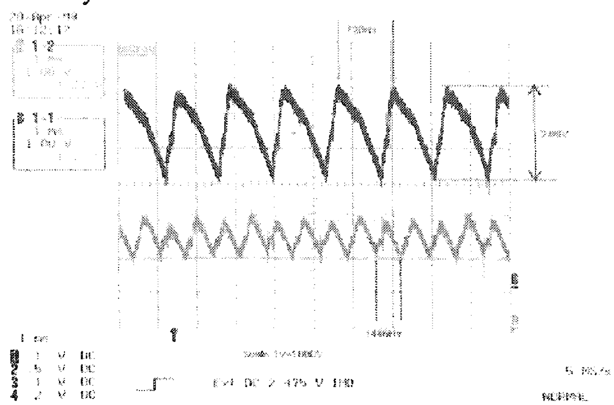

Figure 4. P-Bank ripple before the passive filter, during rectify, between the old and the new transformers

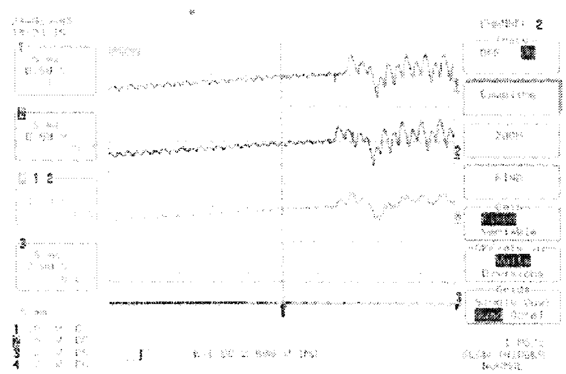

Figure 5. F-Bank to P-Bank transfer waveforms for station 1 and 2.

TESTING OF THE NEW AGS MMPS TRANSFORMERS

Upon receiving the transformers from Niagara, several tests were carried out in order to verify the manufacture specifications and also to verify the ones that were specified by Brookhaven. The first set of tests was to verify the turn's ratio and also the phase shift of the secondary with respect to the primary. In addition, the resistance was measured from phase to phase and from phase to neutral of both the secondaries and primaries. A tolerance of 0.1% was required for the phase shift specification. Once the transformers were connected, all connections were verified. The total resistance from the module SCR terminals to the transformers tabs were measured and compared to measurements made while the old transformers were in place. In the end, a Megger and High Potential, (Hipot), was performed to ensure there were no shorts to ground and no break downs occurred at high voltage. The primaries were meggered to ground at 5KV and Hipotted at 10KV for one minute while the secondaries were meggered at 2KV and Hipotted at 3KV for one minute. At turn on, we did not use the Motor Generator to supply the power to the primaries of the transformers initially; instead we used a small 2.2MVA transformer as a feeder. This was done to verify the proper phase shift and ensure the correct transformer turns ratio at all transformer taps. Later, we connected the AGS ring as a load and ran several cycles starting from low voltage low current to the maximum voltage and current rating of the 2.2MVA transformer. After verifying that the pressure and temperature of the transformers had not changed significantly, we decided to use the MG set as the power source to the transformers. Initially we did not use the AGS as a load. We slowly increased the generator voltage from 2000 volts to 7000 volts. We then stayed at 7000 volts with no load for 2 hours to ensure transformer proper operation. We then connected the AGS ring as a load and slowly increased the power levels in the motor from 2MW to 5MW. Finally we heat ran the power system at 5MW for two days.

PROJECT MANAGEMENT/SCHEDULING ISSUES

Initially when we started this project, it was projected to last for approximately 5 months after receiving the transformers from Niagara. Unfortunately, due to weather conditions, delayed parts, and structural redesign the project took two additional months to complete. One of main contributors for this delay was that the cable trays showed signs of deformation as they were being loaded. As a result, new bracings were required and additional parts were needed to strengthen the structure for both ST1 and ST2. A lot was learned by working on two identical stations, as several unnecessary steps were eliminated, thus resulting in tasks being completed at a much faster rate. For example, initially we scheduled two weeks to run the secondary cables for station 1, while the same task was completed in one week for station 2.

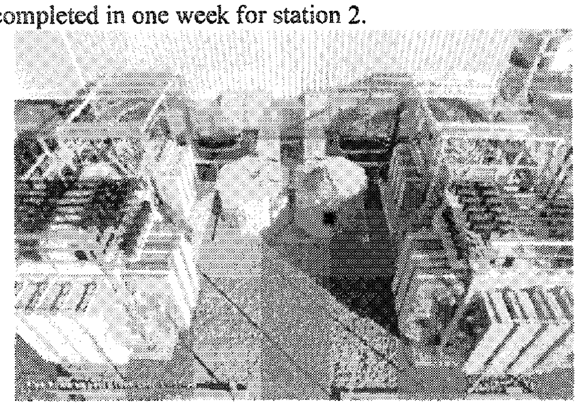

Figure 6. The New AGS MMPS Transformers

Figures 6 and 7 show the New AGS MMPS transformers. Throughout this entire project there were only two tasks that were completed by a contractor and that was laying the new concrete pads and filling the P-Bank transformers with oil. All the other tasks were completed by BNL personnel, and as such the work was managed in a more controllable fashion.

Figure 7. The New AGS MMPS Transformers

CONCLUSION

This was a very large project originally estimated to be completed in 5 months, however it took 7 months. This happened primarily because of cable tray and mechanical bus design issues. Extensive control and power testing during the commissioning resulted in a very successful operation. The idea of using a 2.2MVA transformer before energizing the new transformers from the generator was also very important to avoid any catastrophic failures. The AGS MMPS have been running with the new transformers for the past 5 months without any significant problems, and although the new transformers were very expensive to implement the overall improvements and performance greatly outweighs the cost.

ACKNOWLEDGMENTS

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