ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI056

A NUMBER OF UPGRADES ON RHIC POWER SUPPLY SYSTEM*

C. Mi[#], D. Bruno, A. Di Lieto, J. Drozd, G. Heppner, T. Nolan, F. Orsatti, T. Samms, J. Sandberg, C. Schulthesis, R. Zapasek
Collider-Accelerator Dept., Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

This year marks the 15th run for the Relativistic Heavy Ion Collider (RHIC). Operation of a reliable superconducting magnet power supply system is a key factor of an accelerator's performance. Over the past 15 of years, the RHIC power supply group has made many improvements to increase the machine availability and reduce failures. During these past 15 years of operating RHIC a lot of problems have been solved or addressed. In this paper some of the essential upgrades/improvements are discussed.

INTRODUCTION

There are 6 above ground service buildings and 18 underground tunnel alcoves in the RHIC complex [1]. All power supplies and support instruments are in these locations around the RHIC ring. During the operations, the goal for all of the power supplies is to operate 24/7 without failure over the entire run. To achieve this high reliability a continuous improvement of the power supplies was required to reduce the failures over the years.

MACHINE PERFORMANCE OVER THE PAST SIX RUNS

Run 15 will be 22 weeks long. At the midway point of Run 15, the Mean-Time-Between-Failure (MTBF) rate is approximately 60 hours. This is the highest MTBF the power supply system has achieved. The MTBF has been improving steadily since Run 12. (See Table 1 for comparison)

Table 1: MTBF and Failures Over the Past Six Runs

Run	9	10	11	12	13	14
MTBF (hours)	15.1	35.4	17.7	39.0	40.4	41.1
# of Failures	215	117	205	89	61	82

UPGRADES AND IMPROVEMENTS

The upgrades and improvements were made in many different areas. They include adding new Print Circuit Boards (PCBs) into existing system, replacing power components, rework, adding redundant signal cables in the existing system, developing a drop in replacement power supply system for one type of power supply, swapping out old, obsolete PCBs and components to lengthen the power supply lifetime. All of the upgrades improved the power supplies reliability.

Replacement of Bipolar 300A and Bipolar 150A Power Supply

RHIC was commissioned in 1999. All of the original power supplies are still installed in the ring. Some of them are very reliable but some types have had more failures than other types. Some power supply types are easier to service than others due to the way they were packaged. Because of the serviceability issues, failures and aging a new replacement power supply is being installed.

Figure 1: 3 Kepco 10-100GL Units In Parallel.

There are a total 96 bipolar 150A model power supplies and 14 bipolar 300A model power supplies that are used in the RHIC superconducting power supply system. They are distributed in 6 service buildings. The topology of these power supplies is 3 phase AC input, full-bridge switch-mode pre-regulator with a linear output stage. The 150A model is the base unit and the 300A model is basically two 150A units paralleled to make a 300A unit. Due to the space constraints in the buildings, the packaging of these power supplies is extremely tight. The tight packaging of these power supplies means it is difficult to service them when a problem occurs.

*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.
#cmi@bnl.gov

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI056

Therefore, a new replacement power supply will be installed.

Based on requirements at various locations, we have power supplies that operate between +/-100A, +/-150A and +/-300A. We have chosen a Kepco 10-100GL model [2] as the base unit for this work. This model can be used as single power supply that operates at +/-100A and also can be paralleled up to a maximum of 4 units. This model allowed us to select how many supplies we need to parallel. For under +/-100A load requirement, we only use a single unit to power a magnet; for under +/-150A load requirement, we parallel 2 of these models etc. (See Figure 1 for 3 units in parallel connection)

Another solution is using a unipolar DC power supply as DC source and an h-bridge amplifier as bipolar output stage to provide the bipolar output. The prototype unit is tested successfully. And first article unit is building at this time.

Redundant Wiring Modification

It was discovered that the bipolar 150A and 300A model power supplies had a number of critical feedback connections which would open causing the power supply to operate incorrectly. This would cause the collider to stop running. In order to prevent this from happening, it was decided to "hard wire" or solder wires across these critical connections. Once the power supply was modified with these redundant wires the critical connections could not open up and now the collider could run much more reliably.

Off Trip Problems and its Solution

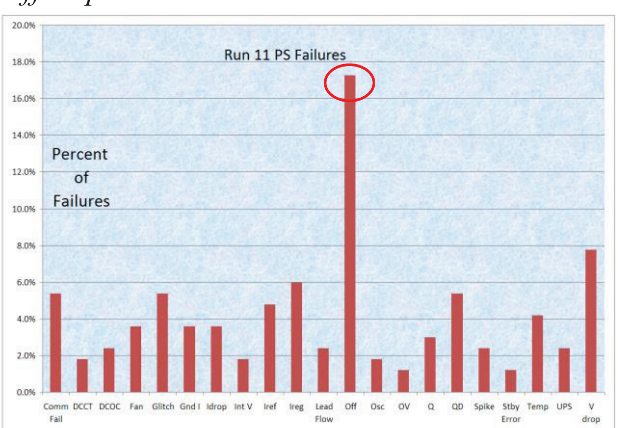

Figure 2: Run 11 Power Supply Failures.

A power supply tripping to the OFF state has been a common problem for all the RHIC runs up until Run 12. [3] Off trip means that the power supply loses control power which cause the voltage and current to drop out. In turn this can cause the beam to be lost or cause other power supplies to trip to a fault state. This is frustrating because after the power supply trips to the off state the power supply can be turned back on most of the time with no sign of any problem. There are 3 possible reasons for this off trip problem. One reason is bad connections from the low level DC supply to the microcontroller on the control card. The second reason is that a remote OFF command (pulse) as small as 1µs could trip the p.s. to the OFF state. The third and most important reason for this off trip problem is that the voltage from the DC supply that feeds the microcontroller, on the control card, was very close to the minimum valve required to power the microcontroller. If there was any low AC voltage on the line input it could cause the microcontroller to shut off and come back on again. Even without an AC voltage drop the microcontroller could shut off.

The main corrective action to fix this off trip problem was a redundant PS Board that was designed, prototyped, tested and installed in all service building and alcove power supplies. The redundant PS board supplies both +5V and +12V DC to the control card if the built in housekeeping power supply's +5V and +12V drop out intermittently. The redundant power supply print circuit board was installed before run 12. Comparing power supply OFF trips between Run 11 and 12 in Figure 2 and 3, it can be seen that the OFF trip failures went to zero in run 12 after the installation of the redundant power supply board.

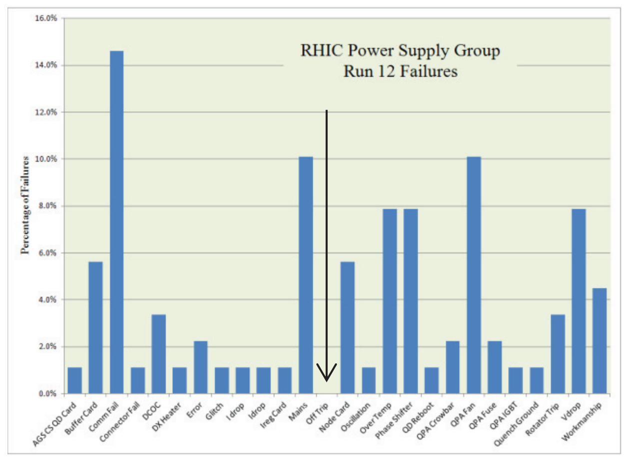

Figure 3: Run 12 Power Supply Failures.

Consolidate Print Circuit Boards (PCBs)

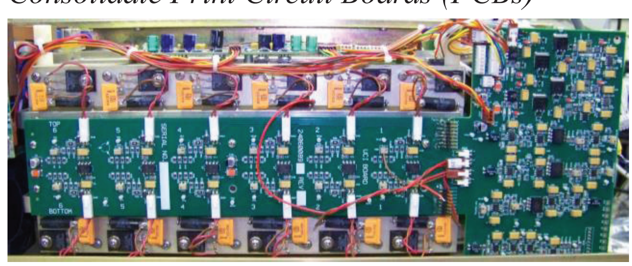

Figure 4: New PCB Installed to Replace Old 3 PCBs in Same Location.

The bipolar 150A/300A model power supplies have many PC boards installed by the original manufacturer. Three critical PC boards are internally connected by box style connectors. A newly designed circuit board, was designed which replaced these 3 critical PC boards. Now the 3 PC boards were consolidated into one PC board (Figure 4). In doing so the original 3 PC board inter-board connections (which were unreliable) were abandoned and are now internal traces on the new board which offers a

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI056

much higher level of reliability. Furthermore, the newly designed circuit board replaces all obsolete parts, and added new ground planes to provide noise immunity. Replacing these 3 original PC boards with one board has increased the reliability of this type power supply.

Dual Resistor Shunt Modification

Another problem that occurred with the bipolar 150A/300A model power supplies is that the FET shunt resistors were running at high temperature causing the FET fuses to overheat and sometimes fail. Dual shunt resistors were added to these model power supplies, consequently the shunt resistors would run cooler which means FET fuses would be cooler.

Soft Start Thermistor Modification

The existing bipolar 150A/300A model power supply soft start circuit has a 10Ω fixed resistor in the IGBT circuit. If the IGBT were to open the 10Ω resistor would be running continuously (instead of just being on for a short duration). This resistor can overheat and open causing the power supply circuit breaker to trip the next time the contactor closes. A Thermistor was added in place of the fixed resistor. If the IGBT were to open, the thermistor would provide 10Ω of soft start resistance, and then drop to low resistance, if the IGBT failed to close. The power dissipation of the thermistor is insignificant during normal operation. Therefore the supply could continue to run with less chance of failure. A LEM circuit was also added so the current of this new soft start circuit could be monitored if desired.

Rework of the 6kA Quench Switch Silicon Controlled Rectifiers (SCRs)

In RHIC, there are a large number of SCRs used in many different areas. Besides using SCRs in the power supplies, SCRs are also used as semiconductor switches for the 6kA quench protection switch assemblies. The purpose of this quench switch is to remove the stored energy from the series-connected string of main dipole magnets in order to protect the superconducting magnets, buses and diodes from overheating. The SCR switches consist of six SCRs in parallel. The SCRs are normally conducting when there is current on the magnets. To insure balanced current sharing between SCRs, a current sharing shunt resistor is in series with each SCR. It is very important that currents are sharing equally during normal operation condition so none of the SCRs are overloaded with too much current.

After 10 years of continuous operation, the current sharing became unstable and one of the quench switches tripped on an overcurrent condition more than once because the current sharing was inadequately. After internal discussions and external discussions with industrial experts the decision was made to re-work the entire group of quench switch SCRs. These SCR assemblies were reworked by an external company. The shunt connections and resistor connections were reworked internally. The SCR assemblies were all tested after installation. After the rework the SCR current sharing was greatly improved and much more stable. No overcurrent has occurred since the rework.

SCR Gate Drive Board Issue

SCR Gate Drive boards are used in many of the RHIC Unipolar SCR supplies. Some gate drive boards have had some channels failed because a specific capacitor shorts. This can sometimes cause the on-board transformer to fail also. This will cause the p.s. output ripple to be incorrect because it will be missing SCR pulses if some gate drive channels are absent. The boards were re-worked by replacing this capacitor with a capacitor that had a much higher pulsed voltage rating. Almost half of these unipolar power supplies in RHIC have had their gate drive boards re-worked.

Obsolete PCBs and Components

Over the years, electronic components are becoming obsolete. Certain components are getting difficult to order as spares or as replacement parts. Maintaining a reasonable spare parts inventory sometimes becomes difficult too. It was decided to replace PC boards that have given us the most problems. These are the new pc boards that were designed over the years: Current regulator card, unipolar voltage regulator card, DCCT board, bipolar DCOC board, control chassis backplane and general purpose isolation amplifier board etc.

CONCLUSION

A number of upgrades and improvements have been discussed this paper. Significant machine improvement has been observed over the past 6 to 7 years as a result of continuous upgrades.

ACKNOWLEDGMENT

The authors would like to thank everyone from RHIC power supply group. This project represents our excellent team work. With everyone's participation, we have shown that our system availability can be improved significantly with thoughtful consideration and implementation. Special thanks go to Richard Kruz, Mitch De La Vergne, Donald Gosline, Erik Rydout, Oluwafemi Bamgbose, Richard Negron, Brian Karpin and Jeff Wilke.

REFERENCES

[1] RHIC Configuration Manual (Magnet Electrical System Section), http://www.c-ad.bnl.gov/Accel/RCM_TOC.htm
[2] Kepco Power Supply 1KW User Manual, Kepco Inc. http://www.kepcopower.com/bophi.htm
[3] RHIC Retreat Website, https://indico.bnl.gov/categoryDisplay.py?categId=40