

# RHIC POWER SUPPLIES: LESSONS LEARNED FROM THE 1999 – 2001 RHIC RUNS\*

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## Abstract

The Relativistic Heavy Ion Collider (RHIC) was commissioned in 1999 and 2000. The two RHIC rings require a total of 933 power supplies (PSs) to supply currents to highly inductive superconducting magnets. These units function as 4 main PSs, 237 insertion region (IR) PSs, 24 sextupole PSs, 24 Gamma-T PSs, 8 snake PSs, 16 spin rotator PSs, and 620 correction PSs. PS reliability in this type of machine is of utmost importance because the IR PSs are nested within other IR PSs, and these are all nested within the main PSs. This means if any main or IR PS trips off due to a PS fault or quench indication, then all the IR and main PSs in that ring must follow. When this happens, the Quench Protection Assemblies (QPA's) for each unit disconnects the PSs from the circuit and absorb the stored energy in the magnets. Commissioning these power supplies and QPA's was and still is a learning experience. A summary of the major problems encountered during these first three RHIC runs will be presented along with solutions.

## 1 INTRODUCTION

The idea behind this paper is not to merely list detailed problems and solutions but to give an overview of the major problems and how they can be avoided the next time. Some detailed problems will be given but they will be used mostly as examples. Of course not all problems can be avoided completely but the more that are tackled up front then the less you have to deal with when the machine is running.

## 2 MANUFACTURING PROBLEMS

### 2.1 Some P.S. Manufacturer Problems

Dealing with manufacturers of the power supplies, at their facility, is where a lot of the problems you encounter can be taken care of up front.

- PSs, from the unipolar IR PS manufacturer, were very dependable when it came to the power components such as the transformers, chokes, and SCR's but the electronics they designed gave us no end of grief. We had problems with their voltage regulator card, firing card and DCCT electronics.
- The unipolar IR PS manufacturer also, had a problem with the way they energized the main contactor with a solid-state relay. This gave us problems because they did not place an MOV across the solid-state relay. A chattering main contactor would result.

- Some other problems encountered with the unipolar IR PS manufacturer were loose bus connections and mis-wiring to the isolation amplifier board.
- The bipolar PS manufacturer that was chosen needed to be shown how to design parts of the PSs. correctly. You should be worried about this manufacturer from the start but you may not have a choice because he may be the lowest bidder.
- The bipolar PS manufacturer was also very, very late with the PSs because of the small facility they had and limited experience with building these PSs.

### 2.2 Some P.S. Manufacturer Solutions

- For any manufacturer, closer monitoring at the facility would have helped solve many of these problems. Some of these problems could have been avoided if someone was up at the manufacturer watching a lot more of the manufacturing process and watching a lot more of the testing that was taking place.
- Choosing a manufacturer that is close also helps because it is easier to make more trips, even unscheduled ones.
- Also, with the unipolar IR PS manufacturer, if we had looked into the history of their electronics we would have seen they were not very dependable in this area. This could be difficult to do. Asking other people who have used their power supplies is a good way to gauge what kind of problems we might have had with their electronics. The other way to avoid this is to use manufacturers of firing cards and DCCT's (or whatever electronics it may be) that are known to be dependable and at the top of their field. You can also design some of the electronics yourself. This is helpful because all the cards are the same.
- Testing. It would have been great if the manufacturer would be able to provide a load, which is as close as possible to the real load. This would bring out a lot of problems that you wouldn't see until you get onto the real load. A burn in that lasts as long as 24 hours is a very good thing but sometimes not enough. Now the whole Power supply (PS) cannot be put into an environmental chamber but the electronics can and running those electronics with variations in temperature and humidity would have brought out a lot of problems for us much earlier.
- Always be suspicious of anything designed from scratch specifically for your PS Always check that standards are being met, such as the proper spacing for pins for a 208VAC connection.

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- Use connections which are very reliable and don't fail if they are removed and replaced many times.

### 2.3 Some QPA Manufacturer Problems

- One of the biggest problems we had with the QPA's in the beginning were these QPA fan faults that were not real. The fans were working but the wrong type of switch was used. An AC switch was used instead of a DC switch, the wrong type of air vane was used and one problem we still have is that these switches are not sealed. Since we do not have the cleanest PS buildings we find that over time dust, dirt and moisture gets into the switches and they have to be removed and replaced because the contacts in the switch get dirty.
- Another problem we had with the QPA's were the transformers on the controller cards. These were mounted on the PC board. After the PC board was finished the manufacturer cleaned the boards off with water, which went into the transformers, and over time they started to fail. All of the transformers were replaced.
- These QPA's contain IGBT's. The IGBT's have IGBT driver cards, which the manufacturer designed. When there was an AC power dip one of the chips on this card would fail. The card was re-designed so this would not happen anymore.

### 2.4 Some QPA Manufacturer Solutions

Once again closer monitoring of the manufacturer could help catch more of these problems but not all. The transformers being contaminated by water someone may have seen if they were there more often. However, some of the design issues are usually left up to the manufacturer, such as, buying the right type of switch or designing an IGBT driver card correctly. It is difficult to catch all of these design problems when something as custom as this is being made. Looking at all aspects of the design in greater detail and asking a lot of questions about the design may have caught some more of these problems, if you have the time and the people. These problems cost the machine a lot of downtime and they have almost all been fixed. We are still looking at replacing the switches with sealed types. A burn in for an extended period of time might have also caught a lot of these problems.

## 3 SYSTEM INTEGRATION PROBLEMS

### 3.1 PLC/Node Card/Fiber Optic Interface Card

In order to test these power supplies locally the control system must be up and running and you need a laptop or a terminal nearby to send commands from. The commands are OFF, STANDBY, ON or RESET. These start from the Front End Computer (FEC) go to the PLC and then to a node card, which distributes the commands to as many as 12 different power supplies. The fiber optic interface card

receives its signal from waveform generators, which reside in the FEC and then convert this signal to an analog signal to run the PSs up in current. There has been many times where one could not test the PSs. locally because the control system was down. There should be a way of just going up to a PS and plugging in one connector and controlling the whole PS from a laptop computer without any dependence on the control system. This would have saved a lot of time. If this did exist it would still be difficult to use in a p.s. setup that exists in RHIC because of something called the quench link. Since many of the PSs are nested, those nested PSs must all trip off if there is a p.s. fault or a magnet quench. Testing PSs individually still requires the quench detection system to be up to protect the magnets and the PSs. However, there are some PSs that are not nested and those could be tested locally without being as dependent on the control system.

### 3.2 Software Level Diagnostic Tools

In a nested p.s. system like this the more tools you have for determining what caused the quench link to drop the better off you are. Having these tools as early as possible also helps tremendously. We did not have all of these at the beginning and that made finding problems much more difficult and time consuming. Here are some of the tools, which we do use now:

- There is a page called a Quench Summary page, which tells you which building drops first when the main quench link drops. We did have this tool during the first run.
- There is a new tool called a Timing Resolver. After you have determined what building dropped the link first, the Timing Resolver will tell you what brought the link down first in the building you are looking at.
- There is something called a Post Mortem viewer. This saves all of the analog PSs setpoint, current, voltage and error signals for 3 seconds before a quench link trip and 1 second after this trip. Using this you can often determine which p.s. caused the link to drop in the building first. This tool also helps in troubleshooting the problem. This data is saved at 720Hz.
- There is a tool called snapshot, which is used for PSs on and off the main link. This gets triggered on any p.s. fault and saves the same four waveforms to look at for troubleshooting purposes. It saves the data for a longer period of time at 30Hz. There is not as much detail here as the 720Hz data but you have a much longer time span you are looking at.
- There is a tool called snapramp, which stores all of the ramps for all of the PSs. This allows you to see how the p.s. is performing while ramping. It also allows you to compare ramps from one p.s. to another p.s.
- There is a tool called BARHSOW, which also saves the ramps of the PSs, and this allows you to compare many different ramps of the same p.s.

- There is a tool called PSCOMPARE, which calculates the difference between whatever analog signals you select and they can also be compared against the wfg signal that is sent to the p.s.
- There is an Alarm Log as well which gives you the history of the p.s. faults
- There is something called QDPLOT which is associated with the quench detector and the magnet voltage taps and the p.s. current signals. This is used to determine if a magnet has quenched. This has been made more user friendly by sending information on which magnet has quenched to a Real Quench page that anyone can read.
- There is a page called PSALL that allows you to look at all of the RHIC PSs in both rings by building or p.s. type.
- The procedure for bringing the main quench link up, before the PSs are even turned on, is not simple and takes a long time when done manually. Only an expert was able to do this. Now programs have been written to do all of these steps automatically. They are still being improved upon.

#### 4 TESTING

Testing at the manufacturers facility is very important and the more that is done the better. However, once we received the PSs it was even more important to run the PSs on the real load and in real building (environmental) conditions for at least two months. Just determining what time constants were needed for the unipolar nested IR PSs, and installing these time constants, took about 2 weeks. They were not optimized at the time and we are still going back and doing this today. Many problems were encountered because we were learning about all of the new p.s. problems and we were trying to integrate the PSs into the whole system, which was brand new. This system integration included not only p.s.' but also QPA's, the quench detection system (quench link), waveform generators, fiber optic interface cards, an MADC (analog readback) system, and a NODE CARD to PLC system for p.s. controls. These are the main ones but problems were found with each and every one of these systems, some of which we are still trying to correct 4 years later. Not all of them are big problems but they still need to be dealt with. Having people available from all of the different groups while this testing is going on is also a big help. Extended burn in times is a high priority test and even turning off and on the circuit breaker feeding the equipment while the equipment is running is a good idea to see how well the equipment survives. This would simulate power failures.

#### 5 SUPPORT

During the construction phase there were a limited number of engineers and technicians. Some of these engineers and technicians stayed on during normal operations and they were the ones that would keep the power supplies running at first. This needed to change and it slowly is changing. At first only the engineers could fix

the problems because they did not know what the problems were. After learning what the major problems were the technicians would be called in to fix the problems with or sometimes without the engineers. The next step was to write procedures and train the support people on shift 24 hours a day to make the repairs, if they were routine, and after consulting with the engineer. This has been a slow process but it is happening. During this last run a lot of progress has been made and the support people on shift have been making a lot of the more of the routine repairs after consulting with the engineer. Then again a lot of the major problems have been fixed so the workers on shift have not had as many problems to deal with. Many procedures have been written to assist with these repairs. A web page for the collider electrical ps. group has been developed so anyone can get to these procedures and any other documentation that deals with the PSs or QPAs. The web page for the Collider Electrical PS Group is <http://www.c-ad.bnl.gov/ceps/default.htm>.

#### 6 DOCUMENTATION

Documentation of existing PSs, QPA's or whatever is being used in the system is very important not only to the engineer but almost more important to people who are not familiar with the equipment. If you are responsible for a piece of equipment and you go on vacation then someone else must know where the documentation is to fix it and the documentation must exist, in a readable format.

Documentation of each and every problem that creates machine downtime must also be done and this in itself can be a full time job. From this documentation many of our major shutdown lists get generated to fix the problems that cost the machine downtime. A philosophy of documenting, and understanding each and every fault must be followed so that all problems that exist can be accounted for and fixed. This will lead to an improvement in machine reliability

#### 7 CONCLUSION

There are many things that can be done the second time around to reduce the number of problems we had when we commissioned and ran the RHIC PSs and QPA's but without the time and the people it would still be very difficult. That is why it is so important to choose the right manufacturer for the job, pay close attention to their design and do as much testing as you can at their facility.

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