EFFICIENCY, POWER LOSS, AND POWER FACTOR MEASUREMENT OF QUADRUPOLE MAGNET POWER SUPPLIES AT THE SPALLATION NEUTRON SOURCE

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Abstract

- The linear accelerator (LINAC) quadrupole magnets are powered by 42 silicon-controlled rectifier (SCR) based power supplies at the Spallation Neutron Source (SNS) facility of Oak Ridge National Laboratory.
- These 35V, 525A power supplies are bulky, inefficient and require both air and water cooling. The reliability of the SNS facility is impacted due to water leaks internal to power supplies and current readback issues associated with their unique control system interface, resulting in multiple downtime events.
- To mitigate this problem, off-the-shelf switch mode power supplies (SMPS) are proposed. These SMPS are air-cooled, more efficient, and more compact owing to their high switching speeds.

Power supply issues

- There are a total of 511 power supplies in the SNS. The Medium Energy Beam Transport (MEBT), the Coupled Cavity LINAC (CCL), and the Superconducting LINAC (SCL) have 14, 8, and 39 quadrupole magnet power sup-plies, respectively.
- The quadrupole magnets are powered by silicon-controlled rectifier power supplies (SCR PS) which are bulky in size(16 U), inefficient, and require both air and water cooling.
- The power supplies utilize a unique power supply interface (PSI) which has current readback issues. The measured current drifts arbitrarily from its setpoint, occasionally exceeding the threshold and tripping the power supply and disabling beam in the LINAC.

Introduction

- The Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory (ORNL) is an accelerator-based pulsed neutron source facility.
- The ion source at the front end of the SNS produces negatively charged hydrogen ions which travel through the LINAC to the accumulator rings, ultimately extracted to a mercury target to produce neutrons.
- The dc power supplies in the LINAC supply constant current to the magnets which helps to focus the beam. The quadrupole power supplies play a vital role in the overall functioning of the SNS facility as failure of one of the power supplies would prevent beam from focusing and result in beam losses in the LINAC.

New LINAC power supply

- The SNS upgraded the MEBT portion of the LINAC with a standard off-the-shelf SMPS in 2018. Since initial installation, these power supplies and their controls have been extremely reliable and experienced no failures. The SMPS has many advantages when compared to the SCR PS.

SCR PS	SMPS
Large in size (16U). Weighs approx. 500 lbs.	Small in size (3U). Weighs approx. 85 lbs.
Additional control box (PSI) is required. Readback issues of PSI.	No PSI needed. It has serial interface. No readback issues.
Air and water cooled.	Completely air cooled.
Efficiency of 75% = Higher power losses.	Efficiency of 81% = Lower power losses.
pf = 0.22.	pf = 0.77.
Stability of 0.57%.	Stability of 0.07%.

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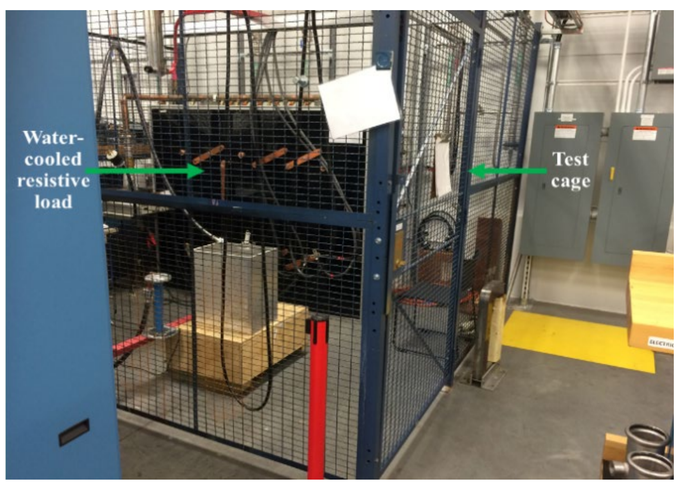
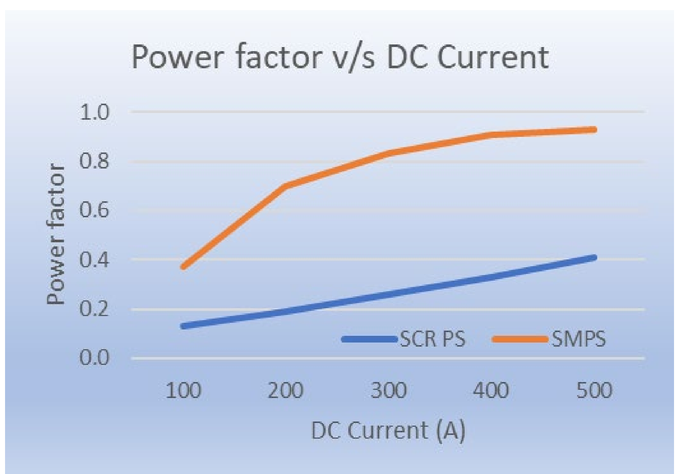
Experimental Results

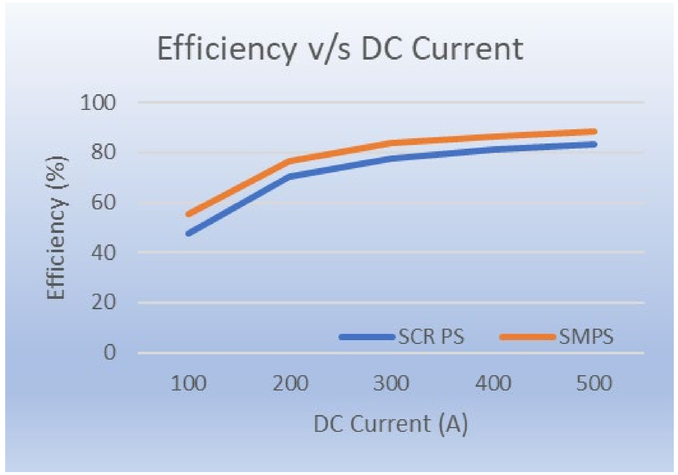
- Both SMPS and SCR PS were installed on a test stand with a high-power water-cooled resistive load inside a protective cage as shown in the figure below. This was done to test the viability of the proposed SMPS.



- The power factor was also measured using the power quality analyzer.
- As the current setpoint increases and reaches close to its full-scale value, the power factor of the SMPS also increases.
- From the figure we can see that the power factor of the SMPS is much better than the SCR PS.



- The efficiency was calculated as a percentage by dividing the output power (Po) by input power (Pin). Po was calculated by multiplying Vdc and Idc. Pin was measured using a power quality analyzer.
- The adjacent figure shows the efficiencies of both SMPS and SCR PS. As we can see, the SMPS is slightly more efficient than the SCR PS because of its topology and efficient semiconductor switches.



- Another requirement in a quadrupole magnet power supply is stability.
- The mean, minimum, maximum, and standard deviation were measured with the help of an oscilloscope.
- The stability which is the coefficient of variation was calculated by dividing the standard deviation by the mean.
- From Table 3, we can see that the SMPS has better stability.

Parameter	SMPS	SCR PS
Measured value	501.5 A	537.1 A
Mean value	501.1 A	536.6 A
Minimum value	499.6 A	527.1 A
Maximum value	502.9 A	552.1 A
Std. deviation	0.34	3.05
Stability	**0.07 %**	**0.57 %**

Conclusion & ongoing work

- A new standard SMPS was proposed as a replacement for the SCR PS.
- Both SMPS and SCR PS were tested under similar conditions, with SMPS exhibiting better efficiency, higher power factor, lower power losses and greater stability.
- Due to its various advantages, the SMPS is considered as a viable option for replacement of the SCR PS.
- A campaign to replace several power supplies during scheduled outages is currently underway. 9 power supplies were replaced recently and 12 more are set to be replaced in the summer of 2021.
- Completion of replacement of the remaining 26 SCR PS are expected by fall of 2022.