Convection Cooled Bridges Offer New Solution to Old Alterrex Water-Cooled Bridges

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Abstract: *The Alterrex generator excitation system was the product of choice from the 1970s through the 1980s. The Alterrex design included an ac rotating exciter whose ac output was connected to stationary water-cooled rectifier bridges located in a doghouse at the end of the turbine generator. Each three phase rectifier bank was rated for 1600 amps with multiple bridges in parallel to match the generator rotor field requirements. See Figure 1. Bridge redundancy was provided in the event of failed power semiconductors or water leaks that could otherwise cause a forced outage. Today, 40 years later, water-cooled bridges are experiencing repeated plumbing issues as worn copper tubing, joint elbows, and Teflon hoses are troubled with bothersome water leaks. An EPRI Report dated 12/19/2002, "Alterrex Cooling Leak Survey Results" identified numerous water leak incidents, and the "Frequency of leaks has increased with Service Time." "and in fact …leaks have occurred since early in many of our units' service histories".*

The Exelon Power Mountain Creek Generating Station in Dallas, Texas, is one of many plants faced with continuing repair and the decision of replacing the existing water cooled Alterrex bridges. This paper describes the decision process that was involved in the actual bridge replacement, the testing, the install and the commissioning of the new system.

I. Introduction

Mountain Creek Unit # 8 is rated for 583 MW, 22 kV, 3600 RPM with rotor field requirements of 4600 Amps. Over the years, the Alterrex water cooled bridges developed recurring water leaks which required repair by removing the bridge from the doghouse. The existing system consists of four (4) water cooled bridges, two on each side of the generator doghouse. See Figure 1. Each bridge consists of 12 rectifier hockey pucks mounted on a heatsink and supplied with snubber circuits that are water cooled via copper and Teflon tubing that carries deionized water from the stator cooling reservoir.

Figure 1. Old Water-Cooled Bridges

Each bridge contains a "No Load Break Disconnect" switch and a neon light panel to display any fail diode within the bridge. The disconnect switch provided the means to remove the ailing bridge from the system for repair. Where the OEM instruction manual suggests not opening the rectifier switch while the system is operating, it is common practice in most systems to open the switch with the bridge in operation.

II. The Problem

On the Southeast corner of the generator doghouse, a major leak on the water cooled rectifier bank was occurring, resulting in 20 drops per second. Operations had isolated the bank and taken it out of service. Since the system is a N+1 design, one out of four rectifier banks could be removed from service. Yet, there was one more water leak on the Southwest corner rectifier bank. The concern was that if the leak got worse like the Southeast leaking bridge, a total of two banks would be out of service, and that would require a derating of the machine MW output. Figure 2 shows corrosion track across the diode from the leaking water.

The OEM did not recommend fixing these water leaks in the field. They recommended removing the bridge and sending the leaking bridges to a licensed service shop that could repair and provide turnaround. The estimate was a six-week effort while an upcoming outage allowed for only one week in the Spring of 2008.

Figure 2. Corrosion tracking of leaking water

The existing “Knife Disconnect Switch” was also a concern. The existing 5 Pole Disconnect Knife Switch did not provide equal tension on the disconnecting AC and dc bus. Some "switch poles" will disconnect sooner than others, causing a hanging up condition, and for some plants, the switch has trouble even opening at all. Figure 3 is an infrared picture of the Nuclear Power Plant dis-connect switch, which also illustrates different spot temperatures on the current carrying switch. Note the temperature varies from 138˚F on one end to 226˚F on the other side of the knife switch. With continuing maintenance and repair being an issue, the decision was made to replace the existing water cooled bridges and disconnect switches for new hardware.

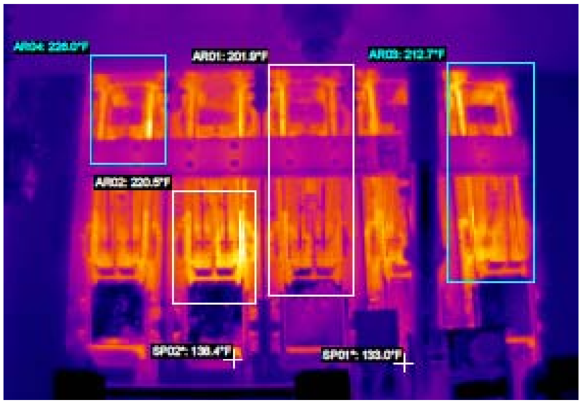

Figure 3. Temperature Readings of the Knife Disconnect Switch at Nuclear Plant in U.S

III. New Design Evaluation

Where a new alternative water-cooled bridge system was an option, it still required deionized water from the stator cooling system just as the existing system. The objective was to eliminate all maintenance and avoid any downtime associated with future bridge design. The Basler Electric Company air-cooled bridges are designed for convection cooling that required no external mechanical or liquidify cooling. Referencing Figure 4, the new air cooled bridge system is a three phase fullwave bridge consisting of just six 5380 ampere average current carrying diodes with a RC snubber circuit around each diode. The diode has a Peak Reverse Voltage of 2800 V. See Table 1 [Ref 1]. Three power fuses with fail indicators on each fuse are included. Two dc current shunts are provided, one for measuring the positive leg current and the other for measuring the negative leg dc current so current can be monitored, one for the Alarm Display Panel Meter and the other shunt for a remote meter. Six RTDS are wired to a terminal block that can be used to monitor temperature via a RTD relay provided with each new rectifier bank, or the RTDs can be wired to a DCS. A new disconnect switch is shown with status indication via an aux contact along with a kirk key interlock.

The new bridge and disconnect switch design reuses the existing mounting holes of the original OEM bridge, so that it would be a drop-in replacement. Unlike the original bridge rating of 1600 amps, the new convection-cooled bridge has a rating of 2000 amperes, which offers a very conservative design to ensure long and reliable life with up to a 250% overload thermal capacity for 30 seconds. Figure 5 represents heat run data and highlights the temperature rise on the new convection cooled bridge based upon a 54˚C ambient temperature. Depending upon the actual operating current of the bridge rectifier, the temperature rise can vary anywhere from 51˚C for a single operating bridge of 1100 amps to 71˚C rise above a 54˚C ambient for a single operating bridge of 1400 amps. Note in Figure 5 that the temperature rise at 2000 amps is 103˚C, demonstrating significant margins regardless of operating current that uses only ambient air and the natural air flow around the rectifier bridge compartment for cooling. It was noted that Mountain Creek #8 system has non-vented doors, so all air flow comes from within the generator doghouse

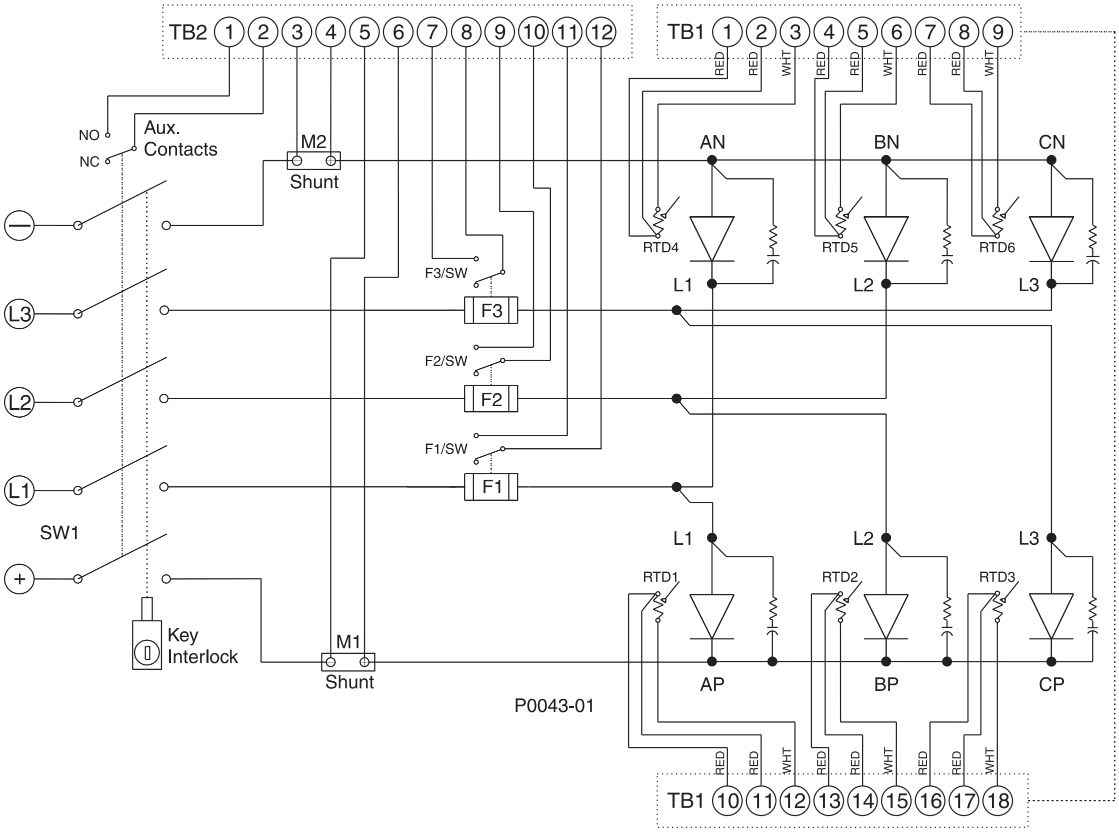

Figure 4. Schematic of New Convection-Cooled Bridge

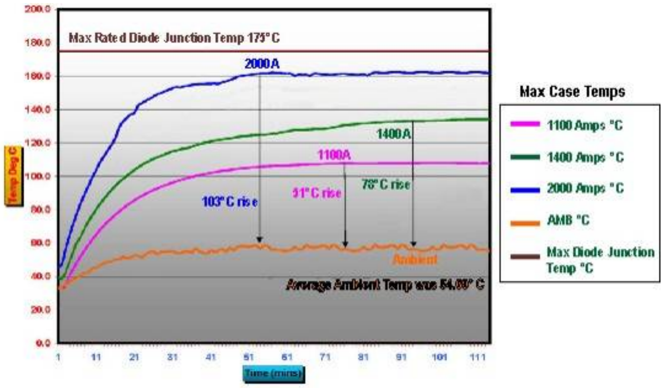

Figure 5. Temperature rise at Various Current Levels of a Single Bridge in Parallel with other Rectifier Bridges

The new 5 pole disconnect switch design offered a bolt action type design that ensures equal pressure on all stabs during switch closing operation; if the disconnect switch were opened, equal tension would be ensured unlike the binding that could occur with the original knife switch operation. Three poles are provided for the three (3) phase input and two poles for the F+, F- connection to the field. AC Input and DC Output both opened at the same time in one switch operation.

The new switch is bus bar connected to the existing horizontal bus via links. To keep the system electrically safe, the new disconnect switch has a clear plastic shield that keeps the operator from touching any potentially hot areas on the disconnect switch when the rectifier door panel is open. The new Disconnect Switch is designed as an actual “Load Break Interrupter” that was fully tested to ensure that it could break 2000 amperes .

Other concerns today involve opening the disconnect switch in an exposed high voltage area. Here, the new Basler system allows for opening the disconnect switch with the rectifier panel door closed. An extension of the disconnect switch handle allows for it to be fed through the front door, one for each rectifier bridge. Hence, it provides a safer barrier of separation between the operator and the disconnect switch. The new disconnect switch also includes a Kirk Key Switch interlock to lock out the switch should it be opened.

RTDs are embedded “into” the double insulated extruded heatsinks to monitor temperature of the conducting diodes. The RTDs are connected to an RTD relay with a 5000 V Teflon patented insulator design, six for each rectifier bridge. Three power fuses, one for each phase is I_2^t coordinated with the power semiconductors to fail before the diode, and a RC snubber circuit for the ac input is supplied.

An alarm display panel is provided for each rectifier bank that includes an ammeter to monitor rectifier bridge current, a RTD lamp to alarm bridge over temperature and three lamps, one for each phase to illuminate should a power semiconductor short and fail a fuse. Last, there is a lamp that indicates whether the disconnect switch is open or closed.

Table 1. Electrical Data Characteristics

DC RATING	**Bridge Voltage rating**
• 2000 Amps continuous, natural convection cooled	• 0-600 VAC
Diode Rectification	**Five Pole Line/Load Disconnect Switch (Optional)**
• General purpose disk (puck) type silicon diodes	• New drop-in replacement provided
• Diodes are compressed between aluminum heatsinks, offering double-sided heat transfer.	• Full load break capability
• Diode average current: 5380 A	• Continuous rated at 2000 Amps, 1000 Volts AC and DC
• Diode repetitive peak forward and reverse blocking voltage: 2800 V	• Lab certified tested, opened under full load with two switches in parallel
• I_2^t for fusing: 20.34 x 106 A2 sec	• Extended through the door handle for operation of switch outside "doghouse" enclosure
• High surge current (IFSM): 70kA	• Standard Kirk key lockout and auxiliary contact provided
• Maximum junction temperature: 175˚C, less demand for cooling	
• Silicon wafer diameter: 78mm	**R/C Snubbers**
• Quantity supplied per bridge: 6	• Capacitors: 2100 VAC, 0.22μF, Oil filled industrial
	• Resistors: 250Ω, 55 Watt
Diode Clamp	**Fuses**
• Double insulated	• Qty 3 semiconductor fuses with blown fuse indicators
• Tested to 10kV Isolation	• Fuse Voltage rating: 1000 VAC
• Provides a double failsafe mode	• Fuse Amperage rating: 2400 AMP
• Built-in force indicators	• Selected to clear before the diodes short.
Designed Ambient: 50˚C	**Control Terminal Strips**
• Convection cooled, no fans	• NT style - 1000 Volt rating
• High reliability due to robustness of convection-cooled design	• Terminal connections for individual RTDs and blown fuse indicators
Overload Rating	**Thermal Detection**
• 250% overload for 30 seconds	• Teflon body, patented design, Resistance Temperature Detectors (RTD), strategically located near each diode junction
	• Supplied as standard
	•More accurate and faster temperature reading

IV. Solution

The evaluation involved corresponding with a number of end users who purchased replacement bridges to obtain their feedback and review site data of recorded RTD temperature data of the bridges where it was available [2]. The decision was made that the best solution was the new Basler Electric Company convection cooled bridges. The delivery lead time of the bridges was 6 weeks that coordinated with the outage schedule. Prior to shipment, the bridges were heat run tested at the factory for 2000 amperes until the temperature stabilized after approximately two (2) hours. The test applied full rated current at a reduced voltage to all four (4) bridges connected in parallel. See Figure 6. The importance of this test was to provide confidence in the bridges operating at the rated current, since Mountain Creek Unit #8 would not be at full capacity until a much later time in summer peak load season after the outage. Table 2 provides a sample of the starting temperature and final temperature of one of the tested rectifier bridges. Besides the full current capacity test, oscilloscope waveform information was gathered to verify that the diode bridge was at 100% conduction. Data shows 2.8 ms between each peak for a three phase full wave bridge. See Figure 7.

Figure 6. Test Setup of 2000 Ampere Heat Run

Table 2. Heat Run Data of one of the 2000 Ampere Bridges

Thermocouple Locations ▶		AP Phase A Positive Heatsink	AN Phase A Negative Heatsink	BP Phase B Positive Heatsink	BN Phase B Negative Heatsink	CP Phase C Positive Heatsink	CN Phase C Negative Heatsink	Ambient Top of Unit
Date	Time	CH 1 Deg. C	CH2 Deg. C	CH3 Deg. C	CH4 Deg. C	CH5 Deg. C	CH6 Deg. C	CH7 Deg. C
02/06	07:21:10	20.1	20.1	20.1	19.9	20.1	20.0	19.6
02/06	09:55:10	87.0	90.7	88.5	91.4	94.7	98.7	23.1

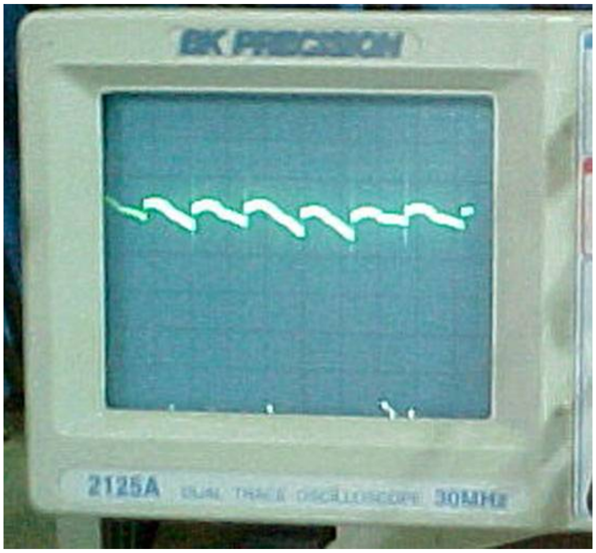

Figure 7. Three Phase Full Wave Bridge Output Waveform

The new bridges were received with a certified test report from the manufacturer. The outage lasted for 7 days, and a four-man team from a local electrical contractor was assigned for the tearout and install of the new bridges. The demolition began on Saturday; it took one day to remove the copper water lines, the rectifier bridges, knife switches, and to cap the incoming water lines. The resultant demolition was a huge pile of fuses, bridges, and switches as space was prepared for the new hardware. The tearout was fast and expedient. See Figure 8 for sample of removed hardware.

Figure 8. Old disconnect switch and fuses removed

Figure 9 shows a photograph of the Stator and Alterrex deionized water cooling system. The new convection cooled Alterrex bridges eliminated the need for water lines going to the Alterrex doghouse located at the back of the generator housing. The "In" and "Out" water lines going to the Alterrex bridges were abandoned and capped, hence eliminating maintenance issues involving false field grounds and leaky water hoses. The results of these changes were improved reliability and reduced downtime.

Since water was no longer required for the new convection cooled bridges, the water cooling system provided increased availability of deionized water for the generator stator cooling system.

Figure 9. Generator Stator and Cooling Water System, Alterrex "In" and "Out" water lines are capped for retrofit to new Convection Cooled 2000 Amp Bridge System.

Shortly after the demolition was complete, the installation of the new convection cooled bridges and new switches commenced. The drop-in air cooled bridges were located into the same mounting holes as the previous bridges. The new disconnect switch mounted above the new rectifier bridge using the same mountings as the previous hardware. A shipped-loose symmetrical three phase snubber circuit consisting of three power resistors and three industrial grade oil filled capacitors connected across the each power diode. The snubber circuit provided a means to eliminate switching harmonics caused by diode commutation.

At time of installation, it was decided to have additional indication of the semiconductor fuse monitor and RTD relay. Here, four (4) relays were added, one for each fuse lamp indicator, one for the RTD relay and one for the disconnect switch disposition. Since the panel to contain this requirement was decided at time of install, two days were spent creating the panel and wiring it into the available space. See Figure 10.

Figure 10. Temperature Relays and Remote Annunciation

Figure 11. New Bolt Action Disconnect Switch and Convection Cooled Bridge

With the new bridges and disconnect switches installed, bus bar links were customized to tie the horizontal bus to the new connecting disconnect switch. One day was used for bus bar measurements, and the next day the links were fabricated. See Figure 12. A new clear plastic shield was provided as a cover for live electrical parts. See Figure 13.

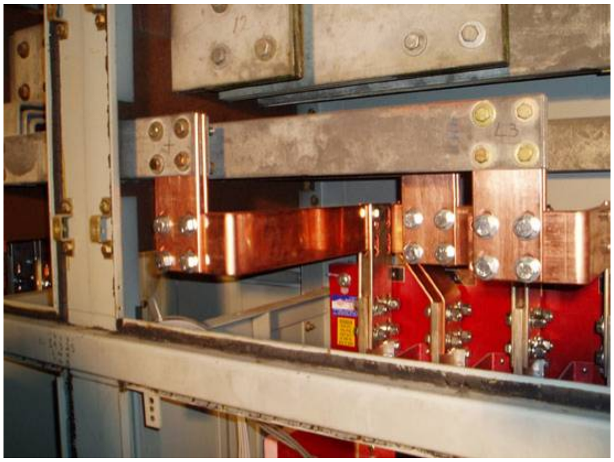

Figure 12. New Bus Bar Links for Connection between Disconnect Switch and Existing Bus

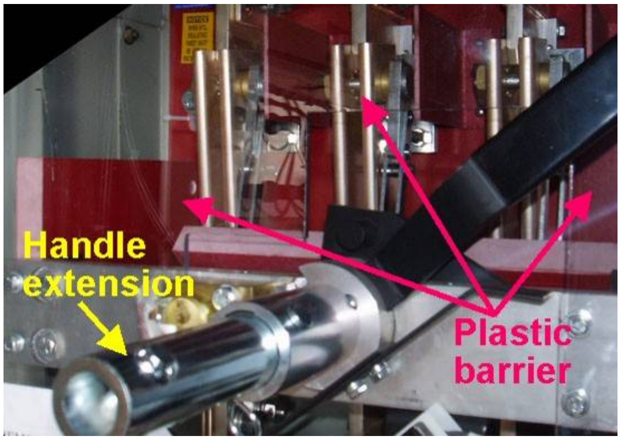

Figure 13. New Clear Plastic Operator Protective Shield over Disconnect Switch and Extended Shaft Coupling

To allow the new disconnect switch to be opened with the door closed, a center hole was drilled using a template measurement scale. See Figure 14.

Figure 14. Center Hole for Outside Disconnect Switch drilled by local electrical contractor Technician Shermco Industries

A new Alarm Panel was installed for the front of each enclosure door which included an Ammeter, three (3) status lights for fail semiconductor fuse indication, One lamp for High Temperature Alarm, and one lamp for Disconnect Switch Status. See Figure 15.

Figure 15. Display Alarm Panel and Hand Disconnect Switch

By Friday, the seventh day, the install was complete and testing verification of the installed rectifier bridges began. Bolt torques were tested on all the new connections based upon a provided chart. A micro ohmmeter (DLRO) was used to determine conductivity of each bolt connection. See Table 3. Note the micro ohm meter registered a maximum of 29 micro ohms.

Table 3.

	Switch Stabs, in micro ohms				
Bridge #	+VC	A	B	C	-VC
1 (NE)	23.2	22.7	21.3	26	22.2
2 (SE)	26.9	24.7	22.5	27.6	23.9
3 (NW)	27.3	22.9	20.5	28.4	24.3
4 (SW)	28.8	25.3	24.3	29	26.3

The new disconnect switches were tested for proper open and closed operation. A three phase variac was applied into each bridge ac input with a power resistor as a burden across each bridge output to verify full-wave rectification at the output.

On Saturday, the eighth day of the outage, the install was complete and the equipment was released back to the plant. See Figure 16. After Unit #8 was released, some time later full load operation occurred, and the RTD relays were calibrated, based upon collected operating temperature of the bridges. Final calibration for the RTD relays was set for 125˚C temperature. Any higher temperature would alarm, indicating excessive bridge thermal conductivity. Figures 15 and 16 show front views of the “Extended outside handle for the “Disconnect Switch Operation” with the front panel meter display.

Figure 16. System Line-up of the SW Panels with Rectifier Panel Doors Closed

V. Observation

Creating bus bar links to transition between the disconnect switch and the horizontal bus slowed the project. Today, the bus bar links are part of the disconnect switch assembly, so it will no longer require a custom fabrication at the job site, saving installation time. See Figure 17.

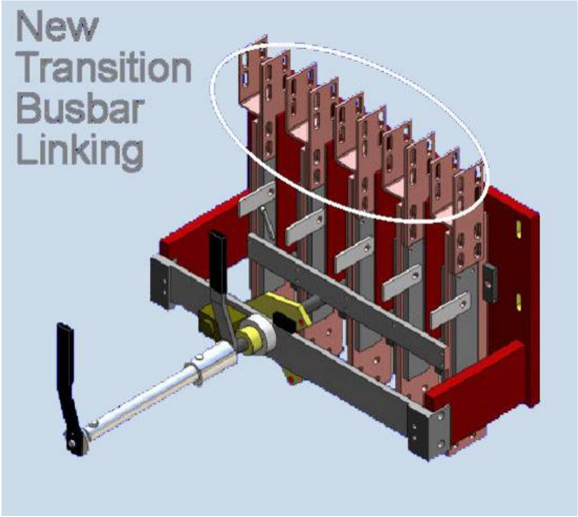

Figure 17. New Disconnect Switch with Connecting Links now provide for easier installation. No special on-site customization required.

A Factory Heat Run of the four (4) bridges at 2000 amperes can be valuable for those machines that may not be reaching full capacity for many months after install. Here, confidence in the project can be fulfilled by a factory certified test run.

Additional relay alarm contacts were added at the job site to meet site specific requirements. For future projects, this panel could be prewired and ready for installation.

VI. Performance Data

Figures 18 and 19 highlight performance data of Mountain Creek #8 SW Bank #4 operating at full load Rated Power Factor on one of the four rectifier bridges. In Figure 17, the rectifier current for each of the four bridges is 760 A DC, where the maximum rating of each bridge is 2000 A DC. Referencing back to Figure 5 temperature data graph, where a bridge is operating at approximately 800 Amps, the expected total temperature of the bridge would be about 90 degrees C for a 50 degrees C ambient temperature. Note in Figure 19 how closely the actual temperature being measured correlates with the expected performance goals for Figure 5.

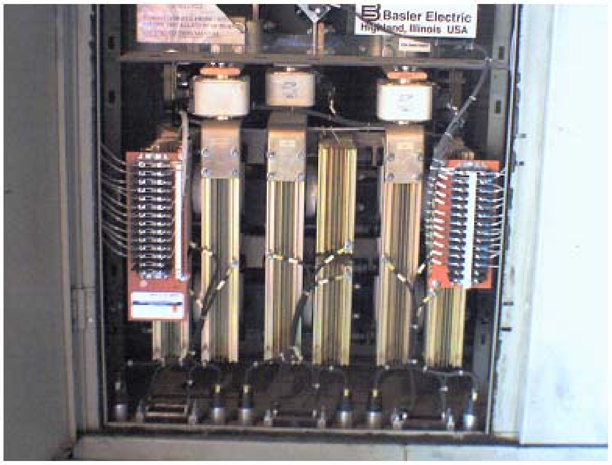

Figure 18. Rectifier Bank SW Bank # 4 operating at 760 A DC (Max Rating of 2000A)

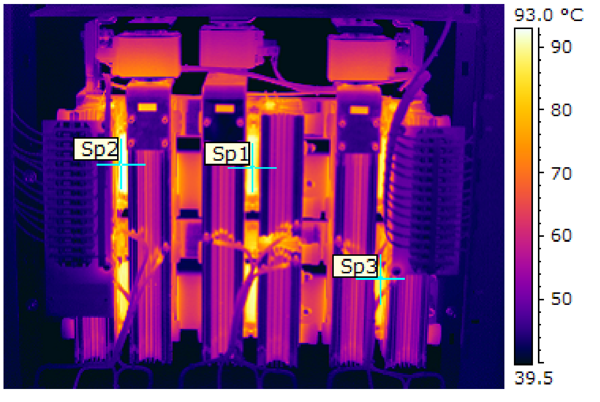

Figure 19. Rectifier Bank SW Bank # 4 operating at 760 A DC (Max Rating of 2000A) showing heat sink temperatures for each phase (1-2-3)

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Sp1 Temperature	90.5 °C (194.9 °F)
Sp2 Temperature	92.5 °C (198.5 °F)
Sp3 Temperature	87.5 °C (189.5 °F)

VII. Conclusion

The project was completed on time, seven days after initiation. Since the install in March of 2008, the plant has been up to full load and the equipment has demonstrated successful operation. Plant personnel are pleased with the new equipment that eliminates the hassles and issues of the water cooled bridges.

References

[1] *Retrofit Solutions for Alterrex Main Field Stationary Bridge,* Application Note, Basler Electric, January 2006.

[2] *Sandow Power Plant Installs "Drop In" Convection-Cooled Rectifier Bridges for Existing Alterrex Water-Cooled Bridges,* Application Note, Basler Electric, January 2007.

Authors’ Biographies

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