CONSTRUCTION OF A SOLID-STATE
2500 ADC REVERSING SWITCH

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July 5, 1979

GENERAL

This note describes the construction of a solid-state 2500 A reversing switch using one SCR per leg. Larger SCRs which are now commercially available, make it possible to construct reversing switches up to about 2500 A, without paralleling SCRs. Parallel SCRs, in dc applications, require current balancing resistors. Sometimes cables can be used for this. These resistors increase the power losses in a 2500 A switch at full current by about 5 kW. Using one SCR per leg reduces cost, size and complexity. It also allows the "standard proton control" for 250 Aadc and 1500 Aadc solid-state reversing switches to be used with the 2500 A switch. It appears, from my experience with experimental area reversing requirements, that 2500 Aadc is a useful size. Practically all our reversing switches operate at 2500 Aadc or less (e. g. BM-109 magnet).

Up to now we have used 5000 Aadc mechanical reversing switches for 2500 A installations. The 5000 A mechanical reversing switch costs about $4,000 more and is costlier to install. It requires rigging for installation and 480 V power for operation. The advantage of the mechanical reversing switches is that they require no water cooling and are practically loss free.

The solid-state reversing switch has a decided advantage in areas where space is at a premium. They can be easily mounted on top of a magnet or on a wall.

Cost, size, and ease of moving make the solid-state 2500 Aadc reversing switch attractive for use in experimental areas.

A data sheet describing the 2500 Aadc reversing switch and some test results are attached.
DATA SHEET
2500 Adc Reversing Switch

1. Switch Rating and Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>2500 Adc</td>
</tr>
<tr>
<td>Voltage</td>
<td>800 Vdc</td>
</tr>
<tr>
<td>Losses</td>
<td>7.5 kW at 2500 A</td>
</tr>
<tr>
<td>Voltage Drop</td>
<td>3 V Total at 2500 A</td>
</tr>
<tr>
<td>Cooling</td>
<td>Water</td>
</tr>
<tr>
<td>Flow</td>
<td>2 GPM Minimum</td>
</tr>
<tr>
<td>Pressure Drop</td>
<td>~5 psi at 2 GPM</td>
</tr>
<tr>
<td>Max Inlet Temperature</td>
<td>38°C (100°F)</td>
</tr>
<tr>
<td>Cooling Hose</td>
<td>1/2&quot; ID</td>
</tr>
<tr>
<td>Switch Dimensions</td>
<td>31&quot; x 16&quot; x 15&quot; H</td>
</tr>
<tr>
<td>Weight</td>
<td>~100 lbs.</td>
</tr>
<tr>
<td>Terminals</td>
<td>Use 6 x 500 MCM per Terminal</td>
</tr>
<tr>
<td>Cost</td>
<td>~$2300 (1979 cost based on material purchase for 2½ switches)</td>
</tr>
<tr>
<td>Control</td>
<td>Remote, not included in cost and size</td>
</tr>
</tbody>
</table>

2. Design Data

- GE C782 PN (1800 V_{DRM})
- 7000 ± 1000 lbs.
- Thermal Associates TA#C-2478
- PSI #9020-10, Fingertight plus one full turn for 8000 lbs.

Double-Side Cooling

- \( R_{\theta JC} = 0.012 \) °C/Watt (Junction to Case)
- \( R_{\theta CS} = 0.005 \) °C/Watt (Case to Sink)
- \( R_{\theta SW} = 0.0045 \) °C/Watt (at 1 GPM)
- \( R_{\theta JW} = 0.0215 \) °C/Watt
Each SCR forward drop at 2500 Adc is 1.5 V.
Each SCR loss is $1.5 \times 2500 = 3750$ W.
Junction temperature rise $0.0215 \times 3750 = 80.6^\circ C$
Maximum inlet water temperature $= 38^\circ C (100^\circ F)$
Temperature rise of water from inlet via sinks at SCR #1B arriving at SCR #1A:
\[
\begin{align*}
\text{Temperature rise of water} &= \frac{3.75 \text{ kW} \times 4^\circ C}{2 \text{ GPM}} \\
&= 7.5^\circ C
\end{align*}
\]
Maximum Junction Temperature $126.1^\circ C$
Allowable Junction Operating Temperature, $T_j$ $= 125^\circ C$ Max.
Maximum sink temperature $3.750 \times 0.0045 + 38 + 7.5 = 62.4^\circ C$
Use $80^\circ C$ Klixon for overtemperature protection
Pressure drop of 6 sinks in series at 2 GPM $\sim 3.7$ psi.

3. Test Data
The switch was run at each tabulated load current for about 15 minutes after which the measurements were taken. The accuracy of the temperature measurements is estimated at $\pm 4^\circ F$.

The switch diagram sketched below shows the test set up:

2500 Adc Reversing Switch
## Tabulation of Measurement

<table>
<thead>
<tr>
<th></th>
<th>SCR 1A and 1B On</th>
<th>SCR 2A and 2B On</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1500 A</td>
<td>2000 A</td>
</tr>
<tr>
<td>Water In psi</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Water Out psi</td>
<td>9 to 10</td>
<td>9 to 10</td>
</tr>
<tr>
<td>Water Flow GPM</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>*Water In oF</td>
<td>66/67</td>
<td>66.5/67</td>
</tr>
<tr>
<td>*Water Out oF</td>
<td>80/80</td>
<td>85.5/86</td>
</tr>
<tr>
<td>**Sink 1b, 2b oF</td>
<td>86/86</td>
<td>93/94</td>
</tr>
<tr>
<td>**Sink 1b/2b oF</td>
<td>88/82</td>
<td>97/88</td>
</tr>
<tr>
<td>**Sink 1a/2a oF</td>
<td>93/84</td>
<td>101/90</td>
</tr>
<tr>
<td>**Sink 1a, 2a oF</td>
<td>87/86</td>
<td>93/91</td>
</tr>
<tr>
<td>***Forward Drop 1A/</td>
<td>1.167/1.173</td>
<td>1.252/1.239</td>
</tr>
<tr>
<td>Volt 2A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>***Forward Drop 1B/</td>
<td>1.226/1.247</td>
<td>1.306/1.325</td>
</tr>
<tr>
<td>2B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Measured on outside of supply and return pipe.

**Measured at a side of the heat sink.

***Includes 10 mV SCR-to-sink drop at each pole at 2500 Adc. Voltage measured from sink-to-sink.
4. Conclusion About the Tests

4.1 The highest observed sink temperature is \(105^\circ F\) which results in \(105 + (100-68) = 137^\circ F\) or \(58.3^\circ C\) with \(100^\circ F\) maximum inlet water temperature. The installation of an \(80^\circ C \pm 5^\circ C\) klixon at the center sink is a good choice for overtemperature (loss of cooling) protection.

4.2 We can roughly check the thermal impedance \(R_{SW}\) from sink to water.

Choose column 2A, 2B On, 2500 A.
Losses are \(2500 \times (1.312 + 1.413) = 6812\) Watts.
Water flow is 2 GPM.
Water temperature rise is \(25^\circ F\) \((13.9^\circ C)\).
The average sink temperature is:
\[
105+94+96+100 \over 4 = 98.75^\circ F.
\]
The average cooling water temperature is:
\[
68+93 \over 2 = 80.5^\circ F.
\]
The average \(\Delta T\) sink-to-water is:
\[
98.75-80.5 = 18.25^\circ F \ (10.14^\circ C).
\]
Thus, 4 sinks dissipating 6812 watt rise 10.14\(^\circ C\) above the cooling water temperature at 2 GPM.
We will define \(R_{SW}^{(1)}\) as the thermal impedance from one sink-to-water.
For 4 parallel sinks we find:
\[
R_{SW}^{(1)} = \frac{10.14}{6812} = 0.00149^\circ C/Watt.
\]
Two sinks are used for double-side cooling. Thus, for double-side cooling we find:
\[
R_{SW}^{(2)} = \frac{R_{SW}^{(1)}}{2} = 0.003^\circ C/W \ at \ 2 \ GPM.
\]
This value is about 66\% of the design value of \(R_{SW}^{(2)} = 0.0045^\circ C/Watt\) at 1 GPM. Cooling at 2 GPM should be more effective. Increasing the flow substantially
beyond 2 GPM does not affect the junction operating
temperature much, since the sum of \((R_{JC} + R_{CS})\) is
constant and about 6 times as large as \(R_{SW}\) at 2 GPM.
From the data we may conclude that cooling is adequate
for continuous operation at 2500 Adc and 2 GPM flow with
100°F water.

5. Acknowledgement
R. Innes and W. Jaskierny assembled the switch, the
test set up and performed the tests. They did a good job.