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CONSTRUCTION OF A SOLID-STATE 2500 ADC REVERSING SWITCH

A. T. Visser

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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 Adc and 1500 Adc solid-state reversing switches to be used with the 2500 A switch. It appears, from my experience with experimental area reversing requirements, that 2500 Adc is a useful size. Practically all our reversing switches operate at 2500 Adc or less (e. g. BM-109 magnet).

Up to now we have used 5000 Adc 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 Adc reversing switch attractive for use in experimental areas.

A data sheet describing the 2500 Adc reversing switch and some test results are attached.

DATA SHEET

2500 Adc Reversing Switch

1. Switch Rating and Data

Current	-	2500 Adc
Voltage	-	800 Vdc
Losses	-	7.5 kW at 2500 A
Voltage Drop	-	3 V Total at 2500 A
Cooling	-	Water
Flow	-	2 GPM Minimum
Pressure Drop	-	~5 psi at 2 GPM
Max Inlet Temperature	-	$38^{\circ}C$ ($100^{\circ}F$)
Cooling Hose	-	1/2" ID
Switch Dimensions	-	31" x 16" x 15" H
Weight	-	~100 lbs.
Terminals	-	Use 6 x 500 MCM per Terminal
Cost	-	~$2300 (1979 cost based on material purchase for 2½ switches)
Control	-	Remote, not included in cost and size

2. Design Data

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

Double-Side Cooling

SCR	$R_{\theta JC}$	=	0.012	°C/Watt	(Junction to Case)
SCR/Sink	$R_{\theta CS}$	=	0.005	"	(Case to Sink)
Sink/Water	$R_{\theta SW}$	=	0.0045	"	(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 x 2500 = 3750 W.

Junction temperature rise 0.0215 x 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 $\left.\right\}$ $\frac{3.75\ \text{kW} \times 4^{\circ}\text{C}}{2\ \text{GPM}}$	=	7.5 $^{\circ}$C
Maximum Junction Temperature		126.1 $^{\circ}$C
Allowable Junction Operating Temperature, T_j	=	125 $^{\circ}$C Max.
Maximum sink temperature 3.750x0.0045+38+7.5	=	62.4 $^{\circ}$C

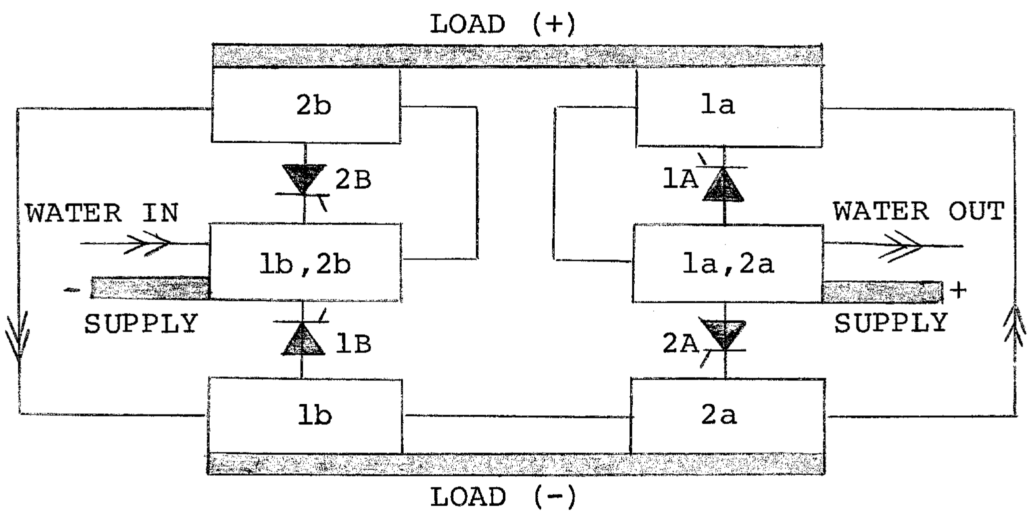
Use 80 $^{\circ}$C Klixon for overtemperature protection

Pressure drop of 6 sinks in series at 2 GPM ~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 ±4 $^{\circ}$F.

The switch diagram sketched below shows the test set up:



2500 Adc Reversing Switch

Tabulation of Measurement

		SCR 1A and 1B On / SCR 2A and 2B On		
		1500 A	2000 A	2500 A
Water In	psi	14	14	14
Water Out	psi	9 to 10	9 to 10	9 to 10
Water Flow	GPM	2	2	2
*Water In	°F	66/67	66.5/67	68/68
*Water Out	°F	80/80	85.5/86	93/93
**Sink 1b, 2b	°F	86/86	93/94	102/105
**Sink 1b/2b	°F	88/82	97/88	104/94
**Sink 1a/2a	°F	93/84	101/90	111/96
**Sink 1a, 2a	°F	87/86	93/91	98/100
***Forward Drop Volt	1A/2A	1.167/1.173	1.252/1.239	1.325/1.312
***Forward Drop	1B/2B	1.226/1.247	1.306/1.325	1.385/1.413

*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°F which results in 105 + (100-68) = 137°F or 58.3°C with 100°F maximum inlet water temperature. The installation of an 80°C ± 5°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 $R_{\theta SW}$ from sink to water.

Choose column 2A, 2B On, 2500 A.

Losses are 2500 x (1.312 + 1.413) = 6812 Watts.

Water flow is 2 GPM.

Water temperature rise is 25°F (13.9°C).

The average sink temperature is:

$$\frac{105+94+96+100}{4} = 98.75^{\circ}F.$$

The average cooling water temperature is:

$$\frac{68+93}{2} = 80.5^{\circ}F.$$

The average ΔT 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°C above the cooling water temperature at 2 GPM.

We will define $R^{(1)}_{\theta SW}$ as the thermal impedance from one sink-to-water.

For 4 parallel sinks we find:

$$\frac{R^{(1)}_{\theta SW}}{4} = \frac{10.14}{6812} = 0.00149^{\circ}C/Watt.$$

Two sinks are used for double-side cooling. Thus, for double-side cooling we find:

$$R^{(2)}_{\theta SW} = \frac{R^{(1)}_{\theta SW}}{2} = 0.003^{\circ}C/W \text{ at 2 GPM.}$$

This value is about 66% of the design value of $R^{(2)}_{\theta SW}$ = 0.0045°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 ($R_{\theta JC}$ + $R_{\theta CS}$) is constant and about 6 times as large as $R_{\theta SW}$ 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.