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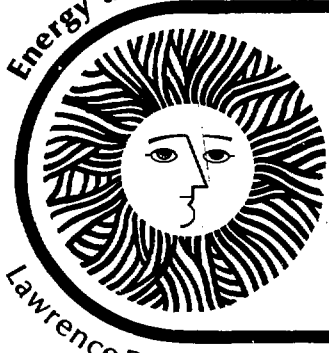

An SCR Series Switch And Impulse Crowbar At The Lawrence Berkeley Laboratory For CTR Neutral Beam Source Development

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AN SCR SERIES SWITCH AND IMPULSE CROWBAR AT THE LAWRENCE BERKELEY LABORATORY FOR CTR NEUTRAL BEAM SOURCE DEVELOPMENT*

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Summary

The series switch is designed to operate at 120kV and pass 65A for 0.5 sec every 30 sec on the Lawrence Berkeley Laboratory CTR Neutral Beam Source Test Stand IIIB. The series switch consists of 400 individual SCR circuits connected in series and is turned on by a simple system of cascaded pulse transformers with multiple single turn secondaries each driving the individual SCR gates. It is turned off by an SCR impulse crowbar that momentarily shorts the power supply allowing the series switch to recover.

The SCR switch has been tested in the impulse crowbar configuration and will reliably commutate up to 90A at 120kV. The series switch and impulse crowbar are now in service in Test Stand IIIB (see Figure 7).

A series switch and impulse crowbar similar in concept is routinely powering a 10 x 10 cm source at 150kV, 20A, 0.5 sec with a 1% duty cycle on the Lawrence Berkeley Laboratory CTR NSB Test Stand IIIA.[1]

System Description

Series Switch Operation

For an SCR series switch and impulse crowbar system to operate properly, it must be used in conjunction with a power supply that is ready to deliver current when the series switch is turned on and which also has sufficient impedance to limit the current build-up during the impulse crowbar interval. In the Berkeley TSIIIB system, this is accomplished by a biased reactor[2] which is charged to the pre-set load current prior to the pulse and which limits the current build-up to about 12A during the crowbar interval.

The impulse crowbar SCR is a unit identical to the series switch and has in shunt with it a series LC commutating network.

Figure 1 illustrates the commutation sequence. During the current pulse, the power supply current (I_1) flows to the load. The load pulse is terminated by firing the shunt crowbar thus diverting the power supply current (I_2) and allowing the series switch SCR to start recovery. Also, the commutating network current (not indicated) "rings" through the crowbar on the positive half-cycle. As the commutating current polarity reverses on the negative half-cycle and exceeds the amplitude of the power supply current, the power supply current (I_3) is again diverted flowing into the LC circuit allowing the crowbar SCR to recover. The commutating current in excess of the power supply current flows through the anti-parallel diode.

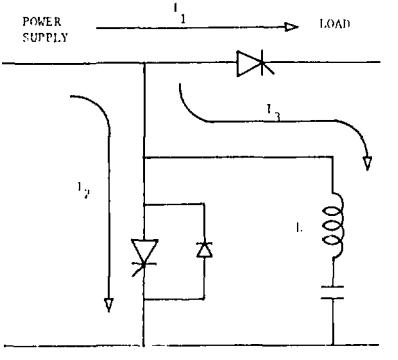


Figure 1
COMMUTATION SEQUENCE

SCR Switch Design

The SCR switch is composed of 400 individual SCR circuits (see Figure 2) connected in series. The 22Ω resistor in series with the gate is for trigger current sharing. The 33Ω resistor in shunt with the gate is to lower the gate impedance and thus reduce the sensitivity to the rate of rise of the reapplied voltage on recovery. The diode in the gate circuit protects the gate against reverse voltage transients. Anode to cathode, the 3 megohm resistor insures dc voltage sharing and the Metal Oxide Varistor (MOV) is for transient voltage limiting. The MOV has an inherent capacity of 1400 pF and a conduction knee of approximately 2mA at ± 300 VDC increasing to 100A at ± 600 VDC. It has an energy rating of 20 joules.

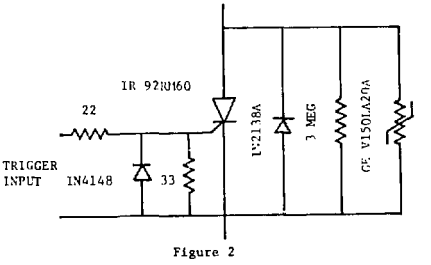


Figure 2
SCR MODULE CIRCUIT

Figure 3 CBB774-3219

120kV, 65A SCR SWITCH

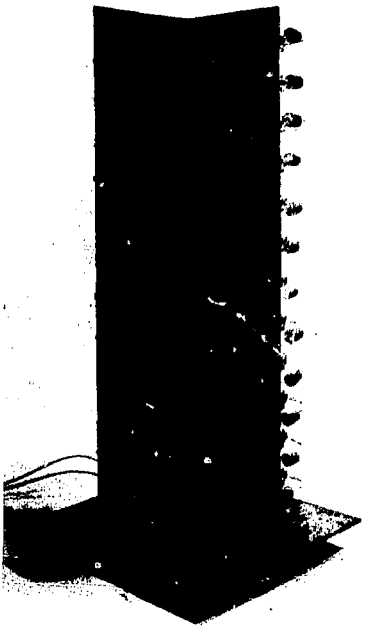


Figure 4 CBB772-1287

CASCADED PULSE TRANSFORMER TRIGGER SYSTEM

Since the SCR is rated at 600 VDC, the MOV will protect it from 100A transients for up to about 3.0μsec. When an MOV fails, it usually fails shorted and continues to protect the SCR.

The inverse parallel diode is provided to carry commutating current in excess of the power supply current. No dv/dt protection is provided at the individual SCR level and must be provided in the form of a snubber across the 120kV module.

Mechanical Design

The 400 individual SCR circuits are built in modular form on aluminum plates and are attached to four 14" x 55" glass mat polyester laminated boards. The circuit modules are placed in skewed rows on 1.5" centers and form a square helix of 4.5" pitch when the four boards are assembled to form the final rectangular assembly (see Figure 3). The individual SCR modules are attached by one screw and are easily replaceable from the outside of the assembly. Six corona rings are electrically attached at 20kV intervals which grade the voltage vertically and hide the sharp edged components from the outside world. A 750 mH inductor, shown at the top of the assembly, limits di/dt to less than 200A/μsec.

Trigger Circuit

Triggering the SCR stack is accomplished by two parallel pulse transformer strings each with six cascaded transformers. Figure 4 shows an inside view of two of the assembled panels and their associated trigger circuit. The pulse transformer cores are Indiana General 0-5 Ferrite, 2.4" OD x 1.4" ID x 1" torroids. The cascade primary and secondary each consist of four turns of "nude" RG-8; this allows the transformer to easily withstand 20kV primary to secondary. Each transformer has 33 or 34 single turn secondaries each going to an individual SCR gate.

The input primaries of the two cascaded transformer strings are driven in series from a pulse source that discharges a 1μF capacitor charged to 400 volts through a 4Ω non-inductive resistor. Figure 5 shows the single turn secondary voltage driving a typical SCR gate from (1) the first pulse transformer and (2) the sixth pulse transformer. The entire series switch is fully turned on in less than 2 μsec. The MOV's easily protect the SCR's from overvoltage during the slight turn-on skew due to pulse transformer delay.

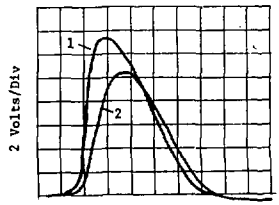
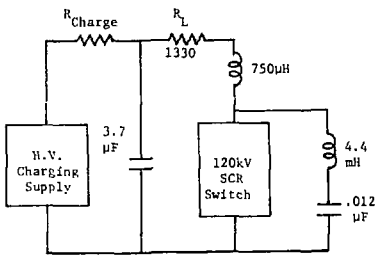


Figure 5

TRIGGER WAVEFORM

Commutating Network

The impulse crowbar commutation network is made up of six series LC sections with L = 733μH and C = .07μF. Each capacitor has 100 megohm in parallel to insure dc voltage sharing and each LC section has a corona ring to grade the 20kV per section. The resulting commutation circuit is equivalent to a 4.4 mH inductance in series with a .012μF capacitor which can operate to 120kV. The circuit, which is designed to commutate up to 90A, has a resonant period of 45.7μsec and a peak current of 192A.



(a) Test Circuit

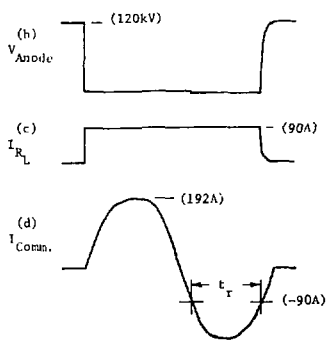


Figure 6

IMPULSE CROWBAR TEST CIRCUIT AND WAVEFORMS

Test Circuit

The SCR switch was tested in the impulse crowbar configuration as shown in Figure 6a. In this configuration, the SCR must pass the power supply current plus the commutating current or a peak 282A. Under these conditions, the commutation current exceeds the power supply current for 15.7μsec which is sufficient for the SCR stack to recover.

Figure 7 CBB779-8512

SERIES SWITCH (UPPER LEFT) AND IMPULSE CROWBAR

Series Switch Power Dissipation

The SCR switch is air cooled, relying mainly on the thermal mass of the SCR case to absorb the heat lost during the conduction period. For the design duty cycle, the switch free connection will be sufficient to cool the unit. With forced air cooling, calculations indicate that the switch should be capable of a 5 sec pulse once per minute. With the addition of water cooling, the unit would operate cw.

* Work done under the auspices of the U.S. Department of Energy. It was done for and with the able guidance of the Lawrence Berkeley Laboratory CTR Group under the direction of William Baker and with technical Assistance from Harvey Owren and Don Hopkins.

References

1. D. B. Hopkins, et al., "A Shunt Regulator for 150-kV 20 A, 0.5-Sec Neutral-Beam-Source Power Supplies", Proceedings of the Ninth Symposium on Fusion Technology, Garmisch-Partenkirchen, Germany, June 14-18, 1976.

2. W. R. Baker, et al., "A Biased-Reactor Fault Current Limiting System for Neutral Beam Source Accel Voltage Supplies", UCID-3834, April 5, 1976.