The Use of Thyristors for Repetitive Narrow Pulse, High Power Switching

S.B. Bayne¹, W.M. Portnoy² and G.J. Rohwein³

1. Department of Electrical Engineering, Texas Tech University, Lubbock, Texas 79409
(Now at the Naval Research Laboratory in Washington, DC)
2. Department of Electrical Engineering, Texas Tech University, Lubbock, Texas 79409
3. Sandia National Laboratory, Albuquerque, New Mexico 87185
(Now at the Mission Research Corporation in Albuquerque, New Mexico)

ABSTRACT

Inverter type thyristors were switched repetitively to failure with 1 μ s pulses at repetition rates of 10, 50 and 100 pps and at peak currents up to 12 kA. Millions of pulses could be obtained before failure if the peak current were held at around 6 kA.

RECEIVED
JAN 28 2000
OSTI

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The Use of Thyristors for Repetitive Narrow Pulse, High Power Switching

INTRODUCTION

Although power semiconductor switches have been used extensively in many power electronics applications, their utilization in pulse power circuitry has remained low. The principle reason has probably been the perception that short pulse operation, particularly under fast turn-on stress, either was not possible at all, or when possible, led to early failure. However, it has been shown [1 - 5] that high peak currents and fast risetimes can be simultaneously obtained for short pulses in discrete semiconductor thyristors, and that the use of single elements in pulse power circuits is feasible for repetitive peak currents up to 10 kA and di/dt values in excess of 20 kA/ μ s in the burst mode [5], but no repetitive measurements have been made to examine the effectiveness of short pulse operation over long periods of time. This work was done to determine the behavior of thyristors as closing switches under repetitive high current, short pulse operation.

EXPERIMENTAL FIXTURE

A preliminary PSPICE design of a ringdown test circuit delivering a 1 μ s pulse (pulse width at half maximum) at peak currents up to at least 10 kA and pulse repetition rates up to 100 Hz was performed. The design required a total capacitance of 10 μ F, discharged into a 60 milliohm load, with a total circuit inductance less than 20 nH. The low value of the inductance required a careful circuit implementation. The circuit was therefore implemented in a complex fixture made up of five parts: an aluminum base plate, an anode capacitor and retaining ring, an inner load ring, and anode and cathode anvils. The load resistance, located on and insulated from the base, was implemented using Evenohm wire, which has a very low temperature coefficient of resistance, in a wagon wheel configuration for the lowest parasitic inductance. The resistance was isolated from the base plate by a Kapton layer and a mica layer, the Kapton providing high

voltage electrical isolation, and the mica, any required thermal isolation. The center of the cathode anvil had an isolated spring loaded gate contact A capacitor mount, incorporation two NWL 5 μ F, 6 kV pulse rated capacitors in parallel was used to connect the capacitors and the power supply to the fixture. Figure 1 shows the complete fixture.

EXPERIMENTAL PROCEDURE

Twenty-eight Westinghouse extended gate, inverter type T-88 devices, rated at a blocking voltage of 2.4 kV and an average current of 650 A, and containing cathode shorts, were tested in the fixture. In order to eliminate the inductance associated with the package, only the wafers, on their thermal matching molybdenum slugs, (shown in figure 2) were tested. These were placed between the anode and cathode anvils, and the capacitor mount was bolted down at a pressure of one to two kilopounds. Although the T-88 has an amplifying gate, this was shorted to the cathode by the pressure loaded gate contact. The purpose of the short was to make a set of measurements consistent with those performed single-shot [3, 5]. In order to assure adequate turn-on, the shorted gate of each device was driven with a 125 A, 0.5 μ s pulse. Wafers were repetitively stressed with pulses between 6 kA and 12 kA, at repetition rates of 10, 50 and 100 pulses per second (pps). A pulse counter was used to count the number of pulses preceding failure, but because of the very large numbers of pulses involved in these measurements, the counter was not driven directly, but by way of an uncalibrated Rogowski coil placed around the device. As long as pulse current continued to flow, the counter continued to count; when a device failed, the counter stopped at the number of pulses delivered before failure.

EXPERIMENTAL RESULTS

Figure 3 illustrates a typical current pulse and voltage fall at 50 pps and 1 kV. The shape of these waveforms is representative of all those obtained in the stress testing. The shape of the waveforms did not change during the pulsing, although the load wires became quite hot because

of the high power dissipation in the load, indicating that no significant changes in the load resistance occurred during the tests. Although every device ultimately failed, some continued to operate for millions of pulses, depending on the repetition rate and the peak pulse current. The devices which failed at a low number of switching events failed generally at peak currents between 12 kA and 14 kA at any repetition rate. However, between 6 kA and 10 kA, tens of thousands of switching events were obtained, and if the peak current was restricted to around 6 kA, millions of pulses were obtained for some devices. Table 1 contains a short list of some of these devices.

Short term failure, excluding infant failures normally to be expected, may probably be attributed to the high power dissipations occurring in the device at high peak currents. For these devices, the width of the turn-on plasma at the peak of the pulse is estimated to be between 25 and 50 μm . Inasmuch as the action integral varies at the square of the current, the thermal stress at high currents in such a small region will be considerably higher than at low currents. Another possibility is overetching of the cathode shorts; these may have been etched too deeply causing the devices to undertrigger. This effect could be observed by distortion in the gate waveform during triggering. Gate current was increased to try to compensate, but failure nevertheless occurred.

The failure at longer test times is attributed to a thermal erosion and punch-through of the cathode aluminum metalization. When a wafer was removed after long term failure, considerable erosion, with accompanying burn spots, could be observed, suggesting that considerable power dissipation was taking place at the interface between the cathode and the cathode anvil, despite clamping at high force. This possibility was tested by reducing the clamping force, but the results were ambiguous, inasmuch as some 13 million pulses were obtained before failure at 6 kA and 50 pps, even when the clamps were only finger tight.

However, it is still believed that performance could be significantly improved if some conforming layer, such as soft copper, were inserted between the cathode anvil and the wafer cathode.

CONCLUSIONS

The feasibility of the use of thyristors for applications requiring narrow high power repetitive pulses has been demonstrated, at least for those applications for which $1\mu\text{s}$ is sufficiently narrow. Excepting process induced failures, long-term failure is likely to be the result of power losses at the contact. The number of pulses, and perhaps the peak currents, for these devices can possibly be increased by better anvil-to-contact configurations.

REFERENCES

1. J.L. Hudgins and W.M. Portnoy, "Fast Transient Behavior in Thyristor Switches," Sixteenth Annual IEEE Power Electronics Specialists Conference, Toulouse, France, June 24 - 28, 1985.
2. J.L. Hudgins and W.M. Portnoy, "High di/dt Pulse Switching of Thyristors," IEEE Transactions on Power Electronics vol. PE-2, pp. 143-148, 1987.
3. V.A. Sankaran, J.L. Hudgins and W.M. Portnoy, "Role of the Amplifying Gate in the Turn-On Process of Involute Structure Thyristors," IEEE Transactions on Power Electronics, vol. PE-5, pp. 125-132, 1990.
4. C.E. Kennedy, J.L. Hudgins, V.A. Sankaran and W.M. Portnoy, "Comparison of GTOs and SCRs for High di/dt Switching," IEEE IAS Record, 1990, pp. 1643-1647.
5. V.A. Sankaran, J.L. Hudgins and W.M. Portnoy, "High Energy Pulse Switching Characteristics of Thyristors," IEEE Transactions on Power Electronics, vol. PE-8, pp 347-354, 1993.

FIGURE CAPTIONS

Figure 1. View of the experimental fixture.

Figure 2. Top view of the T-88 device.

Figure 3. Current pulse and voltage fall for device number 11, at 1 kV anode cathode voltage and 500 pps. The peak pulse current is 6.5 kA. and the time scale is $2\mu\text{s}$ per large division.

Sandia is a multiprogram laboratory
operated by Sandia Corporation, a
Lockheed Martin Company, for the
United States Department of Energy
under contract DE-AC04-94AL85000.

Table 1. Number of Pulses at Failure

Device Number	Repetition Rate (pps)	Anode Current (kA)	Pulses at Failure (millions)
3	50	10	3.6
11	50	6.5	24
16	50	6	13.6
25	10	7	2.4

Figure 1

Figure 2

Figure 3