Improved High Voltage Pulse Generator for Automated Insulator Fault Detection

H. Sanders[ξ], D. Warnow
Silicon Power Corporation, 280 Great Valley Parkway
Malvern, PA, 60510 USA

Abstract

Insulators that have suffered invisible damage can cause catastrophic system failure. Detection of the fault through visual inspection is not possible. An automated non-destructive test method is preferred. We have developed a system capable of peak pulse voltage of > 50 kV with fast rise time and limited pulse energy coupled with a high speed FPGA processor to analyze the output voltage and current for potential insulator faults. This paper will discuss the design and test results of a high-voltage pulse generator with automated fault detection.

This pulse generator has been improved using a new high-voltage solid state switch based on thyristors capable of >100 A/ns and >300 V/ns. Using this switch increased the efficiency by 25% versus an IGBT based switch. This paper will also discuss the design and test results of this new switch.

I. BACKGROUND

Insulator failures in pulsed power systems have been a bane on the pulsed power engineer. Whether it be a stand-off in a Marx generator or the housing of a gas discharge switch, when the insulator fails it can lead to catastrophic results. It is possible to test these insulators using pulsed power to determine if there are any issues. The test needs to not be of sufficient energy as to damage an intact insulator but not too little energy as to fail to detect issues. With experience in designing pulsed power system for kicker magnets, electrostatic kickers, magnetron modulators and high voltage solid state trigger generators, we decided to put together our own test system [1-3].

II. SYSTEM DESIGN

The system consists of a control unit and a high voltage unit. The high voltage unit consisting of a high voltage power supply, a high voltage storage capacitor, a high voltage switch and trigger unit, a step-up transformer, a high-voltage diode, a voltage monitor, a current monitor, and other miscellaneous resistors, line filters, and safety components.

In the initial configuration we used a 10 kV power supply, 25 nF storage capacitor, transistor based switch, 5.5:1 step-up transformer, 15 kV diode, and a 1V/10A current monitor.

The control unit consist of an FPGA and an interface circuit. The interface circuit contains two channel 20 MHz ADC to convert the output voltage and current data for isolated digital input into the FPGA. Sensitivity can be adjusted through a ten-turn potentiometer. The processor can determine within 30 msec if a fault exists through analyzing the current and voltage data. The processor analyzes the data for values including peaks, rate-of-change, and total integrated area. The system is designed to operate at up to 30 pps. Figure 1 shows a picture of the control unit and figure 2 shows a picture of the control circuit layout.

Figure 1. Picture of control unit.

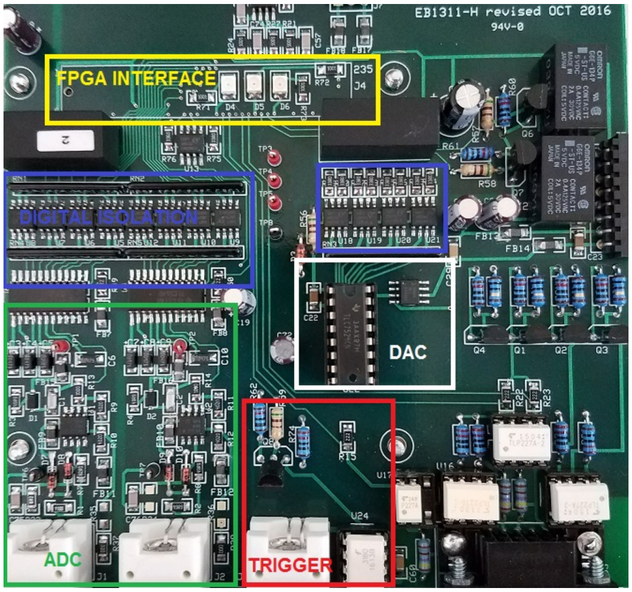

Figure 2. Picture of control circuit board

[ξ] email: howard_sanders@siliconpower.com

If a fault exists then the system would automatically stop pulsing and report an appropriate fault code. However, this can be overridden with a manual operation mode to allow continuous pulsing even when a fault is detected. Manual mode was used in the second set of test.

III. TEST SETUP

The same system was used for all tests. The same charge was used for all tests, operating at about 0.4 J stored energy. The output was connected to two electrodes spaced close enough together that if there was no insulator between them that they would arc with each pulse.

A. Drilled Holes

For the first set of tests the electrodes spaced 0.75" apart. The insulator under test was placed centered between the electrodes. A 0.125" thick sheet of silicone rubber was used as the insulator. The faults were created by drilling holes of various sizes in the insulator. It should be noted that, due to the nature of the silicone rubber, these very small holes would close up after being drilled such that the material could look undamaged without very close visual inspection. Table 1 shows the drill size for the various tests using drilled holes.

Table 1. Drill Size Used to Generate Holes in Insulator

Test	Drill Size
1	1/16
2	3/64
3	60
4	1/32
5	76
6	1/64
7	None

B. Repetitive Pulsing

A second set of test were performed placing the electrodes on opposite surfaces of a black vulcanized rubber insulator and testing at various number of pulses. The carbon particles used as coloring agent will slowly degrade the rubber with pulsing allowing an accelerated failure test. Table 2 shows the number of pulses used for each test. The system was operating at 30 pps during these tests, except for test 6.

Table 2. Pulse Testing of the Insulator

Test	Number of Pulses
1	4500
2	3000
3	1500
4	600
5	300
6	1

IV. TEST RESULTS

A. Drilled Holes

Figure 3 shows the resuts for tests 1 through 7 as defined by table 1. As can be seen in the test results, all of the holes breakdown and would be registered as faults through analysis of the voltage data, showing a fast falling dV/dt, as well as the current data which would show a large current after the breakdown. The very small holes do take longer to breakdown, but that is expected with the way the rubber closes up after being drilled.

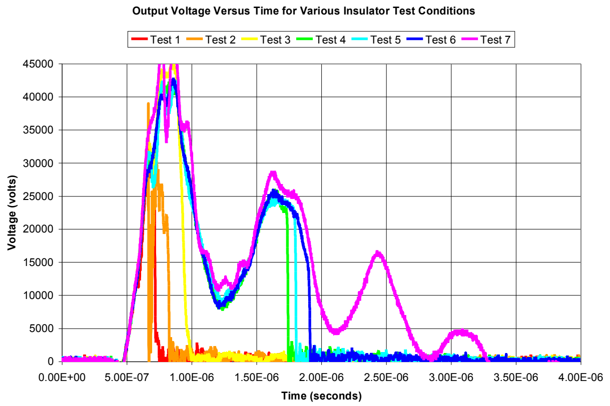

Figure 3. Test results with drilled holes

B. Repetitive Pulsing

Figure 4 shows the resuts for tests 1 through 6 as defined by table 2. As can be seen in the test results, the material resistance falls dramatically with pulsing. All of the results from test 1 to 5 would be considered faults based on the peak and total integrated area of the voltage data falling off dramatically from the expected values. With enough pulses the material starts to arc through channels etched through the material.

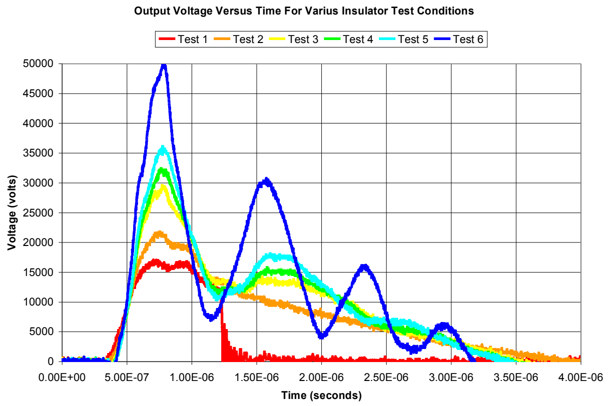

Figure 4. Test results with repetitive pulsing

V. IMPROVED SWITCHING

The initial transistor based switch is sufficient for the task but our expertise is in thyristor based switches. The initial reason for not using one was the worry about thyristor recovery time limiting the pulse rate. However we recently developed a new version of thyristor based switch, our model S70-2-8, with faster turn-on and recovery than our traditional Thyratron replacement switches, such as our model S56-12 [4, 5]. Table 3 summarizes the operational parameters of this new thyristor based switch and figure 5 is a picture of the switch. Figure 6 is a dimensional drawing of the S70-2-8.

Table 3. S70-2-8 Operational Parameters

Parameter	Value
Peak Voltage	12 kV
Peak Current (1 µs)	5 kA
Rate of Current Rise	>100 kA/µs
RMS Current	60 A
Recovery Time	< 400 µs
Jitter	< 2 ns
Leakage Current (10 kV)	150 µA

Figure 5. Picture of S70-2-8

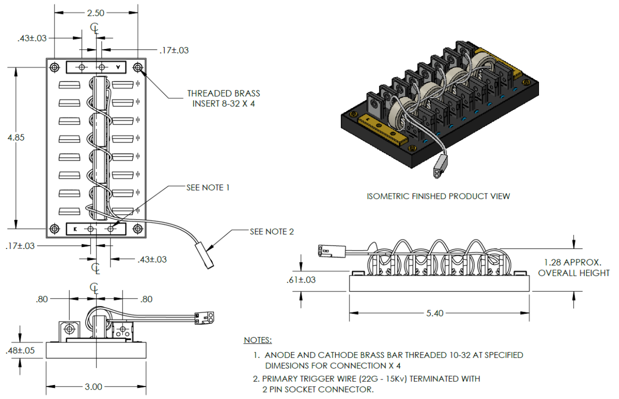

Figure 6. S70-2-8 dimensions

This thyristor based switch uses 8 stages of two TO-247 packaged thyristors in parallel, basically equivalent replacements to a TO-247 transistors in size and cost but with better pulsed power operational parameters [6]. The thyristors have faster rate of current rise and lower on-state resistance, for example, than equivalently packaged IGBT devices. The only disadvantage is that thyristors cannot be turned off like IGBT can. However in this application where the storage capacitor is fully discharged with each pulse and the charge cycle is 100 times longer than the recovery time, the thyristor provides an overall improvement in operational performance. Figure 7 shows the difference between the IGBT based and the new thyristor based switch.

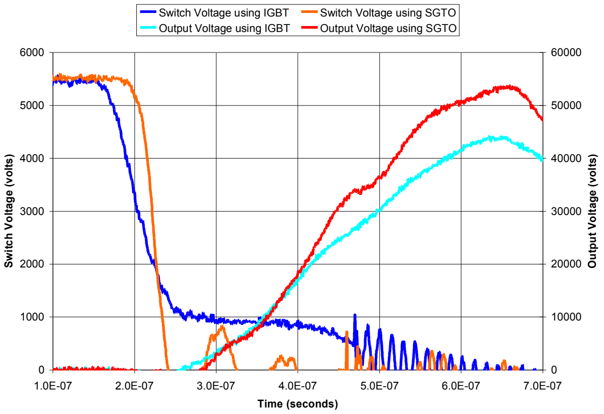

Figure 7. IGBT versus new thyristor switch

As can be seen in figure 7, the thyristor switch turns on faster and to lower on-state resistance than the IGBT switch. This results in a higher output voltage using the same stored energy, improving the test efficiency.

VI. SUMMARY

We have described an automated insulator test system using low energy pulsed discharge improved with a new thyristor based switch which increasing the test efficiency.

VII. REFERENCES

[1] S. Glidden and H. Sanders, "High voltage solid state trigger generators." in Proc. Pulsed Power Conference, 2005, pp. 927-930.

[2] S. Glidden and H. Sanders, "Solid state Marx generator." in Proc. Power Modulator Symposium, 2006, pp. 314-317.

[3] S. Glidden and H. Sanders, "125kV, 100kA, 150ns, 5pps test facility with solid state switched distributed pulse compression?." in Proc. Pulsed Power Conference, 2009, pp. 1207-1209.

[4] Liu, Wanming, et al. "AWA RF mdulator upgrade using solid state thyratron replacement." in Proc. Pulsed Power Conference, 2015, pp 1-4.

[5] H. Sanders, et al., "Thyristor based solid state switches for thyratron replacements." in Proc. Power Modulator and High Voltage Conf., 2012, pp. 335-338.

[6] Waldron, J., K. Brandmier, and V. Temple. "Ultra-fast, high reliability solid state thyratron, ignitron and thyristor replacement." in Proc. Pulsed Power Conference, 2015, pp. 1-5.