FIBER-OPTIC CONTROLLED PCSS TRIGGERS FOR HIGH VOLTAGE PULSED POWER SWITCHES *

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Abstract

Triggers for high voltage (HV) switches have always been critical components for reliable, efficient pulsed power systems because they control the timing synchronization and amplitude variation of multiple pulse forming lines that combine to produce the total system output pulse. In pulsed power systems of the future, the role of trigger systems are even more critical as they trigger more components and produce shaped-pulses by independent timing of individual switches or switch groups. Conventional trigger systems require high voltage trigger cables or line-of-sight optics that complicate design, demand space, and require extensive maintenance. With electrical triggers, large diameter, high voltage transmission line cables must be fed through high field regions. With optical triggers, line-of-sight optics must focus high energy laser beams to the interior of the switches with clean, rigidly-mounted, shock-withstanding optics.

This paper reports on efforts to develop fiber-optically triggered photoconductive semiconductor switches (PCSS) to trigger high voltage switches with improved precision and eliminate the need for large-diameter trigger cables or line-of-sight optics. These triggers simplify design because their optical-isolation allows them to "float" with the switches that they trigger and have truly independent EMP-free timing control over 200 micron diameter optical fibers. They improve the performance of prime power switches, diverters, and diagnostics, because their low-jitter sub-nanosecond rise times are more precise and more easily adjusted than conventional trigger sources. For pulse charged switches, the PCSS triggers can generally derive their trigger energy from the stray fields of the high voltage switch. Test results will be presented that have demonstrated 100 ps r-m-s jitter from a 40 kV, 500 ps rise time, PCSS-triggered 300 kV trigatron gas gap. PCSS design requirements, switching properties, and trade-offs for building high voltage trigger systems will also be described based on many previous experiments with PCSS technology [1]. Results from PCSS Blumlein and PCSS capacitive discharge pulsers will be discussed along with the designs to use these pulsers to trigger both DC and pulse charged high voltage switches

I. INTRODUCTION

PCSS based trigger generators (TG) provide a number of advancements in HV triggering. Sub-nanosecond rise time and jitter enhance HV switch performance over existing triggering techniques. Fiber-optic control of a PCSS-based TG physically located on a HV switch allows the triggering hardware to float, thereby eliminating the need for HV cables traversing high electric field regions or for line-of-sight-optics. Fiber-optically isolated triggers can be independently controlled, monitored, and adjusted from a central control room resulting in improved flexibility, performance, and reliability. Greater simplicity is achieved in design, required space, and required maintenance by using PCSS based TGs. High speed system diagnostics can also be improved by the reduced jitter of the HV switches and by incorporating fiber-based optical diagnostics with the trigger fibers.

The following sections describe research and development of PCSS trigger generators for a variety of HV switches and switching applications. Feasibility tests were performed with a 300 kV hydrogen spark gap that was pulse charged and operating at 10 Hz. Presently we are testing a PCSS TG with a 200 kV DC Russian "Brick" for pulse-shaping applications such as isentropic compression experiments (ICE) where many HV switches require independently adjustable triggers. Future tests will include more commonly used HV switches such as the basic switches in Marx generators and the higher voltage trigatrons used to control timing in large pulsed power systems. Issues addressed are: (1) DC and pulsed charging HV switches, (2) PCSS protection with an intermediary switch, (3) direct triggering of HV switches by a PCSS TG, and (4) a compact, scalable design for a large range of voltage and current applications.

The goals in these experiments are to determine the minimum requirements of the PCSS TG to achieve reliable, low-jitter triggering of each high voltage switch and to develop compact, low cost TGs for future pulsed power applications. The trigger pulse parameters, current, voltage, and width, determine the size of the PCSS and energy storage components, the number of semiconductor lasers and fibers required to trigger the PCSS, the lifetime of the PCSS, and hence the size and cost of the TG.

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II. PREVIOUS PCSS TG TESTS

The feasibility of PCSS TGs was first demonstrated with a 300 kV hydrogen spark gap shown in figure 1. This HV switch was triggered with a simple capacitive discharge system based on a 40 kV PCSS. The entire system was charged under oil with a pulse transformer in 5 µs operating repetitively at 10 Hz. The spark gap delivered 5 kA to a 50 Ω load with 100 ps r-m-s jitter (500 ps spread) using a PCSS based TG delivering a trigger pulse with 500 ps rise time that was adjustable from 20-40 kV. This spark gap used a precision trigatron pin that was carefully adjusted to produce these low jitter results from the PCSS based TG which demonstrated 50 ps r-m-s jitter. The output impedance of the TG was increased from 50 Ω to 200 Ω to reduce the PCSS current requirement and reliable low-jitter triggering continued.

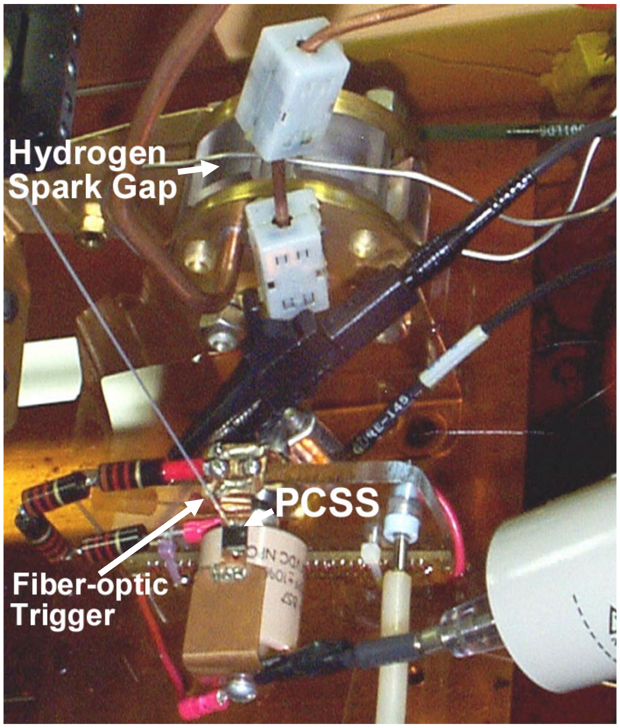

Figure 1. A 300 kV hydrogen gap shown with a 20-40 kV, 500 ps rise time PCSS TG that demonstrated 100 ps r-m-s jitter.

III. PRESENT PCSS TG TESTING

We are currently using a PCSS and an intermediary trigatron to trigger a 200 kV DC Russian switch. The intermediary trigatron serves three functions: (1) it holds-off the DC field from the HV switch, allowing the PCSS to be pulse charged, (2) it protects the PCSS from potential high current feedback when the HV switch closes, and (3) it could potentially trigger several output switches with a single PCSS TG. Two TG circuits (figure 2) were assembled and tested: Blumlein and capacitive discharge pulsers.

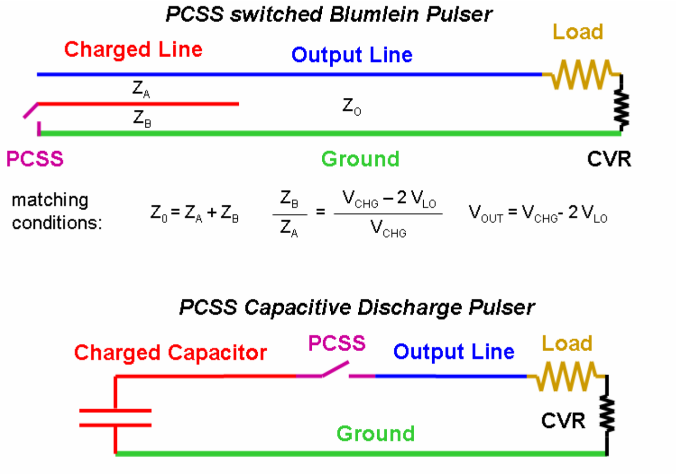

Figure 2. PCSS pulser circuits constructed and tested for this project are shown. The Blumlein Pulser (top) produces a rectangular pulse but is a more complicated circuit to match because of the PCSS on-state (lock-on) voltage. The Capacitive Discharge Pulser (bottom) produces a more complicated pulse that may actually be more compact and efficient.

The Blumlein produces a rectangular pulse and recovers the factor of two voltage that is lost when a transmission line is switched into a matched load. The on-state voltage drop of the PCSS in the high gain switching mode (often called the “lock-on” voltage) complicates the Blumlein because the impedance of the switched leg must be lowered to compensate for the missing lock-on voltage. A high impedance (300 Ω), back-to-back parallel pair of Blumleins (5 plates) was assembled to drive a tri-plate strip line with minimal parasitic capacitance. Tests were performed with charging voltage to 10kV and PCSS current to 300 A. Measurements were taken with voltage derivative monitors and current viewing load resistors. All diagnostics showed reflections caused by the PCSS and load mis-matches. Due to the time required to adjust the Blumlein impedance and the urgency to proceed with a PCSS TG, testing with this pulser was postponed.

A simpler, but less ideal TG, the capacitive discharge pulser (CDP), was assembled using a 20 kV PCSS. The CDP produces a slower, more complicated pulse with rise time limited by the inductance of the capacitor divided by the load resistance followed by an exponential resistance times capacitance decay of the pulse. However, if low inductance capacitors are used, this simpler circuit may provide a more compact and efficient trigger system because nearly the full charging voltage will reach the load and most of the energy is delivered at the front of the pulse when it will be needed to initiate triggering.

Results from the CDP are shown in figure 3. A 2.5 mm long PCSS delivered up to a 14 kV 8 ns wide pulse with a 2 ns rise time to a matched load. This implies that the pulser would deliver 28 kV to the “open” intermediary trigger, which should be sufficient, since the intermediary Trigatron was designed to be triggered with a 25 kV pulse.

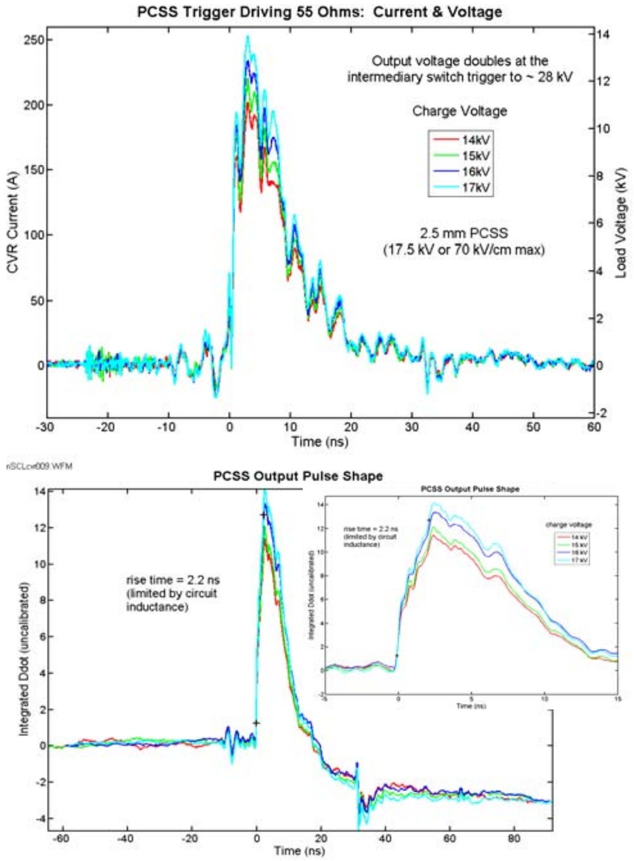

Figure 3. PCSS CDP properties. The top plot shows pulser current and voltage using a 2.5 mm long PCSS charged to 17 kV delivering 14 kV to a matched 50 Ω load. This voltage will double at the open trigatron pin to 28 kV until the trigger gap shorts and the circuit is matched. The bottom shows higher bandwidth but uncalibrated voltage measurements of this pulser obtained with a derivative voltage monitor.

A 100 kV DC trigatron was designed (Jeff Alexander, SNL) to be triggered with a 25 kV pulse from the PCSS trigger. Before attempting to trigger the Russian switch, the trigatron was assembled and tested to verify operation with the PCSS CDP. Except for a large capacitive load, this circuit provided the same operating conditions (DC voltage, polarity, 50 Ω PCSS trigger) for the trigatron that will be present when it is triggering the 200 kV Russian switch. Figure 4 shows some of the test results from triggering the trigatron with the PCSS CDP. In the top plot, PCSS CDP current waveforms are similar to those shown in figure 3, except for the reflections following the main pulse. Our next goal will be to reduce or eliminate these reflections as they can damage the PCSS contacts. Note the agreement of the two current monitors. The current viewing resistor (CVR) is in the transmission line at the output of the PCSS CDP and the integrated current monitor (B-dot) is in a monitor extension tube at the input to the trigatron trigger pin. The trigatron current is shown in the bottom plot. It rings, because a capacitive load with very little damping resistance was used for this test. When triggering output switches, the trigatron will drive matched loads with very little ringing.

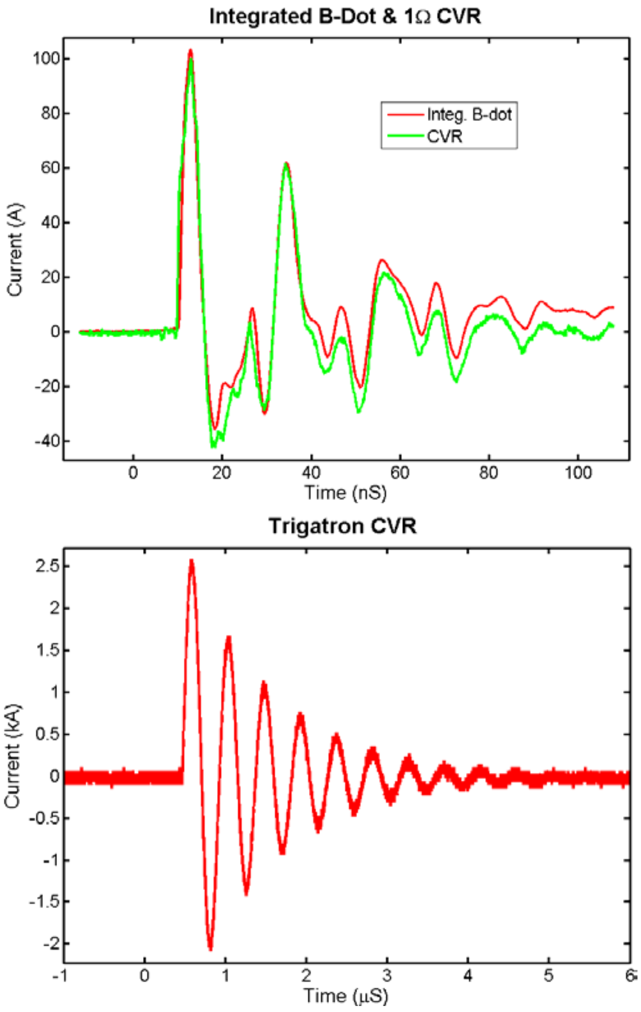

Figure 4. PCSS CDP triggering a 100 kV DC trigatron. The top plot shows the CDP output current compared to the current at the input to the trigatron trigger pin. The bottom plot shows the trigatron output current into a capacitive load.

A drawing of the assembly that is being used to trigger the 200kV DC Russian switch is given in figure 5. The circuit diagram of this assembly along with photographs of some of the system components are in figures 6-8. This apparatus is presently being assembled, and once the circuit is operational, it will be fine-tuned to remove extra reflections and minimize the delay and jitter between the PCSS laser trigger and the output switch current. PCSS voltage, current, and pulse width will be varied to determine the minimum requirements for the low jitter, stable triggering of the output switch.

IV. REFERENCES

[1] See proceedings from Pulsed Power, Power Modulator, and Optically Activated Switching Conferences, IEEE and SPIE, 1985-2003.

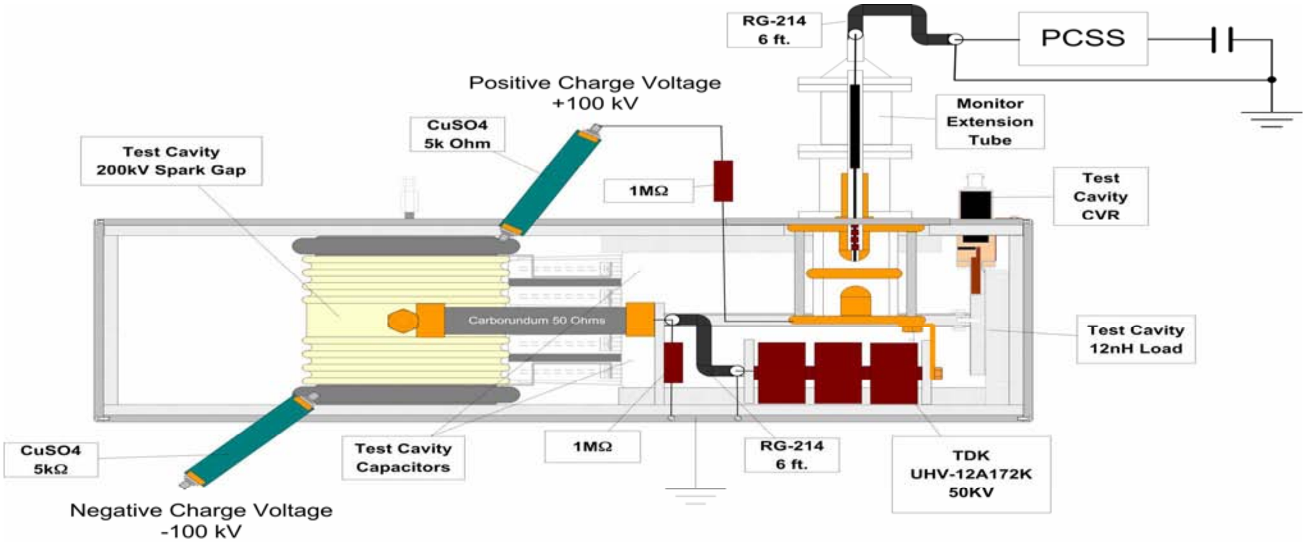

Figure 5. A drawing of the assembly being used to demonstrate PCSS triggering of a 200 kV DC Russian switch. The minimum PCSS requirements for reliable, low-jitter triggering will be determined using this test bed

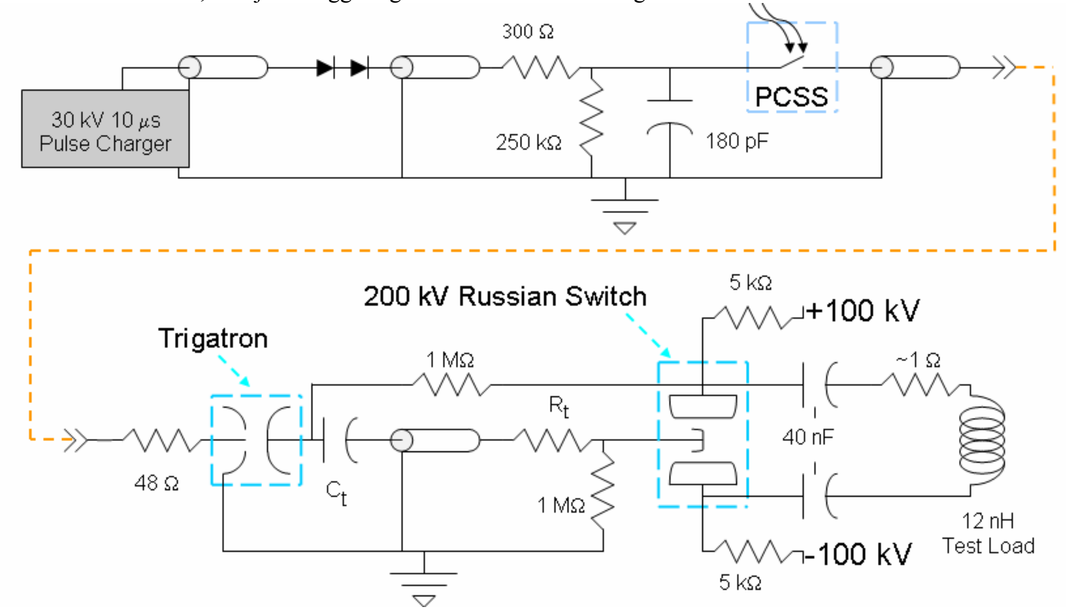

Figure 6. The complete circuit diagram of the assembly being used to demonstrate PCSS triggering of a 200 kV DC Russian switch.

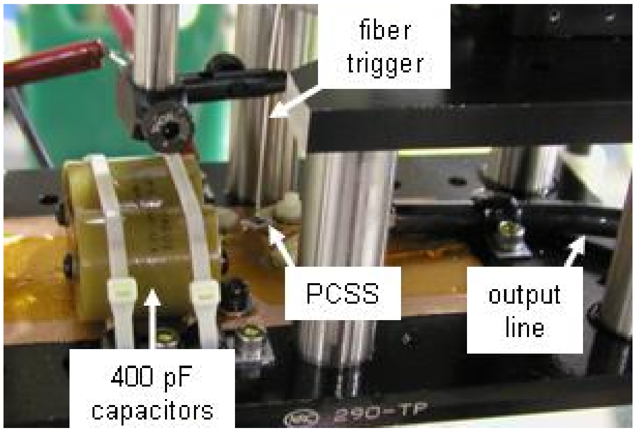

Figure 7. This photo shows the PCSS CDP. The assembly is submerged in oil near the intermediary trigatron.

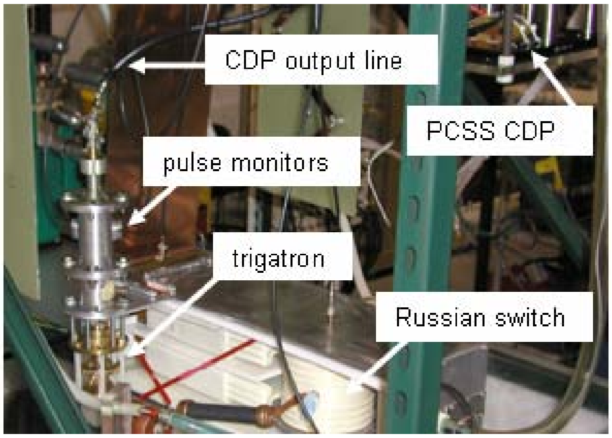

Figure 8. The PCSS CDP, trigatron, and Russian switch are shown as they are configured for testing in this photo.