SAND2017-8077C

TESTING HIGH VOLTAGE (200KV) DC CABLE AND FEED-THROUGH DESIGNS IN REP-RATED MODES*.

Michael G. Mazarakis, Mark L. Kiefer, Joshua J. Leckbee,
Sandia National Laboratories
Albuquerque, NM 87185

Del H. Anderson, Frank L. Wilkins, Robert J. Obergon
National Security Technologies

Abstract

We have constructed a Component Test Stand (CTS) to test various high voltage components to be utilized in near future pulsed-power devices. In addition to cable and oil feed-through design voltage hold off, different types of high voltage switches will be evaluated. The system contains two switches connected in series separated by ~60 ns worth of high voltage cable. The configuration is such that triggering the first switch enables the triggering of the second switch. This way we can evaluate the performance of two switches at the same time and study the influence of one switch on the other. A software system similar to LabView is designed and built to operate and collect data in a rep-rated mode. The two switches are immersed in transformer oil tanks and pressurized with dry air. The present paper will mainly present a cable-oil feed-through design evaluation as a function of repetition rate. The rep-rate will be adjusted to not affect the cable voltage hold-off as well as switch performance. The rep-rate is necessary in order to obtain component lifetime results in a reasonably short time. Apparently the transformer oil in a high voltage DC environment behaves much differently than in AC. Its behavior is similar to a weak electrolyte, and space charge effects seriously affect the current through it as well as the field distribution. This consideration is quite important in designing the proper high voltage DC cable-oil feed-throughs.

I. INTRODUCTION

In the power grid transmission community where a large amount of energy is transmitted to long distances, High Voltage DC transmission becomes more attractive since is more efficient than the counterpart AC lines. In the hydro facilities of Canada and Europe, high DC lines of up to 1 MV are successfully utilized.

Two of the most difficult parts encountered by the people working in the field are the high voltage cable guide and the actual feed-though connection of the cable to the high voltage power sources. Transformer oil is the most common medium utilized to isolate the high voltage components from the ground electrodes. Hence, a lot of research has been recently accomplished related to the behavior of the insulating oil at very high electrical DC stresses. In the pulsed power community high voltage expertise is limited to very short pulses. So for us High Voltage DC is a new paradigm. Our experimental set-up may be the first pulsed power device to operate at 225kV DC. The only power supply we could locate operating in a dry housing and not requiring a high voltage tower and corona protection dome was a SPELLMAN [1] DC power supply normally utilized for commercial x-ray radiography. This power supply is utilized to DC charge our cable pulser. The high voltage cables were jointly designed with Dielectric Sciences Inc. [2], which also manufactured them. The cable impedance is close to optimum and equal to ~30 Ohm. The switches are immersed in transformer oil and charged through especially designed high voltage cable guides and feed-throughs. Special care was taken in designing the cable guides and feed-throughs since the oil at high DC voltages behaves as a weak electrolyte forming space charge regions and increasing the electric field stresses inside the oil close to the cables and inside the solid insulating sleeves of the cable guides. Because the utilized power supply is of negative polarity, the time that the cables remain charged and the rep-rate frequency was limited so as to not exceed the 75s average time of voltage application. According to references [3, 4], at 75 seconds the stresses near the negative electrodes increase by a factor of 2.5 relative to the original applied electric field. Indeed we experienced feed-through failures when the rep rate was high and the duration of the voltage application was longer than 75 seconds. Hence, one of our first concerns was to evaluate the feed–though voltage hold-off against arcing in the transformer oil environment. Cable and cable guide-oil interface design is quite important and

* Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

challenging for high voltage devices. We have experimented with a number of cable guide designs and cable quick disconnects to the switches. The design of the most successful cable guide will also be presented.
In the following sections we describe the experimental apparatus, electrical circuit, and first experimental results.

II. EXPERIMENTAL SET-UP

Figure 1 is a photo of our experimental set-up called "Component Test Stand" (CTS) facility. Figure 2 shows the top of the set-up. In the first stage of experimentation the CTS was composed of five oil cylindrical containers. A larger one (not shown in Fig.1) houses the relay that connects the power supply to the pulser. Normally the power supply remained connected to the system during the experimentation, but it was isolated from the cable pulser with a ~ 5 kΩ resistor located in the left back tank (isolation tank). The two front oil containers enclose the two switches. The switch number #2 is in the left front tank, while the switch # 1 is in the front right tank.

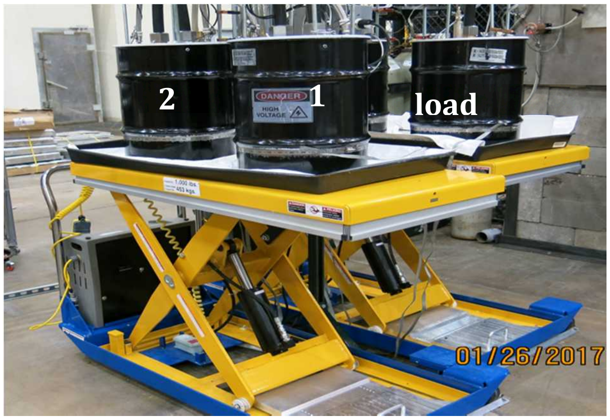

Figure 1. Side view of the CTS. The isolation tank is behind the three tanks.

Figure 2. Top view of the CTS. Here all four oil tanks are shown.

The fourth container located at the back right hand side contains the matched load resistor of 30 Ohm. The four containers are placed on the top of two hydraulic tables capable of being raised and lowered.
The switches and the cable guides together with the cables are permanent affixed on the cover leads of the containers, so that when we lower the tanks for inspection or maintenance, the leads with the switches remain fixed in place (Fig. 3).

Figure 3. The switches are mounted through the cable guides on the top tank leads.

Only the barrels with the oil are lowered down. The power supply is near the relay tank. Both relay tank and power supply are outside the field view of the photos (Fig. 1 and 2). Figure 3 shows one of the cable guide types tested with our CTS facility, and Fig. 4 gives a close-up of this guide.

Figure 4. An early cable guide. The switch is mounted at the top metal plate.

Two L3 [5] trigger generators trigger the two switches at two different preset times (400 -500 ns). The switches, in addition to High Voltage and ground electrode, have also a third electrode (trigger electrode) located exactly at the middle of the two others. The trigger electrode is biased at half the charging voltage. The firing of the device can be rep-rated with up to 6 shots per minute. The switch pressurization and purging, the charging voltage, the triggers, the arming of the scopes and data collection are

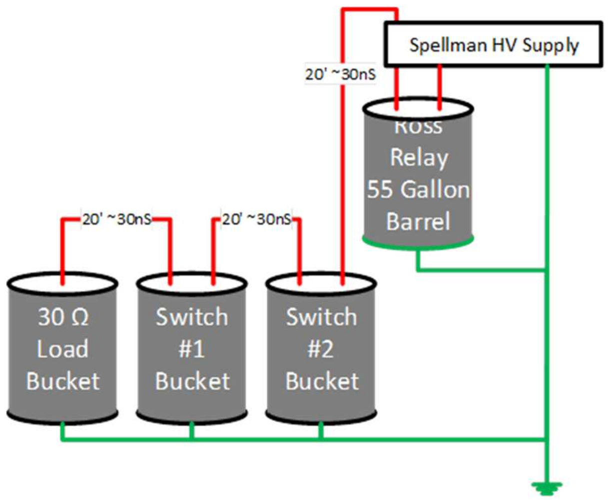

Figure 5. Block diagram of the CTS facility

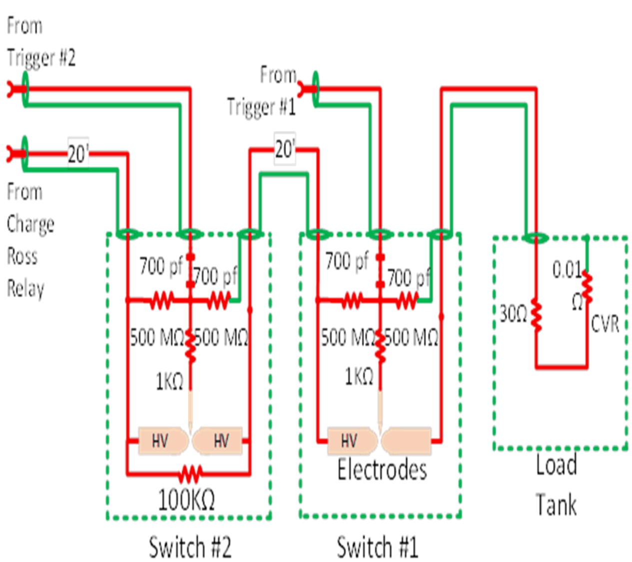

Figure 6. A simplified circuit of the CTS system

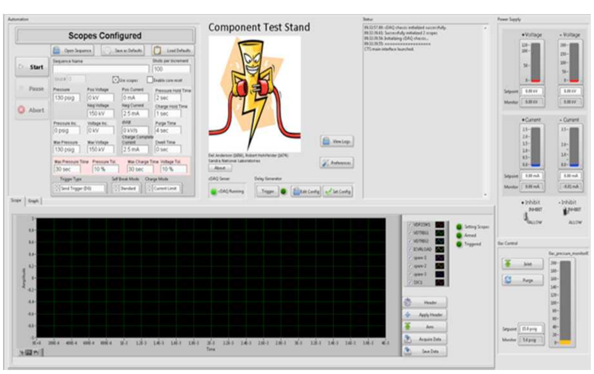

Figure 7. LabView-CTS control panel.

automatically operated through a special LabView [6] software program run by a laptop computer.

We preset the number of shots per run, the voltage, the voltage rise time, the switch air pressure and the dwell time (delay time before triggering following the charge completion of the cables) between pulses; then we press the start button, and the computer takes over and runs the pulser without any intervention from the operator. This way we can collect a lot of data and evaluate components performance in a relatively short time.

The setup described above was the original one we utilized. Because the power supply was not being disconnected from the system following each firing and despite the isolation resistor (~5k Ohm), the power supply continued to charge the feed cable, causing it often to fail. Most recently we installed a second relay in the relay tank that disconnects the power supply immediately following the firing of the switches. Then we eliminated barrel number 3, and we are now directly charging switch #2 straight from the power supply. This way we do not have any more failures of the charging cable. Figures 5 and 6 describe the new arrangement. Figure 7 shows the control panel as presented on the desktop of the computer.

The diagnostics for the time being are quite simple; they are two V-dots to measure the voltage pulses leaving the switches and propagating to the load and another set of V-dots measuring the trigger voltage pulses applied on the trigger electrodes. We measure also the current of each pulse with a current viewing resistor connected in series with the 30-Ohm liquid resistor load. Our long-term goals are to evaluate the switch performance parameters such as self-brake, jitter, capacitance, and closure time (run times) following the arrival of the trigger pulse etc. Another very important study is to evaluate the switch aging as a function of the number of shots. A number of different types of switches will be tested. The simple circuit of Fig. 6 will be modified with slumbers in order to reduce reflections and approach as close as possible to square pulse output.

III. EXPERIMENTAL PROCEDURE AND PRELIMINARY RESULTS

At the start of the firing sequence the high voltage power supply charges all the cables except for the last one that connects the switch number # 1 to a matched load. Both electrodes of switch # 2 and the left electrode of switch #1 are charged to the same voltage through a high resistance resistor of ~100 kΩ. The left electrode of switch # 1 is also charged to the same voltage since it is connected to the right hand side of switch #2.

The trigger power supplies are connected to the trigger electrodes through two small doorknob capacitors in series with 1 kΩ liquid resistors. The trigger electrodes are biased to half the charging voltage relative to the ground with 1 GΩ voltage dividers connected to the charged electrodes of the switches. This is the situation before we trigger the switches. First we fire the trigger generator # 1. A pulse of -50 kV is applied to the trigger electrode, bringing it up to -150 kV (in the case of 200kV charging) and closing the switch. The first pulse is sent to the load. Now the right-hand side of the switch #2 connects to the ground through the closed switch # 1. Hence the voltage difference of the two electrodes of switch # 2 is -200 kV and can be close when the trigger pulse arrives a few hundred nanosecond later and the second pulse is send to the load. The amplitude of the second pulse is a bit lower as compared with the pulse # 1 due to the resistance of the switch # 1 and the longer travel length of the cable. After the first firings the switches are purged and pressurized with dry air. This sequence can be repeated a few times per minute over a long stretch of time.

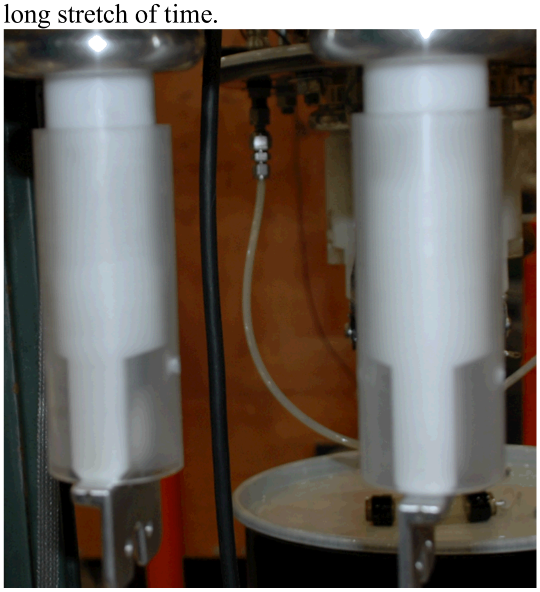

Figure 8. Cable guides with acrylic sleeves

Figures 3 and 4 show one of the cable guide designs tested during our experimentation. Before that, we were using bare cable connection, and we successfully fired 1000 at 170 kV charging without any problem with the high voltage cable connections. The dwell time was 30 seconds. However, with this way of connecting and supporting the switches from the barrel leads, it was difficult to use cable quick disconnects. This is why we originally tried the cable guides of Fig. 3 and Fig. 4 to guide the cables and support the switches. Because of the small thickness of the cable guide walls we observed frequent arcing through the guide wall. Then, to electrically re-enforce the thin walls of the guides, we surrounded them with relatively thin acrylic sleeves (Fig. 8). Now we started arcing through the sleeves. With those tests we discovered that because of the HVDC oil conductivity and polarization of the solid dielectric immersed in the oil, all the DCHV field strength was applied across the thin walls of the plastic sleeves and cable guides. We felt that the solution will be to use monolithic cable guides with enough thickness to hold the entire field stresses across their walls. This is why we developed as a result of our tests and computer simulations the cable guides shown in figures 9 and 10.
These cable guides have the outside shape of vintage “Old Spice cologne” bottles. They have thinner walls at the top near the ground electrode field shaper and much thicker close to the termination of the high voltage cables (Fig.10).

Figure 9. The switches are suspended with the new successful cable guides. The cables are outside of the guides. The oversize banana plugs are also visible.

Figure 10. Close-up of the new cable guide

These cable guides have been proven very successful. Up to the writing of this paper we have fired with no arcing 714 shots at 170kV charging, 550 at 180kV, 528 at 190kV, and 408 shots at 200kV. Our plans are to continue testing the cable and cable guides for up to 220kV.

Figure 11 presents sample of the current double pulses. We are currently working to eliminate excessive noise level affecting the V-dot outputs.

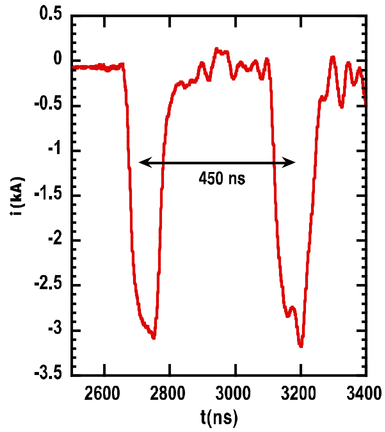

Figure 11. Sample of the current double pulses. The top of the second pulse is affected by ringing visible also on the base line.

IV. SUMMARY

Our component test stand utilizes cables as storage capacitors connected in series through switches in order to generate two high voltage pulses of similar amplitudes. The set-up can be rep-rated quite fast and obtain lifetime results of various pulsed power components at relatively very short time. We have fired up to 500 shots per day. Our first goal was to test the high voltage cables under HVDC and pulsed conditions and certify different types of high voltage cable guides and feed-throughs connected to the switches. We have successfully tested a number of them against arcing for many hundreds of shots. The most promising of them were tested to 200kV charging up to 400 shots with no failure. We are currently shielding the cables and screen room to alleviate the electrical noise problem and also plan to calibrate our diagnostics before proceeding to precise switch performance evaluation. One of the problems we encountered was finding appropriate commercial resistors capable of holding the high voltage and not becoming impregnated by the oil (trigger resistors).

V. REFERENCES

[1] SPELLMAN High Voltage Power Electronics Corporation, 475 Wireless Blvd. Hauppauge, New York, 11788, www.spellmanhv.com, XRV series, XRV225/3000

[2] Dielectric Sciences In., 88 Turnpike Road, Chelmsford, Massachusetts 01824, www.**dielectrics**ciences.com

[3] A. Jacksts, U. Gafvert " Temporal Development of the Electric Field within a Stressed Oil Gap" IEEE Transaction on Electrical Insulation. **23** No. 4 August 1988. P. 723-727

[4] U. Gafvert, A. Jaksts, C. Tornkvist, L.Walfridsson, "Electrical Field Distribution in Transformer Oil" IEEE Transaction on Electrical Insulation. **27** No. 3 June 1992.
P. 647-660.

[5] **L3** Applied Technologies Inc. 2700 Merced Street, San Leandro, Ca 94577

[6] LabView software. National Instruments.
www.ni.com/labview