Meas. Sci. Technol. 6 (1995) 1612–1616. Printed in the UK

A 40 kV high-power earthing switch

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Received 30 December 1994, in final form 12 May 1995, accepted for publication 14 July 1995

Abstract. A high-power earthing switch suitable for use in a high-voltage laboratory has been designed, built, tested and is in operation. The design and operation of the switch is presented. It is shown that the system is free of partial discharges, at the highest operating voltage of 40 kV. The operation of the earthing switch is discussed with reference to safety of personnel and short circuit protection. Its compact size and reliability for fail safe operation over an extended period is also discussed. Its function is discussed with reference to circuit layout.

1. Introduction

In any high-voltage, high-current operation it is imperative that a good grounding system is available. This is primarily for reasons of safety, and protection of personnel [1, 2]. In addition it is important from the stand point of short circuit protection and instrumentation. A high-power earthing switch has been designed, built and is in operation in the high-voltage laboratory at the Royal Melbourne Institute of Technology (RMIT). After several months of operation it has been found to be reliable and fail safe. Its compact size is an attractive feature in a laboratory of limited space. other safety features include microswitches that are brought into a central console from where the experimental rig is operated.

2. Circuit description

The high-current device comprises of four 4 μF, 50 kV capacitors connected in parallel and charged via a half wave rectifier, which in turn is supplied from a high-voltage transformer. The high-voltage transformer is rated at 50 kV (rms) and the secondary current is 1 A. The maximum charging voltage is restricted to 40 kV, and thus the stored energy is limited to 12.8 kJ. The earthing switch consists essentially of three 7.5 kΩ resistors in parallel and a solenoid that has a travel of $\approx$ 135 mm [3, pp 309–20]. The solenoid is placed vertically and the total weight it is called upon to lift, including the mild steel plunger, is 2 kg. Under this scheme the current through the switch, when the capacitor bank is fully charged to rated voltage, is limited to $\approx$ 20 A.

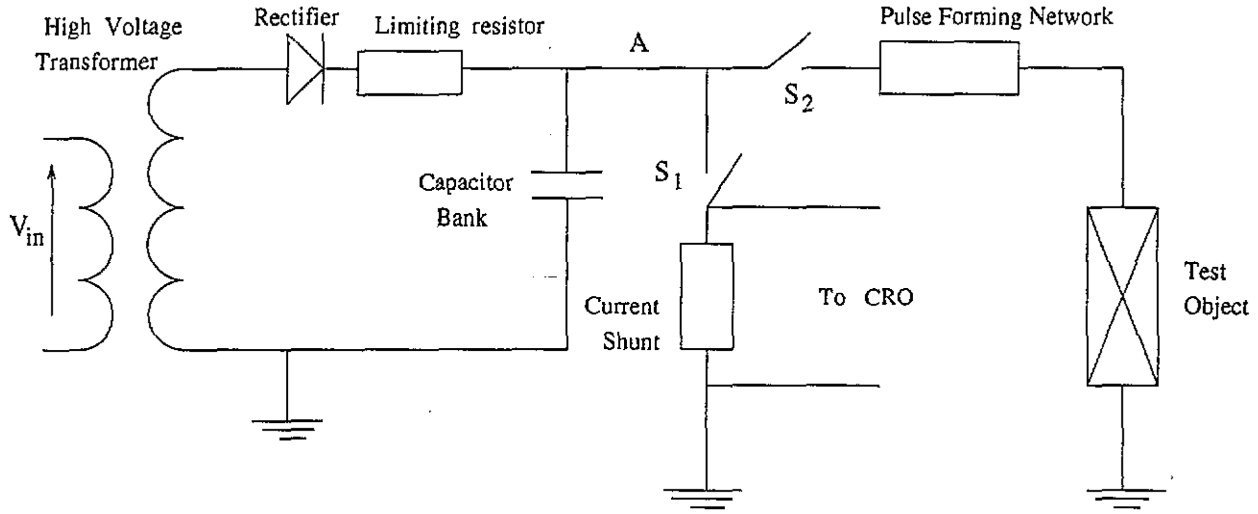

Figure 1. Schematic diagram of circuit for the high-current device. S_1, earthing switch; S_2, three-electrode-high current switch.

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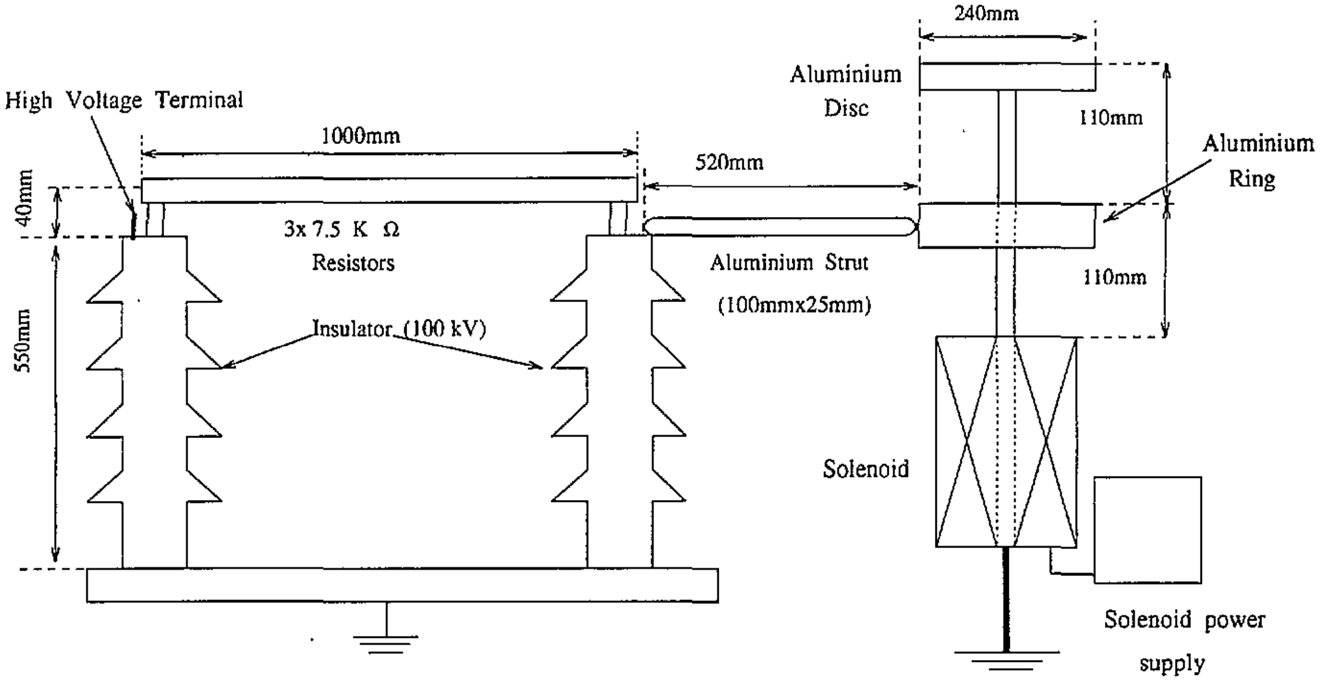

Figure 2. Earthing switch arrangement with all the relevant dimensions given (not to scale). The disc electrode is shown in the open position for normal operation.

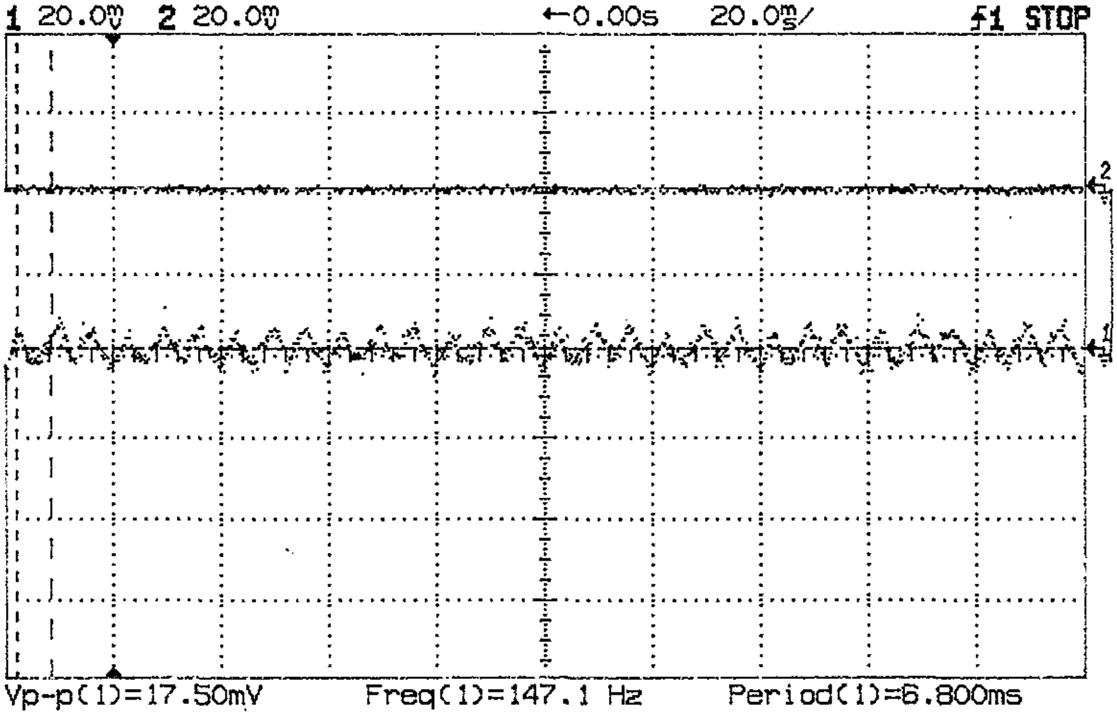

Figure 3. The partial discharge measurement at a distance of 0.5 m from the ring electrode.

3. Circuit operation

Figure 1 shows the schematic arrangement of the experimental set-up. Under normal operating conditions of the high-current device, the capacitors are charged to the required voltage and the three-electrode high-current switch S_2 (model No 40159 Maxwell Labs) is then triggered. The energy is transferred to the test object. The earthing switch S_1 is then closed to drain all residual charge from the capacitors.

Figure 2 shows the earthing switch with the actual physical dimensions (not to scale). The high-voltage terminal is connected directly from the capacitor bank through a high-voltage cable, to the earthing switch. When the experiment is performed, the solenoid raises the earthing disc above the earthing ring which is connected to the high potential side via the parallel resistors. The disc which is carried by the plunger is $\approx$ 110 mm above the earth

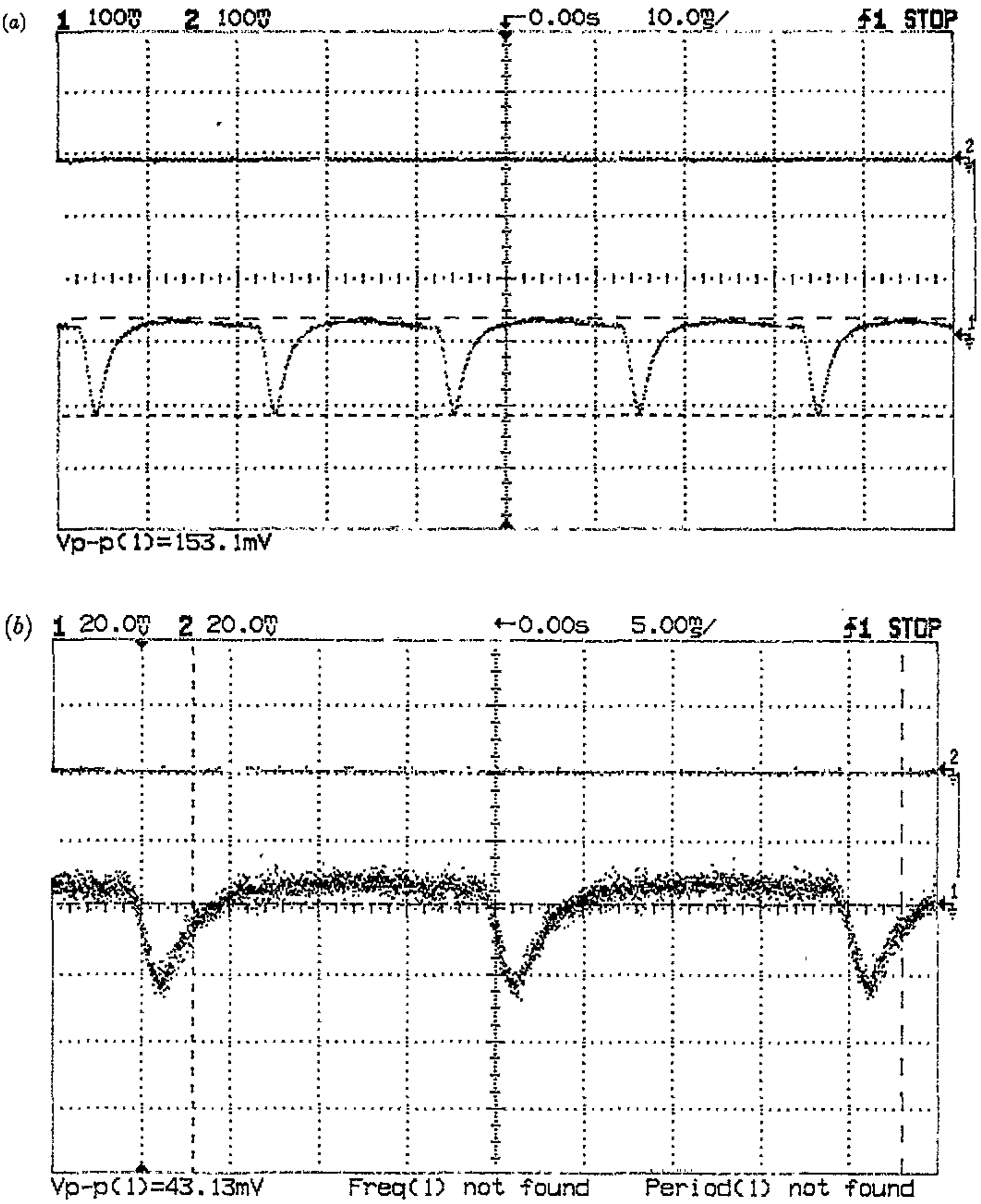

Figure 4. (*a*) Calibration of the electric field probe using a parallel plate electrode configuration. The voltage at the upper electrode is 20 kV. (*b*) The actual field strength measured, using this probe at a distance of 0.5 m from the ring electrode.

side of the switch. The highest voltage of operation of this system is 40 kV positive polarity. The dielectric breakdown strength of atmospheric air is taken as 50 kV m^{-1} [1], and taking equation (3) of reference [1]

$$V = V_l + V_i + K V_e \tag{1}$$

where V_l is the Ohmic voltage drop along conductors, V_e the total earth voltage in the laboratory, V_i the voltage induced into the loop protection system and K is a factor whose value is between 0 and 1.0. Usually V_l is negligible.

The spacing required for an air termination is given by:

$$d \geq \frac{V}{G} \tag{2}$$

where G is the dielectric strength of air, hence $d \geq 0.1$. In the present case the distance between the high-voltage terminal and the nearest earthed object is greater than 10 cm, and the screened wall of the laboratory is ≈ 1 m from the high-voltage terminal. When operating at the maximum rated voltage, the ring electrode shown in figure 2 is at 40 kV DC. Hence it can be seen that there is no possibility of spark developing to the wall. For this to take place S, the distance, has to be about 10 cm even for an electrode of diameter 2 mm [4, 5]. In our case the relative humidity of the laboratory is controlled and never reaches a value of above 40%. The minimum gap spacing in our case is > 10 cm and the diameter of the ring electrode is 220 mm, hence no corona is possible [4]. Also, Allen and Boutlendj [6] have shown that for streamer propagation to occur at humidity of 6.8–7.5 g m^{-3} an electric field of ≈ 480 kV m^{-1} is required for gap lengths of 47 cm and

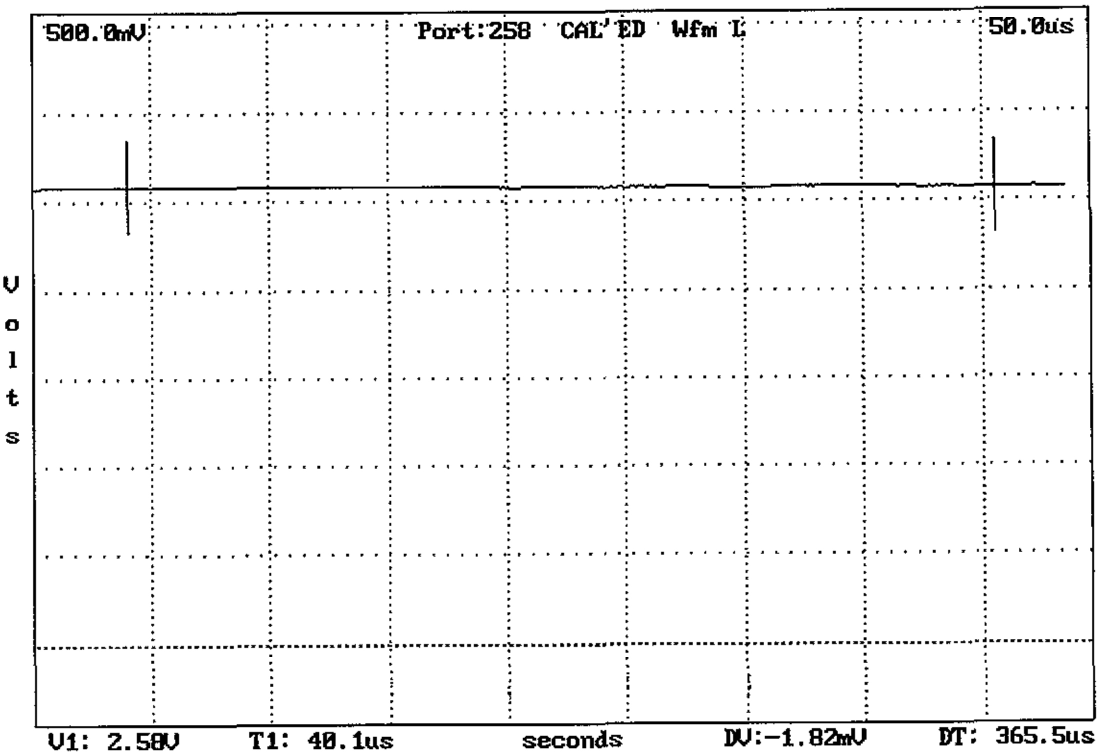

Figure 5. The voltage waveform measured at position A as indicated in figure 1. The ripple voltage is less than 0.05% of peak value. Scales: 5 mV cm^{-1} and 50 μs cm^{-1}.

66 cm. For a higher humidity of 17–18 g m^{-3} the field strength has to be $\approx$ 555 kV m^{-1} (in both cases they give the 50% probability value). In addition, Feser and Schmid [7] have shown a similar dependence on humidity, and in this case the field distribution was highly non-uniform being a rod–rod gap. The field configuration in the present work does not allow for large field gradients to develop at the rate maximum voltage of 40 kV. Thus, space charge enhanced corona that drives ions to the earthed electrodes which eventually lead to streamer breakdown [8–10] is absent. Figure 3 shows the result of a test at 40 kV using a partial discharge detector (ERA discharge detector model 3, type 652) together with a 500 pF coupling capacitor, the sensitivity of the detector is then 0.03 pC. The probe was placed $\approx$ 50 cm from the top end of the ring electrode. As can be seen there is no detectable partial discharge at this voltage. Figure 4 shows the result of measurements to determine the field strength in the vicinity of the switch. Figure 4(*a*) shows calibration of the probe using a parallel plate arrangement, where the distance between the plates is $\approx$ 30 cm. At 20 kV the probe voltage is 193 mV which corresponds to a field strength of 0.67 kV cm^{-1}. Figure 4(*b*) shows the value of the field strength at a distance of $\approx$ 0.5 m from the ring electrode. The same capacitive probe was used for both measurements of field strength and partial discharge. These measured field values are far too low for field enhanced discharge development between the switch and any earthed object.

The measured value of the circuit inductance is $\approx$ 0.02 mH. The rate of change of current ($\mathrm{d}i/\mathrm{d}t$) is 2×10^6 A s^{-1}. Hence the induced voltage $L\,\mathrm{d}i/\mathrm{d}t$ is about 40 V and can hence be ignored.

The plunger carrying the earthing disc is firmly bonded to earth through copper braid. The ring and disc arrangement ensures even current distribution and thus minimizes the current density. The solenoid operates at 19 V DC and 4.1 A, the number of ampere turns is 4150, giving a lifting force of 1.96 N m. When the solenoid is de-energized the plunger falls under gravity, thus ensuring the switch to be fail safe.

4. Results

Figure 5 shows a typical result of voltage waveform at the point A (figure 1) on the network with S_1 and S_2 in the open position. Figure 6 shows the current waveform when the capacitors are discharged to ground through the earthing switch S_1. For voltage measurements we used a 140 MΩ, 140 W resistor with a 10:1 low-voltage divider, and the waveform was recorded on a 400 MHz Tektronix 7844 oscilloscope fitted with a 7416A amplifier and a Tektronix C1001 camera. The captured signal was processed by a laboratory PC to give the final oscillograms. For current measurements a 1.1 mΩ current shunt (Hilo ISM type 100) was placed on the earth braid between the bottom end of the plunger and the earth terminal. The waveform was obtained using the same measuring system as before.

In conclusion we have constructed and now operate a very effective and safe earthing switch for a high-power system. It is inexpensive and compact. It should be of interest to others who may be contemplating setting up a similar earthing arrangement to that described here. However, it must be pointed out that no over-voltage or

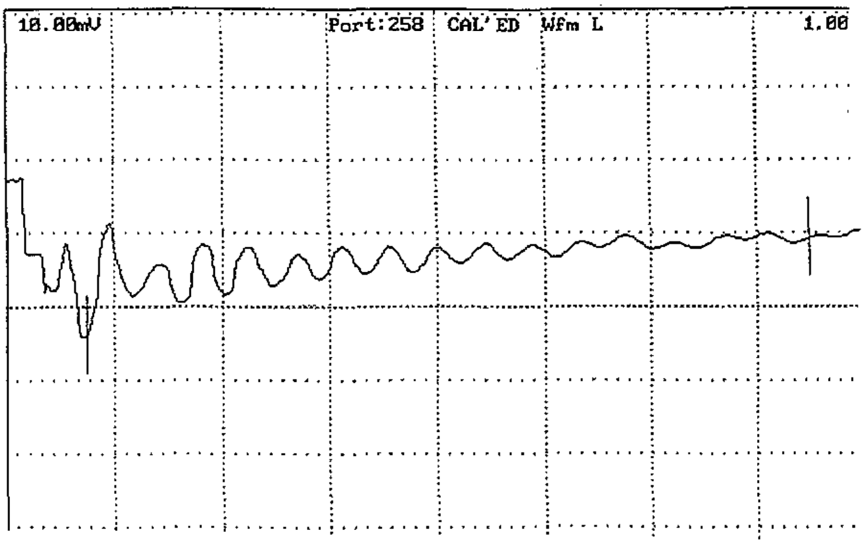

Figure 6. The current waveform measured on the earth braid when the system is discharged to ground with the capacitor bank charged to 40 kV. The peak current is limited to about 20 A and decays to zero in ≈ 10 μs. Scales: 10 mV cm^{-1}, 1 μs cm^{-1}. (1.25 mV corresponds to 1 A.)

impulse tests were carried out to test the switch to IEC standards, as the switch is not a commercial unit.

Acknowledgments

The author wishes to thank Professor S Shihab and the Department of Electrical Engineering at RMIT for financial support and the laboratory facilities. Thanks are also due to Mr Stephen Bicknell for fabricating and installing the switch, Mr V Rao for helping with the measurements, and Mr Charles Patak for valuable discussions on design aspects.

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