College of Engineering

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High-voltage Test Report – Cross Arm Insulation (ENI)

ENI Engineering have approached University of Canterbury (UC) for testing services to ascertain the insulating properties of a new insulation system (as shown in Fig. 1) for steel cross arms for use in electrical distribution networks. UC performed the following HV tests on 24/07/2018.

- Insulation Resistance (IR) and Polarisation Index (PI)
- Dielectric Dissipation Factor
- AC Withstand Test
- Creepage Distance Measurement

The atmospheric conditions on the test day were:

- Temperature – 11°C
- Humidity – 60%,
- Pressure – 1018 hPa

All tests were performed with the cross arm tied to earth and an ASTM D149 electrode (a brass cylinder 25 mm in diameter, 25 mm in length with edges rounded to a radius of 3.2 mm) placed on the outer surface of the insulation, as shown in Fig. 2, connected to the HV source. All measurements were taken with calibrated equipment. All ac voltage values in this report are RMS values.

The sample withstood all key voltages (up to 38.1 kV) during the ac withstand test, which was conducted under a stepped voltage application. The results of surface flashover test show that in the worst case scenario of this experiment, i.e. with a horizontal distance of 100 mm between the HV electrode and the grounded cross arm, the flashover voltage is approximately 36 kV, 26 kV and 12 kV during the dry test, wet test and the salt solution test (1g/L NaCl) respectively.

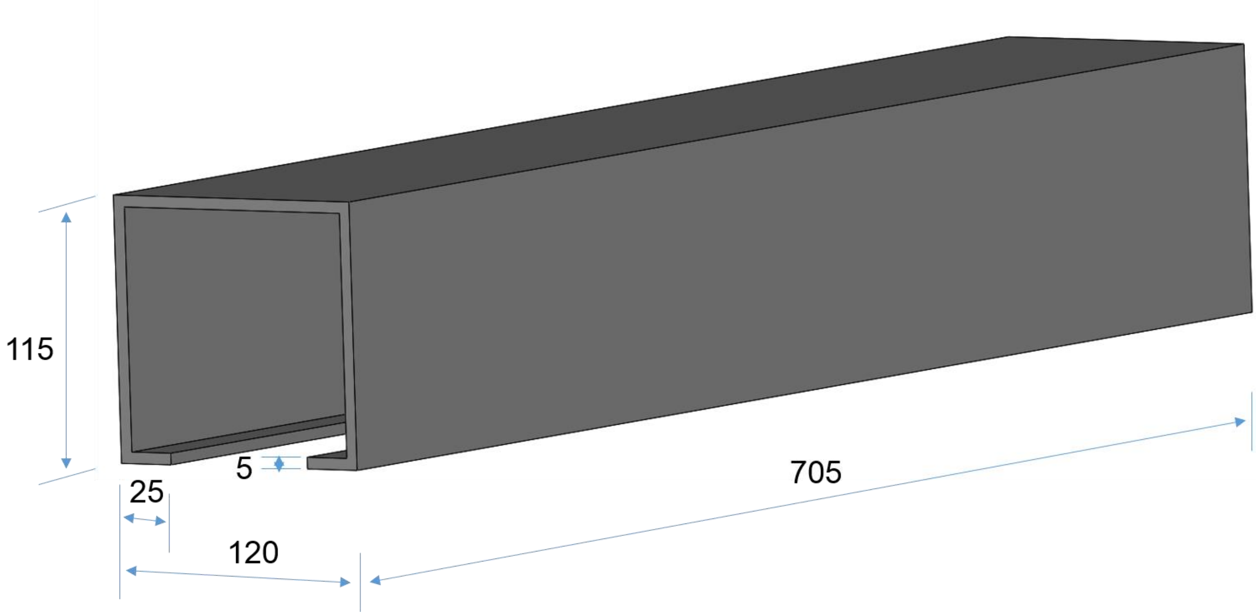


Fig.1 Dimensions of the sample provided by ENI (Unit: mm)

A. Insulation Resistance (IR) and Polarisation Index (PI)

One minute IR and ten minute PI tests at 5000 V dc between the cross arm and the electrode have been conducted. The HV electrode was placed 100mm from the end of the insulation, as shown in Fig. 2. The IR test results are shown in Table 1.

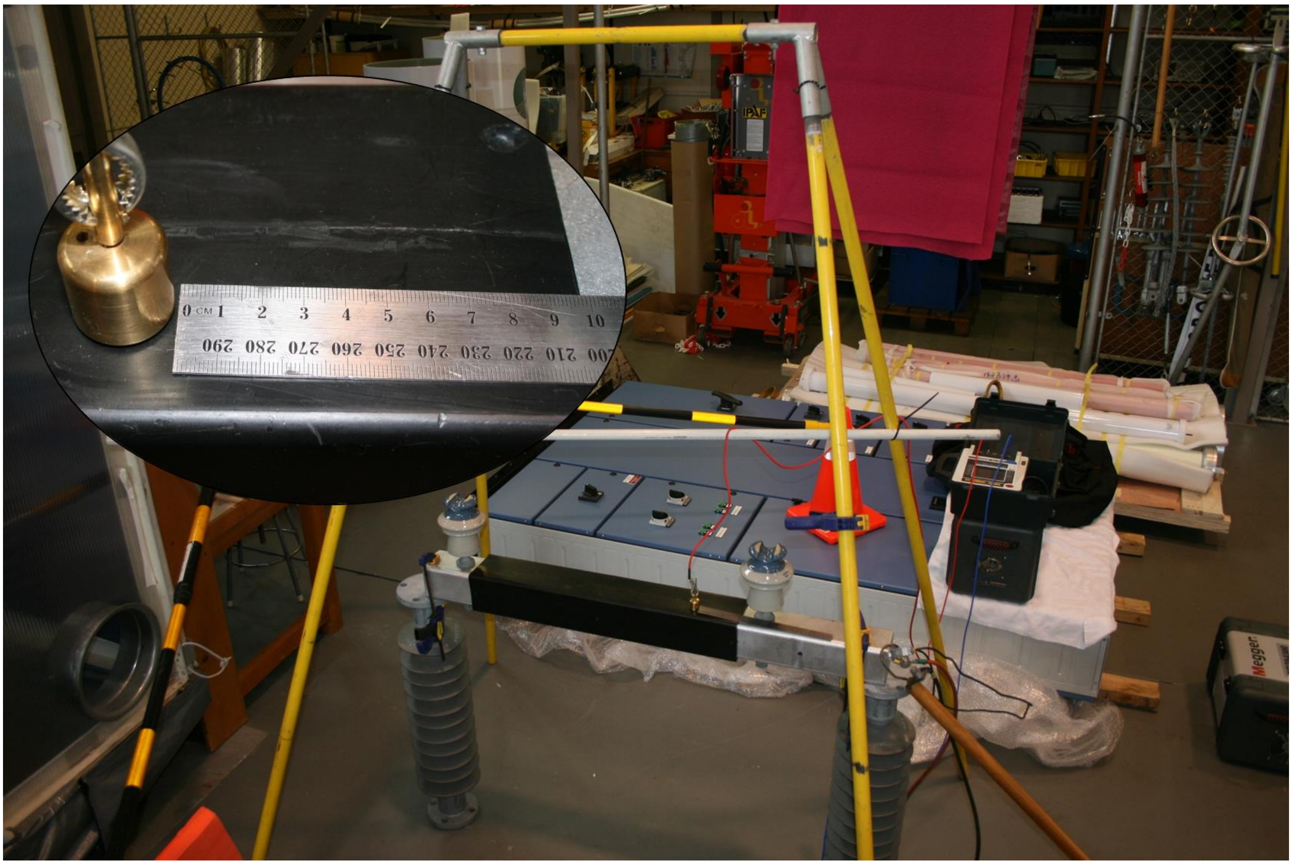


Fig.2 Set-up during the IR measurement

Table 1 IR test results

Time from Start of DC Voltage Application	IR
15 s	74 GΩ
30 s	1.6 TΩ
45 s	2.2 TΩ
1 min	2.9 TΩ
10 min	5.1 TΩ

If the measurement result at 1 min is used for leakage current calculation, when under 5000V dc, the leakage current would be approximately 1.7 nA. Referring to Table 2 in IEEE Standard 43-2000 *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery*, "if the 1 min insulation resistance is above 5000 MΩ, the calculated P.I. may not be meaningful". Therefore, the PI result was not calculated and the sample could be considered to have adequate insulation resistance.

B. Dielectric Dissipation Factor

The measurement of the dielectric losses and capacitance of the insulation was conducted at 10kV ac with a frequency of 50Hz. A length of aluminium tape, as shown in Fig. 3, was attached to the surface of the sample to increase the surface area of the electrode, increasing the capacitance to be measured into the range of the measurement equipment (Megger Delta 4300 was used for this measurement). The ac voltage was applied at the rate of 1 kV/s. The measurement results under different voltages between 2kV and 10kV have been plotted in Fig. 4. Both the dielectric loss and the capacitance increases with the applied voltage. The higher the voltage is, the greater the increase rate of both parameters is.

Fig.3 Set-up during the measurement of dielectric losses and capacitance of the insulation

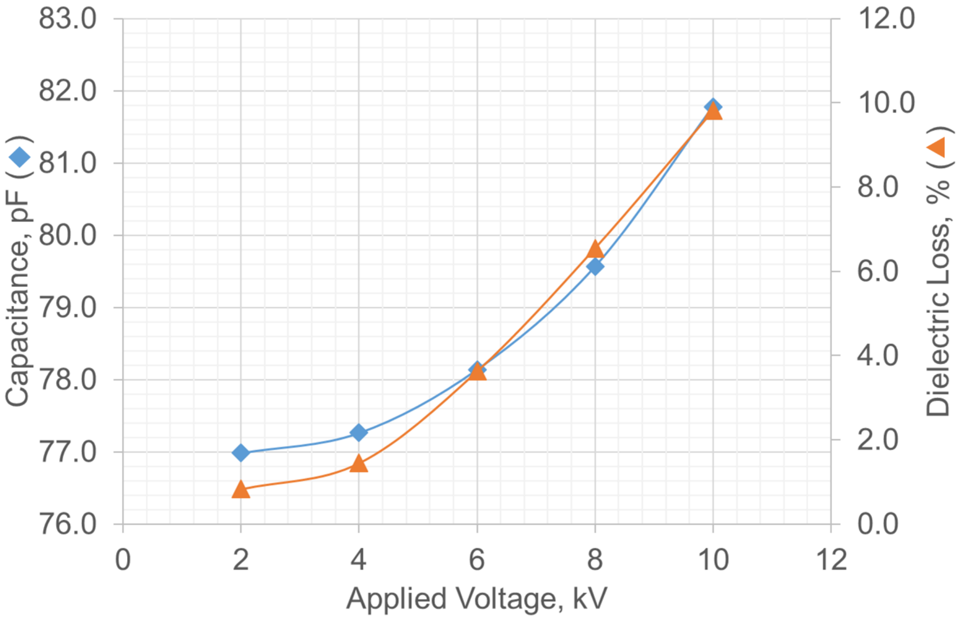


Fig.4 Measurement results of Dielectric Dissipation Factor

C. AC Withstand Test

With the HV electrode placed on the sample in the middle, i.e. with a horizontal distance of 352.5 mm to ground, an ac voltage was increased at 1kV/s, held at the key voltage for 60 seconds then increased at 1 kV/s to the next key voltage where it was held for 60 seconds. After the final key voltage is reached, the applied voltage was increased at 1 kV/s until flashover or breakdown of the insulation. The key voltages are the phase to ground voltages of standard distribution network voltages 6.35 kV (11 kV), 12.7 kV (22 kV), 19.1 kV (33 kV) and 38.1 kV (66 kV). As shown in Fig. 5, no flashover occurred at the key voltages. When the voltage was increased at 1kV/s to 42.0 kV, surface flashover occurred across the circumference of the insulation from the electrode to the grounded cross arm in a similar fashion to Fig 8 (b).

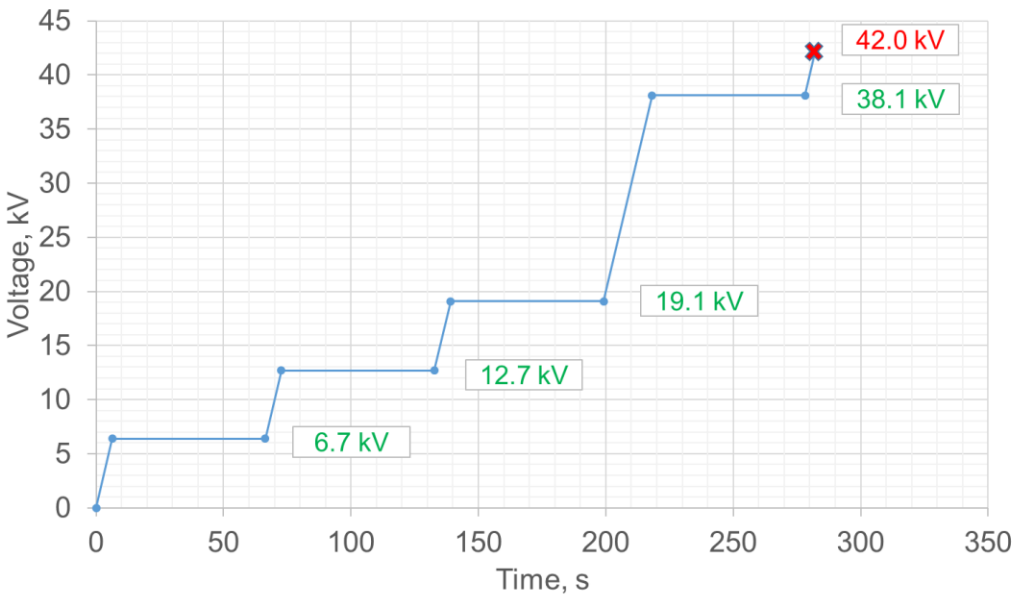


Fig.5 AC withstand test results

D. Creepage Distance Measurement

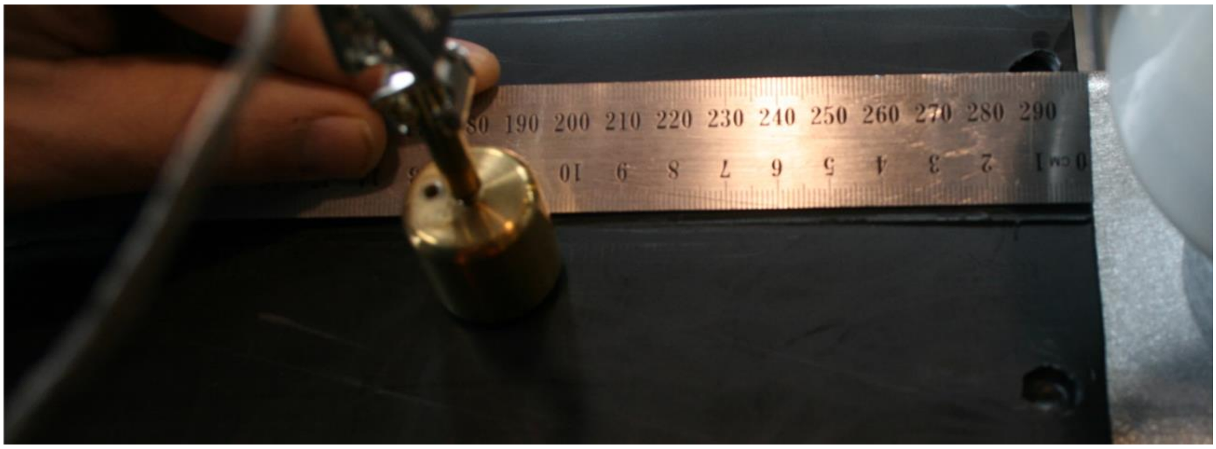
The surface flashover voltage was measured at a horizontal distance of 100mm, 150mm and 200mm to ground, as shown in Fig. 6, for dry, wet and wet with a salt solution (1g/L NaCl) cases. The actual shortest horizontal creepage distance (including the thickness of sample) is 105 mm, 155 mm and 205 mm for the three groups of test, respectively. The applied voltage was increased at approximately 1 kV/s until flashover. Five flashover tests were performed at each distance and surface condition. The dry tests were conducted first and then the wet tests, and finally the test with the salt solution. Both dry test and wet test were conducted at the same end of the sample, whereas the test with the salt solution was conducted at the other end of the sample.

Table 2 and Fig. 7 show the flashover results for the different groups under different conditions. It can be seen that during the dry test, the mean value of flashover voltage tends to saturate with increasing surface length. The reason for this is related to the surface discharge propagation. When the surface length is small, the electric stress of the discharge initiated at the triple junction area is largely affected by the surface length between the HV and the grounded cross arm. The triple junction area is near the edge of the HV electrode close to the surface of sample. A significant electric field would be in this area due to the high permittivity mismatch between the insulation material and the air. However, for a larger surface length, the electric stress of the surface discharge is determined by the local electric field. In this experiment, this is affected by the back electrode, which is the grounded cross arm bar.

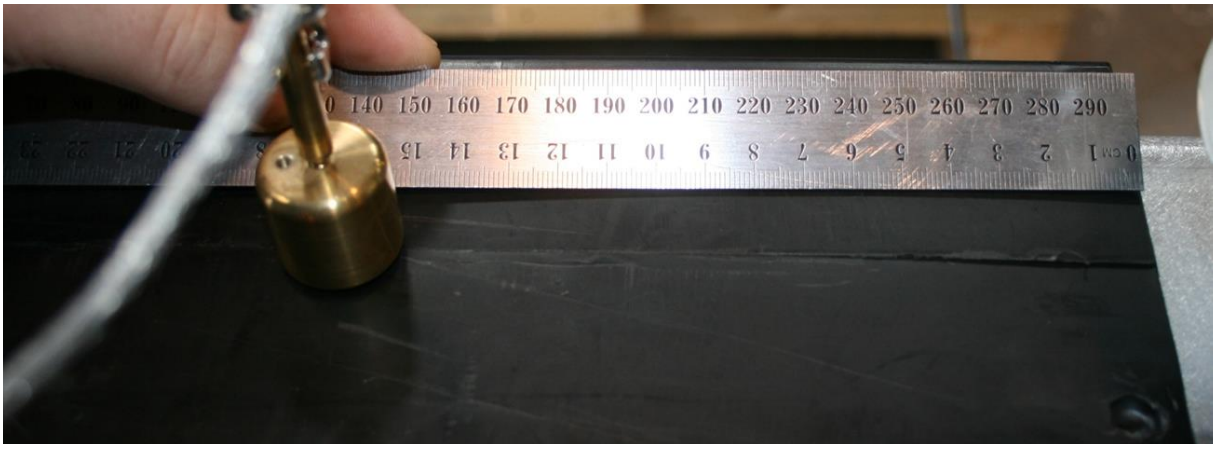
It was also observed that during the test of 150 mm (Fig. 8), other than the flashover along the upper surface of the sample, with the slightly increased voltage, the flashover could also occur along the side surface. Fig. 9 shows the shortest creepage path along the side surface to the grounded part and the surface length is around 193 mm. This can also help to explain the saturation of the flashover voltage with increasing horizontal surface length.

When compared to the dry test, the surface flashover voltage during the wet test (Fig. 10) decreases by 28%, 0% and 10% for the group of 100 mm, 150 mm and 200 mm, respectively. The flashover voltage during the test with salt solution decreases by 67%, 50% and 39% for the group of 100 mm, 150 mm and 200 mm, respectively. The salt solution sprayed on the surface of sample has largely reduced its surface resistance, resulting in larger leakage current when under the high voltage. This is considered an extremely severe test.

An interesting phenomenon was observed after the wet test. Clear trace of treeing could be seen after the wipe of water on the sample's surface, as shown in Fig. 10. This is because of the damaged surface during the flashover, which would affect the surface roughness. The difference of surface roughness results in the clear trace of damaged surface.



(a) 100 mm



(b) 150 mm

(c) 200 mm

Fig.6 Position of the HV electrode during each group of test

Table 2 Surface flashover test results

(kV)	Dry						Wet						Salt Solution					
	1	**2**	**3**	**4**	**5**	**Mean**	**1**	**2**	**3**	**4**	**5**	**Mean**	**1**	**2**	**3**	**4**	**5**	**Mean**
100mm	35	38	39	35	34	36	32	27	26	22	25	26	12	12	13	11	14	12
150mm	41	43	39	41	34	40	42	41	39	39	38	40	16	20	20	23	23	20
200mm	41	41	40	41	42	41	42	39	35	38	32	37	26	22	25	26	25	25

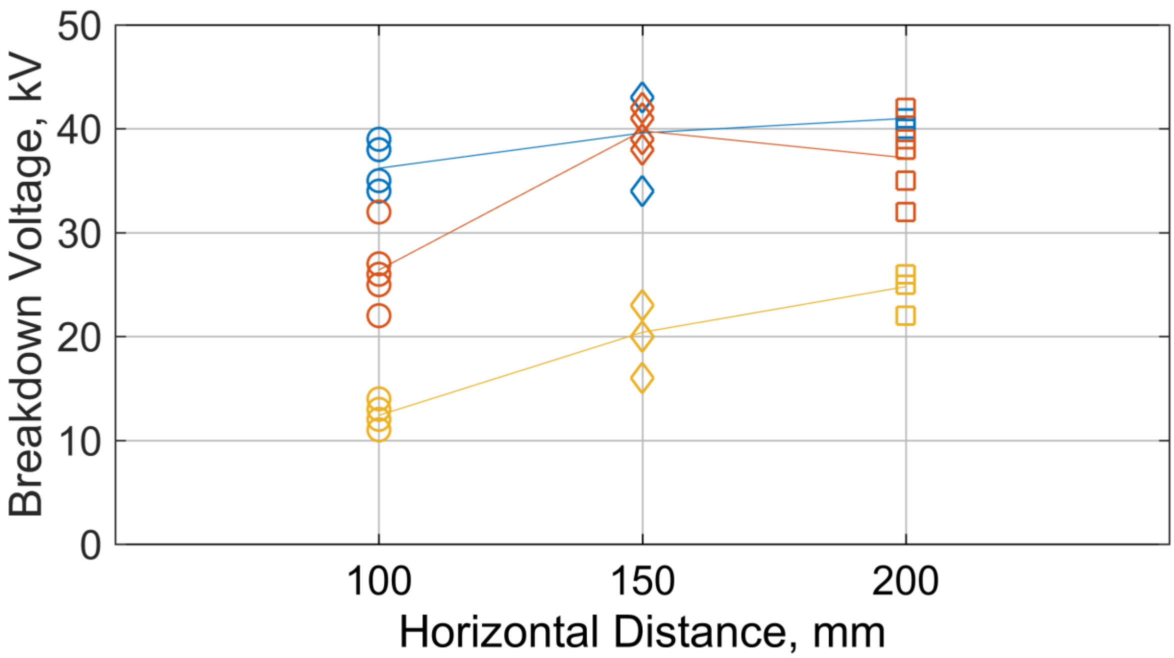
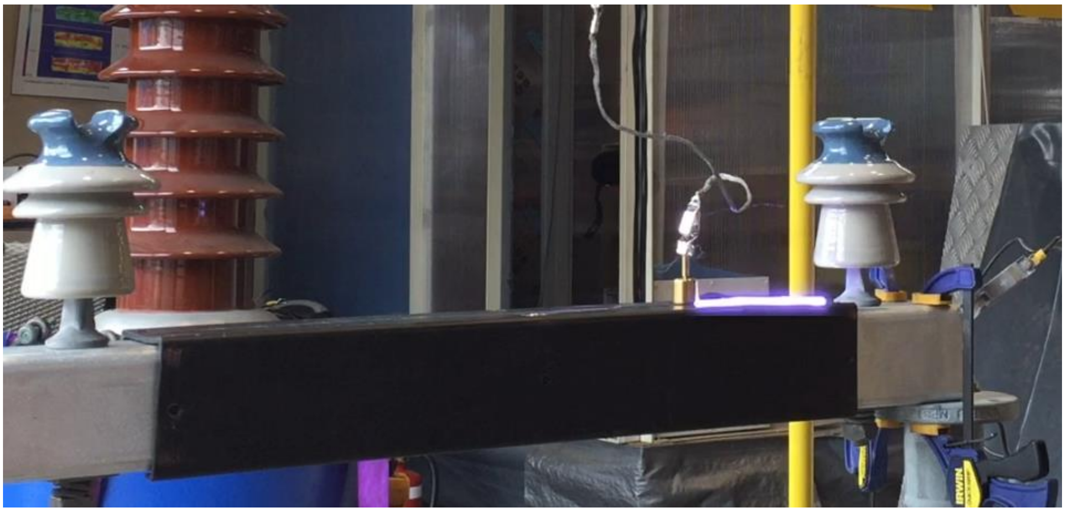
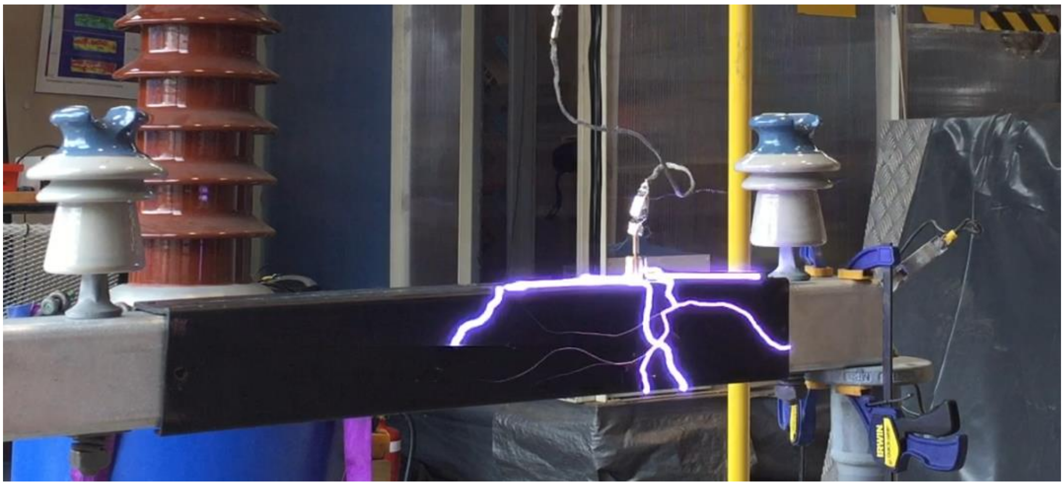


Fig.7 Surface flashover test results
(Blue – Dry test, Red – Wet test, Yellow – Salt solution; Circle – 100 mm, Diamond – 150 mm, Square – 200 mm)



(a) 150 mm, 39 kV



(b) 150 mm, 40 kV

Fig.8 Different surface flashover paths during one test

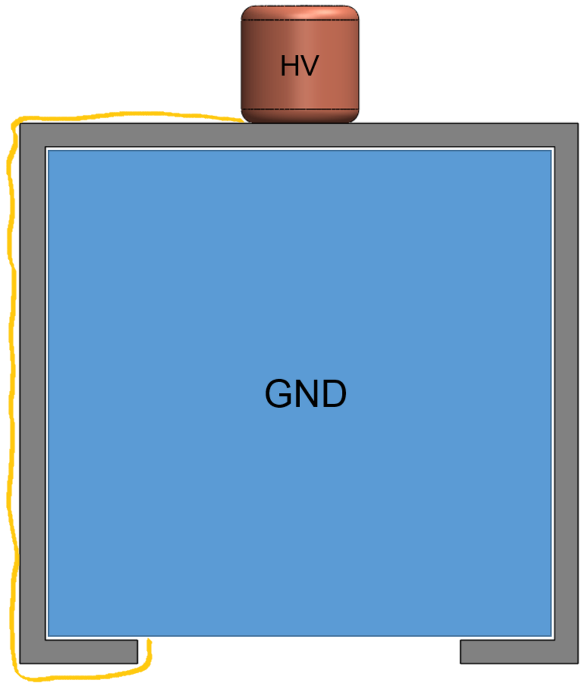


Fig.9 Diagram showing the shortest creepage path along the side surface

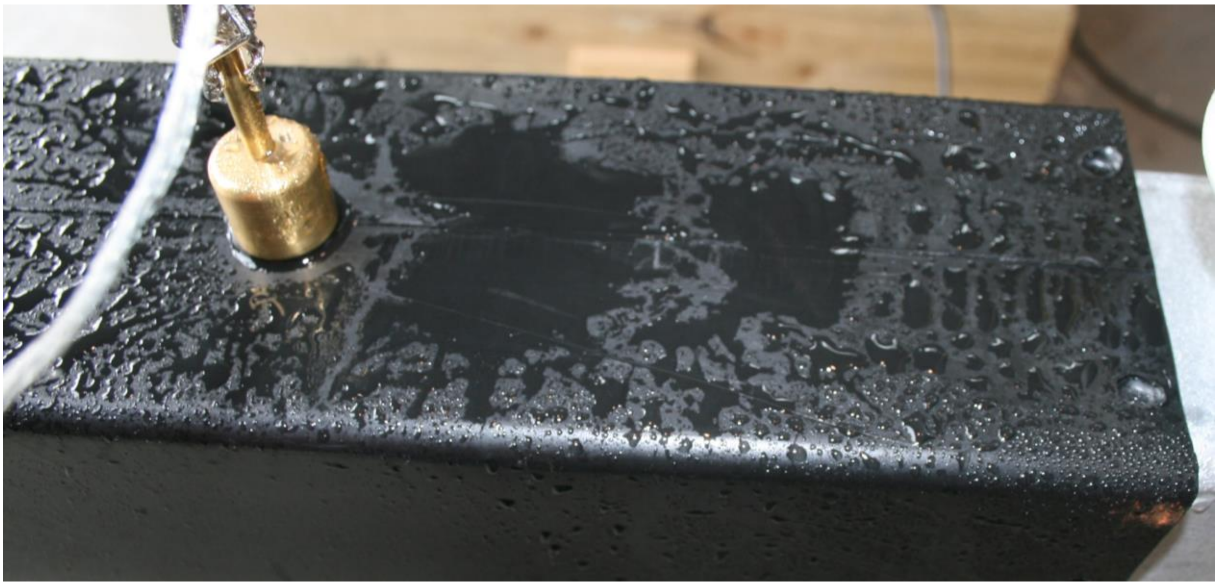


Fig.10 Wet test

Fig.11 Clear trace of treeing after the wipe of water on the sample's surface

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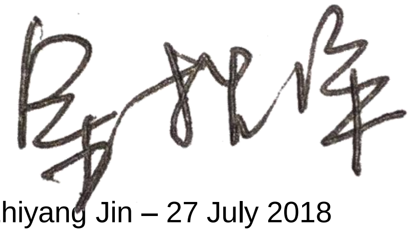

Zhiyang Jin – 27 July 2018

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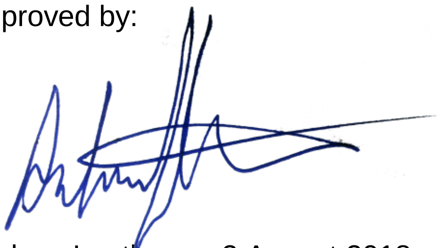

Andrew Lapthorn – 2 August 2018