



## Test Report



### Impulse Voltage Test: Lightning Down-Conductors With Terminations

Report No. LPI2014  
 Customer: Lightning Protection International, Kingston, TAS 7050  
 Date of issue: 12 December 2014  
 Test date: 10-11 December 2014  
 Tested items: HVSC PLUS lightning down-conductors fitted with terminations as supplied by the  
 Quantity: 10

#### Summary

*This test was carried out by Monash University at the Jack Wilson High Voltage Laboratory in accordance with the requirements set out by Lightning Protection International. The maximum lightning impulse voltage values that individual samples withstood were as follows:*

Sample No / Impulse polarity	1	2	3	4	5	6	7	8
Positive	NA	NA	NA	NA	NA	NA	470 kV	> 480 kV
Negative	461 kV	> 496 kV	> 499 kV	> 503 kV	> 497 kV	> 510 kV	NA	NA

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## 1 Introduction

This test was carried out by Monash University at the Jack Wilson High Voltage Laboratory. The test procedure followed requirements set out by the customer, namely, Lightning Protection International. Ten down-conductor samples fitted with terminations on both ends were supplied by the customer for testing. Two out of the ten samples supplied were damaged mechanically during preparation and subsequently they were not tested.

## 2 Sample description

All samples prepared for testing comprised a short length of the HVSC down-conductor terminated at both ends. Both terminations were identical and fitted with connector lugs. Each sample was 6 metres long, lug-to-lug, with the length of down-conductor between terminations of 2.8 m approximately. The sample was looped and terminations joined together using a conductor bar from which it was suspended on an insulator. The photograph in Figure 1 depicts such one sample connected to the impulse generator and ready for testing.

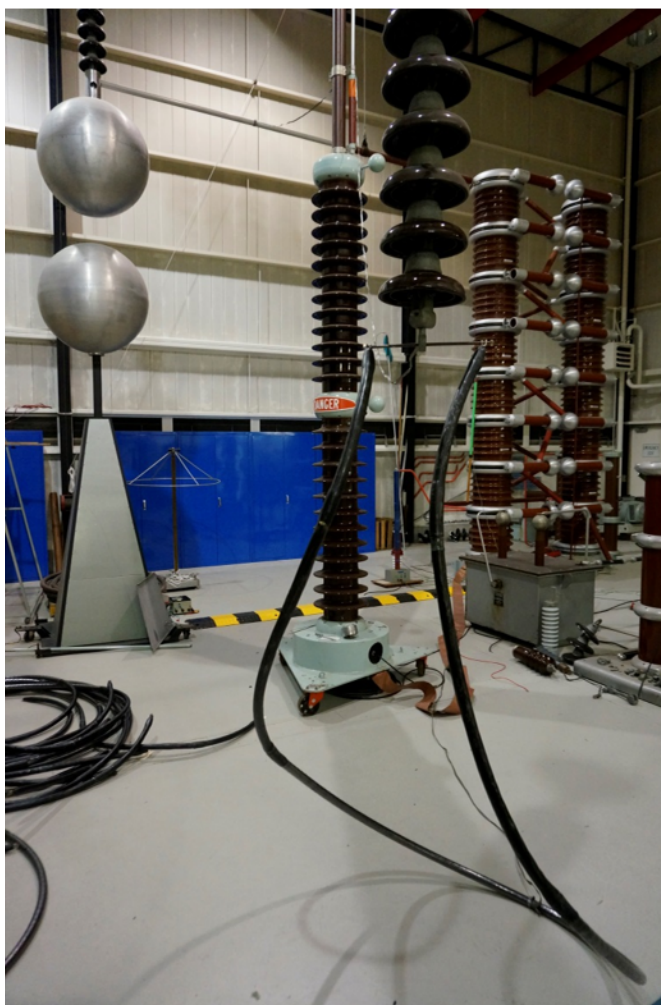


Figure 1: Test sample connected to the impulse generator ready for testing

### 3 Test equipment

The test was conducted in the Jack Wilson High Voltage Laboratory at Monash University. The eight-stage, 1.6 MV Ferranti impulse generator was used as the source of the test voltage. In order to produce the test voltage at the level appropriate for this test, i.e. in the range of 400 kV, four stages out of the eight stages available in the generator were utilised.

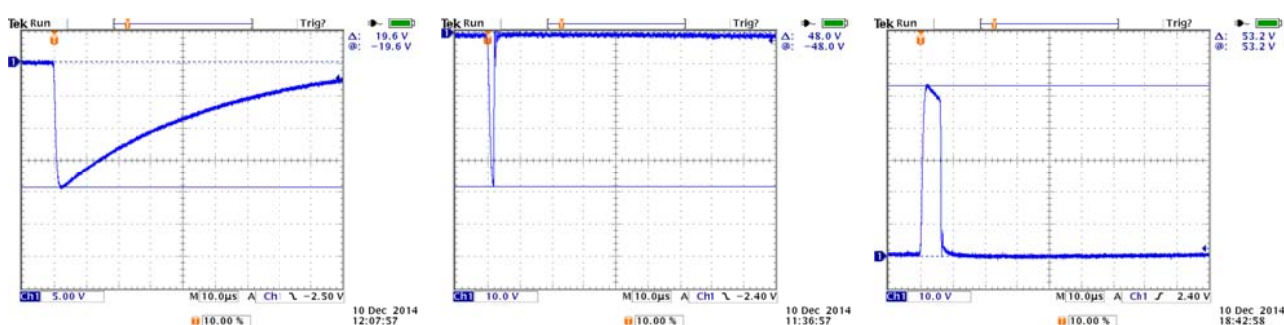
The measurement of the peak value of the generator output voltage was carried out using a 100-cm sphere gap, as per procedure from IEC60052 [1]. The voltage waveforms were recorded and the peak value of the voltage was measured on the Tektronix TDS-3032B digital oscilloscope with the use of the Ferranti 1.6 MV, 400 pF capacitor divider model No. 11685/72053.

### 4 Test procedure

The test procedure was set out by the customer, Lightning Protection International and it was based on AS1931, Part 1 [2]. It required that the test voltage was applied to the sample in increasing steps up to the level at which a disruptive discharge was observed. The voltage was incremented in 10-kV steps at voltages close to the anticipated disruptive discharge level. The variation from AS1931 was in that the test voltage was applied at each level once.

It was anticipated that a disruptive discharge could occur at the voltage level of 400 kV or so. This voltage was used as the target in the calibration procedure. The aim of calibration was to establish the relationship between the generator charging voltage and the output voltage (output/charge ratio) as well as between the output voltage and the oscilloscope reading (voltage divider ratio). Three calibration points were found at 50%, 65% and 80% of the target voltage. The generator charging voltage values for test voltages beyond the 80% level were determined by linear extrapolation from the three calibration points. All generator calibration data and results are included in Appendix A of this report.

The presence of a disruptive discharge in the tested sample was determined from the shape of the impulse waveform recorded on the oscilloscope as well as by visual observation. Examples of a voltage waveform trace with no disruptive discharge and a waveform affected by a disruptive discharge are shown in Figure 2.



**Figure 2: Examples of voltage waveform traces: full negative impulse (left), negative impulse affected by a disruptive discharge (middle) and positive impulse affected by a disruptive discharge (right).**

For the purpose of this testing the following test sequence was adopted:

- 1) Six out of the eight samples were subjected to the test using impulses of negative polarity.
- 2) Two remaining samples were subjected to the test using impulses of positive polarity.
- 3) One impulse at a given voltage level was applied.
- 4) If no disruptive discharges occurred the sample passed the test at that voltage level.
- 5) If a disruptive discharge occurred, an additional pulse at the same level.

- 6) If the disruptive discharge re-occurred upon the application of the additional pulse the sample failed at this voltage level.
- 7) If the disruptive discharge did not occur upon the application of the additional pulse the test was continued at the next voltage level.
- 8) The highest voltage at which there was no disruptive discharge observed was declared to be the withstand voltage of the sample.

## 5 Results

### 5.1 Summary of calibration

The generator calibration procedure comprised

- confirmation of the pulse front time,  $T_1$ , (nominally 1.0 – 5.0  $\mu\text{s}$ )
- confirmation of the time to half-value,  $T_2$ , (nominally 50  $\mu\text{s} \pm 20\%$ )
- determination of the voltage ratio for measurements of impulse amplitude on the oscilloscope

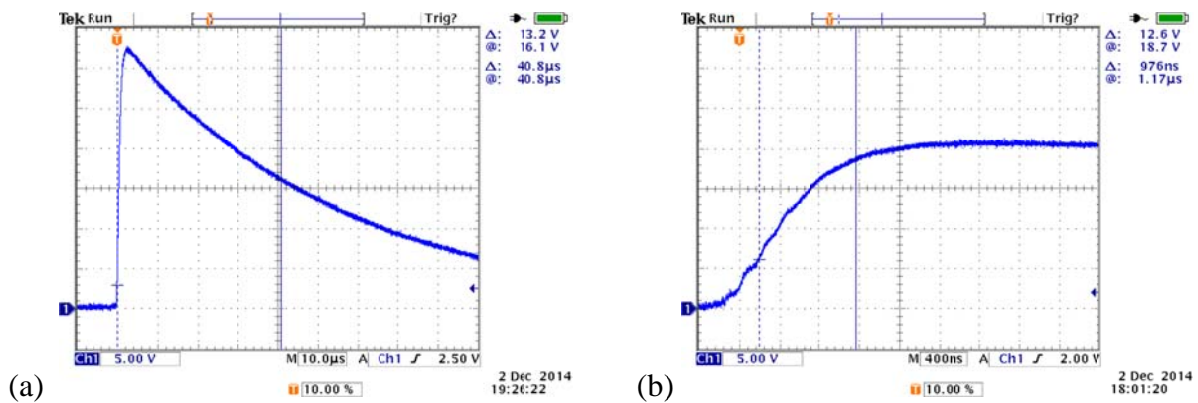


Figure 3: Oscilloscope traces showing the impulse tail (a) and front (b).

Figure 3 shows waveform traces that were used for measuring the pulse front and tail timing. The obtained values were:

$T_1 = 1.95 \mu\text{s}$ , which was within the allowed tolerance of 1.0 - 5.0  $\mu\text{s}$ .

$T_2 = 40.8 \mu\text{s}$ , which was within the allowed tolerance of  $\pm 20\%$

The results of determination of the voltage ratio are shown in the subsequent tables

## 5.2 Summary of test results

The results of all individual pulse applications to all tested samples together with the overall result at each voltage level are included in Appendix A. There existed some discrepancy between the voltage output determined from the output/charge ratio and from the voltage divider ratio. In this situation, the lower value of the two quantities, rounded down to the nearest integer, was used as the sample withstand voltage. Table 1 contains the summary of results in terms of the highest voltage that each tested sample withstood.

**Table 1:** Summary of test results

Sample No.	Sample withstand voltage		Remarks
	positive polarity	negative polarity	
1	Not tested	461 kV	Disruptive discharge (insulation puncture) @ 488 kV
2	Not tested	> 496 kV	Disruptive discharge not reached due to generator limits
3	Not tested	> 499 kV	Disruptive discharge not reached due to generator limits
4	Not tested	> 503 kV	Disruptive discharge not reached due to generator limits
5	Not tested	> 497 kV	Disruptive discharge not reached due to generator limits
6	Not tested	> 510 kV	Disruptive discharge not reached due to generator limits
7	470 kV	Not tested	Disruptive discharge (flashover, no puncture) @ 480 kV
8	> 480 kV	Not tested	Disruptive discharge not reached due to generator limits

As shown in Table 1, six samples out of the eight samples subjected to the test withstood the highest voltages that could be applied in the test setting. In this situation, the true withstand voltage was determined only for the two samples in which a disruptive discharge was observed. One of those two samples was subjected to impulse voltages of positive polarity whereas the other sample was subjected to negative polarity impulses.

It can be said that the impulse withstand voltage obtained from the test was in the vicinity of 500 kV on average. However, a larger number of cables would have to be tested in order to assess the withstand voltage more meaningfully in a statistical sense.

## Summary and conclusions

Eight samples of the HVSC down-conductor were tested for the maximum withstand voltage.

- Samples 1 through to 6 were tested with impulses of negative polarity only,
- Samples 7 and 8 tested with positive impulses only,

Six out of the eight samples tested withstood the highest voltage that could be applied in the test setting. Therefore, the true disruptive discharge voltage for these samples is not known. Based on these samples, the withstand voltage was no less than 496 kV for the negative impulse polarity and at least 480 kV for the positive impulse polarity. On average, these six samples withstood the voltage of an order of 500 kV.

The disruptive discharge level was reached in two samples only, namely, Sample 1 and Sample 7. Based on these two results, the withstand impulse voltage from a negative impulse was 461 kV and the withstand voltage for the positive impulse was 480 kV respectively.

## References

- [1] International Standard IEC60052, Third Edition, 2002-10, **Voltage measurements by means of standard air gaps.**
- [2] International Standard IEC60060-1, Edition 3.0, 2010, **High Voltage Test Techniques. Part 1: General definitions and test requirements.**

**Appendix A**

**Impulse voltage test, LPI 2014**

**1. Atmospheric conditions  
(calibration)**

27/11/2014

- Ambient Temperature (°C) : 25.0
- Atmosphere Pressure (mb) : 1009.9
- Humidity (%) : 44
- Correction Factor : 0.980

**2. Calibration result summary**

- Determination of pulse timing

Pulse ampl.	20.8 V	T1	1.95 μs
30%	6.2 V	T2	40.8 μs
90%	18.7		
Δt	1.17 μs		

- Target voltage: 400kV      Sphere size: 100 cm

1	2	3	4	5	6	7	8
Voltage Level (%)	Sphere Gap (mm)	Nominal Gap Voltage (kV)	Corrected Gap Voltage (kV)	Charging voltage (kV)	Oscillosc. Peak (V/div)	Voltage Divider Ratio (x1000 )	Pulse/charge ratio
50	75	203	199.0	70.6	20.80	9566	2.82
65	100	266	260.7	93.1	27.10	9621	2.80
80	120	318	311.7	112.0	32.30	9650	2.78
100	x	x	400.0	142.8	41.61	9613	2.80

### 3. Test results

Charging voltage steps for a 10kV output increment: 3.6 kV

Result legend: o - no discharge x - discharge

Ambient conditions:

20.6 deg  
 at start C 1012 hPa  
 22.1 deg  
 at finish C 1011 hPa

#### Negative polarity pulse sequence

##### **Sample 1**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from voltage divider ratio (kV)
70.6	o	20.2	197.7	194.2
74.1	o	21.1	207.5	202.8
77.7	o	22.1	217.5	212.4
81.2	o	23.1	227.5	222.1
85.0	o	24.1	238.1	231.7
88.6	o	25.1	248.1	241.3
92.1	o	26.2	258.1	251.9
95.7	o	27.2	268.1	261.5
99.5	o	28.2	278.7	271.1
103.1	o	29.3	288.7	281.7
106.8	o	30.2	299.1	290.3
110.4	o	31.3	309.1	300.9
113.9	o	32.3	319.1	310.5
117.5	o	33.4	329.1	321.1
121.0	o	34.3	338.9	329.7
124.6	o	35.3	348.9	339.3
128.1	o	36.2	358.9	348.0
131.6	o	37.1	368.6	356.6
135.2	o	38.4	378.6	369.1
138.6	o	39.2	388.2	376.8
142.2	o	40.2	398.2	386.4
145.7	o	41.2	408.2	396.0
149.3	o	42.2	418.2	405.7
153.0	o	43.0	428.5	413.3
156.6	o	44.0	438.5	423.0
160.1	o	45.0	448.5	432.6
163.7	o	46.0	458.5	442.2
167.3	o	47.0	468.5	451.8
170.9	o	48.0	478.5	461.4
174.4	x	-	488.5	flashover and puncture

Result: 461 kV

**Sample 2**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from voltage divider ratio (kV)
70.6	o	19.6	197.7	188.4
93.1	o	25.7	260.7	247.0
112.2	o	30.8	314.2	296.1
119.3	o	32.8	334.2	315.3
126.5	o	34.6	354.3	332.6
133.6	o	36.8	374.3	353.7
140.8	o	38.6	394.3	371.1
144.3	o	39.6	404.3	380.7
147.9	o	40.4	414.3	388.4
151.5	o	41.4	424.3	398.0
155.3	o	42.4	435.0	407.6
158.9	o	43.4	445.0	417.2
162.4	o	44.2	455.0	424.9
166.0	o	45.4	465.0	436.4
169.6	o	46.2	475.0	444.1
173.2	o	47.0	485.0	451.8
176.7	o	50.6	495.0	486.4
180.3	o	51.6	505.0	496.0

*Result:* 496 kV

*Note:* Generator charging capacity did not allow continuing the test beyond this voltage level.

**Sample 3**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from voltage divider ratio (kV)
70.6	o	19.5	197.7	187.4
93.6	o	25.7	262.1	247.0
112.3	o	30.9	314.5	297.0
142.8	o	39.0	399.9	374.9
146.4	o	39.8	409.9	382.6
149.9	o	40.8	419.9	392.2
153.5	o	41.8	430.0	401.8
157.1	o	42.6	440.0	409.5
160.7	o	43.6	450.0	419.1
164.2	o	44.8	460.0	430.6
167.8	o	45.6	470.0	438.3
171.4	o	46.6	480.0	448.0
174.9	o	47.6	490.0	457.6
178.5	o	50.8	500.0	488.3
182.1	o	52.0	510.0	499.9

*Result:* 499 kV

*Note:* Generator charging capacity did not allow continuing the test beyond this voltage level.



**Sample 4**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from divider raito (kV)
142.8	o	39.4	399.9	378.7
149.9	o	41.2	419.9	396.0
157.1	o	43.0	440.0	413.3
164.2	o	44.8	460.0	430.6
167.8	o	46.0	470.0	442.2
171.4	o	47.0	480.0	451.8
174.9	o	48.0	490.0	461.4
178.5	o	51.2	500.0	492.2
182.1	o	52.4	510.0	503.7
<i>Result:</i> 503 kV				

**Sample 5**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from divider raito (kV)
142.8	o	39.8	399.9	382.6
149.9	o	41.6	419.9	399.9
157.1	o	43.4	440.0	417.2
164.2	o	45.6	460.0	438.3
167.8	o	46.6	470.0	448.0
171.4	o	47.6	480.0	457.6
174.9	o	50.2	490.0	482.6
178.5	o	51.8	500.0	497.9
182.1	x	-	510.0	NA
<i>Result:</i> 497 kV				

**Sample 6**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from voltage divider raito (kV)
142.8	o	44.0	399.9	423.0
149.9	o	46.2	419.9	444.1
157.1	o	48.0	440.0	461.4
164.2	o	50.2	460.0	482.6
167.8	o	51.4	470.0	494.1
171.4	o	52.4	480.0	503.7
174.9	o	53.2	490.0	511.4
178.5	o	54.0	500.0	519.1
182.1	o	55.4	510.0	532.5
<i>Result:</i> 510 kV				

Note: Generator charging capacity did not allow continuing the test beyond this voltage level.

Positive polarity pulse sequence

**Sample 7**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from voltage divider ratio (kV)
142.8	o	44.4	399.9	426.8
149.9	o	46.4	419.9	446.0
157.1	o	48.6	440.0	467.2
164.2	o	50.6	460.0	486.4
167.8	o	51.6	470.0	496.0
171.4	x x	53.2	480.0	511.4

re-checked after the flashover @171.4kV and withstood consistent flashover during two attempts at this voltage

*Result:* 470 kV

**Sample 8**

Charging (kV)	Result	Oscilloscope reading (V)	Actual voltage from pulse/charge ratio (kV)	Actual voltage from voltage divider ratio (kV)
142.8	o	42.5	399.9	408.5
149.9	o	47.0	419.9	451.8
157.1	o	49.6	440.0	476.8
164.2	o	51.6	460.0	496.0
167.8	x o o	52.6	470.0	505.6
171.4	o	54.0	480.0	519.1

*Result:* 480 kV

Generator charging capacity did not allow continuing the test beyond this voltage

*Note:* level.

**Calibration procedure data:**

Level	50%	gap	75mm															Nbd
Charge	kV																	
3	71.5																	1
2	71.0		x		x													5
1	70.5		o		o													3
0	70.0	o																0
																		Nb 9
																		A 16
																		B 32
																		Mean kV 70.6
																		std kV 0.34
Level	65%	gap	100mm															Nbd
Charge	kV																	
2	93.5	x		x		x												8
1	93.0		o		o													3
0	92.5																	0
																		Nb 11
																		A 19
																		B 35
																		Mean kV 93.1
																		std kV 0.18
Level	80%	gap	120mm															Nbd
Charge	kV																	
2	112.0	x																5
1	111.5		x		x													5
0	111.0			o		o												Nb 10
																		A 15
																		B 25
																		Mean kV 112.0
																		std kV 0.23