Wet-test Performance of Insulating Fibreglass Sticks Used for Live Working *

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SUMMARY: Increasing reliability demands on electricity networks call for rapid restoration of supply, and the continuing move to line-line maintenance means operation and maintenance on live systems in wet weather is an increasing possibility. The effect of deteriorating surface condition of insulating sticks may be of concern in the context of worker safety.

Tests were carried out on samples lengths of 700mm and each sample was subjected to a test voltage of 58 kVrms under dry and wet conditions. The tests compared the effects of surface condition, together with the effects of fitting weathersheds commonly supplied for qualifying insulating sticks for work in precipitation. Proposals are made for the fitting of weathersheds and the in-service maintenance of insulating sticks by field users.

1 INTRODUCTION

Increasing demands by customers for reliability and availability of supply require electricity companies to isolate faults and restore supply quickly, no matter what the weather. As the majority of Australian networks are overhead, operating outdoors is a core activity for network managers in this country.

Since most network operations are performed manually with insulating operating sticks, it is of interest to know how insulating operating sticks perform in wet weather. Some insulating sticks have weathersheds fitted for use in precipitation, but it is recognised that the surface condition of an insulating stick, which can deteriorate in service, also has a bearing on its electrical performance when wet. It is not known whether the presence of weathersheds provides a benefit for “in-service” sticks with an insulating surface which is in less-than-perfect condition.

The manufacturing type tests specified in IEC855 1 are used for qualifying new materials for service. Test methods are also available in IEEE Standard 978 2 for assessing the serviceability of insulating line-line sticks while in use in the field.

A programme of tests was carried out at the University of Queensland High Voltage Laboratory to investigate and compare the electrical performance of insulating sticks in new and used condition, and the effect of weathersheds on each type.

2 TEST OBJECTIVE

The objective of the test programme at the University of Queensland was to investigate the comparative performances of new and used sticks, with and without weathersheds fitted, under wet conditions.

The tests investigated the time dependency of leakage current across the insulating surfaces when voltage stress was continuously applied for up to one hour, with the dry condition used as a reference baseline for comparison. This is seen as being representative of the practical situation in which a field operator must work.

A previous test programme carried out in 1984 3 conducted dry and wet tests on new and used sticks of fibreglass and wood. However, these tests investigated the comparative performance based on voltage dependency of leakage current, with particular interest in the contribution of surface preparation using silicone wiping cloths as used in the current test programme. Direct comparison with these results was not possible.


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3 TEST METHOD

3.1 Test Voltage

Tests were carried out generally in accordance with the methods specified in IEC 855. Under this standard, dry tests are 1-minute tests at an average voltage stress of 100 kV/100 mm, whereas wet tests are of 1-hour duration with a stress of 100 kV/1200 mm.

A single voltage stress was required for the conduct of both wet and dry tests to establish the comparative effect of precipitation on the test pieces. This voltage stress should exceed the highest stress occurring in the field in normal operation, and if possible align with a standard voltage stress used under one of the testing regimes specified for insulating sticks.

The Minimum Approach Distance is the minimum distance specified in a regulatory code from an operator to a live part when performing live work. Table 1 compares voltage stresses at minimum approach distances compared with the voltage stresses applied under standard test regimes. The test acceptance criteria are also included in table 1. The voltage gradient selected for the test programme was equal to the standard IEC wet-test gradient (which equates to 83.3 kV/m), as this gradient exceeds the highest stress to earth at the minimum approach distance of an operator.

3.2 Parameters Measured

Two parameters were identified for investigation:

- Power-frequency leakage current;
- Power-frequency flashover voltage.

Although the total leakage current measured at the ground electrode contains both resistive and reactive components, it was decided to measure only the total rms current. This is considered adequate since the sample length is sufficiently long to ensure that capacitive currents are relatively low in relation to expected leakage currents for poorly performing surfaces. In addition, as mentioned before, the interest was in relative, rather than absolute, performance.

### Table 1
Voltage Stresses Allowed in Service and Occurring under Test

<table>
<thead>
<tr>
<th>State/Std</th>
<th>Operating Voltage</th>
<th>Minimum Approach Distance (MAD) mm</th>
<th>Highest voltage stress (Note 1) at MAD kV/m</th>
<th>Dry/Wet Test voltage kV rms/Duration</th>
<th>Max leakage current µA</th>
<th>Test Voltage stress kV/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>QLD</td>
<td>Up to 33kV 66kV</td>
<td>700</td>
<td>29.7</td>
<td>D70/1 min D140/1 min D185/1 min</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>110/132</td>
<td>1000</td>
<td>41.6</td>
<td></td>
<td>140</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1400</td>
<td>59.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSW</td>
<td>11kV 22-66kV 132kV</td>
<td>700</td>
<td>9.9</td>
<td>D43kV per 300mm/1 mm</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000</td>
<td>41.6</td>
<td></td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1200</td>
<td>55.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDE 0681</td>
<td>11kV 22kV 33kV 66kV 110kV</td>
<td>500</td>
<td>27.7</td>
<td>To IEC 855 Dry: 100kV/300min/1 min Wet: 110kV/1200min/1h</td>
<td>100</td>
<td>83.3</td>
</tr>
<tr>
<td>(2 sheds req'd)</td>
<td></td>
<td>525</td>
<td>39.6</td>
<td>Dry: 10_A Wet: Not specified (See Note 2)</td>
<td>100</td>
<td>83.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>900</td>
<td>46.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1300</td>
<td>54.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Voltage stress is measured as a phase-earth voltage per metre, evaluated at highest voltage for equipment $U_{e}$.

**Note 2:** No quantitative limit is specified. However there must be no tracking, damage or heating, nor visible damage to occur to the insulating surface.
3.3 Test Samples

"New" samples were taken directly from production, and were treated before testing with a silicone-imregnated wiping cloth of a type normally used for preparing and maintaining insulating operating sticks for service. Used or "old" samples were from a variety of sources, from sticks recovered from service, and were not treated with the silicone cloth.

The weathersheds are annular devices applied over an insulating stick typically during manufacture or maintenance, and increase the leakage distance across the surface as well as affording a discontinuity in the apparent leakage current path. Weathersheds are required under some European standards for work in precipitation.

The weathersheds used were solid grey silicone-rubber slip-on sheds. The grey type has the advantage of affording mechanical protection by preventing sticks from rolling on the ground or abrading against each other in storage. The sample sizes were insufficient to establish a meaningful comparative performance between the two types of sheds, although differences were found in the flashover mechanisms, as will be noted later. Figure 1 shows these sheds fitted to a new and a used stick.

One additional sample was assembled from a red heat-shrink anti-tracking tube with slip-on flat sheds, to simulate a "home-made" attempt to weather-protect existing equipment in the field. This sample did not use a mastic sealing layer at the insulating interfaces.

The surface condition of the old samples was quite variable, including some with visible evidence of damage. As this was a qualitative and subjective judgment, no effort was made to classify the surface condition of old sticks. Detailed investigation of the surfaces, for example by microscopy or other methods, was beyond the scope of the test programme, and in addition was not meaningful because of the lack of knowledge of the operating environments of the old samples.

As only five sets of samples were tested, it is recognised that the variation in service condition of used sticks encompassed within the test programme is limited. Further work may be warranted for a wider examination of the effect of deterioration of surface condition.

3.4 Sample Length

The length of sample tested was important, as the shortest-possible samples were required to fit within the coverage area of the wet-test sprays. However, the tests aimed at a representative coverage of service voltage ranges using samples of a practical length used in the field. Therefore, preliminary investigations were carried out to determine a length of operating stick which could be used as a representative practical sample for a range of operating voltages.

Figure 2 shows that the voltage gradient required to produce a leakage current of 15 μA rms under dry conditions was relatively constant down to a stick length of 700 mm. Shorter lengths are subject to "end effects" due to the influence of capacitive currents. A sample length of 700 mm was chosen, and each sample was subjected to a test voltage of 58.3 kV rms.

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Figure 1: Grey silicone-rubber weathersheds
The samples were arranged generally in accordance with figure B1 of IEC855. Samples were fitted with guard electrodes as specified, and were inclined at an angle of 45 degrees to the horizontal. Dry tests were carried out singly, as leakage currents were measured after a test duration of 1-minute only.

Wet test sprays were configured to meet the requirements of IEC publication 60-1 as specified in 5. Because wet tests last for 1 hour each, the first set of tests was very slow on single samples. To speed up the test programme, four samples (one of each type of sample) were tested in each test array. However, the area covered by the spray is limited in terms of maintaining uniformity of horizontal and vertical components of precipitation. Therefore the samples were spaced 500 mm apart to ensure that the area of spray coverage would be minimised to about 2 m x 1 m.

At such close spacing, capacitive coupling was found to have an influence on the results for adjacent parallel samples. Therefore, a configuration was developed with alternative samples oriented at 90 degrees to each other in parallel vertical planes to reduce coupling. Coupling tests were carried out to establish the effect of adjacent sticks at low levels of leakage current, as described in the next section.

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Figure 2: Power frequency dry tests - new samples voltage gradient for constant leakage current

Figure 3: Test arrangement
3.5 Measurement Accuracy

Measurements for dry tests were made with a Fluke multimeter, measuring true rms currents. However, capturing and recording the rms current data over a 1-hour wet test required the use of a Hioki 8835 RMS recorder.

Leakage currents were measured by terminating each of the four measuring circuits in a 100kΩ 1% resistor to convert the leakage current into a voltage large enough to be unaffected by stray voltages in the measuring circuit. These voltages were input to the channels of the Hioki recorder, which measured 20 pieces of rms data per second on each channel with an analogue accuracy of 0.4%. The rms value data were recorded every 2 minutes and stored on a floppy disc in text files and input to a spreadsheet for processing and graphing.

To test the effect of coupling between adjacent samples, dry tests were carried out as per Table 2 below.

<table>
<thead>
<tr>
<th>Samples energised</th>
<th>Leakage current measured in Sample #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3 only (centre)</td>
<td>8μA</td>
</tr>
<tr>
<td>#3, #4 (right)</td>
<td>12μA</td>
</tr>
<tr>
<td>#2 (left), #3 (centre), #4 (right)</td>
<td>12μA</td>
</tr>
</tbody>
</table>

The presence of more than two samples does not appear to contribute to additional leakage currents. An error analysis was conducted using projected values of capacitive components due to the presence of adjacent multiple samples, and as expected the errors are significant at leakage current values of about 10 μA. However, such error currents are not considered significant for the purposes of assessment of comparative performance, and in any case dry tests are conducted with single samples, and coupling from an adjacent sample is not a consideration.

For wet test leakage currents above 50 μA, errors fall below 5%, which is also not significant for evaluation of comparative performance. Coupling was considered to be affected by geometry of the test layout only, and independent of the presence of water spray in the test area. To further ensure that the effect of coupling between adjacent samples is eliminated, for each of the four sets of wet tests carried out the positions of the samples were rotated sequentially. No effect of position could be discerned in the wet test results.

4 RESULTS

4.1 Dry Test Results

Dry tests were carried out on individual samples to the nominated voltage stress. Results are summarised in figure 4.

![Figure 4: Dry tests - leakage current and flashover voltages](image-url)
A new surface in good condition under the applied voltage gradient typically has a leakage current of less than 10µA. It appears that, under dry conditions, an old surface condition has inferior electrical performance in terms of higher leakage current and more variation in flashover voltage. Presence of the sheds seems to improve performance of an old surface under dry conditions, although the leakage current is still subject to wide variation. (Note that the samples tested with and without sheds were not the same samples.)

4.2 Wet Test Results

Four sets of wet tests were carried out, each with four samples in a test array, one of each of the following types:

- New surface, no sheds
- Old surface, no sheds
- New surface, with sheds fitted
- Old surface, with sheds fitted

One set of tests was terminated after 22 minutes because of the imminent failure of an incorrect hollow sample, which was wrongly installed on the test rig. Results for this sample were not recorded.

A fifth set of tests was conducted separately on individual samples. All results were consolidated. The effect of surface condition and presence of weathersheds was analysed in terms of effect on leakage currents and flashover voltages.

Effect of Surface Condition under Precipitation

Figure 5 shows the results for bare surfaces with no weathersheds fitted. It is apparent that the performance of surfaces of both types is variable, although new surfaces seem to be more resistant to the rise in leakage current with time of applied voltage stress. In contrast, leakage over old surfaces rises steadily with time as soon as the voltage stress is applied.

The prospective final leakage currents at the end of the one-hour test are similar for both types of surfaces, although new surfaces are inclined to exhibit lower values of leakage current.

Effect of Weathersheds on New Surfaces under Precipitation

Figure 6 shows the results for new surfaces with and without weathersheds fitted.

![Figure 5: Wet tests - bare surfaces, effect of surface condition](image-url)
Figure 6: Effect of weather sheds on new surfaces

The results show that the weather sheds have a positive effect on new surfaces in good condition, with all except one sample (with the red weather sheds fitted) having leakage currents less than 100 μA at the end of the one-hour period. In contrast, the unshedded samples generally exhibited increasing leakage currents to final values well in excess of the criterion value of 100 μA.

Effect of Weathersheds on Old Surfaces under Precipitation

Figure 7 shows the results for old surfaces with and without weather sheds fitted. Again, as for the new surfaces, weather sheds seem to have a beneficial effect, although the variation in

Figure 7: Effect of weather sheds on old surfaces
final leakage currents is much wider and one shedded sample exhibited leakage current similar to that of the unshedded samples. However, in this case it is interesting to note that the leakage current stabilised after rising to an initial high value.

**Effect of Duration of Voltage Application**

In all of the wet tests, leakage currents generally started to rise after 20-30 minutes of voltage application, although some poor surfaces exhibit high leakage almost immediately. To what extent this effect may be cumulative could not be established due to the limited scope of the test programme.

**Flashover Voltage and Leakage Current Performance**

Figures 8 and 9 show the dry and wet flashover voltage stresses for all samples under dry and wet conditions compared with their respective final leakage currents.

There appears to be a broad correlation between higher leakage current and lower flashover voltage stress. As mentioned previously, under dry conditions, all samples have consistent flashover performance except for old surfaces without sheds, which exhibit variability in flashover voltage and higher leakage currents.

**Figure 8:** FOV vs final leakage current sticks without weathersheds

**Figure 9:** FOV vs final leakage current sticks with weathersheds

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Addition of weathersheds appears to improve the dry performance of old surfaces. Under wet conditions, shedded samples appear to exhibit higher flashover voltage stresses and lower leakage currents. However, the presence of one "outlier" point, a new sample with sheds exhibiting a relatively low flashover voltage stress after low leakage current at the end of the one-hour test, highlights the extreme variability in the performance of all combinations of surface condition and shed provision.

Flashover Paths

Although it was not intended to rigorously investigate the mechanism of flashover under wet conditions, all samples were examined after flashover. In one sample with silicone rubber "slip-on" sheds, flashover was observed under the shed itself, although there was no damage to the stick surface. It was found that this sample had evidence of moisture beneath the shed and on the surface of the stick. This sample had been prepared differently in that the shed was installed before wiping with the silicone cloth. Subsequent samples, which were wiped with the silicone cloth before installing the sheds, flashed over across external surfaces.

In contrast, the single sample with red sheds exhibited damaging flashovers under the heat shrink tube and under the slip-on shed itself.

5 CONCLUSIONS

These results indicate that the fitting of weathersheds is beneficial for improving the performance of insulating sticks under dry and wet conditions. However, fitting of weathersheds alone does not appear to guarantee improved performance if the stick surface itself is in poor condition.

The beneficial effect of silicone cloth application was observed in [3]. Methods of in-service maintenance and workshop refurbishment of stick surface condition are well-known and implemented by many users around the world.

The rise of leakage current under wet conditions is time-dependent, but such effect may or may not be cumulative. It is proposed that regular restoration of the stick surface between the sheds may act to overcome any cumulative deterioration in service.

The method of fitting the weathersheds appears to have an influence on the flashover performance, as evidenced by the flashover of samples after tracking under the sheds along insulating interfaces. In the absence of silicone preparation of the surface to which it is applied, a slip-on shed may flash over under the shed itself.

Therefore it is considered that a slip-on weathershed has the potential for improving the performance of an insulating stick providing the stick surface itself is correctly maintained and refurbished. Solid sheds which offer mechanical protection by preventing abrasion of the surface on the ground or against adjacent sticks, will contribute to maintaining good electrical performance of the insulating stick, providing they are correctly fitted.

ACKNOWLEDGEMENTS

The assistance of the University of Queensland is acknowledged in providing the facilities for conduct of the test programme. Thew & McCann Pty Ltd provided the test samples, the test rig and the instrumentation for the multiple-sample wet tests.

The authors acknowledge the assistance, advice and suggestions from Mr Steven Wright, HV Laboratory Supervisor of the University of Queensland, and from Mr Adolf Lamprecht, Technical Consultant, Thew & McCann Pty Ltd, for preparation of samples and the test rig.

REFERENCES

1. IEC 858: Insulating foam-filled tubes and solid rods for live working.
APPENDIX: ERROR ANALYSIS

Three samples were prepared, each 700 mm long. Samples were energised under dry conditions at 58.3 kV. Leakage currents were measured with a single sample, then with one additional sample adjacent, and with two additional samples, one either side of the original sample. Results were as follows.

One sample: leakage current = 8 μA
Two samples: leakage current = 12 μA
Three samples: leakage current = 12 μA

Assume the resistive component of the leakage current is constant in all configurations, and is equal to \( I_R \). The variation in leakage current with the adjacent sample is therefore only due to additional capacitive current in quadrature.

Initial measured current:

\( I_{M1} = \sqrt{I_R^2 + I_{C1}^2} = 8 \mu A \)

Adding an adjacent sample, the new measured current is:

\( I_{M2} = \sqrt{I_R^2 + I_{C2}^2} = 12 \mu A \)

Therefore:

\( I_{C1}^2 - I_{C2}^2 = I_{R1}^2 - I_{R2}^2 \)

Limit Conditions:

If \( I_{C1} = 0 \), \( I_{C2} = 8.9 \mu A \)
If \( I_{C2} = I_{R2} \), then \( I_{C1} = 12 \mu A \)

These values are the maximum values of the error due to capacitive coupling to adjacent samples. The desired measurement is the resistive component, \( I_R \).

Measured current \( I_R = (I_{M2}^2 - I_{C2}^2)^{1/2} \)

Measurement error \( = (I_{M1} - I_{M2})/I_{M1} = 1/(1 - (I_{C2}/I_{M2})^2) \cdot 1 \)

This error is a function of measured current with the capacitive component \( I_{C2} \) as a parameter.

As can be seen, if the leakage current rises above 50 μA the error is below 3%.

<table>
<thead>
<tr>
<th>Capacitive current with adjacent sample in place ( I_{C2} )</th>
<th>Error in Measured Value of Current % (for capacitive current ( I_{C2} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured Value μA</td>
</tr>
<tr>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>12.0</td>
<td></td>
</tr>
</tbody>
</table>

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