APPARATUS TESTING IN POOR WEATHER CONDITIONS

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Apparatus testing in poor and/or extreme weather conditions presents several challenges – access to equipment, safety, and setting up the equipment under test so as to provide useful results. This paper looks at some individual case studies which demonstrate the precautions needed and the "Do's and Don'ts" of such testing.

SAFETY

In general, any outdoor activity in bad weather constitutes a risk and should not be performed without a thorough risk assessment and appropriate authorization. A severe risk is posed by lightning. Doble Engineering does not recommend testing in any situation where lightning is a present or an imminent threat.

EQUIPMENT STATUS AND MOTIVATION FOR TESTING

Before we start testing, are there reasons to suspect the equipment may be in poor condition? If not – can the testing be deferred? If there are, then the motivation for testing is based on suspicions in regard to the equipment condition, and we must use that knowledge to guide us toward the tests to be performed and subsequent interpretation of test results.

Poor weather will affect results through temperature and through contamination of the test object with water, ice, snow, etc. Lower temperatures will affect the inductance, capacitance, and resistance directly, but will also lead to water crystallization in dielectric material. The ice crystals will affect results and may lead to erroneous conclusions.

In situations where the equipment, say a power transformer, has recently been switched out of service, it is likely still warm; therefore, testing should be planned to take place before it has significantly cooled down. As long as appropriate safety measures are taken, valid test results should be obtained.

INDIVIDUAL TEST EXPECTATIONS

Different tests will be affected by poor weather in different ways.

Power Factor – Surface contamination and low temperatures may affect both the current and watts losses, giving either overly pessimistic or overly optimistic power-factor results. Care should be taken to include test guards and in interpretation of results in low temperatures.

Capacitance and DC Resistance – These tests should not be significantly affected by temperature or surface contamination, but this will depend on the level of contamination and the temperature change. DC resistance should decrease with lower temperatures – but the effect may be masked through connection and contact resistances and appropriate correction curves should be used.

Sweep Frequency Response Analysis – This test relies on inductance-capacitance combinations to produce resonances to a low-voltage ac signal. Impulse tests used to produce a frequency response may be very susceptible to temperature and surface contamination issues while sweep systems are relatively immune, unless the surface contamination is extreme.

Leakage Reactance – This is a high current test which may be significantly affected by surface contamination but much less affected by temperature variations.

CASE 1: POWER TRANSFORMER TEST IN FREEZING CONDITIONS

Three high voltage General Electric type U bushings were tested in a large, oil-filled, power transformer during a winter storm that had snow, ice, and freezing rain as part of the weather conditions. The transformer was tested with the oil temperature well below freezing. The three bushing temperatures were also below freezing when tested.

The test results for the transformer's power-factor overall winding tests were not acceptable for service, with power-factor values greater than 1.0 percent for low-voltage and high-voltage windings (CL & CH). Bushing power-factor values, the C1 test as given in Table 1, were also higher than acceptable for in-service bushings of this type.

TABLE 1: *Power Factors Measured in Freezing Conditions*

Bushing	H1	H2	H3
Power Factor – Freezing	0.96%	0.92%	1.04%
Power Factor - Nameplate	0.60%	0.62%	0.60%

Inverted C1 test values for the bushings were comparable to the standard C1 test values which indicated the high C1 power factor-values were attributed to the bushing's internal main core insulation and not being influenced negatively by exterior conditions. Such testing is very useful to further determine the impact of surface contaminants on results.

The transformer was warmed up and all bushing surfaces were dried. The power-factor tests were performed a second time and the transformer overall power factor improved significantly. The bushing C1 test values remained at the higher than acceptable test value that was obtained in the previous test. The bushings were tented, and heat was applied to warm the bushings above freezing. After several hours of heating, the bushings were again tested and all of the C1 and inverted C1 power-factor values were within 0.1 percent of the nameplate value, as shown in Table 2.

TABLE 2: *Power Factors Measured in Normal Conditions*

Bushing	H1	H2	H3
Power Factor – Normal	0.50%	0.53%	0.51%
Power Factor - Nameplate	0.60%	0.62%	0.60%

The results above freezing are significantly improved and demonstrate the susceptibility of such test results to temperature. Interpretation of such results requires an understanding of the impact of surface contaminants and of temperature on the test process and the results themselves.

Bushing temperature studies performed by Doble have shown that GE, type U bushing C1 power-factor value is influenced by temperature. When this type of bushing is tested below freezing, the power factor values increase and level off to an elevated value above the recorded nameplate value. This change in power factor with temperature was seen in both a known good bushing and a known defective bushing.

Doble Engineering provides temperature correction tables which begin at 0°C.

CASE 2: POWER TRANSFORMER TESTS IN HIGH HUMIDITY

In this case, a power transformer was tested in high humidity, over 94 percent, with onshore ocean breezes simultaneously bringing aerosol moisture to the unit. Overall test results are given in Table 3.

TABLE 3: *Test Results in High Humidity, Damp Conditions*

Measure	mA	Watts	%PF measured	%PF corrected	Capacitance pF	Doble Expert Diagnosis
CH	12.010	0.773	0.640	0.770	3,824	Deteriorated
CHL	25.000	0.597	0.240	0.290	7,957	Good
CL	36.160	2.311	0.640	0.770	11,511	Deteriorated

Both high-voltage and low-voltage winding power factors (CH and CL) are higher than normal, while the interwinding power factor (CHL) is acceptable. This type of variation is an indication of possible surface contamination effects as the interwinding insulation test does not include ground path losses as part of the measurement.

The same transformer was tested later on the same day. Winds were now offshore, bushings were cleaned and dried, and the sun had warmed the porcelain which helped to remove any remnant moisture accumulated before retesting the bushings. Test results are given in Table 4.

TABLE 4: *Test Results in Warm and Dry Conditions*

Measure	mA	Watts	%PF measured	%PF corrected	Capacitance pF	Doble Expert Diagnosis
CH	11.196	0.407	0.340	0.390	3,807	Good
CHL	24.990	0.612	0.240	0.280	7,957	Good
CL	35.970	1.187	0.330	0.380	11,451	Good

Under the same test regime, the mA results have not changed greatly, but the watts loss results have reduced substantially, reflecting the surface contamination impact. CHL has not changed significantly, but the values of CH and CHL have come within expected ranges for a new transformer and are acceptable.

The drying of bushings has produced acceptable CH and CL values, as expected.

CASE 3: POWER TRANSFORMER LEAKAGE REACTANCE AND SFRA IN FREEZING CONDITIONS

In this case a 230/72 kV 50/67/83 MVA power transformer had come out of service after a low-voltage bushing failure. The bushing was replaced and the transformer cleaned internally. A range of tests was performed to ensure the integrity of the transformer had not been compromised prior to re-energization. Leakage reactance results had not been taken for the unit since factory tests, and sweep frequency results were taken for the first time. The transformer is pictured in Figure 1.

FIGURE 1: *Transformer Under Test in Freezing Conditions*

With appropriate precautions, the following tests were performed:

- Bushing C1 and C2 and power-factor measurements
- Winding power factor and capacitance
- HV single-phase excitation
- DC winding resistance
- Turns ratio
- Sweep frequency response analysis
- Leakage reactance

Everything was acceptable except for anomalous leakage reactance measurements which indicated a variation that was not seen in the sweep frequency response analysis measurements. Leakage reactance responses which included the tertiary winding showed an anomaly, indicating variation on one phase.

By ensuring that the test object had been suitably cleaned and prepared, there was sufficient support for the integrity of the measurements for a cause of anomaly to be found within the transformer. This was eventually traced to two CT shorting blocks which had both, in fact, not been shorted and which thus showed as extra burden on the leakage reactance results.

In this case good test practices allowed for reliable results and subsequent analysis which identified the cause of the anomaly within the transformer.

RECOMMENDED PRACTICES

When power-factor testing in subzero conditions, water or moisture in the apparatus could condense and freeze. This will alter the overall dielectric condition, affecting the test results, typically reducing the watts loss, and subsequently yielding lower power-factor values. This may give the false impression of an improvement in the overall condition of the insulation system! Care should be taken when testing in freezing conditions to make sure the context and interpretation of results are clear and understood.

Can power-factor tests be performed on apparatus which is at a temperature above freezing but when the ambient is below freezing? Yes! Again, care must be taken and there are correction curves available to reference test results to standard temperatures.

There are clear risks when testing in rain or snow that are associated with safety. They include electrocution and slip and trip hazards. The variation in surface leakage impedances will mean that power-factor and related measurements will be compromised as watts loss will rise as the ground path capacity increases. High humidity may have the same effect. However, sweep frequency response analysis measurements and dc resistance measurements should be relatively unaffected and may be performed unless the surface contamination yields a short circuit across the surface. Addition of a collar to the testing regime may yield further information about the state of the insulation and thus aid in diagnoses.

CONCLUSIONS

It is important when testing in poor or unfavorable weather to understand both the motivation for test and the likely impact of the adverse weather on actual test results. In terms of motivation, we must consider what we expect to find – are there reasons to suspect the integrity of the apparatus under test? In terms of interpretation of results, we must consider the individual test made and the likely impact of adverse conditions on those results and thus the interpretation of those results.

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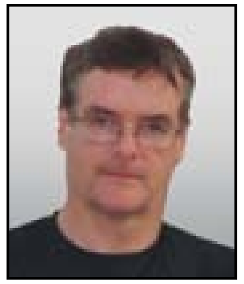

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