Dielectric Testing Circuit Breakers and Switchgear – Part 1

January 18, 2019

Establishing the correct dielectric properties for electrical equipment is one of the most critical aspects of the design process. Testing to validate dielectric integrity can be one of the more confusing processes in the IEEE standards because as the testing continues, the insulation system is being degraded. This technical brief is Part 1 and discusses the longer duration testing procedures of Power Frequency Withstand, Bus Bar Insulation Testing and Partial Discharge Testing. Part 2 (PTB 139) discusses Impulse Testing.

Factory Power Frequency Testing

The Power Frequency Withstand test is so named because it uses an AC voltage at the normal operating frequency of the equipment. This test is performed as part of the Development (Type) Testing program for circuit breakers and switchgear and repeated as part of the Factory Production testing. The test voltage level may be adjusted for atmospheric conditions from altitude and humidity in accordance with IEEE Standard 4, however, unless the conditions call for a higher voltage, the adjustments are rarely made.

Generally speaking, the Power Frequency (High Potential or Hipot) tests are not considered destructive tests unless there is a serious component flashover. This does not mean that repeated full rating tests will not overstress the insulation system. After the equipment leaves the factory, the test voltage level is reduced to 75% of rating.

How the rated voltage value is derived is a mystery that is based on a number of factors that affect insulation coordination. It is not a completely linear relationship, but closely resembles (1.85 x max voltage) + 9.5 (the approximate coordination factor). Alternately, the equation could be 2 x max voltage + a coordination factor that varies downward as the voltage class goes up.

The voltage is applied phase-to-phase and phase-to-ground for 1-minute. No breakdown is allowed. Leakage current is not measured during this test it is the pass/fail criteria. The test equipment is set to shutdown voltage when the current flow exceeds the set point for a significant duration. Corona and non-sustained discharges are not considered a failure. Only a full breakdown to ground resulting in the test device shutdown is considered a failure.

Factory Power Frequency Testing Verses Field High Potential (Hipot) Testing

To avoid unnecessary stresses and to compensate for field conditions, the IEEE recommends the field test voltages be reduced to 75% of the design test rating.

Additionally, the IEEE Standards offer an “equivalent” DC test value for 4.760V and 15kV equipment. This is for convenience when field testing as the DC test unit is a much more portable device and does provide validation that there are no immediate defects in the insulation system. It is generally thought that the DC test set does not have the potential for equipment damage because the typical leakage currents are orders of magnitude less than those of the AC test, which means routine maintenance testing is not damaging the insulation system. Unfortunately, the standards offer no “equivalent” test values at the 27kV and 38kV levels and the DC test does not stress the insulation system in the same way an AC test does.

Powell Industries, Inc.
PO Box 12818
Houston, TX • 77217

Tel: 713.944.6900 • Fax: 713.947.4453
www.powellind.com
info@powellind.com

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Effect of Frequency

Frequency plays two roles in dielectric testing. The first, and by far most important, is that it stresses the capacitive coupling that exists between the conductors, the insulation, and the surrounding air. Removing the frequency element from this test eliminates evaluation of this capacitive coupling. This is most noticeable when testing devices with capacitive grading.

Higher voltages generally require larger spacing between components, but by capacitive grading the insulation, the size can be made more manageable. The downside to the capacitive grading is that it draws current on the initial energization to charge the capacitance and to a DC Hipot, that current inrush can appear to be a breakdown failure. Switching over to an AC test set eliminates the inrush current problem, but requires a test set considerably larger than its DC equivalent; presenting logistical issues for Field testing. This issue is discussed in detail with respect to testing Powell 27kV and 38kV switchgear in Technical Brief PTB117.

The second frequency related role is that of waveform shape, and more specifically, the rise time to peak, polarity, and number of peaks during a given test. In a typical power frequency test, the rise times are really not that significant as they are not that fast. The AC waveform stresses the insulation in both positive and negative polarities, which can have a significant effect on the performance as the insulation system cannot polarize in a single orientation. The number of peak voltages points is also significant as the standards allow that higher frequency testing qualifies lower frequency application. This means a 60 Hz test would qualify 50 Hz application.

In field testing, the number of voltage peaks is not significant, but the polarity reversal and reduction in inrush current for capacitance graded systems is very useful. One method for evaluating capacitive graded equipment without the size issues of a standard AC Hipot is to use a Very Low Frequency supply (VLF). This device outputs an AC low frequency signal such that the capacitive coupling and polarity reversal are addressed without the inrush issues associated with the lower trip thresholds of DC test sets. While there are no established voltage levels for VLF testing, use of the recommended 75% field test level for the 1-minute Power Frequency Withstand Test voltage (found in the Standards and on the equipment nameplate) should get satisfactory results.

Bus Insulation

The Bus Bar Insulation test is unique to the requirements of Metal-Clad Switchgear in IEEE C37.20.2. It is quite simply a validation that any material used to insulate the bus bars in Metal-Clad will provide enough insulation to prevent “incidental contact” from causing an arcing fault. It does not validate that the bus is fully insulated such that it can be placed directly on ground or another phase (remember, air is the primary insulation in air insulated switchgear).

This test will find voids in the insulation and areas where the material may be inadequate due to its dielectric properties or because there is not enough material thickness.

This test requires an AC voltage be applied at the maximum rating of the equipment to the bus for 1 minute with the surface of the insulation covered by a ground plane in intimate contact with the insulation. This is a design or type test and as such, is destructive in nature and not intended for use as a production test. Note it must be performed on any material used to insulate the bus, so taped joints and bus boots are subject to being tested using this method.

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Partial Discharge (Corona) Testing

Partial Discharge (PD) testing is common as a production test in Canada. It has not yet become a required test in the IEEE/ANSI world although various equipment Standards are recognizing it as an optional test by adding it to informative annexes.

Partial Discharge testing pushes the insulation system into an overvoltage condition that causes partial voltage discharge into the insulation, but not a full dielectric breakdown, to observe the insulation system recovery capabilities when the voltage returns to the normal line-to-ground value. Successful testing shows that transient overvoltage events do not initiate discharges that persist and cause damaging long-term stresses that breakdown the insulation system.

This test must be performed as an AC test and uses voltages that do not exceed the maximum voltage levels used for Power Frequency Withstand. The test duration, however, is considerably longer than the standard 1 minute Power Frequency Withstand test, typically lasting around 3 minutes to build up to voltage, establish corona, and then taper down to a corona extinction level where it is held for two minutes. Because the levels generally do not exceed the Power Frequency Withstand values it is considered a non-destructive test, even though there is a significantly longer duration.

Partial Discharge testing is not a requirement of IEEE or ANSI rated equipment, but is a requirement for CSA rated equipment. Many manufacturers evaluate their insulation system designs using PD testing, even though they do not use it in production testing, as a general assessment for long-term functionality.

Michael Wactor, P.E.
Technical Director – R&D

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PO Box 12818
Houston, TX • 77217

Tel: 713.944.6900 • Fax: 713.947.4453
www.powellind.com
info@powellind.com