Dielectric Testing Circuit Breakers and Switchgear – Part 2

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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. Part 1 (PTB 128) discusses the longer duration testing procedures; Power Frequency Withstand, Bus Bar Insulation Testing and Partial Discharge Testing. The following technical brief is Part 2 and discusses Lightning Impulse Withstand Testing.

Lightning Impulse Withstand Testing

Basic Lightning Impulse Insulation Level testing (BIL), referred to as Lightning Impulse Withstand testing in the circuit breaker and switchgear documents, is so named because it represents the effect of a lightning strike on the system. The test is applied between conductors and between conductors and ground to show that the isolating distance between these components can withstand the rapid rise in voltage caused by a lightning strike. It is often thought of as a test of strike distance, the shortest physical path between the components, to verify the insulation system has sufficient distances for the insulation medium used. Generally speaking, we are referring to the air gap between components in air insulated equipment, but this may be altered by bus insulation, insulating barriers, or a gas other than air with different dielectric characteristics.

The Lightning Impulse is a fast-rising singular direction voltage event. The standard Lightning Impulse waveform is defined in IEEE Standard 4 as a 1.2µs x 50 µs wave where:

T_1 = 1.2µs - The time to reach 100% peak voltage (rise time)
T_2 = 50µs - The time to decay down from peak voltage to 50% voltage (tail time)

The tendency is to think of this test in terms of a DC event. The capacitive component of device under test can affect the wave shape and alter the rise or tail time. The resistive component (distance travelled to get from a conductor to ground or a second conductor) is primarily what impedes the breakdown.

Both positive and negative polarities are used to evaluate the insulation system as the stresses are different. Positively charged impulses tend to be more stressful. This can be further enhanced by the physical configuration. Areas where the configuration concentrates the field can fail the positive polarity test and often easily pass the negative. This is explained on the particle charge level by noting that the positive and negative charges are equal, but the mass of the particles is very different. The positive field can create significantly more electron acceleration and more charge movement with the same electric field generated force.

Proper spacing between the components isn't just for lightning strikes. It also protects against overvoltage events from switching transients, which can cause as much as a 3x voltage rise with very fast dV/dt.

Designing to Improve Performance

The voltage field created by the Lightning Impulse is mitigated by keeping the voltage stresses as close to equal across the tested area as possible. Sharp surfaces, like protruding hardware or the edge of a thin conductor, cause the concentration of the Electric Field to increase at those points. Shaping the

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conductors into better field configurations or altering the configuration between the insulation and the conductor at the point of transition between the two can improve performance. Caution must be exercised when making any modifications to the bus work. This includes properly replacing boots and tape when checking the torque on bus joints and assuring proper insulation is applied when the field cable connections are made. The transition points between insulation types, such as where solid bus insulation stops and tape or a boot is added to cover the connection, is particularly suceptible to stresses on the edge to the solid insulation. Boots should be designed to provide significant overlap of that surface. Taped joints should be wrapped down the bus past the edge at the full level thickness provided in the manufacturer's instructions.

Ratings

When lightning strikes equipment it does not recognize the designed voltage limits of that equipment, it simply strikes. So why is 38kV equipment rated for 150kV BIL and 4.76kV equipment rated for 60kV BIL when the lightning could strike either? The ratings are based in part on the anticipated switching transient levels for equipment at that voltage and in part on where that equipment will be placed relative to the exposed overhead incoming lines that could experience a lightning strike.

Since there is no way to predict what level of lightning strike will occur, there is no need to test for additional margin above the recommended IEEE ratings. Where strikes are expected, appropriately sized surge arresters are the recommended solution. Where the application reduces the overall dielectric strength of the surrounding air, such as at higher elevations, it is necessary to de-rate the equipment or use higher rated equipment to compensate for the decreases dielectric capability.

Lightning Impulse Withstand as a Production Test

There has been a trend in the industry to repeat some Design (Type) Testing on production orders in an attempt to validate the performance matches the original design. This is a false assumption. Lightning Impulse Withstand testing is destructive. The energy released in a very small concentrated area is capable of blowing holes in the solid insulation materials. Because of the extremely high stresses created, even successful testing is considered destructive. The insulated components on the test sample may no longer be capable of providing full level performance in the field and fail prematurely. There is no way to predict this, so tested equipment samples may not be sold.

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