TESTING DISTRIBUTION SWITCHGEAR FOR PARTIAL DISCHARGE IN THE LABORATORY AND THE FIELD

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ABSTRACT

Over the past 30 years handheld instrumentation has been developed that enables the detection of partial discharge activity with the plant in normal service. The continuing challenge in making meaningful field based partial discharge measurements is to reliably relate the severity of any detected partial discharge activity to the risk of failure of the item under test. The risk will be a function of such factors as the location within the test item, ambient conditions, materials, the severity of the activity and the history of failure (if any). This paper describes some of the field experience gained whist using this equipment and also introduces results from laboratory based accelerated ageing tests on 11kV vacuum switchgear that employed cast resin insulation material where partial discharge activity was observed from inception to failure..

INTRODUCTION

There is a general trend within electricity distribution utilities and operators of large private electricity networks to extend intervals between intrusive maintenance of HV/MV switchgear. This brings with it a need for interim condition assessment and the application of diagnostic techniques to give confidence in the continuing safety and reliability of the equipment. There are a number of techniques available for assessing the condition of insulation and appropriate use of these tools provides valuable data that can effectively target maintenance and ensure resources are more efficiently deployed during outage periods.

Partial discharge activity has long been accepted as a major cause of failure of HV/MV switchgear [1 & 2]. Reference [1] states that "PD measurements are an ideal method for evaluating switchgear apparatus with non-self-restoring insulation. During a temporary over-voltage, during a high-voltage test, or under transient voltage conditions during operation, partial discharges may occur on insulation of this type, which includes gas, liquid, and solid materials. If these partial discharges are sustained due to poor materials, design, and/or foreign inclusions in the insulation, degradation and possible failure of the insulation structure may occur."

Traditional techniques for the detection of partial discharge involved taking plant out of service and energising via a discharge free power supply and measuring signals using coupling capacitors and conventional PD detectors e.g. according to IEC 60270. Whilst practical and beneficial for factory acceptance testing or further investigation work, this type of testing by its nature is not suited to wide ranging in-field application. Instead owners and operators of electricity distribution networks have looked to employ handheld non-intrusive partial discharge detection instruments for the purposes of both condition assessment and enhancing operator safety [3]. Where the cost can be justified, the use of more permanent monitoring options for critical and targeted switchboards is expanding as additional monitoring solutions are introduced into the market [4].

PARTIAL DISCHARGE IN SWITCHGEAR

In practice, partial discharge in HV/MV insulation can be considered to take two forms, surface partial discharge and internal partial discharge. When surface partial discharge is present, tracking occurs across the surface of the insulation which is exacerbated by airborne contamination and moisture leading to erosion of the insulation. Internal partial discharge occurs within the bulk of insulation materials and is caused by age, poor materials or poor quality manufacturing processes. If allowed to continue unchecked, either mechanism will lead to failure of the insulation system under normal working stress potentially resulting in catastrophic failure of the equipment.

From extensive testing of switchgear with partial discharge tracking across the surface of insulation it has been observed that surface discharge activity often has low amplitude but very high discharge rate. An example of this can be seen in Fig.1 where surface discharge was occurring across the polymeric insulation of an 11kV circuit breaker.

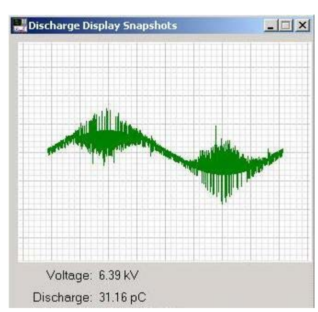

Fig. 1: Surface PD activity on an 11kV circuit breaker. Low discharge amplitude, high discharge rate

Due to the low amplitude of surface discharges one of the most appropriate methods for detection is using ultrasonic techniques [2&3].

In contrast to surface discharges, internal void discharges as they develop will have consistently high amplitude levels but have much lower discharge rates. Fig.2 shows one example of PD measurement on a cast resin CT on switchgear operating at 10kV.

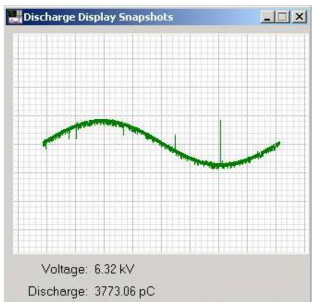

Fig. 2: Internal PD activity on a 10kV current transformer. High discharge amplitude, low discharge rate

One of the most commonly used methods of detection of this type of internal discharge is through electromagnetic techniques and the detection of Transient Earth Voltages (TEV) occurring in the 3 – 80MHz frequency range [2&3].

For internal partial discharge problems, it has been found that the level of these TEV signals are proportional to the condition of the insulation for switchgear of the same type and model, measured at the same point. This produced a very powerful comparative technique for non-invasively checking the condition of switches of the same type and manufacture. Since 1983, EA Technology has assembled, with the co-operation of the UK Electricity Companies, a database of substation partial discharge survey results with over 15,000 entries covering all different manufacturers, types of MV switchgear, and associated equipment.

This means some sort of quantification of risk can be undertaken for TEV measurements, taking into account equipment type, insulation medium, failure history and increasing levels of magnitude and severity (function of the magnitude and discharge rate). However, for ultrasonic detection of surface discharge activity, it was much more uncertain what the profile of discharge may be as insulation deteriorates towards disruptive failure of the equipment.

It is also true to say that surface discharge problems have been increasing within the population of distribution switchgear as more air insulated switchgear with smaller dimensions has been introduced onto distribution networks. Also, switchgear manufacturers have largely moved from using ceramic materials for solid insulation over to polymeric materials. Although polymeric materials generally offer good electrical insulation properties they are more prone to surface ageing and degradation processes and any electrical activity on the surface of such materials will eventually cause tracking damage.

LABORATORY WORK

It was therefore decided to carry out some laboratory work on a piece of switchgear with the main objective of profiling surface discharge activity through to failure using direct measurement equipment and airborne ultrasonic detectors.

It is generally accepted from many years of on-site partial discharge testing using a range of instruments and techniques that the local environment is an important factor in determining the likelihood of the presence and severity of surface partial discharge activity. The secondary purpose of the work was to further investigate this relationship.

Laboratory Testing

A test environment was constructed in a laboratory that consisted of an 11kV circuit breaker and cubicle inside a locked steel cage. The circuit breaker was supplied by a power utility from a de-commissioned substation where it had been in service for approximately 15 years and was of a design that is widely installed on the distribution network in the UK and is known to be prone to partial discharge activity particularly under poor environmental conditions.

The circuit breaker utilises a vacuum interruption medium and essentially has three vacuum bottles mounted on a cast resin monobloc that forms a withdrawable ‘truck’. The truck can be withdrawn and the circuit breaker locked into the earth position for maintenance or any other purpose.

A Robinsons DD5 partial discharge detector with a data logger was installed to observe the level of partial discharge activity. In addition, an ultrasonic monitor was employed using five ultrasonic microphones operating at 40kHz and strategically placed around the circuit breaker to observe and record the level of ultrasonic activity resulting from surface partial discharge. Further data loggers with integral sensors to measure temperature and relative humidity were placed inside the front of the circuit breaker cubicle, inside the open cable box and at some distance away from the circuit breaker to provide ambient background readings for comparison. Finally, transparent perspex covers were placed around the front of the circuit breaker cubicle and a humidification unit was installed inside the covers to increase and control the relative humidity. In addition, a small fan was installed to ensure an even air flow.

Before the initiation of the testing period each of the phases was tested in turn in the open and closed positions. The voltage was controlled from a variable source and increased incrementally up to a maximum of 10kV ac phase to ground. The yellow and blue phases were found to be discharge free up to 10kV whilst the red phase was found to have 100pC of discharge in the closed position at an inception voltage of 7.5kV. There was no visual evidence of significant levels of partial discharge activity on the circuit breaker.

The circuit breaker was then energised under controlled conditions in using a three phase discharge-free test transformer at the nominal working voltage of 11kV (6.35kV phase to ground) with the monitoring equipment installed onto the red phase of the test equipment. Apart from occasionally being de-energised for observation and testing purposes the equipment was in continuous operation until eventual failure some 27 months from the start of testing.

Test Results

When the circuit breaker was first energised no partial discharge was measured using the direct measurement equipment or non-intrusive instruments. To initiate discharge activity at working voltage, the humidity level was increased and within 5 minutes partial discharge activity was measured at 30pC, increasing to 200pC after a further 30 minutes. TEV measurements recorded 14dBmV with a count rate of 679 (approximately 7 pulses per cycle) and the UltraTEV ultrasonic indicator light showed red – this ultrasonic indication was apparent at the 30pC discharge level.

Testing continued for the next 12 months and the discharge activity varied between zero and 800pC largely depending upon the ambient conditions. However, although there was correlation, there was no direct link between the magnitude of discharge activity in pC, the magnitude of ultrasonic noise and the percentage Relative Humidity (%RH) in the atmosphere. Sixteen months into the testing, the partial discharge activity had become audible so the circuit breaker was de-energised and the truck was racked out and inspected for signs of partial discharge activity, Fig. 3.

Fig. 3: Tracking on Circuit Breaker 16 months into testing

White powder, verdigris and significant amounts of tracking can easily be seen at the top of the red phase vacuum bottle and from the closest earthed metalwork. The discharge area was left untouched and the circuit breaker was put back into service and re-energised.

Somewhat surprisingly, Fig.4 shows that after the examination where the circuit breaker had been allowed to dry out and the humidity within the test environment was allowed to follow the natural profile, the level of discharge activity measured in pC dropped to very low levels and sometimes zero.

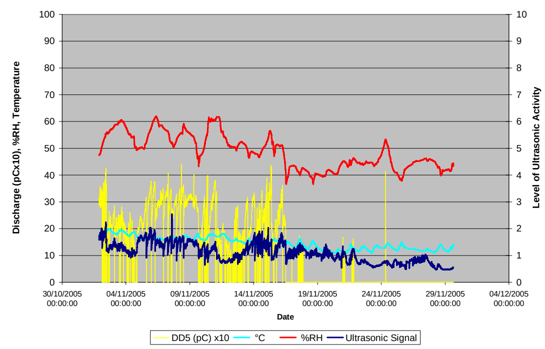

Fig. 4: Discharge Profile 16 to 17 months into testing

The level of ultrasonic activity correspondingly dropped with the reduction in partial discharge as the humidity naturally fell and remained below 50%RH; this despite the obviously degraded state of the primary insulation as shown in Fig. 3. Note, in Fig. 4 the base line for no detectable ultrasonic activity is a level of 0.5 on the secondary y-axis.

The test continued for another twelve months and again the circuit breaker truck was racked out and visually examined. During this examination, the cast resin monobloc appeared damp with moisture that was subsequently found to be nitric acid with a pH level of 3. The continuing very advanced path of partial discharge development between the top of the 'live' vacuum bottle retention clamp and the nearest earthed part can again be seen in Fig. 5. Comparison of Fig. 3 and Fig. 5 reveals how the treeing and tracking effectively advanced from the 'live' towards earth and the earth towards 'live'.

Fig. 5: Tracking on Circuit Breaker 26 months into testing

Twenty-seven months after the start of the test, the circuit breaker was de-energised. When it was re-energised a short time later, it failed producing a substantial quantity of smoke and a large deposit of carbon and other material within the enclosure, Fig 6. Upon inspection, it was plain that the tracking had caused a low resistance conductive path and short circuit allowing the release of fault energy.

Fig. 6: Failure 27 months into testing

Discussion of Results

The objectives of this project was to record the profile of surface discharge activity as a piece of switchgear progresses through to failure and to attempt to quantify the long held belief from many years of field testing switchgear and other substation plant that environmental conditions play a significant role in the inception and development of partial discharge activity.

The levels of relative humidity, particularly when condensed on the surfaces of the circuit breaker, lead to an almost instantaneous increase in the levels of recorded surface partial discharge and it was remarkable to observe how the partial discharge activity could cease during dry periods, even during the advanced stages of damage to the cast resin insulation. It was also clearly observable that the absolute level of recorded ultrasonic activity showed no apparent upward trend as the degradation increased although a correlation was observed between the levels of relative humidity and the presence and magnitude of partial discharge activity.

Short term correlations were observed between the magnitude of pC discharge activity and the level of recorded ultrasonic noise but they were not directly repeatable over a longer term i.e. over short term intervals higher pC meant higher ultrasonic noise but over longer terms the same level of recorded pC's did not necessarily produce same level of noise. It was clear during this test that no direct link could be found between the level of discharge in pC with expected insulation life when partial discharge was causing tracking and treeing on the surface of insulation.

CONCLUSIONS

Non-intrusive detection of internal void type discharge activity can be achieved by detection of Transient Earth Voltages (TEV's). Comparison of TEV measurements with previous tests and a database of results enables measurements to be quantified in terms of severity and likelihood of failure. For surface discharge activity ultrasonic techniques are often the most sensitive due to the low amplitude of discharge activity tracking across the surface of insulation.

The laboratory work on switchgear taken from a distribution network has illustrated two serious points for consideration:

(i). For surface discharge activity there is no correlation between the amplitude of discharge activity measured in pC, the extent of insulation damage and the proximity to failure.

(ii). It is not possible to infer any reliable relationship between the amplitude of ultrasonic activity, the extent of insulation damage and the proximity to failure.

Attempting to trend levels of ultrasonic activity and trying to relate them to the potential seriousness of surface partial discharge or end of life is not valid and could potentially lead to misleading conclusions. It can be stated with confidence that following the detection of ultrasonic activity a visual examination is always necessary to quantify the seriousness of the discharge problem.

A clear link was observed between environmental conditions in substations and the likely presence of partial discharge activity and hence condition of switchgear. The relative speed of degradation of modern insulation materials such as cast resin under optimum environmental conditions is remarkably rapid. In a substation environment, the degradation rate should be sufficient to allow annual inspections with partial discharge detectors that will detect any surface (or internal) partial discharge activity. This should leave enough time to visually inspect any detected activity and carry out necessary remedial work.

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