BENEFITS AND EXPERIENCES OF NON-INTRUSIVE PARTIAL DISCHARGE MEASUREMENTS ON MV SWITCHGEAR

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ABSTRACT

Partial discharge activity has long been accepted as a major cause of failure of Medium Voltage (MV) switchgear. 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 according to IEC 60270. Over the last 25 years or so instrumentation has been developed that enables the detection of partial discharge activity with the plant in normal service.

This paper will show the how two power utility companies have successfully introduced the widespread use of partial discharge testing, what their main drivers are behind the adoption and the practical results, experiences and benefits gained as a result.

INTRODUCTION

Over recent years the popularity of non-intrusive partial discharge testing has increased as network operators have started to appreciate the need for regular testing and realised the benefits that can be gained from the approach. However, until recently there was still a major barrier to wholesale adoption of partial discharge testing for MV switchgear and that was the capital cost of the test equipment coupled with the requirement for skilled engineers to carry out the testing in the days of downsized workforces.

The recent introduction to the market of low-cost, simple to use instruments that combine the ability to detect discharge activity using electromagnetic and ultrasonic methods has effectively removed this barrier to adoption. This is resulting in changes to the way power utility companies are approaching the condition assessment and management of switchgear assets and at the same time enhancing the safety of operators working on the system.

Partial Discharge

Partial discharge in MV Switchgear can be considered to take two forms, **surface discharge** where tracking occurs across the surface of the insulation, exacerbated by airborne contamination and moisture, and **internal discharge** within the insulation which, if allowed to continue, eventually causes the insulation to break down catastrophically.

Surface Discharge

Surface discharges are often best detected using an ultrasonic listening instrument. However, there must be an uninterrupted air path between the discharge site and the instrument to allow the ultrasound waves to be detected. Surface discharges tends to occur between the particles of a contaminant, producing heat, light, sound, electromagnetic radiation, Ozone and Nitrogen gasses. In the early stages of this type of degradation process, and if an air path from the discharge site to outside of the equipment is present, the high frequency sound waves generated by the partial discharge are readily detected using ultrasonic detection equipment in the 40 KHz range. Often moisture combines with the NOx gasses to produce Nitric acid, which attacks both the insulation and surrounding metalwork, which can become seriously rusted. Insulation surfaces affected by such an acid attack produce an ideal surface for tracking to occur. Tracking is the result of carbonisation of the surface of insulation often brought on in the early stages by the breakdown of contaminates. These carbon tracks electrically shorten the insulation causing the process to accelerate to eventual flashover.

Solid Insulation Internal Discharge

Within all insulation material, however manufactured, there are small voids, often microscopic. In use, the insulator has one end connected to HV and the other to earth, which cause these voids to charge up like small capacitors. When sufficiently charged they discharge with a small spark across the air void as the breakdown strength of the air is lower than that of the surrounding insulation and the electric stress across the void is high. These sparks produce heat, light, noise and electromagnetic radiation. Only the electromagnetic radiation can escape. The discharge action also erodes the voids making them bigger, and as they get bigger the discharge energy dissipated with each discharge increases in magnitude. During this process carbonisation of the inner surface also occurs, which progressively builds up to make the void conductive. This increases the electrical stress on the next void and the process repeats itself. Eventually there are sufficient conductive voids throughout the insulation large enough to cause the insulation to fail.

The electromagnetic pulses produced by partial discharges are in large part conducted away by the surrounding metalwork but a small proportion impinges onto the inner surface of the casing. These small charges (between 0.1 mV to 1 V) escape through joints in the metalwork, or a gasket on a gas insulated switch, and pass, as local raised voltages, across the surface of the switch to earth. These pulses of charge were first researched at EA Technology in 1974 by a Dr John Reeves, who named them Transient Earth Voltages (TEV).

It was 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. It is from this large body of results that EA Technology was able to determine appropriate threshold levels for a simple to use instrument called the UltraTEV.

UltraTEV

The UltraTEV detects the presence of both surface and TEV discharges and indicates, using different coloured LEDs, if further investigation is required. This instrument is designed for use by staff with minimal training and is used extensively for a first pass indicator for the presence of partial discharge.

The UltraTEV Instrument

This low cost instrument, the first to combine both electromagnetic and ultrasonic testing capabilities, has changed the way in which a number of power utility companies throughout the world approach the condition assessment and management of switchgear assets and at the same time enhances the safety of operators working on the system.

THE CLP EXPERIENCE

CLP Power Hong Kong (CLP) is a vertically integrated power company with total installed generation capacity of over 8,000 MW and total transmission and distribution transformer capacity of over 54 thousand MVA. Its annual local energy consumption is in excess of 30 thousand GWh.

Installed at more than 12,000 customer substations, there are over 43,000 11kV switchgear panels (70% VCB with air-insulated busbars) connecting more than 16,000 distribution transformers, distributing electricity to over 2.2 million customers. Condition monitoring of such a large asset group becomes an important task in response to the increasing expectation of stakeholders on higher equipment availability and reliability, greater safety, longer life span and lower O&M costs.

Strategy for Equipment Condition Monitoring

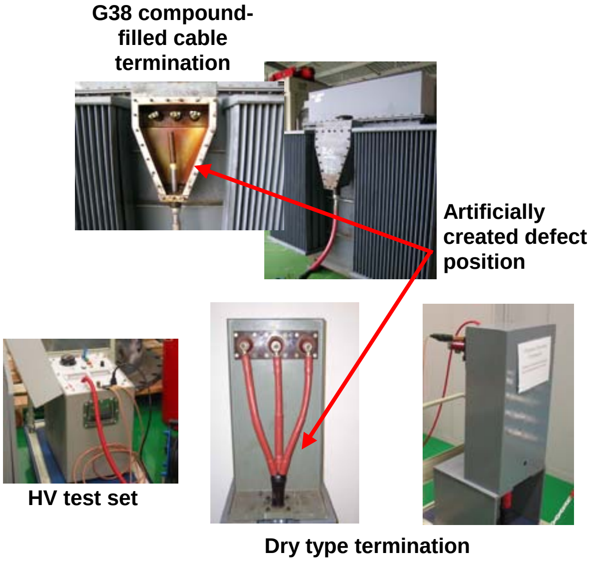
PD detection is one of the important condition monitoring tasks to ensure the operational integrity of substation MV equipment. Remedial actions could be taken at an early stage when PD signals are detected before developing into catastrophic failure. Before the introduction of the Transient Earth Voltage (TEV) technology, like many other power companies, CLP adopted traditional ultrasonic technology to detect the PD signal of MV equipment at 11kV level. Due to its high sensitivity characteristic, the ultrasonic detection device is capable of picking up small PD signals at its early stage of development. However, in CLP's operational experience, there are some limitations on using only ultrasonic detection, which include:

- Ultrasonic signal is easily influenced by high frequency noises from the environment;
- PD detection holes or openings must be available on the equipment to be tested;
- Ultrasonic detection is relatively directional and so the sensor must be pointed directly to the source for effective detection;
- Ultrasonic testing will only detect discharge activity occurring on the surface of insulation;
- Readings on the ultrasonic detector cannot be easily interpreted by site staff or tradesman.

With the introduction of TEV detection technology, PD signals could easily be detected with the detector placed on a convenient position of the metallic cover of the equipment. The "UltraTEV" detector possesses the advantages of both the ultrasonic and TEV detection and its green/red/yellow light indicator also provides simple and clear indication to site staff about the detection result.

Before full adoption of the UltraTEV, CLP conducted laboratory experiments and field trials to verify its effectiveness.

Tests on both G38 compound-filled and dry type cable boxes with the UltraTEV were concluded with positive results. Feedback from field trials were also satisfactory.



Testing Arrangement

Operational Experience

In order to enhance operational safety, the UltraTEV detector is being used for PD detection on switchgear panels and cable boxes when operational staff enter a substation. In addition, regular condition monitoring will be conducted with the UltraTEV as a first scan and further detailed investigation will be conducted whenever an abnormal condition is found.

In general, field staff members' feedback showed that the UltraTEV is an easy-to-use tool for PD detection. It increased their confidence on the integrity of equipment when working inside a substation.

Since the actual field use of the UltraTEV detector in March 2006, abnormal PD activities have been successfully identified at an 11kV primary substation installed with AIS panels aged over 30 years. Subsequent detailed investigation identified a PD source inside the CT chamber. The panel was then isolated for follow up remedial improvement work.

Further Application

After gaining the experience on 11kV switchboards, CLP is exploring the usage of UltraTEV detection on other equipment including cable uptake installed on overhead line poles and cable body etc. In order to achieve continuous monitoring on critical equipment, use of on-line TEV detection system to detect PD activities at 11kV primary substations will also be explored.

THE ESB EXPERIENCE

ESB Networks is the owner and operator of the electricity network in the Republic of Ireland. As the licensed Distribution System Operator it is responsible for maintaining all the sub-transmission, medium and low voltage electricity network infrastructure in the country. This includes all overhead electricity lines, poles, substations, and underground cables that are used to bring power to Ireland's 1.7 million Domestic, Commercial and Industrial customers. ESB Networks also owns and maintains the higher voltage Transmission system.

Operational Problem

In 2002 two unrelated but serious incidents occurred that brought safe working practices to the top of the ESB agenda. One of these incidents involved a cast resin 10kV ring main unit which catastrophically failed 30 minutes after a manual switching operation. Subsequent investigation indicated insulation failure. For this reason all 250 substations equipped with the same type of switchgear were placed under operational restriction requiring switching operations only to be carried out 'off-line'. Because of the customer supply disruption caused, ESB asked EA Technology to assist in developing an operational protocol to help remove the restriction.

As the incident was caused by insulation failure it is reasonable to consider that partial discharge within the insulation was occurring prior to failure and that with the proper detection equipment this could have been detected.

The Solution

EA Technology and ESB worked together developing a protocol that used the recently introduced UltraTEV instrument. Because the UltraTEV detects both internal and surface discharge activity and indicates with simple red and green lights the presence or absence of discharge, the instrument was ideal as a 'safe to operate'/ 'not safe to operate' indicator. The protocol required the threshold settings within the UltraTEV to accurately and demonstrably indicate when significant partial discharge was present or absent. It was proposed that a trial be undertaken to test the protocol. This would involve testing a selection of the suspect ring main units with the UltraTEV. Further checks would also be carried out using the MiniTEV instrument for internal discharges, and a sensitive ultrasonic detection instrument to check for surface discharge. The ring main unit would then be switched 'out' ('alive, or 'dead' as indicated by the instruments), racked out, and a detailed inspection undertaken for any signs of partial discharge.

If the UltraTEV instrument indicated the absence of discharge, and this was confirmed by a detailed visual inspection, and this was true for all the switches of the ring main unit, then the restriction could be lifted for that substation.

This protocol was agreed by the Safety Representatives of ESB and in November 2003, and later that month tested on a selection of substations in Cork.

Results of the Protocol Testing

Ten substations equipped with the ring main units in the City of Cork were subject to a full non-intrusive partial discharge survey followed by a comprehensive visual examination.

The results of the testing and inspections indicated that the protocol was viable and provided a basis for practical management of the 250 ring main units of this type on the network. It also determined that the threshold levels of the UltraTEV were correct, sensitive enough to detect dangerous levels of discharge but not over sensitive to result in unwarranted restriction to normal operation of the network.

Other Switches on the ESB Network

ESB also have over 5000 10kV fused cast resin to air switchgear on their network. This switchgear also suffered numerous disruptive failures and the opportunity arose during the Cork trials to survey 2 of these units. Both switchgear units exhibited red lights on the UltraTEV indicating the need for maintenance or replacement.

This result led ESB to consider incorporating the UltraTEV into routine working practices prior to operation of switchgear. This, it was argued, would significantly improve the safety and reliability of operational activities as well as target their resources to best effect.

The ESB network also includes some modern SF6 switchgear, oil filled ring main units, and open cubicle substations.

Adoption of the Protocol Across the ESB Network

The protocol developed and tested in Cork was adopted nationally and all operational switching and inspection staff were issued with an UltraTEV instrument for use prior to all switching operations. Over 400 instruments were issued between May 2004 and March 2005.

Operational Experience After 12 Months

During 2006 over 5,000 inspections were carried out using the UltraTEV. These results are split into 2 basic areas, Cast Resin, which account for 70% of the tests, and Others, which include terminations on SF6 switchgear, Oil Filled RMU terminations, and Open Cubicle equipment.

Cast Resin Switchgear: 93% Green 7% Red

This result was better than expected and is likely to improve as the causes of the red lights are removed from the system.

Others: 95% Green 5% Red

ESB are pleased with the overall results in that they have not been swamped by defective equipment as had been expected, and that operational staff are not being unknowingly exposed to dangerous situations.

CONCLUSIONS

Prior to adopting the widespread use of instruments for partial discharge surveying of MV plant, companies have an understandable concern that an unwarranted level of equipment would be highlighted as needing further investigation.

The laboratory and field trials carried out by CLP and ESB demonstrated the applicability of the UltraTEV instrument and validated the chosen threshold levels. These threshold levels were carefully selected by EA Technology based on many thousands of survey results from all types of switchgear operating between 3.3 and 33kV. Both companies have now further corroborated the threshold levels through comprehensive field experience.

The operational staff of CLP and ESB have embraced the newly available partial discharge technology and it has become 'business as normal' in both companies. Adoption of the simple to use UltraTEV as a first line tool for both condition assessment and enhancement of operational safety has been a success for both companies.

The strongest common message coming from the companies is that the use of the instrument has **increased operational staff confidence on the integrity of equipment when working inside a substation**.

Both companies have also found a clear commercial benefit in the widespread use of the UltraTEV through the reliable condition assessment of switchgear and the accurate targeting of maintenance and replacement resources towards plant in need of attention.

For ESB in particular further major benefits have been in the management of a significant operational problem, identification of switches that were not to be switched live, increased safety for operational staff and the removal of onerous operational restrictions.

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