CONDITION MONITORING DEVELOPMENTS FOR ASSET MANAGEMENT IN MV SWITCHGEAR WITHIN ETHEKWINI ELECTRICITY

Author : M.P Lokothwayo MEng – Chief Technician eThekwini Electricity

Co-authors: S Cele Diploma – Technician eThekwini Electricity, N Zulu BTech – Chief Technician eThekwini Electricity and P.M. Ntombela BSc – Engineer eThekwini Electricity

Abstract: Medium voltage switchgear is one of the key assets in eThekwini Electricity distribution network. Its main function is to distribute supply and to selectively disconnect loads. Traditionally, switchgear maintenance has been done periodically by visual inspections. The cable terminations, instrument transformers and switchgear component are continuing to gradually fail while in operation. Commonly these failures are associated with partial discharge activity. Condition monitoring plays a crucial role in the safety, reliable and continuous operation of switchgear. Partial discharge detection is amongst the essential methods of condition monitoring in switchgear as it is capable of detecting early deterioration and minimise risks of failures. This paper presents a practical implementation of partial discharge measurements in switchgear condition monitoring as part of asset management.

1 INTRODUCTION

The aim of eThekwini Electricity is to operate electrical assets in the field without any defects at minimum cost; hence, improve service delivery, increase safety of personnel & equipment and ensure occupational health and safety environment. Electricity distribution assets comprise overhead lines, power transformers, instrument transformers, switchgear and cables. This paper is centered around Medium Voltage (MV) switchgear.

MV switchgear is exposed to various stresses during operation. Partial discharge (PD) activity is considered as the major source of defect in MV switchgear insulation [1]. Therefore, PD detection and location is an effective method to reveal the insulation condition in MV switchgear. The asset management (AM) plan that incorporate a non-invasive PD detection allows for strategic decision based on asset's PD activity level to be taken and resources to be deployed effectively during planned outage.

The capital investment made to deliver electricity to the end users must correlate to the management of these assets throughout their life span [2]. Thus, the initial step in implementing a condition monitoring program is to collect and analyse historical failure records for similar types of asset. This help to determine the cause and magnitude of problems and resources are appropriately utilised in dealing with the causes. According to [1], a large number of substation defect originate from insulation failures as presented in table 1.

Tab.1: Insulation system failure statistics [1]

Component	Percentage of insulation failure
Transformers	84%
Circuit Breakers	21%
Disconnect Switches	15%
Insulated switchgear bus	95%
Bus dust	90%
Cable	91%
Cable joints	89%
Cable terminations	87%

This paper focuses on assessing the condition of the MV switchgear using a non-invasive partial discharge detection technology. The overview of a non-invasive PD measurements and MV switchgear defects which were identified are presented and discussed.

2 ASSET MANAGEMENT

According to [3], “AM is the process of maximising the return on investment of equipment over its entire life cycle, by maximising performance and minimizing costs”. AM is the well-organised use of resources, with focus on increasing the remaining useful life of the equipment. Its ultimate purpose is to effectively and efficiently use the equipment service life. It guarantees that critical assets will continue meeting the mandatory level of performance for the duration of the life of the equipment. From the electricity distribution perspective, AM is a systematic process of, relating engineering practices and economic analysis to manage electrical assets in a cost effective manner.

There are five types of assets classification that need to be considered in achieving the organizational strategic plan successfully [4]. This includes physical assets, human assets, data assets, financial assets and intangible assets. Cost, risk and performance are three pillars in managing the life cycle of MV switchgear effectively. The attributes that impact switchgear remaining life are: insulation failure; mechanical problems; improper cable termination; failure on instrument transformers; and malfunctioning. Risk evaluation and prioritization most of the time poses a challenge in decision making process for AM system. CM approach based on PD detection in MV switchgear allows for proper decision making to either dispose or repair the matured switchgear completely and Capital expenditure (CAPEX) available is used appropriately. It is in this way that CM supports the AM system and allows for optimising asset performance at a reduced operational cost.

3 CONDITION MONITORING

3.1. Partial discharge concept

According to IEC 60270 [4], “PD can be described as an electrical pulse or discharge in a gas filled void or on a dielectric surface of a solid or liquid insulation system”. PD can develop in electrical assets under normal working condition. It is caused by number of factors including improper installation, ageing, manufacturing defects, environmental and third party damage. PD in electrical insulation is caused by void or flaws and if left undetected can eventually manifest to full breakdown of insulation system.

PD phenomenon is an indication of degradation of insulation materials. Thus, the detection of PD at early stages plays a crucial role in increasing the service life of electrical assets [5]. By carry out a non-invasive PD testing in monitoring critical assets it is possible to provide an early warning of pending insulation failure. PD experience has shown that early PD detection followed by remedial action lead to simpler and lower cost solution maintenance [6].

The ability to comprehend theory of PD is very helpful in interpreting the PD measurement results. PD activity behaviour is greatly influenced by voltage and temperature (mainly humidity). Low humidity can cause PD activity to be undetectable and develop again when humidity increases. Figure 1 show energy types emitted during PD activity:

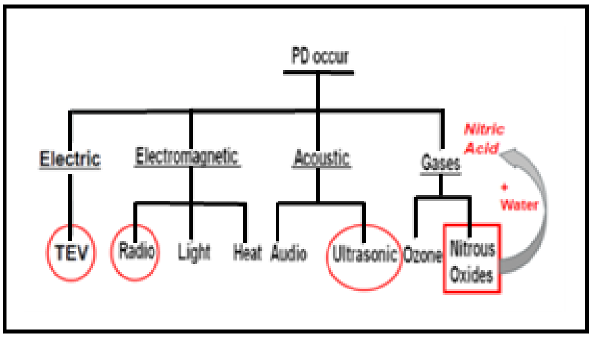

Fig. 1: Energy emitted during PD activity [7]

3.1 PD classification

Two types of PD can be identified in MV switchgear, namely surface discharge and internal discharge [4].

3.2.1. Surface Discharge

When surface PD is present, tracking occurs across the surface of the insulation which is worsened by floating contamination and moisture leading to erosion of the insulation [5]. 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 carbonization of the surface of insulation by the breakdown of contaminates in the early stages [6].

3.2.1.1 Surface discharge detection

The high frequency sound waves generated by the partial discharge activity on the surface of the insulation can be detected using 40 kHz range Ultrasonic detector [6]. Quantifying the seriousness of detected ultrasonic signals sometimes poses a challenge and therefore, further visual investigation is needed irrespective of the signal level. Appendix A present risk interpretation for surface discharges [7].

3.2.2 Internal Partial Discharge

Internal PD occurs within the insulation materials and is caused by age, poor materials or poor quality manufacturing processes [5]. If allowed to continue, eventually causes the insulation to break down catastrophically.

3.2.2.1 Internal discharge detection

The discharge activity within solid insulation can be detected using Transient Earth Voltage (TEV) detection. The TEV measurement technique operates within a bandwidth of 3 to 70 MHz, to detect and locate the PD source from the phase terminations to earth usually caused by voids and surface discharge to earthed metalwork [6]. Figure 2 illustrate the TEV practical concept.

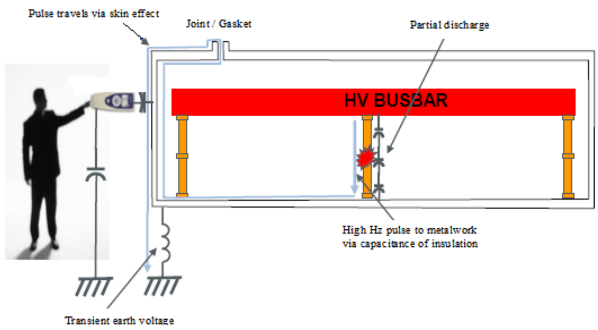

Fig. 2: Internal PD effect [7]

When a discharge occurs a small quantity of electrical charge is transferred capacitively from the live conductor to the earthed metal-cladding. Due to the skin effect the transient voltages on the inside of the metalwork cannot be directly detected outside the switchgear. However, at an opening in the metal cladding, such as the gasket joint the electromagnetic wave can propagate out into free space. The wave front impinges on the outside of the metal cladding generating a transient earth voltage on the metal surface. Hence, the technique is called TEV for transient earth voltage. TEV signals will propagate from all types of chambers, i.e. the technique can be applied to gas insulated chambers, as well as oil, bitumen and air insulated chambers [6]. Appendix B present risk interpretation for internal discharges [7].

4 PRACTICAL EXPERIENCE AND ANALYSIS

Based on the risk interpretation in Appendix A, serious discharge activity was identified on 11 kV switchgear cubicles.

The planned outage was scheduled via an Ellipse Asset Register. The visual inspection findings and analysis are presented next.

4.1. Case 1 – Distribution Substation 413

4.1.1. Cluster contact

Fig. 6: Cluster contact @ 11 kV switchgear panel

Locator Reading – 34 dBuV Ultrasonic

Defects – Serious rusting

Possible Cause – Nitric acid produced by combination of moisture and NOx gasses attacking insulation and surrounding metalwork.

4.1.2. Tracking Cable termination

Fig. 7: Cable termination @ 11 kV switchgear panel

Locator Reading - 27 dBuV Ultrasonic

Defects – Carbon discharge & a bubble on one of the phase.

Possible Cause – Poor workmanship

4.1.3. Tracking CT's

Fig. 8: Tracking CT's @ 11 kV switchgear panel

Locator Reading – 44 dBuV Ultrasonic

Defects – Treeing and tracking discharges

Possible Cause – Imperfections in the insulation system.

4.2. Case 2 – Distribution Substation 1123

4.2.1. Cluster contact

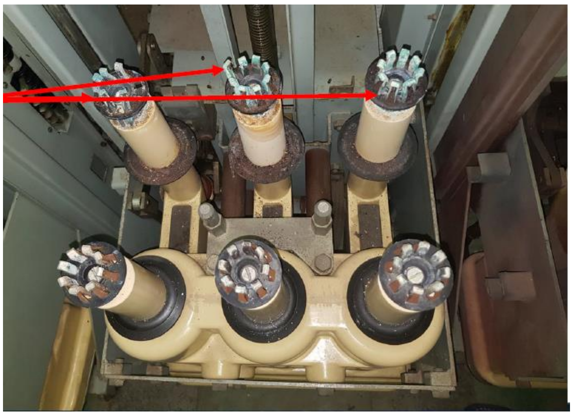

Fig. 9: Cluster contact @ 11 kV switchgear panel

PD locator reading – 32 dBuV Ultrasonic

Defects – Rust and loose cluster contact fingers compromises the mechanical strength of the cluster.

Possible Cause –The loose cluster contact fingers and mechanic damage on the cluster contact creates an effective way for partial discharges to develop.

4.2.2. Busbar bushing connection

Fig. 10: busbar - bushing connection @ 11 kV switchgear panel

PD locator reading – 43 dBuV Ultrasonic

Defects – Discharge traces in the busbar - bushing connection.

Possible Cause – Water due to high humidity level treating a conducting path on the insulation surface.

4.2.3. Tracking CT's

Fig. 11: Tracking CT's @ 11 kV switchgear panel

Locator Reading – 38 dBuV Ultrasonic

Defects – Water ingress on the CT's.

Possible Cause – Design issues.

4.3. Case 3 – Distribution Substation failures

4.3.1. Cable termination failure due to PD

The PD were detected on this MV switchgear termination. However it was not given attention on recommended time due to load challenges and it failed.

Fig. 12: 11 kV switchgear cable termination failure

Locator Reading – 31 dBuV Ultrasonic

Defects – Cable termination failure

Possible Cause – Poor workmanship.

4.3.2. Busbar - failure due to PD

The PD were detected on this MV switchgear panel. The consumer requested to postpone a planned shutdown, due to production demands. Therefore this resulted to a busbar failure and an unplanned shutdown.

Fig. 13: 11 kV Busbar failure

Locator Reading – 34 dBuV Ultrasonic

Defects – 11 kV Busbar failure

Possible Cause – Poor workmanship.

These failures would have been prevented if remedial work done was prioritise according to risk interpretation in Appendix A.

5 DISCUSSION

The PD measurement results in conjunction with defects identified clearly indicate that PD testing in MV switchgear is an excellent non-invasive monitoring tool. PD monitoring identifies risks of failure in MV switchgear. The use of a non-invasive PD analysis can identify areas of immediate concern. The results can be prioritised and trended. Moreover, outages are planned and repairs can be budgeted.

6 CONCLUSION

This paper has presented a concept and implementation of asset condition monitoring in MV switchgear. The effectiveness of MV switchgear condition monitoring based on a non-invasive PD testing has been successful implemented. PD theory has been used to better understand the causes of defects in switchgear component. Visible evidence of PD defects and possible causes have been identified and discussed. The switchgear measurement results together with the identified defects was analysed and solutions actioned efficiently and effectively. Condition monitoring is an important element of power system asset management. The decision to replace or repair the asset is achieved better when the condition status of the asset is known. CM enhances reliability and aid in life extension of critical assets in power distribution system.

7 APPENDIX

Appendix A: Ultrasonic risk interpretation

Ultra dB	Category	Comments
< 6	Good background	No observable/measurable deterioration
7 - 10	Fair Very slight fizzing only just above the background	**Minor Deterioration** which requires no specific action
11 - 20	Poor Heavy fizzing or crackling	**Moderate Deterioration** Item can be returned to service. Reinspect in 30 days.
> 20	Action Required Spitting or sparking or heard with the naked ear	**Serious Deterioration** Item cannot be returned to service without shut down or engineering advise

Appendix B: TEV risk Interpretation

<table>
<tr><td rowspan="2">TEV dB</td><td colspan="4">Pulses/Cycle</td></tr>
<tr><td>< 0.5</td><td>0.5-6</td><td>6- 30</td><td>> 31</td></tr>
<tr><td>0</td><td colspan="4">No TEV Detected</td></tr>
<tr><td>10 - 19</td><td rowspan="3">No TEV Detected</td><td>Possible Low Level Internal PD</td><td>Possible Low Surface PD</td><td rowspan="2">Interference or low level surface PD</td></tr>
<tr><td>20 - 29</td><td>Low Level Internal PD</td><td>Low Level Surface PD</td></tr>
<tr><td>> 30</td><td>High risk of internal PD</td><td colspan="2">Likely floating object or poor contact PD</td></tr>
</table>

8 ACKNOWLEDGMENT

The authors would like to express their gratitude to the management of eThekwini Electricity Unit for giving them support to author the paper. Moreover, we thank all the colleagues who contributed in this paper.

9 REFERENCES

[1] IEEE Standard 493-1997, "IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems – Gold Book", IEEE Inc New York, NY, 1998.

[2] I.E. Davidson, "Utility Asset Management in the Electrical Power Distribution Sector'', IEEE Conference and Exposition in Africa Durban, South Africa, July 2005.

[3] S. Silveira, “Building sustainable Energy systems- Swedish Experiences”, Swedish National Energy Administration Stockholm, ISBN 91-7332-961-4, 2002.

[4] British Standards Institution., IEC 60270: High-voltage test techniques – partial discharge measurements. London: BSI, 2001.

[5] D. Jones. "Testing Distribution Switchgear for Partial Discharge in the Laboratory and the Field", Conference Record of the 2008 IEEE International Symposium on Electrical Insulation, 06/2008.

[6] P. Shiel, "Non-intrusive partial discharge measurements of MV switchgear", International Conference on Condition Monitoring and Diagnosis, 2008.

[7] N Davies, “Partial Discharge (PD) techniques for measuring the condition of ageing HV/MV switchgear”, EA Technology International, 2009.