1. Introduction

The City of Cape Town has sustained a significant number of bushing failures in medium voltage switchgear, mostly effecting catastrophic damage to buildings and adjacent plant. The purpose of this paper is to share experiences regarding the causes of these failures and possible remedies.

Picture 1: Langa Metrorail Substation

2. Background

With the expansion of SF6 and vacuum technology, manufacturers also replaced Bakelite paper bushings with resin cast bushings.

Advantages of resin cast technology would be:

2.1 Better suited for mass production
2.2 Superior fault toleration
2.3 Scratch and mechanical damage resistant
2.4 Cheaper

Contrary to the above, The City of Cape Town experience is that bakelite paper bushings outperform resin cast bushings by far.
Some manufacturers would redesign existing breakers to SF6 and resin cast technology to fit in the same panel as the previous generation oil breaker.

The City Of Cape Town utilizes three models of SF6 MV switchgear rack in truck breakers from the same manufacturer, which are all interchangeable with previous generation oil breakers.

A large number of bushing failures, mostly due to partial discharge activity across the surface of bushings, were experienced at least on two models of the same panel and manufacturer, while severe partial discharge activity, but no catastrophic failures on a third model of the same manufacturer.

3. Some of the Failures and Observations Made

3.1 Tygervalley waterfront

Some of the first recorded failures in the City Of Cape Town were at the Tygervalley Waterfront Substation. Staff entered the substation for switching operations. They experienced a strong smell of chlorine in the substation and on further investigation they found the “Falls” breaker with severe discharge degradation on bushing insulation and cluster contacts.

Picture 2: Tygervalley Waterfront Substation (Falls Breaker) 2004

Note the white phase bus bar side undamaged with different stages of degradation on other clusters and bushing.
Picture 3: Waterfront Substation, Quarry breaker (Nov 05).

Note severe cluster damage.

3.2 Plaspack Substation

Picture 4: Plaspack Substation breaker failure
3.3 Santyger Substation

Picture 5: Bushing failure at Santyger Substation

3.4 Faasen Substation

Picture 6: Bushing failure at Faasen Substation
3.5 Junction Substation

Picture 7: Bushing failure at Junction Substation

Bushing failures at Santyger, Faasen and Junction were in similar fashion, at the earth screen layer within the resin of the insulation; the top of this screen being close to the vermin guard position.

3.6 Southern Sewing Substation

Picture 8: Tracking, Southern Sewing
Note the severe degradation of insulators and cluster.

### 3.7 Bellaire Substation

The Bellaire blue phase busbar side breaker bushing was in the initial stages of PD damage and it can be clearly seen that tracking was associated with the moulding seam line, similarly to most other cases.

**Picture 10:** Bellaire blue phase busbar side bushing
3.8 Solway Substation

Picture 11: Solway Orifice (female) bushing cut open in laboratory in England

Picture 12: Pores in Solway orifice bushing photographed in laboratory in England

Note greasy appearance on breaker bushing; this is typical of nitric acid contamination.
Picture 13: Solway Substation pores also visible beneath the skin of the resin photographed at laboratory in England

Picture 14: Solway Substation, individual pore photographed in laboratory in England
3.9 Nqubulani Substation

In Nqubulani Substation, there was discharge between the concertina boots. These boots were originally fitted on request of the City Of Cape Town to cover conductive parts, but are now retrofitted to solid shrouds, filled with compound, which provide a good airgap between phases.
3.10 Cape Substation

Picture 17: Discharge around breaker bushing due to misalignment of shutter boxes

Picture 18: Discharge around bushing due to misaligned shutter box – single bushing

4. Partial Discharges: Contributing Factors of Activity in Breakers

4.1 Bushing Design

Design must be ample. Safety factors must be built into bushing design.

The following must be taken into consideration:

4.1.1 Environmental conditions and possible exceeding of expected conditions
4.1.2 Material used and possible quality variance of materials
4.1.3 Available skills to manufacture
4.1.4 Quality control during manufacture
4.1.5 Natural and industrial pollution
4.1.6 Maintenance skills available
4.2 Effect of voids, pores and bubbles in moldings

Male and female bushings must be smooth and free of voids, bubbles and molding lines, each of which can create local regions of increased electrical stress thereby increasing the probability of PD activity.

4.3 Moisture

Humid air and especially droplets of moisture are exponentially contributory to the total PD activity in the bushing assembly. Moisture carried in air [humidity] modifies the dielectric properties of air, which in modern switchgear is a significant part of the insulation system. The reduced breakdown strength of the air increases the probability of partial discharge.

Most new switchgear panels are fitted with heaters ranging from 80 to 120 watt, while some manufacturers specify panel heaters as optional.

The City Of Cape Town monitored humidity over a 4-day period in the substations perceived to be the wettest. Substations monitored were within the specification of the manufacturer, although the manufacturer did not have a thorough specification.

Heaters are controversial as they can consume considerable amounts of energy. The City Of Cape Town has 5 497 MV protected breakers installed. If all panels are fitted with 100 watt heaters, total yearly consumption will be 4 815 372 kWh. At the City’s Medium Voltage Large Power Bulk Tariff, energy cost will be approximately R1.46 million per year, excluding VAT.

Heaters reduce the risk of condensation forming by increasing the temperature of the switchgear relative to the dew point of the air in the substation. As a result, heaters reduce the risk of condensation forming on the components they are warming. Dehumidifiers in a substation would reduce moisture content from the air and treat the whole environment and provide a more complete means of improving the electrical environment for the switchgear.

Where the substation environment is controlled with either heaters of dehumidifiers, it is important that this equipment is regularly checked during maintenance as there are known cases of heaters that tripped and catastrophic failures of breakers occurred within 6 months after installation.

4.4 Alignment of Breaker or Shutter Box: Shutter Box design

Misalignment of breakers and shutter boxes may have following effects:

4.4.1 Breaker bushings do not align with respective orifice bushings, resulting in an inconsistent electric field around the bushing due to irregular positioning of the shutter box apertures.

4.4.2 Misaligned shutter boxes may have the same effect as the above.

4.4.3 Misaligned breakers may also cause the orifice (female) bushing to be damaged and tracking may occur. These breakers may be dangerous to operate.

4.4.4 Misalignment may lead to increased PD action within the cluster, but the exact contribution of this is not known.

Picture 19: Orifice bushing damaged by cluster
Picture 20: Breaker supplied by manufacturer - misaligned on trolley

Picture 21: Misaligned shutter boxes, Cape Substation
4.5 *Introduction of foreign objects – Vermin Guards*

Silicon rubber vermin guards were added to seal the top part of the bushing assembly against vermin ingress.

These vermin guards could however add to discharge activity in the following ways:

4.5.1 Proper adhesion between the silicon vermin guard resin breaker bushing is not achievable. As there are air gaps between the vermin guards and bushings, this will lead to increased PD activity;

4.5.2 Dirt (surface contamination) is trapped between the poorly adhered vermin seal and the breaker bushing. This leads to increased PD activity in the area of the vermin seal;

4.5.3 Adverse modification of the electric field in a region of potentially high stress.
In many cases, degradation started between the breaker bushing and vermin guards.

Picture 25: Solway (short) vermin guard showing shallow depth with extensive PD tracking which eroded through the guard

4.6 Maintenance Intervals and cleaning

Due to scarcity of skills, maintenance targets are very seldom achieved.

The introduction of gas insulated and vacuum technology with casing cast bushings created the expectation that maintenance intervals may be decreased.

NRS 089-3-2: 2005 (Draft) calls for a 5-yearly maintenance cycle for medium voltage SF6 switchgear. The manufacturer recommends a 1-yearly trip test and 5-yearly maintenance.

Recommended additional maintenance tasks are as follows:

4.6.1 Yearly cleaning of breaker bushings when trip testing is done. Generally it is not recommended that cleaning solvents be used, but only when there are signs of PD
tracking, a solution of sodium bicarbonate is recommended to clean off and neutralize possible acidic nitric acid, a possible by-product of PD activity on resin bushings.

4.6.2 Monthly checking of heaters (with monthly inspection)

4.7 Cluster contact design

There may be increased PD activity within the air gaps in the cluster contacts. Changing to another model of cluster contacts may contribute to decreased PD activity at the cluster contacts.

5. Early Detection of Activity

Partial discharge is quite often audible when entering the substation and it is very often accompanied by a strong ozone smell, however sometimes neither of these is present. When the activity is this well developed it is of concern and significant access restrictions should be placed on that substation.

The City Of Cape Town is currently using a handheld instrument, the Ultra TEV Plus, to detect and pinpoint partial discharges which may also be used for detecting PD discharges on transformer bushings, cable terminations, busbars, etc.

Similar equipment is available on the market.

If partial discharge activity is intermittent, recorders may be installed.

Permanently mounted discharge monitoring equipment may also be considered.

As a result, regular Ultrasonic and TEV PD survey with UltraTEV* to determine the extent of PD activity within the switchgear should be carried out. This will identify issues significantly before they are failing and thus improve safety of staff required to work in the substation and also increase the reliability of the network due to reduced unplanned outages.

6. Partial Discharge Activity

Partial discharge is an electrical discharge or spark that bridges a portion of the insulation between two conducting electrodes.

Partial discharge can occur at any location within the insulation system (between the two electrodes) where the electric field strength exceeds the breakdown strength of that portion of the insulating material. Partial discharge can occur in voids within solid insulation, across the surface of insulating material due to contaminants or irregularities, within gas bubbles in liquid insulation or around an electrode in gas (corona activity).

Prominences or defects at conductor surfaces can lead to stress concentration. Partial discharge activity is a progressive mechanism in which an insulation system apparently operating within the intrinsic breakdown strength levels of the materials can progress to failure because of local concentration of the stress.

Voltage stress across insulation depends on the physical geometry and the relative electrical permittivity of the insulation components. Where components of differing permittivity are effectively in series, the stress will be higher across the components with lower permittivity. Gaseous gaps therefore tend to experience higher stress then the adjacent solid or liquid insulations. Small gaps are most susceptible to partial discharge activity.

The energy liberated at a partial discharge site will often degrade the insulation. It may form tree-like tracks through or over the surface of solid insulation. The tracks may be conductive, typically because of the presence of carbon from the degradation of the insulation, so that electrical stress is concentrated at the advancing tips of the trees.

Partial discharge may occur in aged, defective or poor quality insulation and can propagate and develop until the insulation is unable to withstand the electrical stress leading to flashover and failure.
When partial discharge activity occurs, it emits energy in the following ways:

6.1 Electromagnetic
6.1.1 Radio
6.1.2 Light
6.1.3 Heat

6.2 Acoustic
6.2.1 Audio
6.2.2 Ultrasonic

6.3 Gaseous
6.3.1 Ozone
6.3.2 Nitrous oxides

7. Conclusion

Most of the problems experienced are associated with partial discharge activity causing degradation across the surface of bushings.

Apart from possible design constraints, elevated moisture levels in substations are the greatest contributing factor to increased PD activity in the City Of Cape Town case. Substations have to be dehumidified and/or panel heaters installed in all panels where breakers with resin bushings are used.

PD damaged bushings cannot be repaired.

During inspections, bushings with signs of partial discharge damage must be inspected, evaluated and replaced if necessary. It should be noted that partial discharge activity products may additionally be present on surrounding components.

The use and function of vermin seals must be revisited.

Alignment of breakers must be critically looked at. Damaged bushings must be replaced. Shutter boxes have to be realigned. On one particular model, the manufacturer is busy redesigning the shutter box altogether to provide increased clearance from the shutter box hinge to the top of the breaker and these shutter boxes have to replaced.

The maintenance frequency must be increased i.e. breakers must be racked out, inspected and cleaned at least once a year.

8. References

8.1 Medium Voltage Switchgear Partial Discharge Investigation for The City Of Cape Town by A Rogerson of EA Technology Services;
8.2 Paper on partial discharges by N Davies and A Rogerson of EA Technology Services.