Condition Monitoring of equipment to improve quality of supply to customers by averting failures

Abstract
This paper covers the results obtained from performing condition monitoring on equipment before the World Cup Soccer 2010 tournament, which was estimated to have saved City Power R85mil in failures that were averted. Many of these failures would have occurred during the World Cup Soccer tournament and this would not have been good for City Power and South Africa.

1. Introduction
City Power and Singapore Power Global Solutions have entered into a strategic partnership that is now bearing fruit. The Singapore Power Global Solutions is the consulting division of Singapore Power responsible for ensuring that electrical utilities and end users can implement condition monitoring to improve the reliability of supply.

Singapore Power has successfully implemented condition monitoring over the past 20 years. Condition monitoring is one of the key contributing factors for Singapore Power becoming one of the most reliable utility in the World. Based on the latest performance indices a customer in Singapore would experience a power failure only once in every 142 years (System Average Interruption Frequency Index - SAIFI) and the longest fault any customer would experience is roughly 30 seconds (System Average Interruption Duration Index - SAIDI). These figures are absolutely amazing, but possible!
2. Benefits of performing condition monitoring

City Power has now implemented condition monitoring and the following benefits planned to be achieved;

- Reduced faults to weaken electrical networks will be experienced, therefore less forced outages.
- Improved reliability and quality of supply. (SAIDI, CAIFI and NRS 048 etc.)
- Evidence of root cause is not destroyed and preventive maintenance can be done before failures occur. The rectification costs prior to a failure are much cheaper than repair cost after failure.
- Reduction in maintenance and post failure repair costs.
- Extended equipment life
- Extend intrusive maintenance intervals

3. Root cause of equipment failures

Partial Discharge (PD) is the root cause of most network related failures experienced by City Power, excluding vandalism and theft. Once PD has begun it will always worsen leading to Insulation breakdown equipment failure.

Partial discharge is defined as a localised discharge process in which the distance between two electrodes is partially bridged. Partial discharges may originate directly at one of the electrodes or occur in a void or cavity inside the dielectric.
Corona discharges: These occur as a result of a non uniform field on sharp edges of a conductor subjected to high voltages.

Surface discharges: Occur on the surface of the different dielectric material.

Cavity discharges: These occur when cavities are formed in solid or liquid insulating materials where the gas in the cavity is overstressed and discharges occur.

PD is a resultant of many contributing factors including:

- Poor workmanship (clearances, installation errors and loss of skills)
- Incorrect application of products (technology changes)
- Overload leading to insulation breakdown (Heat causes insulation to breakdown)
- Manufacturing defects
- Poor equipment designs

Once the PD causes the insulation medium to breakdown, a power flashover from live to earth occurs.

PD in medium voltage switchgear is measurable in two different ways with EA Technology instruments;

- Capacitive probe for the detection of Transient Earth Voltages (TEVs) in the VHF Electromagnetic Spectrum (3 – 80MHz)
  - Internal Discharge
  - High level surface discharge to earth
- Ultrasonic airborne microphone or contact probe generally centred at 40kHz
  - Surface discharge

The recommended Singapore condition monitoring test equipment and techniques are able to detect potential faults on equipment before a failure occurs. As these potential faults are detected before a failure occurs, their location and root cause can be identified and rectified before they fail. This then ensures safety of staff and our communities by preventing potential dangerous failures. The reliability and quality of supply is improved every time we prevent a failure which normally results in customer outages and voltage dips.

City Power is able to carry out pro-active condition-based maintenance on the network and move away from current time-based maintenance practices, which have missed many potential faults. City Power in the future would only shutdown the switchgear if it is absolutely necessary to perform preventative maintenance.

City Power has already saved lots of money on maintenance and post failure repair costs. One day power interruptions should be reduced to hopefully only vandalism and theft related failures.
4. Implementation

City Power has a long way to go with condition monitoring, but the next steps are to train all team leaders and operators how to use the handheld PD detection equipment. This makes big inroads to the problems we have not been able to detect before equipment failed in the past.

Pictures 1 and 2: Singapore technical staff training City Power staff to perform new PD testing.

Below are the simple steps to test a transformer cable box, but the same test will be done on all MV switchgear.

Pictures 3, 4 and 5: Singapore technical staff performing PD testing on a transformer cable box.

In March 2010 City Power purchase R300k worth of new innovative and technological partial discharge test equipment that are designed to assess the condition of any electrical asset.
Now in May 2011 City Power purchased an additional R15mil worth of partial discharge test equipment. The new test equipment purchased comprised of:

1. 100 off handheld EA Technology UltraTEV units for all electrician and operators, to ensure safety before and after operating.
2. 4 off EA Technology PD UltraTEV locator units for advanced PD location.
3. 6 off on-line and 10 off-line SEBA OWTS cable partial discharge testers, to assist in identifying partial discharge existence and locations in cable networks.
4. 10 off FLIR Thermal Imagers to perform thermal scanning to identify hot spots and difference in temperatures.

**Ultrasonic Detection**

**Green** | **Red**

**TEV Detection**

**Green** | **Amber** | **Red**

![Ultrasonic Detection](image1.jpg) ![TEV Detection](image2.jpg)

Pictures 6 and 7: EA Technologies ULTRATEV handheld PD tester unit – with built in 2 modes.

![Pictures 8: EA Technologies PD UltraTEV Locator tester unit](image3.jpg)

Pictures 8: EA Technologies PD UltraTEV Locator tester unit – able to locate the source of the PD
Graph 3: SEBA OWTS PD test on a PILC MV cable – PD scattered difficult to Analyses.

Graph 4: SEBA OWTS PD test on a XLPE MV cable – PD scattered simple to Analyses.
Graph 5: SEBA OWTS PD test on a XLPE MV cable after first joint was removed out of the circuit.

Picture 9: Infrared thermal image of GIS switchgear clearly show a difference in temperature.

It is now possible to detect insulation problems in cables, transformers, switchgears, and other electrical equipment in our electrical networks. Condition monitoring testing will become part of everyday business within City Power and not a special once off project.
Table 1: Summary of possible condition monitoring systems that can be applied.

<table>
<thead>
<tr>
<th>Condition Monitoring Systems</th>
<th>What they detect</th>
<th>Applied to</th>
</tr>
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<tbody>
<tr>
<td>Thermal Scanning</td>
<td>Overheating</td>
<td>Equipment</td>
</tr>
<tr>
<td>Dissolved Gas Analysis</td>
<td>Abnormal oil contents</td>
<td>Equipment &amp; cables</td>
</tr>
<tr>
<td>Oil Pressure Monitoring</td>
<td>Low pressure</td>
<td>Cables</td>
</tr>
<tr>
<td>Distributed Temperature Sensing</td>
<td>Hot spots</td>
<td>Cables</td>
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<tr>
<td>Very Low Frequency Test</td>
<td>Low insulation</td>
<td>Cables</td>
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<tr>
<td>Partial Discharge Monitoring</td>
<td>Minute current leakage</td>
<td>Equipment &amp; cables</td>
</tr>
<tr>
<td>Operating Mechanism Monitoring</td>
<td>Abnormal operation</td>
<td>Equipment</td>
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The highest failure rates in City Power are from cable termination and joint failures. The reason for these failures has a lot to do with the jointers skills. In City Power we subcontract lots of work to contractors and to ensure they perform the joint or termination you need to perform the correct test which will confirm the quality of the workmanship.

In the past City Power has done typical SANS 10198-13 recommended commissioning test which include voltage pressure test which are “go” or “no go” tests. This has proven not to be adequate as a poorly installed joint may withstand the applied voltage pressure test but if PD is present a fault occurs after a certain time period because the PD eventually weakens the insulation which leads to a failure. It must be remember that all insulation ages over time and it is important for us to monitor and know the condition of the insulation to prevent failures.

Cable testing with DC voltage has also proven to be unable to detect potential faults in joints, terminations and cables, unless they are bad faults. The use of AC voltage test equipment is a must to ensure we test the permittivity of insulation materials which is what all equipment will experience when energized.

Singapore Power now PD tests all new XLPE cable systems to detect any unacceptable PD activity in joints and terminations. This detected PD over time breaks down the insulation if not corrected immediately. The days of only performing a “go” or “no go” pressure test to prove the reliability of the cable are over. It is now time to record finger prints of MV cable networks and then monitor them over their life cycle to ensure reliability of supply.

If PD is detected during testing, the system cable system should not be energized, but investigated.

City Power have now changed from paper insulated MV cable (PILC) to Crosslinked polyethylene insulated MV cables (XLPE) so that PD testing cable be performed to ensure the joints are PD free to acceptable predefined limits. It is to be remembered that the new generation these days are water resistant, so the same bad failures experienced in the 1970s will not be experienced.
By design PILC cables PD is present and this makes PD location very difficult.

Lastly, Dissolved Gas Analysis (DGA) is a very important condition monitoring tool for power transformers. City Power has been doing DGA test for 10 years already and is able to analysis the results in our own laboratory. When analysing the GDA results for a specific transformer the data needs to be trended to ensure correct analysis is done and correct decisions are made with regards to these critical assets.

![Graph 6: DGA interpretation to identify potential internal fault.](image)

City Power is busy commissioning on-line transformers 8 gas monitors. On-line transformers 8 gas monitors is a standard for all new City Power’s Power transformers.

![Picture 10: Typical on-line DGA monitor installed on a power transformer.](image)
5. Road map to make condition monitoring a success

Below is Singapore’s recommended condition monitoring road map.

![Diagram 2: Singapore’s condition monitoring road map](image)

6. Case studies

The following faults have been avoided by performing PD tests on switchgear as covered above.

![Picture 11: Insulation board with partial discharge activity (tracking and erosion)](image)
Picture 12: Unscreened bushing with PD activity in the small air gap to earth plane

Picture 13: Loose contact on MV CB that was really hot

Picture 14 and 15: Damaged terminations from a loose contact that was really hot
Picture 16: Voltage Transformer (VT) where shutters had not stayed open and earth was laying on the unscreened live MV bushing.

Picture 17 and 18: Incorrectly termination used – should have been screened connectors.
Terminations with signs of high PD at screen cut

Picture 19: Terminations with signs of high PD at screen cut

Picture 20: Single core terminations from same phase discharging as screen cuts are not in the same place and earth is now in the high stress area.
Picture 21 & 22: Insulation board with high discharge between phases.

Picture 23: Unscreened jumpers with high PD where air clearances have not be maintained.

7. Summary of cost benefits of condition monitoring.

Typical savings from performing condition monitoring are shown below. Savings from avoiding failures depend on the type and nature of fault averted. Clearly by spending time and money on doing effective condition monitoring, failures will be reduced. The money that would have had to be made available to pay for repairs can now be used to strengthen the networks. Now maintenance will only be done when the equipment condition requires maintenance. Time based maintenance is not effective and can be very draining on resources and budgets.
8. Conclusion

The vision of City Power’s management is commendable to strategically partner with Singapore Power who is one of the world’s most reliable electricity utility to make a step difference with regards to preventing potential failures and also improving the reliability of supply to our end customers.

The results obtained from performing condition monitoring before the World Cup Soccer, was already estimated to have saved City Power R85mil in failures that have now been averted. Many of these failures would have occurred during the World Cup Soccer and this would not have been good for City Power and South Africa.

City Power has also introduce the **First-Time-Right** policy, which will ensure we don’t introduce potential failures by not doing things right first the time.