AMS – Victorian Electricity Transmission Network

Condition Monitoring

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Disclaimer

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1 Executive Summary

The purpose of condition monitoring is to detect early signs of asset degradation before poor condition begins to present unacceptable risks of failure. Condition Monitoring (CM) is an increasingly essential component of sound asset management and supports the development of efficient maintenance and asset replacement programs. CM data collected assists in preventing asset failures. CM benefits include improved reliability, safety and reduced operating costs. Condition information is used in optimising maintenance schedules and prioritising asset replacement plans through the development of risk based models. CM techniques are constantly improving; becoming more accurate and less intrusive.

Existing CM programs for the Victorian electricity transmission network comprise visual inspections, off-line diagnostic tests, on-line or real time monitoring and routine non-invasive scanning. Existing CM techniques include:

- CAMS (CVT asset monitoring system, real-time monitoring of CVTS using SCADA);
- Oil and SF_6 sampling for analysis (CBs, GIS, Transformers, oil filled regulators, OLTCs & CTs;
- Climbing inspections every 3 years of transmission line structures to assess conductor, fittings insulators, attachment points, steel work and foundation condition;
- CM of power transformers using 6 yearly testing of bushings, windings, insulation and surge arrestors;
- UHF partial discharge (PD) monitoring for GIS;
- Diagnostic testing of CBs and motorised disconnectors (contact resistance, mechanism and pole timing, etc).

Although AusNet Services manages a large CM program, the application of contemporary condition monitoring techniques to all network assets has not yet been fully implemented. Limited application of new technologies has taken place due to high costs of particular monitoring systems, resource constraints and the developing nature of certain condition monitoring techniques. The limited use of new techniques presents risks through the manifestation of failure modes not identifiable (hidden failures) using conventional inspection means.

Failure of phase conductor on the Heywood (HYTS) to Alcoa Portland (APD) 500 kV line in 2008 is an example of a hidden failure which was not detected during regular climbing inspections. The use of Smart Aerial Image Processing (SAIP), a contemporary conductor assessment method, would have identified the corroded conductor before failure. Similarly explosive failures of extra high voltage Current Transformers (CTs) in the period between 2006 and 2008 were not detectable using the traditional inspection techniques. However, the use of contemporary Radio Frequency (RF) scanning would almost certainly have prevented some of these hazardous failures.

AusNet Services will further embed contemporary condition monitoring systems into business as usual inspection programs. Techniques such as SAIP offer cost effective means of preventing conductor drops whilst supporting the development of long term replacement strategies which avoid premature capital investment. The expansion of other condition monitoring techniques including Overhead Line Corrosion Detection (OHLCD) tests, otherwise known as CORMON inspections, are scheduled.

Expansion of the use of 24x7 partial discharge (PD) monitoring at terminal stations has commenced. This technology, which provides the ability to detect impending asset failure, will be installed permanently at terminal stations where major augmentation works are proposed.

2 Introduction

2.1 Scope

This Condition Monitoring (CM) strategy covers the assets forming the Victorian electricity transmission network which is operated by AusNet Services. This document does not cover aspects of the distribution network.

2.2 Purpose

This document defines the scope of condition monitoring strategies for assets forming the Victorian electricity transmission network for the period until 2022. Its purpose is to use condition monitoring to guide the establishment of economic asset maintenance, refurbishment and replacement programs while focussed on sustainable management of worker and public safety, network reliability, and security risks. This strategy also focuses the development of condition monitoring techniques, processes and systems on the objective measurement of the condition of key network assets.

2.3 Background

The main purpose of condition monitoring is to detect early stages of degradation before asset condition becomes a significant risk to the safety of personnel, the environment and asset and network reliability.

Condition Monitoring is also an essential component of the AusNet Services Asset Management Strategy. Condition data, generated through condition monitoring, allows AusNet Services to evaluate, quantify and manage a variety of asset risks including risks to compliance, performance and safety. These evaluations in turn allow AusNet Services to plan economically efficient maintenance and renewal programs that meet the networks objectives.

CM includes a range of technologies which are constantly developing, creating opportunities for more accurate and less disruptive asset condition evaluations. Non-invasive scanning technologies are particularly promising and AusNet Services is exploring opportunities to use these more extensively. AusNet Services also supports other condition monitoring research through collaboration with universities and research organisations.

2.4 Input to Asset Risk Modelling

As assets degrade, their risk of failure increases which creates compliance, safety and performance hazards. AusNet Services manages these risks by maintaining the assets and eventually by replacing them.

However, to do this in a cost efficient manner AusNet Services needs to analyse a variety of maintenance and replacement options, evaluating the benefits and costs. Invariably, one of the major costs is the cost of failure and so to estimate the cost, a good estimate of the probability of failure is required. This is estimated based on service age, performance history and most importantly, asset condition.

Condition data is particularly important, since without it risk modelling would rely on just age and performance. In many cases, this would result in uneconomic renewal and maintenance programs based on age alone. Under this approach many assets would end up being replaced too early or too late, simply because they degrade slower or faster than expected—a common situation. Ultimately, this would result in higher capital costs for lower levels of network performance.

2.5 The 'Condition Score' and Condition Indices

Condition monitoring gathers data using a variety of techniques creating several measures of condition (known as 'asset health indices') for each asset. To ensure a common approach to risk modelling, AusNet Services combines these measures into a single 'Condition Score', measured on a scale of 1-5.

3 Drivers

The business drivers for condition monitoring are:

- Asset failure risks;
- Safety Obligations;
- Capital efficiency;
- Operational efficiency.

3.1 Asset Failure Risks

The primary reason for condition monitoring is to gather information that helps manage the risks associated with asset failure. Broadly these are:

- **Safety:** Several asset types exhibit hazardous failure modes, including explosive failures. These failures pose a risk to workers and occasionally the public. For instance, the explosive failure of a transformer in a hazardous bushfire risk area has the potential to ignite a fire endangering nearby communities.
- **Quality and Reliability of Service:** Asset failure reduces the overall level of service AusNet Services delivers, and can lead to customer outages, market constraints and financial penalties.
- **Compliance:** Compliance risks generally relate to the quality and reliability of service or safety. Although a separate risk, compliance essentially supports the need to address these.

3.2 Obligations

AusNet Services is subject to several explicit legislative obligations concerning worker safety.
The Electricity Safety Act requires AusNet Services to *design, construct, operate, maintain and decommission its supply network to minimise, as far as is practicable, the hazards and risks to the safety of any person arising from the supply network*.[1] What is considered "practicable" is determined by having regard to:

- the severity of the hazard or risk in question; and
- state of knowledge about the hazard or risk and any ways of removing or mitigating the hazard or risk; and
- the availability and suitability of ways to remove or mitigate the hazard or risk; and
- the cost of removing or mitigating the hazard or risk.[2]

The *Occupational Health and Safety Act 2004* (Vic) (**OHSA**) requires AusNet Services to: *as far as is reasonably practicable, provide and maintain for employees of the employer a working environment that is safe and without risks to health.*[3]

[1] Electricity Safety Act 1998, section 98(a).
[2] Electricity Safety Act 1998, section 3.
[3] Section 21(1).

When determining what is (or what was, at a particular time), reasonably practicable in ensuring health and safety, the OHSA requires that regard be had to the following matters:

- the likelihood of the hazard or risk concerned eventuating;
- the degree of harm that would result if the hazard or risk eventuated;
- what the person concerned knows, or ought reasonably to know, about the hazard or risk and any ways of eliminating or reducing the hazard or risk;
- the availability and suitability of ways to eliminate or reduce the hazard or risk;[4]
- In economic terms; "reasonably practicable" requires AusNet Services to address safety hazards up until the point that the costs of remediation become grossly disproportionate to the benefits.

3.3 Capital Efficiency

One requirement of capital efficiency is that capital is invested where and when it is needed. Condition monitoring helps AusNet Services achieve this by determining the quantum and rate of deterioration of individual assets, rather than how degraded their service age or duty history suggests. This allows asset replacement to be more precisely scheduled to simultaneously avoid failures and minimise investment.
Capital efficiency is one of the objectives of the economic regulation governing transmission networks in Australia.[5] Condition monitoring helps support these objectives.

3.4 Operating Efficiency

Similar to capital efficiency, a requirement of efficient operating expenditure is that maintenance is carried out when it's needed most, at the least overall cost. Within this context, condition data helps asset managers plan maintenance programs. For instance, a poor condition asset may need more regular maintenance or monitoring or may need to be replaced. Objective condition data helps asset managers make this decision.
Operating efficiency is also an objective of the economic regulation governing AusNet Services.[6] This is considered when introducing or trialling new condition monitoring approaches, as different condition monitoring approaches have different cost profiles and implications. For example, visual inspection techniques can be quite labour intensive and off-line condition monitoring requires an asset to be taken from service, creating further security risks within the network. Partial Discharge monitoring of substations using RF scanning method, on the other hand, can be carried out remotely with the asset still in service. This kind of real time surveillance system also helps avoid explosive failures which, due to its nature, can lead to collateral damage and costs.

[4] Occupational Health and Safety Act 2010, section 20(2).
[5] National Electricity Rules V54, 6A.6.7(c).
[6] National Electricity Rules V54, 6A.6.6(c).

4 Existing CM Programs

AusNet Services manages a number of existing condition monitoring programs. Broadly these programs can be broken down into four categories as discussed below.

4.1 Visual

Although visual inspections are expensive to conduct, they are necessary in the absence of equivalent and cost efficient automated systems. Examples of visual inspection methods include:

4.1.1 Tower climbing inspection

Tower climbing and visual inspection of transmission line assets takes placed every 3 years. These inspections require inspectors to rate the condition of assets on approximately 13,000 towers by assigning condition scores in terms of wear and corrosion. A condition grading guide removes the objectivity of this task by providing photographs for each asset in each of the stages of its life cycle.

4.1.2 Transmission line easement

Routine inspection patrols of transmission line easements are conducted every 12 months to ensure that lines and easements are maintained in a serviceable condition. These patrols are targeted to identify and record vegetation that may infringe or approach the clearance space.

4.1.3 Dig & inspect tower foundations

A program of visual inspection of foundations on steel towers provides a gauge on metal loss for direct buried steel foundations. This program, which is also known as SOX, ensures that risk of structure collapse is minimised.

4.1.4 Pumps & fan operations

Visual inspections of the pumps and fans are conducted to confirm condition and functionality of power transformer cooling systems.

4.2 Off-Line

Diagnostic tests are generally undertaken during planned maintenance of an asset but may also be used to guide the diagnosis and repair of asset failures. This objective test information is very useful in assessing deterioration rates, adjusting maintenance requirements, establishing the likelihood of an in-service failure and determining remaining service potential. Although these techniques are constrained due to the need for a circuit outage, the information is vital and off-line diagnostic testing will continue until new on-line techniques become economic.

While offline CM provides benefits the need to take outages to perform tests limits its use. Furthermore these tests are constrained by in-service voltage levels and cannot prove integrity of asset under abnormal system conditions such as lightning and switching surges. A mature approach is to use combination of off-line and on-line CM techniques to address majority of failure mechanisms. Given below are some of the key off-line CM techniques used.

4.2.1 Power transformer condition monitoring

Various tests conducted such as winding impedance/resistance, ratios across all taps and frequency response analysis (FRA) for power transformer and oil filled reactors' winding condition assessment. In addition, tests such as capacitance & Dielectric Dissipation Factor (DDF), partial discharge (PD) are also carried out for the bushings, insulation and surge arrestors. This provides definitive information on the condition and integrity of transformer components. All transformer tanks (over 200 in number) undergo these tests on a periodic basis (6 yearly) as per the intervals specified in the plant guidance and information document (PGI 02-01-02). The deterioration rates of at-risk transformers are tested on a more frequent basis to schedule interventions or alter alarm and protection system parameters, cooling systems and operating temperatures.

4.2.2 Circuit Breaker Interrupter Contact Resistance Tests

Ductor sets are used to measure the CB interrupter contact resistance. This is a good indicator of CB contact deterioration and is used to trend degradation rates required to plan for the condition based maintenance.

4.2.3 Circuit Breaker Mechanism and pole timing

This test assists in determining CB operating times the results of which provide useful condition information for planning future maintenance schedules especially for the CB mechanism. CB counts of operation can provide a guide to remaining service potential.

4.2.4 Remote Operated Isolator mis-adjustment and binding

This involves testing the driving motors on motorised disconnectors. This ensures reliable operation of disconnectors whose operation are essential to isolating assets so scheduled and unscheduled works can be performed.

4.2.5 Insulator voltage tests

Voltage measurements across each disc of the porcelain cap & pin insulators taken after insulator washing to determine integrity. This test allows the identification of "flat discs" which adversely affect the insulating properties of an insulator string. These tests are applicable to only porcelain insulators and not the modern polymer insulators.

4.3 On-line

These are the preferred CM programs as they can be carried out whilst assets are in service. The online CM program can be based on either real time (continuous) or discreet measurements. The following programs are currently in use and will continue until a more effective and efficient method is found to achieve the same outcome.

4.3.1 Oil test and dissolved gas analysis (DGA)

Taking oil samples from transformers, oil filled reactors, on-load tap changers (OLTC) and current transformers (CT) and conducting complete oil testing (dielectric breakdown voltage, moisture in oil, acidity, Interfacial Tension (IFT) and DGA (hydrogen, acetylene and other gases) is still the most effective and economic CM approach to avoid imminent failure as well as to develop trends for failure probability. The oil sampling time intervals are defined in the PGI 02-01-02. All transformer and oil filled reactor tanks (over 200) and OLTC tanks (over 200) are sampled annually and oil filled CTs (over 1300) are sampled every 4 year. This results in 700 to 800 oil samples for oil tests and DGA every year.

A number of analytical software packages have been developed to analyse the gas concentration levels and ratios for accurate prediction of the root cause and risks. However, this is a discreet measurement method and there is a residual risk of a fault developing within the oil sampling windows. This risk is further mitigated by deploying regular non-invasive scanning programs as described in the next section.

4.3.2 SF_6 gas chromatography and density

SF_6 Gas Insulated Switchgear (GIS) installations require regular moisture and SO_2 checks as per the PGI-SF_6-TESTS. This condition information is to avoid imminent failure as well as to develop trends for failure probability. This is a discreet method and there is a residual risk of a fault developing between the gas sampling windows. This risk is further mitigated by deploying regular non-invasive scanning programs as described in the next section.

4.3.3 CAMS-CVT asset monitoring system

Real time voltage data from SCADA to monitor secondary voltages and their ratios of EHV CVTs (over 500) has proved to be the most efficient CM technique. The drift in voltage ratio is indicative of emerging problems in the capacitor cans or magnetic circuits. This is a real time system and has worked extremely well in removing CVTs from service before failure thus avoiding reliability and safety hazards. It is intended to continue this CM program and expand CAMS to cover all 66kV CVTs as well.

4.3.4 On-line CB monitors

Proprietary real time CB monitoring systems have been deployed to monitor the condition (CB timing curves and fault current analysis) of new CBs (over 50 CBs). It is proposed to make existing on-line CB monitoring systems working so as to gather real time data. This is an effective CM program but requires some maintenance effort to keep the hardware, software and firmware working for the life of asset (>45 years). This program is under review to find a better CM technique for CBs in the future.

4.3.5 On-line gas and moisture monitors

This technique monitors gas composition and moisture in power transformers in real time. AusNet Services specifies these monitors as standard on all new transformers and has done so since 1997. There is also a program to retrofit to existing transformers. This program has been deployed on a limited basis (only few locations at the moment) and will be expanded to cover the most ‘at risk’ transformers in the next regulatory reset period. AusNet Services currently has online gas and moisture monitors on approximately one third of the transformer fleet.

4.3.6 Partial discharge monitors

Ultra High Frequency (UHF) Partial Discharge (PD) detectors are real time monitoring system for GIS. This is an effective and efficient CM program and will continue.

4.3.7 Winding temperature indicators

Winding Temperature Indicator (WTI) monitors allow inspectors to view the transformer winding temperature remotely in real time. This CM program is essential for operational management under peak loading conditions, during contingency events and longer term asset renewal planning.

4.3.8 Battery monitors

This system monitors and sends alarms when the voltage levels of the station DC batteries falls below thresholds. This program has been deployed on a limited basis and will be expanded.

4.3.9 Pollution monitors

These monitors detect leakage current on transmission line towers that correlate with pollution deposition on the line insulators. This information is useful in scheduling condition based insulator washing. This program is under review to find a better CM technique.

4.4 Scanning

Considering the high costs and efforts required for the online and offline CM techniques, AusNet Services has investigated several innovative solutions which offer more effective and economic outcomes. The new approach is to scan (non-intrusively) the larger switchyard area to identify emerging condition issues and then focus on narrower areas for in-depth monitoring using multiple techniques to validate and confirm the condition of selected at-risk assets. This program has shown encouraging results so far. Station scanning using multiple non-invasive techniques is done on a regular basis (annual) and also on selective basis to mitigate risks of failure threatening network reliability during peak loading periods (pre summer) and the safety of workers undertaking maintenance or augmentation projects. The defects identified by the routine scans are prioritised and addressed using a combination of notifications and work orders generated in the asset management system.

4.4.1 Infrared scanning

Infrared (IR) scanning is a non-invasive technique to detect the thermal signatures of emerging faults on substation plant and lines. Infrared scanning has been accepted as an essential CM technique for all station equipment and transmission lines and will continue in the future. Transmission line conductor hardware is scanned every three years meaning that over 2,100 route kilometres of the lines are scanned every year. The ageing nature of transmission lines asset means that the number of "hot" joints and connection palms identified annually is expected to increase.

4.4.2 Portable Radio Frequency scanning

Scanning of substation for Radio Frequency (RF) discharges is a very cost effective technique to survey wide areas and identify smaller areas for in-depth investigations. This is a non-invasive technique using a hand held detector to detect PD related faults on substation plant and equipment. The portable RF scanner has been used extensively on AusNet Services' network to avoid potential explosive failures and ensure safe working area for maintenance and augmentation projects. This has become part of routine substation scanning.

The RF scanning device was found to be very useful in managing risks of explosive failures of a current transformer fleet with known design issues during the current regulatory reset period. The stations with these known types of CTs were scanned daily or weekly depending upon the project or maintenance work planned. It took several years to replace the hazardous CT fleet and RF scanning was useful during those years in avoiding failures. Several EHV CTs were removed from service and subsequently tested in the laboratory to calibrate the accuracy of the RF scanning technique.

Commercially available systems using long metallic antenna (shown to the left in Figure 1) in the substations were deemed unsafe. A smart non-metallic and planner antenna system was developed through R&D efforts (shown to the right in Figure 1).

Figure 1 – Portable RF scanners

This is the most powerful technique available to date to avoid potential explosive or hazardous failures impinging network reliability and people safety. However, this is a periodic test and does not provide coverage against the faults developed and progressed in between the scanning window. Therefore, efforts have been made to develop 24x7 RF scanning of the substation for a better outcome in terms of reliability, safety and cost.

4.4.3 Other Scanning Methods

A routine station scanning (annual) and focussed scanning uses multiple devices to collect and validate information on the deteriorated asset condition and imminent failure. Some of the techniques are listed below:

- UV – Using ultraviolet camera (corona camera) to detect faults on substation plant and lines especially insulators. This is a standard tool to assess condition of asset and is a part of the kit used for the routine substation scanning.
- Ultrasonic – To detect faults on substation plant and lines. This is also part of the kit used for the routine substation scanning. A more efficient ultrasonic technique is being trialled at the moment.
- TEV – Transient earth voltage or TEV is a very convenient tool to detect and locate faults on substation plants especially indoor switch gear. This is a part of the kit used for the routine substation scanning.
- Temperature probe – Using thermal gun to check temperature on the spot for plant items is part of the routine CM kit used for non-invasive scanning.
- SF_6 leak detection – Use SF_6 camera to detect leaks from switchgears. This is in use and is expected to be used more extensively in the future.

4.4.4 Asset Analytics

Data analytics utilising the asset management system OSIPi has been beneficial in providing relevant information to the planners and asset specialists. Greater use of collected data to generate network intelligence is proposed such as the use of OSI Pi analytics & predictive modelling, utilisation factors for equipment, thermal deterioration modelling, wear out forecasting and three-phase current balance from SCADA data.

4.4.5 Overhead Line Corrosion Detector (OHLCD - CORMON)

An accurate assessment of the condition of aluminium conductor steel reinforced (ACSR) bare conductor is difficult to achieve through visual inspection. Although it is possible to assess levels of corrosion of outer aluminium strands, a clear indication of the steel core's condition is difficult to obtain. An indication of the depletion of the galvanic layer of the steel core is an early warning indicator compared to the visual signs of bulging or caging of the entire conductor. In order to assess the steel core condition; conductor removal, disassembly testing and analysis of multiple representative samples is required. This approach is costly, involves lengthy circuit outages and its resource commitments relegates this technique to validation of a decision to replace conductor rather than a regular scheduled assessment of condition.

AusNet Services has used an OHLCD unit (also called as 'CORMON') to measure levels of steel core deterioration on targeted ACSR phase conductors and aerial earth wires. The OHLCD unit is a remote controlled, radio-linked eddy current device that is placed upon the phase conductor(s). The alternating flux induces a voltage in the pick-up coil that is processed to give an output voltage, the magnitudes of which depend upon the quality of the galvanised or aluminium clad layer. This output voltage is used to score the tested sample for galvanised lost on a five point scale with a score of one being the best. This data is then used to gauge remaining service potential of conductors tested and supports robust asset management decision making.

Two programs of conductor assessments have been successfully implemented using an OHLCD unit obtaining results for more than 170 spans. The results were generally good and indicated that only two per cent of spans tested had lost more than 50 per cent of galvanising from the steel strands. Although the benefits of using OHLCD to assess the condition of ACSR are clear, the technology is still at the development stages and there remain some doubts about its accuracy.

AusNet Services is removing samples of conductor already tested using the OHLCD so that laboratory inspection of the steel core can take place. This exercise will calibrate the accuracy of the process and assist in determining the extent of further OHLCD inspections.

5 Proposed CM Programs

5.1 Continue the existing CM program

Continue with the ongoing CM program as described in the Section 3. The current CM program involving visual inspections, offline & online monitoring and scanning has been and will continue to be successful in facilitating the collection of condition data, prevention of asset failures, development of risk based asset replacement models and development optimised maintenance schedules.

5.2 Deploy new available CM techniques

5.2.1 24/7 PD Monitoring System for Substations using fixed RF scanner

AusNet Services has developed a fixed RF monitoring system detecting partial discharge activity 24x7 within entire substation. The system, shown in Figure 2, can alert the utility to any primary network asset abnormality or impending explosive plant failure. This system is capable of monitoring an entire switchyard non-intrusively for free to air PD on 24 hour / 7 day basis. A working prototype has been developed following a three-year research project with Monash University under the Australian Research Council (ARC) linkage project.

The newly developed and innovative solution is the least cost, most effective for network asset reliability and safety. This system has been installed and tested for its performance at one of the terminal stations (SVTS). This is being connected with station SCADA to record real data. It is proposed to commercialise the research prototype and deploy this technology at terminal stations where major augmentation work is planned over the next decade. These terminal stations are the most risk locations based upon the asset service age, asset condition and worker exposure due to augmentation projects. These systems can be relocated to next at-risk sites as projects are completed.

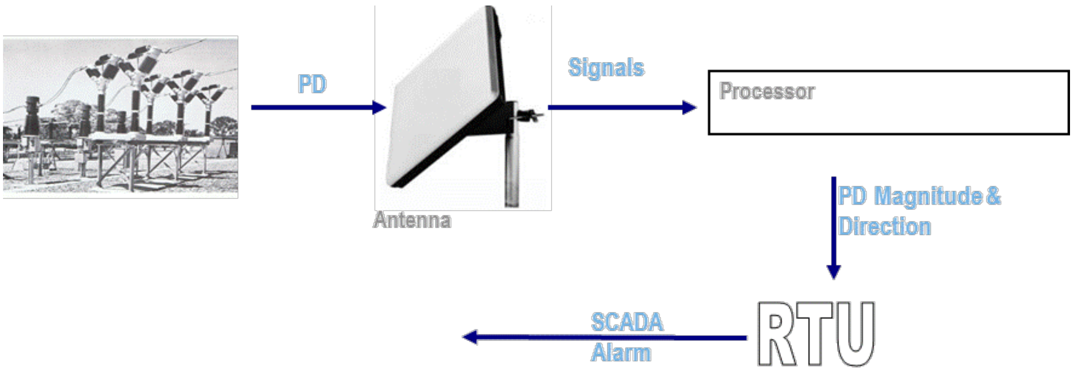

Figure 2 – 24x7 PD monitoring system for substations

Smart Aerial Image Processing (SAIP)

Although the CORMON condition assessment system can detect corrosion in bare aerial conductors at a much earlier stage, it is an expensive and intrusive monitoring technique which limits its economic use. AusNet Services will target the continuing use of CORMON as an investigative tool whilst utilising a less intrusive and lower cost scanning technique to economically survey large proportions of network conductors on a regular schedule to assess condition and hence failure risks.

The failure of aluminium conductors with steel reinforcing (ACSR) on the Heywood to Alcoa Portland (HYTS-APD) 500kV line in 2008 demonstrated that existing conductor condition monitoring practices were limited in accuracy and application. Acknowledging these limitations, AusNet Services began development of an emerging technology known as SAIP.

The SAIP system includes continuous capture of high resolution digital images of the conductor from a helicopter and the use of automatic image recognition technology to locate and prioritise conductor corrosion or damage. This technology enables the efficient capture of highly detailed conductor images over the complete length of long transmission lines. Captured images are analysed using specially developed software which automates the identification of signs of corrosion including the presence of white powder, conductor bulging or broken strands.

This technology has been used in assessing the condition of conductor and, in particular, the ACSR ground-wire on the Hazelwood to South Morang (HWTS-SMTS) 500kV line. The SAIP system revealed numerous sections of ground-wire were heavily corroded and SAIP information will now support the development of an effective replacement program.

AusNet Services recognises the great technical and financial benefits associated with this technology and plans to expand its use in a new aerial conductor inspection and automated image assessment program for transmission line conductors and aerial earth wires. A program of inspection involving a full coverage over a 3 year period followed by a reduced ongoing program to cover 50% in each following 3 year period is proposed to obtain early warning of the internal corrosion at lower monitoring costs. Adoption of this program would result in benefits arising from deferral of capital expenditure to replace conductors and an annual increase in operational expenditure to undertake SAIP.

Figure 3 summarises at a high level the SAIP process, with examples shown in Figure 4

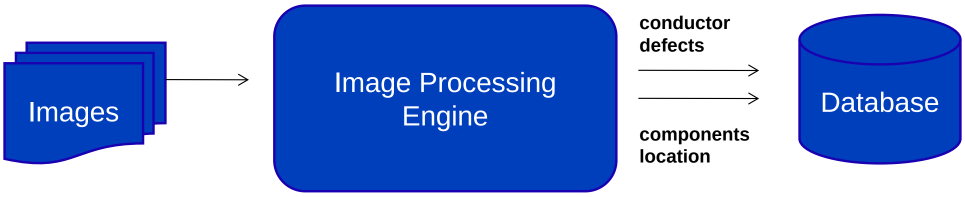

Figure 3 – Summary of SAIP conductor condition assessment process

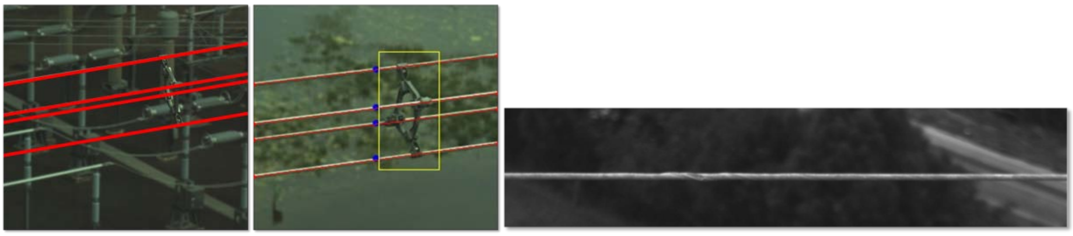

Figure 4 – SAIP examples

5.2.2 LiDAR (light detection and ranging)

This is a laser based surveying technique which can create a three dimensional digital topology of a transmission line and its easement corridor to quantify the physical clearances between the electrical phases of a transmission circuit, the extent of conductor movement and the physical clearances to vegetation, ground and encroachments in the line easement.

This inspection technique has been used to assess the condition of vegetation and the adequacy of easement dimensions as well as validating conductor to ground clearances under varying loading conditions. As the cost of LiDAR surveys is becoming more economic, its usage will grow allowing a greater level of surety over vegetation clearances, electrical safety clearances and transmission line ratings.

5.3 Develop new CM techniques

While the existing CM program is evolving to meet emerging asset assessment needs, there are additional CM needs due to:

- Asset classes including surge arrestors, SVCs, synchronous condensors, polymer insulators and underground cables currently not having adequate CM coverage.
- Addition of new classes of assets in the network based on different technologies.
- Inadequacy of existing CM to accurately measure condition of deteriorating assets in real time or unable to address critical failure modes or provide sufficient early warning to enable remedial actions.
- High CM costs limiting the application of proven measurement techniques as a widespread technique for regular surveys.

An optimal approach used to resolve network issues comprising of:

a) Research & development on possible new CM technologies by supporting educational and research organisations;
b) Trialling new technologies offered by vendors; and
c) Developing and trialling innovative CM solutions in-house.

5.3.1 Transmission Tower Foundation Integrity

This testing is required to prove the integrity of tower foundations especially if the tower has been subjected to disturbance such as by flood or earthquake. There are two known techniques which will be trialled:

Polarisation resistance – This involves measuring the potential of each tower leg with reference to a copper sulphate half-cell. This is a method of obtaining corrosion rates without the need for excavation.
Transient dynamic response (TDR) – involves application of mechanical vibration signals through the tower foundation. This is a method for confirming the integrity of concrete foundations.

5.3.2 Enhanced CM regime for Circuit breakers & Disconnectors

Vibration monitoring of CB operation and timing is a technique which is proposed for further research.

5.3.3 Simpler non-invasive monitors for personnel safety

While permanent installations of 24x7 PD scanning systems will provide safety warnings for workers in and around switchyards from explosive asset failures, small pocket size Electromagnetic (EMF) devices are available for personal protection and warning. A number of such devices have been trialled and will be more widely deployed in the future.

5.3.4 Perform autopsies of removed assets

It is proposed to strip open bulk oil CBs under laboratory conditions to confirm failure modes and accurate condition rating criteria for this large and ageing fleet. If successful, a full plan will be developed to strip and test other critical asset categories to calibrate the key indicators of condition and remaining life.

5.3.5 Condition Monitoring of polymer insulators

Polymeric insulators offer advantages in terms of light weight and non-hazardous failure modes. The population of non-ceramic insulators has grown over the last 20 years. It is estimated that 27% of the total insulator population is now polymeric and this is expected to increase. There is currently no authentic and cost efficient CM technique available for the polymer insulators to prove integrity which is very important for live line replacement work and remaining life assessment. Some literature refers to a 30 year life for polymer insulators which is yet to be proven for the wide range of service environments.

AusNet Services has had limited success in using spectroscopic methods such as FTIR (Fourier transform infra-red) in which absorption and scattering infra-red light determines the level of chemical degradation of polymer and silicon material. In addition, trials have also been conducted using electro-magnetic scanning (Positron) to determine the integrity of insulators.

5.3.6 Monitor Condition Monitoring developments

The innovation program includes identifying and conducting trials of leading edge technologies. It is our aim to focus the condition monitoring research and development program on resolving most urgent and important network problems. Involvement of Victorian educational and research institutions thus leveraging other research funds available from Australian research council (ARC) or through cooperative research centres (CRCs) is an important factor. It is intended to commercialise, wherever possible, the key technologies developed in order to ensure a cost effective supply of the new product or services for the benefit of AusNet Services as well for all the transmission network service providers.

AusNet Services has consciously kept the CM development program small, targeted and outcome focused. However it is frequently necessary to explore several technologies in parallel to establish the most practical and economic for broader application. Based upon the success of the innovation and research program the following new technological advances are being explored as the basis for future CM programs:

- Line fault detection system;
- Portable x-ray using digital image;
- Robotics for asset inspections;
- Nano technology (sensors, coatings and fluids).

6 Strategies

6.1 Continue the existing Condition Monitoring program

The existing CM program is embedded within current business processes and is managed from the asset management system via notifications and work orders. Strategies associated with current condition monitoring programs include:

- CAMS (CVT asset monitoring system, real-time monitoring of CVTS using SCADA).
- Oil and SF_6 sampling for analysis (CBs, GIS, Transformers, oil filled regulators, OLTCs, CTs as per the intervals specified in the plant guidance and information document (PGI 02-01-02).
- Climbing inspections every 3 years of transmission line structures to assess conductor, fittings insulators, attachment points, steel work and foundation condition.
- CM of power transformers using 6 yearly testing of bushings, windings, insulation and surge arresters.
- UHF partial discharge (PD) monitoring for GIS.
- Diagnostic testing of CBs and motorised disconnectors(contact resistance, mechanism and pole timing, etc.)

6.2 Deploy successfully trialled CM techniques more widely

More effective and economic CM techniques have been developed. These have proven and will be further deployed to mitigate known and hidden asset failure risks.
Strategies associated with successfully trialled condition monitoring programs include:

- Aerial survey and automated image processing (SAIP) to detect ACSR conductor defects involving a full coverage over a 3 year period followed by a reduced ongoing program to cover 50% in each following 3 year period.
- Commercialise and deploy 24/7 PD monitoring system in terminal stations where major augmentation works are proposed.
- Using LiDAR for vegetation & easement management, calibration of dynamic line rating system and network safety information on ground clearances.

6.3 Develop new CM techniques

While the existing CM program is evolving to meet emerging asset assessment needs, there are multiple drivers for development of new techniques including:

- Formalise economic CM methods for surge arrestors, SVCs, synchronous condensers[7], polymer insulators and underground cables.
- Develop end of life condition modelling based on autopsies of removed assets.
- Investigate condition monitoring of polymer insulators.
- Research techniques for condition assessment of transmission tower foundations.
- Perform further research on introducing additional early warning methods for the transmission line conductor corrosion.
- Develop a power line fault detection system.
- Continue to support commercial innovation and participate in R&D Collaborations.

[7] Development will only occur if an ongoing need to maintain the existing synchronous condensers is established.

7 Condition Monitoring Techniques

Table 1 illustrates a typical asset blueprint for condition monitoring techniques aligning failure modes.

Diagnostic Techniques	Failure Mode																					Issues	Effectiveness			Reliability	
																								Costs		Score	
	Does not close	Does not Open	Self Close	Self Open	No current make	No current break	Internal Breakdown	External Breakdown	Pole discrepancy	Slow Open	Bushing Fault	Hydraulic Fault	Air Fault	SF_6 Leak	Spring Change	Overheating Contacts	Secondary	Mechanical drive / integrity failures	Oil condition	Arc erosion of contacts	Restriking		Technical	M	OLM	M	OLM
Traveltime Curve	•	•			•	•			•	•		•					•	•					H	H	L	5	3
Contact Timing	•	•			•	•			•	•							•						H	H	L	6	
Dynamic Resistance	•				•	•										•				•			H	H	L	8	
Phase Current	•	•	•	•	•	•				•	•					•					•		M	L		5	
SF_6 Density – Transducers							•				•			•									H	M		4	
Oil DGA – Oil Breakdown							•			•	•												H	L		3	
Ultrasonic Leak												•	•										M	L		5	
Operation Counters			•	•														•		•			M	L		4	
Ultrasonic Timing / Vibrator	•	•			•	•			•	•													M	H		7	
Bushing DGA							•				•												H	H		5	
RF Scan							•	•		•	•												M	M	H	6	
Motor Current															•		•						L	M	M	8	8
Running Time / Pumps / Compression													•		•								H	L		3	
Alarms / Indicators	•	•	•	•	•	•	•		•	•		•	•	•	•		•			•			H	L		3	
Contact Wear Inspection					•	•				•											•		H	L		5	
Circuit Supervision / Battery Supply	•	•	•	•						•					•		•						H	H		3	
Coil Current			•	•											•		•			•			M	M	L	6	5
Operation Check	•	•	•	•			•		•	•		•									•		H	H		6	
Ductoring	•	•			•	•					•					•				•			H	H		5	
Bushing DLA + PD – online and offline											•												H	H		5	
IR Test / Megger					•	•	•	•			•						•						H	H		5	
Operational Checks	•	•	•	•						•			•		•		•						M	L		4	
Oil breakdown / particle test + DGA							•			•	•																
Thermovision / Infrared							•				•					•							H	M		4	
CB Management	•	•	•	•	•	•			•	•													M	H		6	
Pump Starts Counter (Hydraulics)																											

Table 1 – A Typical Asset Blueprint Using Failure Mode Analysis