Acoustic Survey of Overhead Electricity Networks

Authors and Presenters:

Goran Stojadinovic, Maintenance Manager, Northpower Ltd

Michael-John Parkin, Electricity Network Asset Manager, Vector Ltd

“EEA Conference & Exhibition 2014, 18 - 20 June, Auckland”

ABSTRACT

This paper discusses the learning and experience gained during field trials of Acoustic Survey technology on parts of Vector's electricity overhead network in Auckland, and Northpower's electricity network in Whangarei.

In 2013 Vector introduced a new acoustic survey technology that can add significant value to overhead network inspections. Initial field trials covered 1,000 power poles, lines and associated hardware on the Vector network. In May 2013 Northpower assisted with the inspection of a further 10,000 poles and by the end of 2013 Northpower had inspected an additional 20,000 poles on the Vector network and 6,500 poles on its own network in Whangarei. Using this technology we identified over 600 defects that previously had not been picked up from a standard visual inspection. Many of those defects identified had the potential to adversely impact reliability (SAIDI).

This new technology supports the rapid visual inspection of overhead networks. It is based around a directional ultrasonic detector which detects the acoustic noise emitted by a piece of equipment under electrical stress. The emitted noise level and its waveform are dependent upon the type of stress and degree of degradation of that equipment. The ultrasound information is supported by high definition photography of the equipment. Analysis of both the noise information together with the photographs is then undertaken to provide a condition assessment. Typically in an urban area a crew of two can survey 300 poles per day.

This technology has the potential to:

- Significantly reduce faults by finding defective equipment before it fails
- Challenge the way in which planned visual inspections are undertaken
- Assist in the determination of intermittent faults
- Be used to proactively survey a feeder following fault restoration to identify any further overhead equipment that may have come under electrical stress as a result of the initial fault
- Reduce accidents by identifying faulty components before they are worked on (e.g. glass insulators)
- Lift professionalism with improved build quality, installation practices and safe work practices by better understanding defect causes and effects

Northpower is now utilising this new technology for both planned and reactive inspections of overhead distribution and transmission lines on its own, Vector's and other networks. Recently Northpower was approached by another lines company to help identify the cause of an intermittent fault on one of its 33kV overhead feeders. Within an hour of using this technology we were able to successfully locate several different defects across 43 poles which contributed to the intermittent fault.

1.0 BACKGROUND

Overhead electricity grids and networks are the backbone of transmission and distribution lines companies. Overhead lines consist of conductors and hardware suspended by towers or utility poles, to provide safe electrical clearances. Since most of the insulation is provided by air, they are generally the lowest-cost method of transmission and distribution of large amounts of electric energy over long distances.

However, they are more vulnerable and exposed to weather elements and human interference than underground cable circuits, and also tend to deteriorate quicker. Overhead lines can be adversely affected by weather conditions like storms, wind, rain, lightning strikes, UV radiation, heat and cold, humidity, sea salt spray, and other environmental factors like vegetation, mould, bird strikes, possums, and electrolytic oxidation processes and rust caused by industrial gaseous contaminants. Most of these factors have a detrimental effect on the condition of overhead lines and will cause premature deterioration, can cause power outages or even bring the lines down.

The failures occur due to mechanical, chemical and/or electrical (electromechanical and electrochemical) stresses and damage. In addition, every high voltage feeder fault has a potential to cause further faults or cause damage to the surrounding hardware and to the upstream distribution lines – largely as result of high electrical currents.

2.0 PREVENTATIVE MAINTENANCE INSPECTION METHODS

A great challenge for transmission and electricity distribution lines companies is to increase the transmission and distribution efficiency of their overhead lines, while retaining the low cost benefits. Another challenge is to manage the increased cost of maintenance resulting from aging of overhead networks. At the same time, the safety and reliability of the installations have to be maintained.

Preventative maintenance is a key tool in short and long term planning for asset maintenance and replacement. Inspecting overhead lines has become the most important tool and determining factor for a successful preventative maintenance regime.

2.1 The current industry practices

Traditional preventative maintenance inspections of overhead lines include:

- Visual inspection (to identify obvious defects)
- Infrared inspection (thermal imaging)
- Ultrasound (traditional RFI)
- Partial discharge detection (PD)
- UV detection of corona discharge

(the latter methods assist in detecting problems not evident during routine inspections)

Some non-traditional and emerging inspection methods:

- Aerial video inspections
- Wire-climbing robots

2.2 Limitations of traditional inspection methods

Most transmission and distribution line companies use visual inspections on an annual basis as the primary means for their preventative maintenance regime. This inspection method can detect only the obvious defects that are visible from the ground, like mechanical defects, structural damage, and oil leaks.

However, this method can’t detect an electrical defect unless there is a visual manifestation of it, like discoloration, overheating, and compound leaks. Furthermore, even if there is an obvious visual sign of overheating, it is impossible to tell whether is it historical or current, thus indicating that an asset may be about to fail. It therefore usually requires a follow up with some other inspection method like using an infrared camera. In most cases these visual signs are just the end results of an electrical defect which was developing over a long time, and it is often too late to do any preventative maintenance on an asset, because by the time visible damage occurred, it has deteriorated beyond repair.

In summary – it is difficult or impossible to detect purely electrical defects using the visual inspection method only.

The other inspection methods are usually reactive - they are deployed after a visual inspection identifies a defect that needs further investigation. Some companies use these methods to regularly target particular troublesome or critical overhead assets, however they are not cost-effective to deploy on large scale surveys.

Some emerging inspection methods, like aerial video inspection, can be effective but they are still very expensive and face many other practical challenges and legal requirements. These methods enhance, but do not replace visual inspections unless additional partial discharge or infrared sensors are used. The same limitation of visual inspections still applies.

3.0 NEW ACOUSTIC TECHNOLOGY FOR INSPECTION OF OVERHEAD LINES

Vector and Northpower have successfully introduced and trialled a new type of ultrasonic inspection method (developed in Korea), and tested it on over 60,000 poles on their own networks. Northpower has also inspected over 15,000 poles on other distribution networks and some transmission lines. This technology for the first time allows electrical defects to be positively identified at early stage. It also offers the major benefit of rapid inspection speed - a crew of two can inspect more than 300 poles and associated lines per day. It is currently used in Korea, New York, Brazil, Mexico, Indonesia, Malaysia and Jamaica.

3.1 Brief overview of the acoustic inspection device

This new acoustic inspection technology was originally invented and developed in 2008 for KEPCO (Korean Electric Power Corporation), and became its major inspection method covering over 90% of overhead inspections on the Korean distribution network. It allowed KEPCO to reduce power outages by more than 40% during the last five years of intensive performance tests on over 7 million distribution poles and associated lines. *"KEPCO has remarkably enhanced efficiency of distribution operation by realizing predictive prevention of power failure and accident",* thanks to adoption of this new ultrasonic technology [1]. The equipment consists of:

- A uniquely shaped ultrasound detector which narrowly targets the intended device over a distance and minimizes the background noise. This allows the detection of ultrasound signals emitted by stressed electrical assets on lines even from a moving vehicle.
- An electronic unit which filters input signals from the receiver and, converts them into audible frequency bands. It also transfers the data into output devices, like the display window, recording and audio devices.
- Analysis software.

In addition, analysis support is provided by the development laboratory in Korea.

It is a tool for early detection of electrical defects and faults on OH lines. It detects ultrasound waves caused by electrical defects e.g. electrical discharges which can't be detected visually. It is the only drive-by ultrasonic inspection method which enables the inspection of overhead lines from a moving vehicle at a speed of approximately 30 km/h. It is so sensitive that it detects ultrasound emissions at 30~40 metres, with minimal interference from background noise. It dramatically reduces inspection time, while providing pinpoint accuracy. It is therefore cost-effective and very efficient compared to traditional inspection methods.

For basic technical data and comparison with other inspection methods refer to Appendix 1.

3.2 Advantages of New Acoustic Inspection Technology

The new acoustic inspection technology can detect with pinpoint accuracy the location of any type of electrical discharge caused by defects on the following hardware:

- Conductors – corrosion, pitting, bad binders and connectors, jumpers touching insulators, tree contact, fatigue failure of wire and hardware components, broken outer conductor strands usually emanating under the binders with intermittent contacts with conductor (insulated binding wires or binding wires over insulated conductors);

- Connectors – severe wear of contact surface and interface, bi-metal connections (Al-Cu), broken outer conductor strands usually emanating from the ends of mid span joints or wedge type connectors;

- Insulators – contamination/pollution, cracks, delamination, hairline cracks on glass insulators, pin corrosion, puncture of polymer insulators;

- HV cable terminations - nuts and washers between lugs, Cu-Al contacts, internal partial discharge between the layers of insulation on single cores, overheating;

- Air-break switches and other hardware - rusty connections, loose hardware, internal defects; and

- any equipment in distress which creates an electrical discharge.

In most cases, especially at early stages, these defects and the degree of asset deterioration are not identifiable by visual inspection. This new approach therefore provides early indication of impending problems – normally in time to repair rather than replace assets.

3.3 Failure mechanism of electrical defects that create sound and/or ultrasound

An electrical fault can cause multiple secondary failures of upstream assets, or put them under additional electromechanical stress and cause premature deterioration. Most electrical defects cause sound emission through an electrical discharge.

Electric discharge is any flow of electric charge through a gas, liquid or solid between two electrodes [2]. Examples of electric discharge include electric arc, brush discharge, partial discharge (dielectric barrier discharge), corona discharge, electric glow discharge, electrostatic discharge, electric discharge in gasses, and leader (spark) electric discharge. Each of these electrical discharges can deliver significant energy to the electrodes at the ends of the discharge, and create sound over a wide audio spectrum.

"During the discharge, due to ionisation processes, a channel of ionised gas is formed between the electrodes. The channel expands as a result of the intense Joule heating. The gas channel radiates an intense shock wave that promptly transforms into an acoustic pressure pulse that propagates into the surrounding medium at the local speed of sound" [3].

The following analysis presents the typical failure mechanisms of electrical defects on distribution lines, which have been supported by many examples identified on Vector and Northpower networks using the new acoustic inspection technology.

3.3.1 Gap between two contact points (electrodes) resulting in micro-arcing or arcing

The most vulnerable electrical parts of overhead networks are electrical contacts. Every failure of electrical contacts in the field starts with a gap between two contact points on the contact surface interface, which is the result of "surface films produced by natural aging mechanisms" [4]. It initially creates micro-arcing. As the gap increases, supported by microscopic movement of the interface, it results in more severe arcing between the contact points (electrodes). The arcing creates a sound and/or an ultrasound wave which can be detected with the new acoustic technology.

Examples: Loose contacts on HV cable terminations; loose connectors

Fig. 1 Arcing caused by a gap

3.3.2 Reduced Clearance Distance resulting in the dielectric breakdown of ionized air

Clearance distance is measured through air. It is the shortest distance between two conductive parts, or between a conductive part and the bounding surface of the hardware. It is affected by relative humidity, temperature, and the degree of environmental pollution. An inadequate clearance distance results in the dielectric breakdown of ionized air between electrodes (arcing), which is detectable with the new acoustic technology.

Examples: jumpers touching insulators, or very close to each other; tree contact

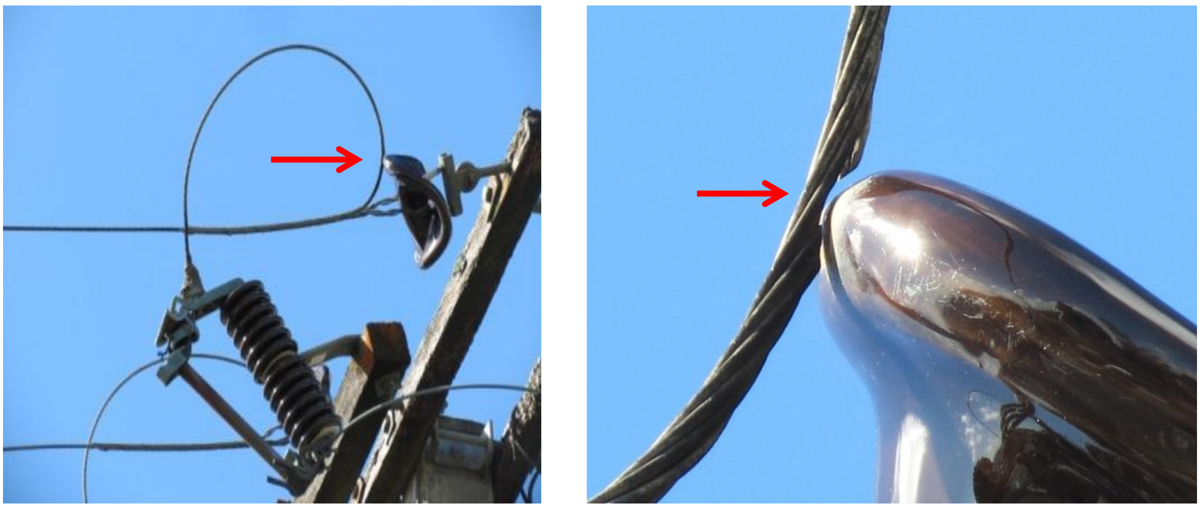

Fig. 2 Flash-over and heavy erosion caused by a jumper touching insulator

3.3.3 Reduced Creepage Distance resulting in Flash-overs

The insulator creepage (leakage) distance is the shortest distance along the insulator surface between the metal parts at the insulator ends. Insulators must provide enough creepage distance to avoid any leakage current from live electrical conductors to flow to the earth through non-electrical hardware. Atmospheric pollution (salt, dust, industrial contaminants) forms a conducting layer on the insulator surface, which shortens the length of the leakage path that could result in a flash-over. Insulator cracks also shorten this path. Flash-overs emit sound which is detectable with the new acoustic technology.

Examples: Insulators contamination, cracks, delamination, hairline cracks on glass insulators, pin corrosion which causes insulators to crack

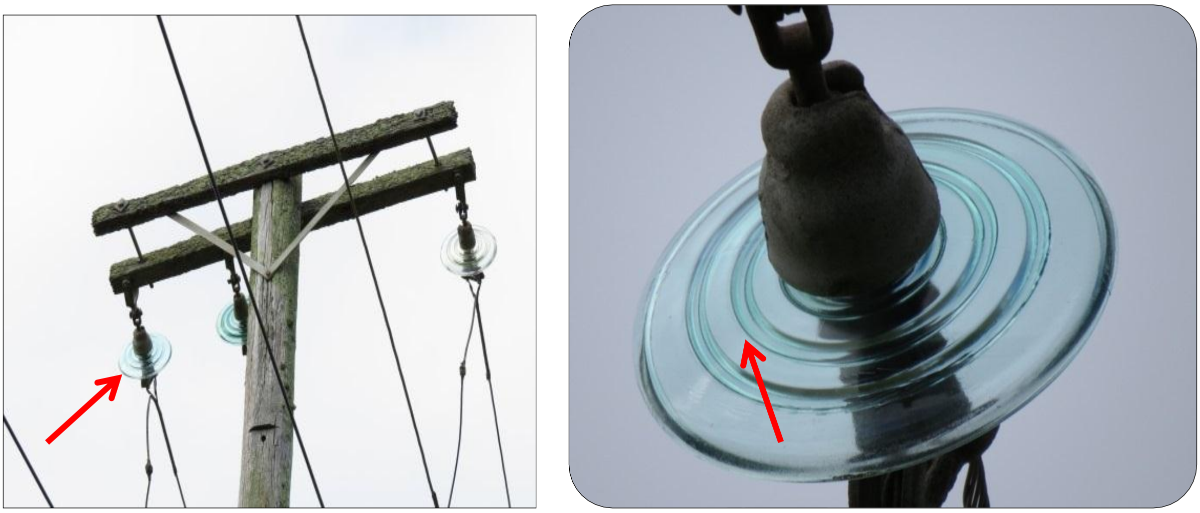

Fig. 3 Flash-over caused by a hairline crack on a glass insulator

3.3.4 Increased contact resistance resulting in arcing and overheating

Examples: HV cable terminations - loose contact between lugs which results in arcing and overheating; extra nuts and washers between lugs resulting in rusty connections; air-break switches and other hardware - rusty connections, loose hardware, internal defects

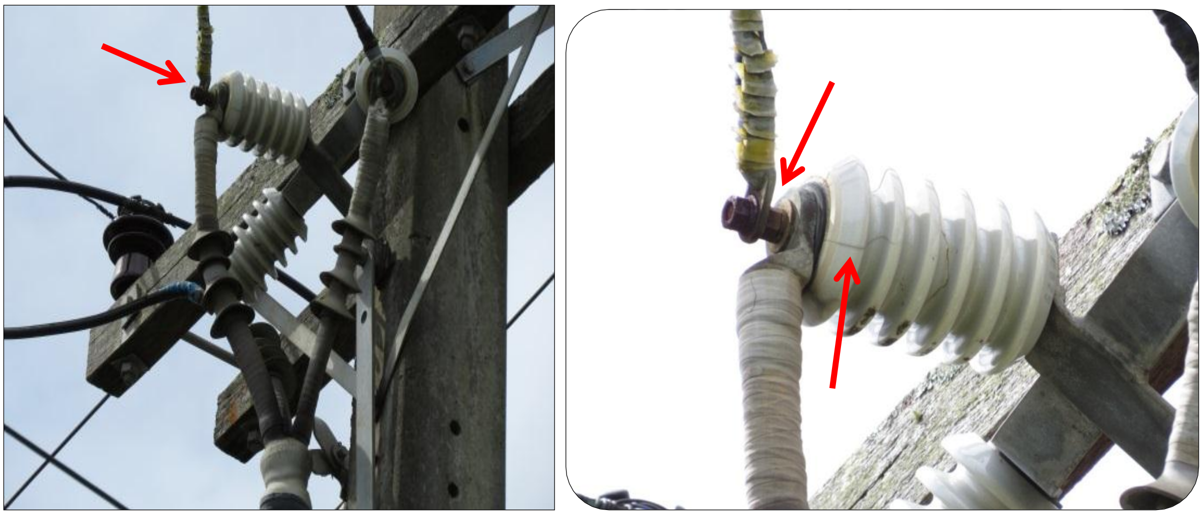

Fig. 4 Rusty nut and washer between lugs resulting in overheating and insulator cracks

3.3.5 Galvanic corrosion (electro-chemical processes) resulting in micro-arcing

Examples: Al-Cu connections where the aluminium will pit to the copper leaving less surface area for contact.

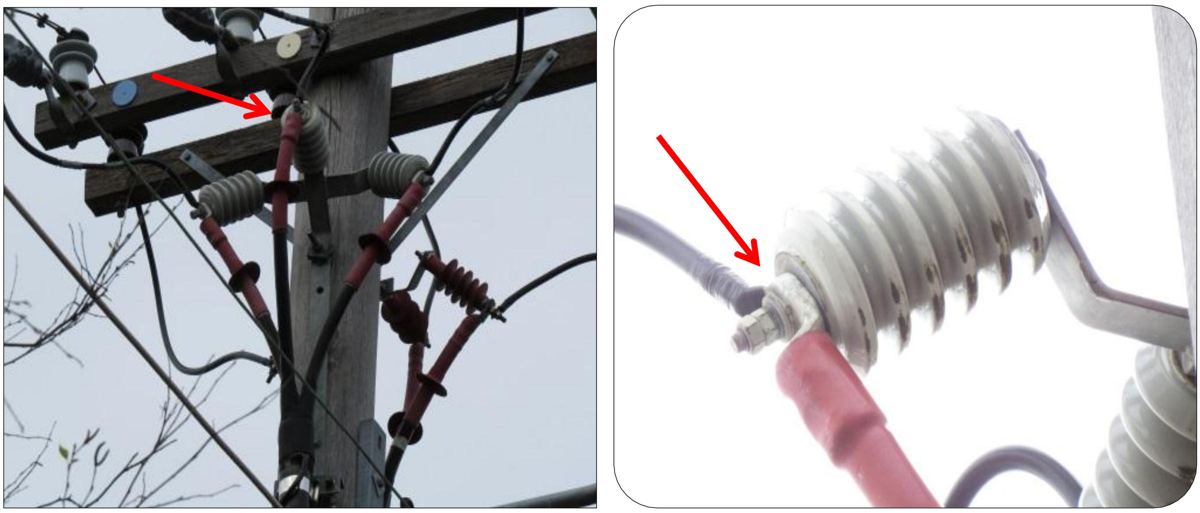

Fig. 5 Al-Cu connection resulting in micro-arcing and overheating

3.3.6 Intermittent contacts resulting in electrical discharge

Binding of bare conductor to an insulator should be done with a bare wire (binder) in close spaced spiral around the conductor to ensure good electrical contact. If it is not sufficiently firm and tight, it will result in the development of intermittent contacts. The same will happen if there is any insulation between a conductor and binding wire e.g. insulated binding wire, insulated conductor or both. Intermittent contacts along a binding wire will result in electrical discharge and arcing, which is detectable with the new acoustic technology.

Examples: Bare binders over insulated conductor or insulated binder wire over bare conductor, with sharp edges at the binder ends.

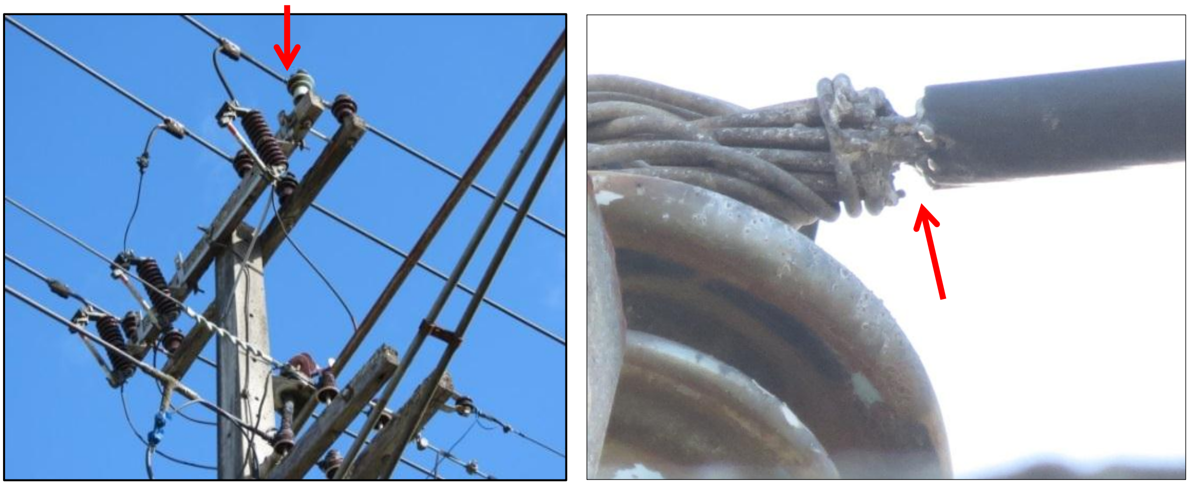

Fig. 6 Bare binder over insulated conductor resulting in el. discharge and heavy erosion

3.3.7 Partial discharge resulting in random arcing or sparking

Partial Discharge can occur along the surface of solid insulating materials. A good example is the surface of contaminated insulators in high humidity. It happens if the surface tangential electric field is high enough to cause a breakdown along the insulator surface [5].

It seems that the discharge can also occur between the insulating layers on a single phase conductor of HV termination, which results in random arcing or sparking. During the recent acoustic inspections, several cable terminations had one phase-conductor emitting ultrasound.

Examples: PD along the surface of solid insulating materials like contaminated insulators, PD between two insulating surfaces on HV cable termination single core

Fig. 7 Suspected PD between two insulating surfaces resulting in random arcing

4.0 BENEFITS DERIVED FROM ADOPTING THE NEW TECHNOLOGY

As noted above, the major advantages that the acoustic sensing devices offer is the enhanced ability to identify potential asset failure at a very early stage, and the ease and speed with which inspections can be carried out. These in turn lead to:

- Early detection of electrical defects and pre-fault condition that allows asset repair rather than (later) replacement.
- It provides improved information for corrective maintenance plans, and can for a key input into a condition based risk management program (CBRM).
- Condition can be tracked over time – having identified electrical noise, this can be monitored and if further deterioration (beyond a threshold) is noticed, it could be the signal to act.
- Improved reliability and customer experience by minimizing equipment failure.
- Enhanced inspection of overhead network, allowing larger areas to be covered in shorter time-frames.
- Improved management (prioritization and scheduling of remedial works).
- Improved quality of post-fault inspection patrols.
- Feedback tool to facilitate the review and continuous improvement of current design and work practices.
- A tool to determine the cause of some intermittent faults.
- Pre-commissioning tool (ensuring fault-free installations).

5.0 CONCLUSION

This paper has outlined the innovative acoustic technology for the inspection of overhead lines that Vector and Northpower have introduced. The technology allows for a rapid inspection and unmatched accuracy in detection of electrical defects on overhead lines and hardware. It is based on the principle that any type of electrical discharge emits sound, which can mostly be detected.

The concept of this technological innovation has been validated and the method proved in extensive field trials and tests in eight countries, with over seven million poles and associated hardware inspected in last five years. In all cases where the technology was compared with the traditional methods, a dramatic improvement has been achieved.

We believe that this unique technology will be a game changer in the NZ electricity industry.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge contributions and support received from:

- Des Abercrombie, Vector Technical Specialist
- The Korean experts: Inshik Woo, David Woo, Gimun Kim and Dugong Jang
- All of the Vector and Northpower people involved in the testing and commissioning
- The Managers who empowered us to bring this unique technology to the NZ industry

REFERENCES:

[1] "Certificate of approval" by Jung-Keun Park, Vice President, KEPCO, Korea (7/10/2011)

[2] http://en.wikipedia.org/wiki/Electric_discharge

[3] C. Ayraulta, P. B´equina and S. Baudinb, (2012), "Characteristics of a spark discharge as an adjustable acoustic source for scale model measurements", University of Maine, France

[4] Electrical Contacts - 1989. Proceedings of the Thirty Fifth Meeting of the IEEE Holm Conference on Electrical Contacts (Cat. No.89CH2779-7)

[5] http://en.wikipedia.org/wiki/Partial_discharge

APPENDIX 1: Comparison Table

	Acoustic Technology	RFI/TVI Detector	PD Detector	Corona camera	Thermographic camera
Detects	Ultrasonic signal caused by any electrical discharge	Radio frequency	Capacitive leakage to earth through voids (partial breakdown of insulation)	Ultrasonic discharge caused by steady glow or brush discharge in air	Infrared radiation
Frequency range	20 - 150 kHz	37kHz – 43kHz	10MHz – 45MHz	20MHz – 100MHz	Infrared spectrum
Receiver	Microphone	Antennae (dish)	Transient earth voltage detector	'Ultrasonic' detector	IR detector
Drive by	Yes	No	No	No	No
Accuracy	Pinpoint accuracy	Limited	Good (after the event)	Good (after the event)	Good (after the event)
Inspections per day	300 +	Less than 30	Less than 30	Less than 30	Less than 30