Overhead Conductor Condition Monitoring
ASTP/API Progress Report (No.2 2019)

Prepared by:

Dr Lakshitha Naranpanawe, Dr Hui Ma and Professor Tapan Saha

Power & Energy Systems Research Group

School of Information Technology & Electrical Engineering

The University of Queensland

Brisbane, Queensland

8th November 2019

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Overhead Conductor Condition Monitoring

Progress Report (No.2 2019)

Produced by

Dr Lakshitha Naranpanawe, Dr Hui Ma and Professor Tapan Saha

This report was prepared as part of the "Overhead Conductor Condition Monitoring" project being funded by the Energy Networks Association Limited.

To be cited as "Overhead Conductor Condition Monitoring (Progress Report No 2 of 2019)", The University of Queensland, St. Lucia, 2019.

Power & Energy Systems Research Group
Axon building (#47), Staff House Road, St. Lucia Campus
The University of Queensland
Brisbane, QLD 4072 Australia

November 8, 2019

Issue	Changes	Date
1	New document	November 8, 2019

Checked by Project Industry Partners:

The technical content presented in the report is 'work in progress' and industry team is working with the UQ team to finalise the technical outcome of milestone 3 of the project.

	Signature	Date
Ayan Ghosal (Western Power)		
Scott Merillo (Energy Queensland)		
Matthew Cupples (AusGrid)		
Peter Livingston/ Tim Gowland (CitiPower/Powercor/United Energy)		

Executive Summary

Energy Networks Association (ENA) member utilities have almost 800,000 kilometres of overhead conductor in service, valued at several billion dollars. Many of this critical infrastructure are ageing with some already reaching 70 years or replacement age. This project investigates the effective ways of condition monitoring of overhead conductor in Australian distribution networks. The objectives are:

- Review of conductor failure modes, degradation mechanisms and ageing parameters and current Australian industry practices to asset manage overhead conductors.
- Define the criteria for quantifying conductor condition and its end-of-life, and determine the probability of conductor failure and estimate its remaining useful life.
- Identify the core areas of research and development for improving condition assessment of conductors in Australian Distribution Network Service Providers (DNSPs) networks.
- Survey state-of-the-art conductor condition monitoring techniques that could be used to monitor distribution conductor condition and assess the practicality and economics of applying these techniques in Australian networks.

This project was started on June 20, 2018. Having been working closely with project industry partners, the UQ team has successfully completed Milestone 1 and Milestone 2 tasks, including:

- A comprehensive review on the types, failures modes and geographical locations of conductors in Australian DNSPs' networks. The review was based on an extensive literature study on Energy Networks Association (ENA) 2015-2016 conductor survey, individual utility surveys, open source databases, IEEE, IEC and CIGRE standards and recommendations, and other literature as well as discussions with industry experts.
- A comprehensive study to understand the conductor degradation mechanism and parameters that affect each type of conductor failure in Australian DNSPs' networks.
- After a survey of the current Australian DNSPs' practice on conductor asset management and their requirements for a proactive yet cost-effective conductor condition monitoring, the UQ team identified core areas of research and development for an improved condition assessment of conductors on Australian DNSPs' overhead lines
- Identified a heath index methodology suitable for the bare overhead conductors in the Australian power distribution network. The methodology uses a set of input parameters identified by analysing the Australian conductor failure statistics.
- The proposed health index methodology was trialled on a set of field data provided by the industry partners of the project. The calculated health index values were in a good agreement with the industry experts' conductor health condition predictions.
- A mathematical model, which can model the probability of conductor failures in Australian DNSPs' networks was proposed.

The Milestone 1 and 2 reports were submitted to ENA on December 20, 2018 and August 20, 2019 respectively. Since the completion of the first two milestones, the UQ team has been conducting a survey of the state-of-the-art conductor condition monitoring techniques, which could be suitable for monitoring distribution conductors to supplement and extend the Health Index projections.

In the past two and half months (from the 20th of August to the 8th of November 2019), the UQ team have made the following progress:

- Identified a method to correlate the health index with this probability of conductor failure (this part is an extension of Milestone 2).

- Investigated two emerging distribution network fault identification techniques, i.e. IND technology's Early Fault Detection (EFD) technology and Lord consulting's Distribution Fault Anticipation (DFA) technology.
- Conducted a preliminary study on possibility of using drone based advanced visual inspections for conductor condition monitoring.

Several Australian DNSPs are currently using IND technology's EFD technology on their networks. However, the project team has concluded that the EFD technology is more suitable for fault detection & prediction (in short term) than long term condition assessment of distribution conductors. Even though the project team will conduct further investigation on IND technology's EFD method, the main focus of Millstone 3 is now on the feasibility of drone based advance visual inspections for condition monitoring of bare overhead conductors in the Australian power distribution network.

The UQ team along with industry partners, is also working on a plan for the successful implementation of the project into distribution utility businesses.

Table of Contents

1. Introduction

ENA members have almost 800,000 circuit kilometres of overhead conductor in service. This represents an asset, which is conservatively valued over several billion dollars. Overhead conductor asset can be of different metal types, different sizes and capacities, and is deployed in all climatic zones including tropical, temperate, arid, and highlands. Many conductor assets are ageing with some already reaching 70 years. Though many advancements in technology have been achieved throughout these years, approaches to cost-effectively monitor condition of conductors have not substantially changed. Existing conductor condition monitoring practices still rely on visual inspections and conductor replacement is usually driven by the frequency of conductor failures. Reliable and cost-effective methods to assess the likelihood of a conductor failure have not yet been developed for the Australian distribution network service providers (DNSP) networks.

On June 20th 2018, ENA approved a research project proposal submitted by the University of Queensland (UQ) team. The project is aimed at investigating how to effectively monitor and assess the condition of overhead conductor for an improved asset management of conductors in Australian distribution networks. The research works conducted in this project are:

1. An establishment of a knowledge base of overhead conductors in Australian distribution networks and subsequently the identification of the current core areas of research and development for an improved conductor condition assessment.
2. A methodology for quantifying conductor condition through Health Index (HI).
3. Estimation of probability of failure and residual life using HI (ongoing work)
4. Identification of the state-of-the-art commercially available conductor monitoring system and emerging smart sensor-based system and possibly evaluating a smart sensor with data collection methods.

The project was formally started on June 20, 2018. Milestone 1 tasks were completed in December 2018 and Milestone 1 report was submitted to ENA on December 20, 2018. Tasks of the second milestone were completed in August 2019 and Milestone 2 report was submitted to ENA on August 20, 2019. After that, the UQ team has been working on the tasks of Milestone 3. This report highlights the research works performed for the period from August 20 to November 8, 2019.

2. Highlight of Project Progress

Having been working closely with project industry partners and two industry experts Colin Lee and Keith Callaghan, the UQ team have made significant progress.

During the period of Milestone 1, the UQ team and industry partners reviewed conductor population on Australian Distribution Network Service Providers (DNSPs) overhead lines including the types, failure modes and geographical locations of conductors [1]. The UQ team performed a comprehensive study to understand the conductor degradation mechanism and parameters that affect each type of degradation mechanism. Moreover, the UQ team reviewed the current Australian DNSP's practice on conductor asset management and their requirements for a proactive yet cost-effective conductor condition monitoring. The UQ team identified core areas of research and development for an improved condition assessment of conductors in Australian DNSPs' networks.

During the period of Milestone 2, the UQ team and industry partners reviewed several publicly available health index methodologies. The UQ team with strong support from industry partners then developed and implemented an algorithm for health index calculation of the bare overhead conductors used on the Australian power distribution network. Corrosion and annealing were identified as the most critical conductor degradation mechanisms. Thus, in the algorithm each of these degradation mechanisms was associated with a set of quantifiable sub-condition parameters. The values of parameters and their weighting factors were determined based on conductor failure statistics, industry partners' experience, and industry experts' knowledge. The developed health index methodology was trialled on a set of field measurements received from the project participating partners. After the validation of the health index method, a methodology for calculation of the probability of conductor failure based on service data is proposed. Finally, the probability of conductor failure of copper conductors (based on a selected distribution network) was calculated and compared with the real service results.

During the past two and a half months (from August 20 to November 8 2019), the UQ team has reviewed the various methods for assessing the residual mechanical strength of aged conductors for condition monitoring; and along with industry partners, proposed a plan on how the project's results can be implemented into distribution utility businesses. Appendix 1 outlines the proposed implementation plan along with a flowchart of the condition monitoring process.

The UQ team has also reviewed a number of existing and emerging conductor condition monitoring and fault detection techniques. As a result, the team was able to identify several conductor fault detection techniques and a condition monitoring method, which could be suitable for the Australian distribution networks. After the above investigation and discussion with industry partners, the team has decided to focus on a drone based advanced visual inspection technology for conductor condition assessment. A detailed information on this part of the work will be presented in Milestone 3 report.

3. Project Methodology

- No changes to the project scope

4. Conductor Monitoring Methodologies

4.1 A Brief Review of Early Fault Detection (EFD) Method

IND technology's early fault detection (EFD) method is a continuous conductor monitoring solution. It can remotely detect and locate radio frequency (RF) signals emitted from a faulty section of a conductor. The sensors used are antennas or Rogowski coils (placed every 5 km), which can detect micro arcs or Partial discharge (PD) signals. The data captured by the sensors are continuously uploaded to a cloud-based information management system. The collected data is analysed using machine learning algorithms in real-time. Figure 1 illustrates the components of the EFD method.

The EFD technology claims to be able to detect deteriorating, damaged and broken overhead conductors, powerline vegetation encroachment and line contacts.

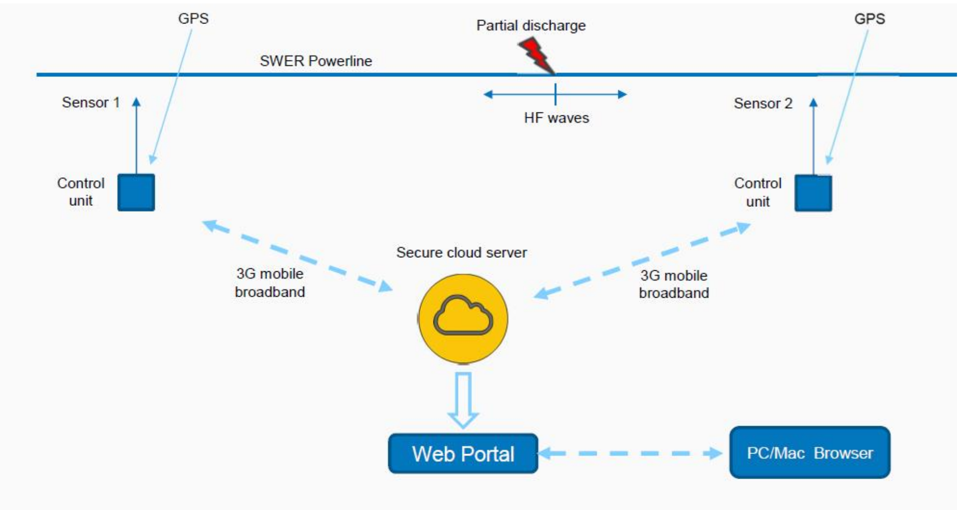

Figure 1 Illustration of IND technology's early fault detection (EFD) method for continuous conductor monitoring [2]

4.2 A Brief Review of LORD Technology's Distribution Fault Anticipation (DFA) Method

The LORD Technology's DFA method is also an online real-time condition monitoring technology, which is intended to raise the asset managers awareness of the current system health condition and developing events. Unlike IND's EFD, the DFA uses Current Transformers (CTs) and Potential Transformers (PTs) to perform the measurements. The CT and PT waveforms are then sent to a software tool for classification, as illustrated in Figure 2.

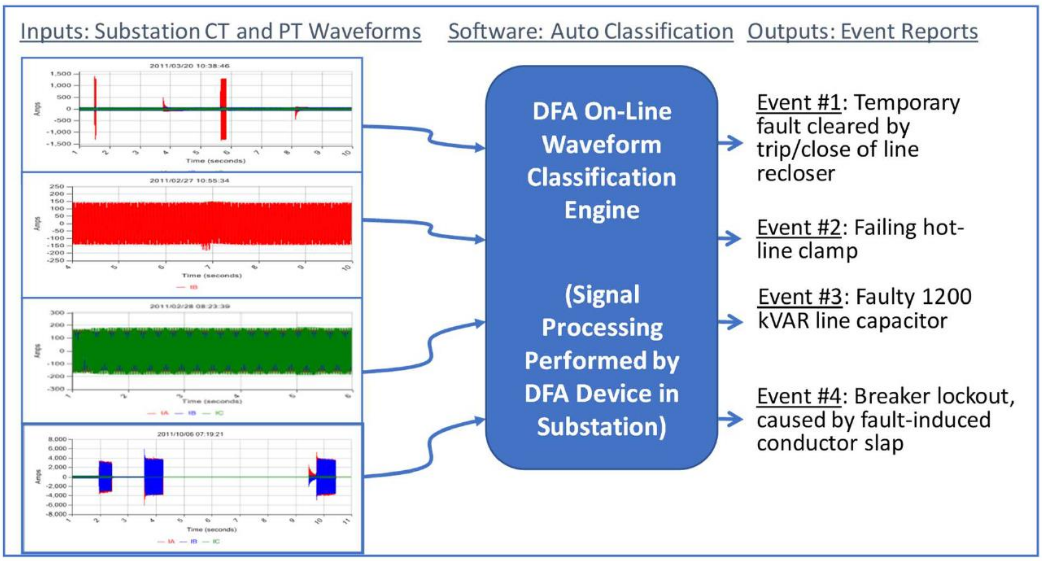

Figure 2 Illustration of LORD Technology's DFA method [3]

4.3 A Brief Review of Drone based Advanced Visual Inspection of Conductors

Recent developments in drone technology have made drone based advance visual inspections of overhead conductors a realistic alternative for conductor condition monitoring [4-6]. The drones can be positioned in close proximity to the overhead conductors (3 to 5 metres) to capture high resolution images. The technical challenges are how to effectively process the captured images and videos and accurately retrieve information regarding the conductor condition [7]. The UQ team has been conducting a feasibility study of the drone based advanced visual inspection for conductor condition monitoring.

The UQ team has received sample drone captured images of overhead conductors form the project partners. An example is shown in Figure 3. The sample photos are of high resolution and can be used to identify defects and make an assessment of the condition of overhead conductors. However, proper intelligent techniques need to be implemented in a software environment to automatically analyse these photos/videos and evaluate the conductor's condition.

Figure 3 Sample Drone captured image of an overhead conductor

5. Next Steps

During the remaining time of the project, the UQ team will work closely with the industry partners to complete the feasibility study of a drone based visual inspection methodology of the overhead conductors. The aims of the study are to identify:

1) Advantages and disadvantage of capturing conductor data as still images and high-resolution videos
2) Image processing and pattern recognition tools that can be used for drone captured visual data analysis
3) Cost benefit analysis

6. Conclusions

The Project team reviewed two existing conductor fault detection technologies namely IND technology's EFD and LORD technology's DFA, which can be used in the Australian distribution network. The review revealed that, though both technologies are capable of detecting faults in the lines such as broken strands etc. the data captured from these technologies may not provide valuable information for longer term forward looking assessment of condition of overhead conductors, as useful as that potentially available from visual or photographic images.

The UQ team has proposed a method for calculating the probability of failure of aged conductors and reviewed the various methods for assessing the mechanical condition of conductors. Along with industry partners, the UQ team is working on developing a plan for the implementation into distribution utility businesses.

Drone based visual inspections is another method, which has the potential for advanced visual inspection of bare overhead conductors in the Australian power distribution networks. Several Australian DNSPs are already using or trialling drones for the visual assessment of other power system assets. However, after discussions with the industries that have trialled drone based visual inspections of overhead conductors, it was concluded that further work is required for improving the accuracy of drone based visual inspections of overhead lines and processing of the images using image recognition software and machine-learning.

7. References

1. Lakshitha Naranpanawe, H.M., Tapan Saha, *Overhead Conductor Condition Monitoring : Milestone Report 1*.
2. Ltd, I.T.P., *EFD SWER Trial*. 2019. p. https://www.energy.vic.gov.au/__data/assets/pdf_file/0025/426733/Fault-Signature-Final-Report.pdf.

3. *DFA: HV Line Monitoring & Management*. [cited 2019 28th October]; Available from: https://www.lordpowerequipment.com/dfa/dfa-hv-line-monitoring-management.

4. Costea, I., C. Dumitrescu, and F. Nemtanu. *Advanced Terrestrial and Aerial Monitoring and Inspection System for Critical Infrastructures*. in *2018 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*. 2018.

5. Qasem, H., A. Mnatsakanyan, and P. Banda. *Assessing dust on PV modules using image processing techniques*. in *2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC)*. 2016.

6. Flammini, F., C. Pragliola, and G. Smarra. *Railway infrastructure monitoring by drones*. in *2016 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC)*. 2016.

7. G. Kunlun, C.Q. *An intelligent power line inspection image (Video) analysis system*. in *Cigre Science & Engineering*. 2019.

APPENDIX 1 – IMPLEMENTATION PLAN FOR CONDUCTOR CONDITION MONITORING

1.0 Objective of the project
- 1.1 What the project is delivering
- 1.2 What is the potential benefit of implementation
- 1.3 Who are the potential beneficiaries

2.0 Implementation plan
- 2.1 Utility engagement (for DNSPs not already part of the project)
  - 2.1.1 Publication of report(s)
  - 2.1.2 State-based workshop(s)
- 2.2 Condition Based Health Index
  - 2.2.1 Overview of parameters used
  - 2.2.2 Inputs required
  - 2.2.3 Interpretation of output
- 2.3 Assessment/Prediction of asset condition using Health Index
  - 2.3.1 Probability of Failure (PoF)
  - 2.3.2 Residual life
  - 2.3.3 HI criteria for more detailed assessment (e.g mechanical testing or drone inspections)
- 2.4 Validation with Aged/Replaced Conductors
  - 2.4.1 Data availability
  - 2.4.2 Ongoing refinement & validation using local knowledge & test data
- 2.5 Health Index Tool and User Manual
- 2.6 Roll-out (within each DNSP or via Webex)
  - 2.6.1 Pre roll-out trial
  - 2.6.2 Stakeholder engagement
  - 2.6.3 Integration with existing methods & systems
  - 2.6.4 Impact assessment
  - 2.6.5 Roll-out
- 2.7 Discussion on condition monitoring technology techniques and trial

3.0 Monitoring & Continuous Improvement
- 3.1 Feedback mechanism
- 3.2 Benchmarking (between DNSPs)
- 3.3 Governance & change management
- 3.4 Future improvement opportunities

Conductor Condition Monitoring Process