Date of Submission

July 2017

Network Innovation Allowance Project Closure Report

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Project Progress

Project Title

Overhead Line Vibration Monitoring Phase 2

Project Reference

NIA_SSEPD_0017

Funding Licensee(s)

Scottish Hydro Electric Power Distribution,
Southern Electric Power Distribution

Project Start Date

October 2015

Project Duration

9 months

Nominated Project Contact(s)

David MacLeman

Scope

This project will complete the development of a technical method that commenced in a previous Innovation Funding Incentive (IFI) project. In that project, wire mounted sensors incorporating electronics for detecting change in angle, wire sag and impact of a wire strike were developed. The IFI phase led to the production of prototype sensors which demonstrated proof of concept through successful vibration testing on overhead lines.

This project will install a sample of the prototypes on representative sections of live overhead lines and monitor their performance, as well as that of the server, over a period of 3 months. At the end, an evaluation will be carried out to confirm the suitability of the system for vibration and movement monitoring in a live high voltage environment.

This project will include the final development and demonstrate the ability of previously developed prototype sensors and the supporting server to provide notification of impacts to Overhead Line (OHL) conductors and/or movement of the supporting poles, so that the Distribution Network Operator (DNO) control room can be able to decide on the appropriate action that could avoid outages, reduce the impact of vegetation on the overhead network, and reduce the potential for serious injury/death to members of the public.

Objective(s)

1. To demonstrate that wire mounted sensors can sense and differentiate between wire strikes and wire sags, and other sources of conductor movement including e.g. wind, animal rubbing, birds perching and vehicles passing.

2. To demonstrate that the information from the sensors can be used to discriminate between varying types of wire impacts, and reject false positives, e.g. heavy birds landing or colliding with the line.
3. This project will try to establish if the prototype sensors can be self-powered using energy harvested off the line, are able to operate at voltages between 11kV and 70kV and that the associated server software is fit for purpose.

Success Criteria

The project will be a success if it can demonstrate whether or not wire mounted sensors can be used to improve customer service by improving the management of contact with, and damage to, overhead lines and poles.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

The use of the Power Networks Demonstration Centre (PNDC) to carry out the testing allowed the project to develop in a controlled environment, where tests could be easily replicated over a period of time. A test matrix was developed which provided for each of the project test cases to be examined and the results were recorded for analysis. The OHL used was energised providing 30 A current to each phase to allow the sensors to harvest energy off the line. The data aggregator was located within 30m and powered by low voltage from the building supplies. The data aggregator sent data to the System Management Server (SMS) in the USA via the mobile phone network. The SMS was monitored from the PNDC via an internet connection. The vibration waveforms and alarms generated by the sensors were transmitted wirelessly to the data aggregator, where it was collated and sent to the SMS. The SMS passed the waveform data into the 2 algorithms that Tollgrade had developed under the previous IFI project, for processing. These algorithms are the Ground Clearance Tracker (GCT) which uses initial position data and angle data from the sensor to compute distance to ground, and the Motion Analyser which uses the vibration waveform data to determine the probability of a collision event being hazardous.

The data produced by the sensors showed that data can be collected in real time, which can be used to determine if a potentially hazardous event has occurred.
The GCT software showed that it could determine distance to ground extremely accurately, with the calculated distance being compared with actual measurements taken on site.
The MA algorithms have proved able to classify the conductor movements as recorded by the sensors, as hazardous or non-hazardous with a high level of probability. There was one exception, and that was for the fishing line snag test. This test produced extra variations in the motion that had not been seen in previous tests. The MA algorithm will be amended to take this motion into account.
The MA correctly classified all of the simulated 'vehicle collisions', in a manner that was similar to those found during the testing under the IFI project. A new 'vehicle collision' test was planned but not carried out, due to safety considerations within the PNDC compound.

The results of all of the tests carried out in accordance with the test matrix showed that the sensors and the supporting software on the server are able to detect and differentiate between wire sags and wire collisions, caused by a number of different collision factors, and so have satisfactorily met Objective 1.

The results also showed that the algorithms used by the server are able to differentiate between hazardous and non-hazardous collisions, and by tuning the algorithms sensitivity, the potential for false positives can be minimized, and so the project has met the requirements of Objective 2.

All six sensors are based on the standard production current sensor produced by Tollgrade, and were used at PNDC on a live line, so that they self-powered, and auto connected to the server, once the line was energized. The sensors and the server software both showed their suitability to provide an easily maintained system, where the sensors will use line current to energise themselves, and so they meet the requirement of Objective 3.

By providing a network control room with information on the probable cause of a trip on an overhead line, the sensors and server system have demonstrated that they could be used to provide the control room with the necessary data in order to make a decision on when to reclose to re-energise a circuit, and thus minimize the time that customers are off supply, and the project can be regarded as a success.

Required Modifications to the Planned Approach During the Course of the Project

The project scope had to be reduced in order to refrain from potentially causing inadvertent outages to customers on the overhead line network. By using the PNDC network, energised OHL could be used without the potential to cause an outage. Some test cases were limited in their ability to be carried out due to safety constraints, however, these did not negate the test results that were obtained.

Lessons Learnt for Future Projects

1) The project has shown that line mounted sensors can be developed to sense and report on physical events as well as the electrical events that occur to an overhead line.
2) By using advanced algorithms it is possible to analyse the vibration waveform from an accelerometer, and determine the probability of occurrence of several differing causes of the impact that initiated the vibration.
3) By using an advanced algorithm it is possible to analyse signals from an inclinometer sensor and determine the height of the line from a datum point (the ground beneath the line).
4) It would now be beneficial to have the sensors and aggregator installed on a live line for an extended period in order to develop fully the use of the data that is available from the sensor. These installations should be across a wide range of sites, to encompass as many of the varying line environments as possible.
5) As the sensors retain their ability to measure and report on line current, the information that can be obtained via the SMS should be considered, so that a full benefits analysis can be developed.

Note: The following sections are only required for those Projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

The main part of the project was the proving of the analysis algorithms developed in the IFI project previously. These algorithms have been developed for the data collected during the IFI project, by prototype sensors mounted on an energized low voltage line at an SSEN test facility. These sensors were not constructed to full manufacture standards.

The sensors supplied for this project were full production prototypes, along with production aggregators. The data was sent to the SMS which carried out the analysis, and produced results in near real time. This timing is important, as there is only a short time period for the system to warn of a potentially hazardous collision so that action can be taken to keep a line de-energised and investigate the cause of the alarm.

The system as installed demonstrated that in most circumstances, the system would produce the correct outputs, with minimal false positives. This would give control engineers confidence that the alarms that they receive in the control room are an indication of a hazardous condition on a line. The section below describes the simulation work done and the tests carried out to complete the analysis.

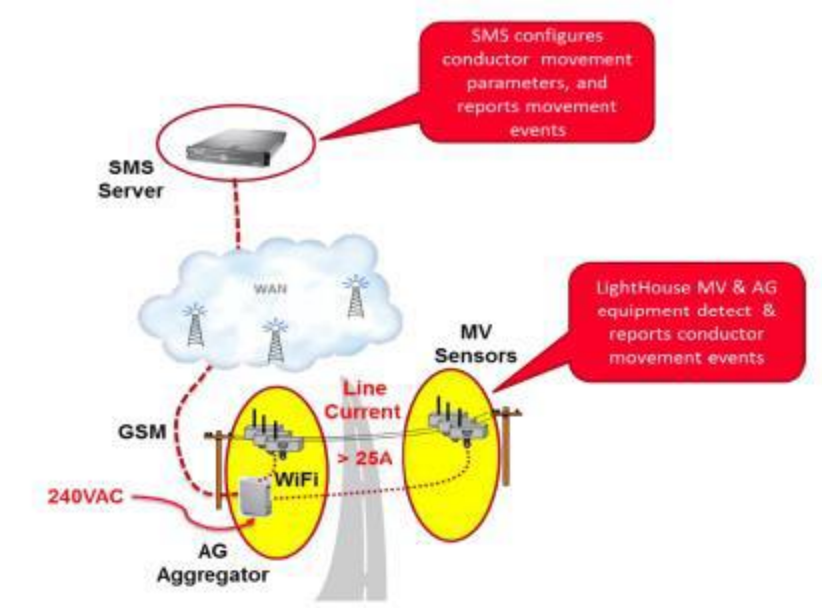

Figure 1. Test simulation set up at PNDC.

After installing the sensors on the overhead line, but before any testing started, the datum for the GCT needed to be set. Figure 2 shows the parameters required, in particular s, h0, h1, and h2. The rest can be calculated by the algorithm in real time, and provides a measure for the distance q from the conductor to the ground. These parameters are needed for each sensor, as the SMS stores their positions seperately.

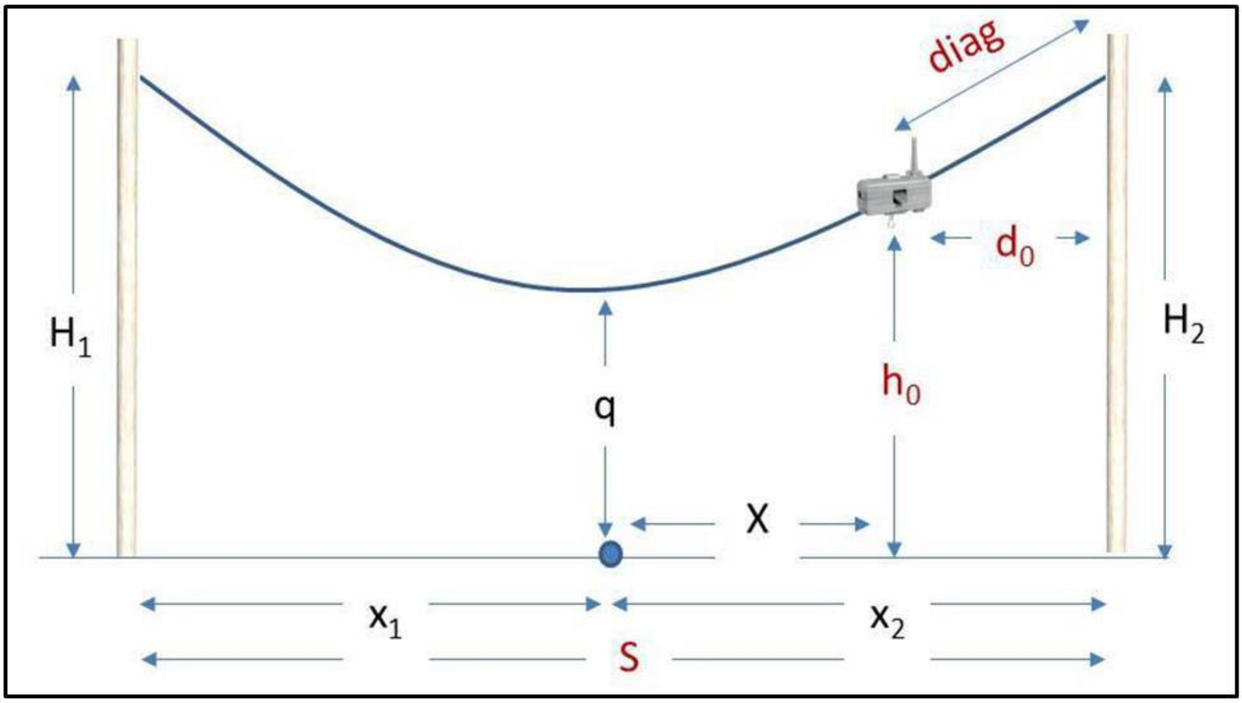

Figure 2. Parameters required to measure conductor sag.

The test cases considered for the tests are in Table 1. Each test is carried out a number of times, to ensure that the readings taken are replicable.

Test Case	Event Description	Test to Simulate the Event
Non-hazardous Impact		
1	Tree branch falls onto the conductors and remains in contact.	From the scaffold (mid-span) or MEWP bucket (at one end of the span), the lineman holds a 2.2m long 50x50cms piece of timber about 1 meter above the conductors and drops it onto them. Leaves it laid on the conductors
2	Intermittent tree branch contact - the branch falls onto the conductors and rises up again.	Same as previous but lift the timber back up off the conductors right away after contact.
3	Small bird or other animal lands or jumps onto the conductor.	Drop a 1.3 kg weight into a bucket suspended from the conductor.
4	Large bird or other animal lands or jumps onto the conductor.	Drop a 4 kg weight into a bucket suspended from the conductor.
Hazardous Impact		
5	Vehicle contact with phase(s) from below and stays in contact, holding conductors in displaced position.	Test specified to use MEWP bucket to displace conductors but was not allowed. Instead had lineman bring lumber cross in contact from below with two conductors simultaneously.
6	Vehicle contact with single phase from the side, horizontal attack, vehicle stays in contact.	Test specified to use MEWP bucket to displace conductor but was not allowed. Instead had lineman bring straight timber piece in contact with one of the outer (X) conductors, at attack angle parallel to ground. Conductor was held in displaced position for 20 seconds.
7	Vehicle contact with single phase from the side, horizontal attack, vehicle immediately pulls away.	See previous, but instead immediately pull timber away after attack.
8	Fishing line snags the conductor from directly below.	Tie a rope to the conductor and from the ground repeatedly tug on the rope for about 20 seconds, from a position directly below the conductor.
9	Fishing line snags the conductor from an angle.	Same as test case #7, but change position of the tugging direction to be 45 degrees instead of straight from below.
10	Vehicle contact with single phase from the side, attack at an angle, vehicle stays in contact.	Test specified to use MEWP bucket to displace conductor, was not allowed. Instead had lineman bring straight timber piece in contact with one of the outer (X) conductors, at attack angle 45 degrees to ground. Conductor was held in displaced position for 20 seconds.

Table 1. Test Cases

During the testing, results were recorded and are tabulated in Table 2. The discrepancies were noted and discussed with the engineering team and designers. The conclusions are given after Table 2.

Test Case	Event Description	Number of Iterations	Location of Stimulus	Classification Results	Remarks
Non-hazardous Impact					
1	Tree branch falls onto the conductors and remains in contact.	10 10	Mid Span Left End	10 out of 10 correct 7 out of 10 correct	
2	Intermittent tree branch contact - the branch falls onto the conductors and rises up again.	10 10	Mid Span Left End	10 out of 10 correct 3 out of 10 correct	Twisted sensors were re-tightened. Sensors became twisted, causing diminishment of Z-axis acceleration
3	Small bird or other animal lands or jumps onto the conductor.	5	Mid Span	5 out of 5 correct	No waveforms sent. Impacts did not exceed threshold for any of the simulated bird tests.
4	Large bird or other animal lands or jumps onto the conductor.	5 5	Mid Span Left End	5 out of 5 correct 5 out of 5 correct	No waveforms sent. Impacts did not exceed threshold for any of the simulated bird tests.
Hazardous Impact					
5	Vehicle contact with phase(s) from below and stays in contact, holding conductors in displaced position.	10 10	Mid Span Left End	1 out of 10 correct 0 out of 10 correct	Waveforms received in all 10 cases, but classified as non-hazardous. See below for further discussion. In 9 of 10 cases, stimulus applied by humans (instead of desired vehicle) was insufficient to exceed threshold.
6	Vehicle contact with single phase from the side, horizontal attack, vehicle stays in contact.	10	Mid Span	4 out of 10 correct	First 6 attempts failed to exceed threshold. Tester then instructed to strike harder with timber, last 4 iterations

		10	Left End	9 out of 10 correct	registered hazardous. 'Hard strike' method was used for all iterations in this test set
7	Vehicle contact with single phase from the side, horizontal attack, vehicle immediately pulls away.	10 10	Mid Span Left End	10 out of 10 correct 7 out of 10 correct	'Hard strike' method was used for all iterations in this test set
8	Fishing line snags the conductor from directly below.	10 10	Mid Span Left End	0 out of 10 correct 0 out of 10 correct	Fishing line motion seen in this round of testing differed greatly from that of Phase 1B, which produced the data for algorithm development. See below for further discussion.
9	Fishing line snags the conductor from an angle.	10 10	Mid Span Left End	1 out of 10 correct 1 out of 10 correct	
10	Vehicle contact with single phase from the side, attack at an angle, vehicle stays in contact.	10	Mid Span	4 out of 10 correct	Only 4 events exceeded impact threshold, those 4 all were classified hazardous. Skipped left-end, deemed very similar to Case 6.

Table 2. Test results.

The Impact Tests – Non Hazardous

The results from simulated bird landings on the line show that the impacts are unlikely to exceed the thresholds and so will not alarm. In this case the sensors will not record waveforms and no data will be sent to the SMS. The sensors effectively filter out such nuisance events. This was further confirmed on the last day, when we arrived at the test site to see several large crows hopping up and down the lines, and crossing from one to another. The SMS had no record of this avian activity.
Tree and branch impacts were also recorded correctly as non-hazardous. Some anomalies were seen, but this was shown to be due to the sensors twisting around the y-axis, along the wire, and so the datum for the measurement axes was compromised. Development of the MA algorithm is intended so that a displacement of this form can be taken into account.

Hazardous

For the vehicle contact tests, the intention was to impact the lines by driving a Mobile Elevated Work Platform (MEWP) bucket into them. The equipment provided by the PNDC, a lightweight track mounted MEWP, was deemed to be unsafe to carry out this test, by the PNDC Safety Officer, and so an alternative means was sort. The best that we could do in the time that was available for testing was to try and simulate a vehicular impact using a length of timber. However, the amount of effort required to simulate a vehicle of several tonnes impacting a line, with a length of timber of around 4 Kg in weight, meant that the tests were inconclusive. In comparison, when the tests were carried out in a previous phase using a vehicle mounted MEWP, the resulting waveforms were quite clear that an impact had occurred, and these prior results were used to develop the algorithm that was being used in this project. The tests for an impact on the line from below were inconclusive. The impact was applied using a T shaped former, constructed of timber, but 2 linesmen were not able to lift it with enough force to provide signals that exceeded the threshold. The side impacts were simulated by the linesmen standing at the side of the line, on a scaffold tower, and applying the impact with the wood former. This was more successful when the linesmen were asked to use more force, to provide higher acceleration to the line.

The sag tests were carried out by loosening the stays of the pole at one end of the span. A small amount of loosening resulting in a large movement of the top of the pole. This movement was successfully picked up by the sensors and alarms created when the threshold was exceeded.
The calculated distance of the midspan point to ground was compared to the measured distance on the day, and was found to have an error range of 6% to 8%, averaged across all 6 sensors. This error indicating that the clearance to the ground is less than it actually is. There was an issue with the measurement of the distances required to set the datum. The laser rangefinder used by the test team proved to be problematic in use. In order to change the measurement from horizontal to vertical, the rangefinder mode had to be changed. This caused a movement in the position of the rangefinder (it was hand held) which resulted in a loss of confidence in the accuracy of the rangefinder. For installs on a live network, the test team recommends that a tripod mounted rangefinder be used, that does not require a mode change in order to carry out the measurements. It also proved difficult, in the atmospheric conditions at the time, to see the sensors through the rangefinder. The test team is looking at marking the sensors with a high vis marker to improve visibility, when using rangefinders to measure distance to sensor.

Planned Implementation

A proposal to install pre-production sensors on a wide range of test case sites on the live OHL network is being considered. This will provide learning on the installation and configuration of the sensors in a live environment, and demonstrate that the sensors are able to withstand the day to day environmental change that they will be subject to in a live environment.

A separate project will be raised if this proposal is to be taken further.

Other Comments