LOCATION OF ARC FAULTS ON 11 KV OVERHEAD LINES USING RADIOMETRY

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ABSTRACT

The further development of a project to locate OHL faults through the detection of radiated electromagnetic noise has been described. Propagations tests have indicated that the arc induced radiation may be detected at distances up to 5 km. A trial system involving 4 receiving stations has been installed on a SP Energy Networks (SPEN) OHL network in the Edinburgh region. The maximum distance between the stations is ~4 km. The trial has revealed several problematic issues in the operation of the system that have now been resolved. Further results will prove the accuracy of the system.

INTRODUCTION

This proof of concept project continues learning generated through a previous Innovation Funding Initiative (IFI) project (IFI1413 Portable RAFL) [1,2] to investigate the feasibility of a portable Radiometric Arc Fault Locator (RAFL) to identify the location and to facilitate the quicker resolution of arc fault incidents on the overhead line (OHL) distribution network. This project is funded via Ofgems Networks Innovation Allowance (NIA) funding mechanism [3] which aims to enable Distribution Network Operators (DNOs) to develop and trial new technologies and solutions for the betterment of the customers they serve.

Transient faults on the OHL distribution network can be costly to repair, impact on customer service and quality of supply, and contribute to increased Customer Interruptions (CIs) and Customer Minutes Lost (CML) penalties. Generally OHL networks have sufficient detection and protection capability, but limited fault location capability especially for rural networks. Permanent faults, such as grounded conductors, are in general relatively easy to identify. However, incipient or intermittent faults can be less obvious to field staff and more time consuming to locate and repair. The circuit continually trips, field staff manually reset and re-energise, but this does not address the root cause behind the faults, which are frequently frustrating, time consuming and costly to locate. Accumulated regulatory penalties resulting from the inability to quickly locate and identify these types of faults are the real consequences of an inability to establish the root cause of relatively minor, but frequent incidents.

There are a number of conventional technologies available to address this issue and although they do go some way to addressing the problem, a solution is still lacking for the accurate location of faults which would significantly improve the fault performance of DNOs and reduce the amount of interruptions and length of time customers are off supply.

The use of Fault Passage Indicators (FPIs) [4] has improved the location and identification of intermittent faults, however this technology still relies on time consuming line patrols and does not identify specific fault locations from a single trip, relying instead on narrowing down the potential fault location through the use of portable FPIs and visual network inspections. Typically these types of problematic, transient faults will trip the circuit on multiple occasions, significantly impacting on the customers served. Although FPIs in general can lead to improved network performance and quicker identification of faults when used, this is of little comfort to customers who may be interrupted on multiple occasions from the same unidentified fault.

Impedance measurement techniques [5] can be used to identify fault location on OHL networks. However the use of this method for rural distribution feeders represent a greater challenge, due in part to the diverse network topology which frequently includes multiple tee points, cable dips and spur lines, coupled with low impedance faults and inaccurate network drawings – all of which can significantly reduce the accuracy of this technology.

Whilst these technologies have helped to improve the identification of fault in a general area, potential within an isolation zone, there can still be a requirement to patrol large section of networks. Devices such as steel-work testers can be used to prove that an insulator is compromised, by supporting channel-work being proven as live. However on a substantial circuit this can be prohibitive time-wise as every pole in the section will have to be accessed and the tester physically applied.

A RAFL system will provide a means of locating incidents in a specific location following a single trip thus improving the use of resources by reducing time spent tracing faults and decreasing the amount of CI/CMLs and their associated fines.

RADIO FREQUENCY MEASUREMENTS

Introduction

During an OHL fault, the insulation of the HV conductor is compromised resulting in the rapid development of an unwanted current path, either to the ground, or between the phases, due to arcing. The initial breakdown of the insulation leads to an extremely rapid rise in current – i.e. within a timescale of < 1us - that is sufficient to generate radio-frequency (rf) radiation [6]. The magnitude of the rf radiation is influenced by the change in voltage at the point of the breakdown and the efficiency of the conduction path routes acting as antennas. Note that the rf radiation occurs well before the development of the 50 Hz follow-through current. Thus, the occurrence of an OHL arc can be detected by measuring the radiated rf signal – in essence radiometry.

An important aspect to this work is the distance over which arc fault generated rf signals can be readily detected. As a general rule, the propagation distance of rf signals is inversely proportional to the frequency: for example wifi signals (typically 2.4 GHz) will only propagate over a direct line of sight, whereas am radio signals (< 1MHz) are capable of crossing continents. Earlier work in this field [2] has shown that the VHF band (30 – 300 MHz) is the most suitable region of the rf spectrum to be used for the remote detection of arcing faults. At the lower end of this band - < 100 MHz – radio wave propagation 'follows' the contours of earth's surface allowing detection to be performed without direct line of sight to the fault point. This is an essential requirement of a radiometric fault location system where the OHL network may be situated in hilly terrain.

Propagation Tests

A knowledge of the magnitude of the rf signal radiated from the fault site is needed to estimate over what distance the arc may be reliably detected. Consequently, a test was set up using an 11 kV normally-open-point, pole-mounted disconnector which was operated to generate arc induced rf radiation. The radiated signal was measured from a vehicle equipped with a roof-mounted 1.5m monopole antenna connected to a 300 MHz bandwidth oscilloscope. With the vehicle adjacent to the pole (11 m distant), the operation of the disconnector produced a signal as shown in Figure 1; Figure 2 shows the same effect at a distance of 162 m.

It can be seen that the act of closing the disconnector produces an impulsive 'spike' in the signal measured by the oscilloscope. The impulsive spike signals were similar, but not identical, for repeated operation of the disconnector; there was no discernible difference between opening or closing operations. A frequency spectrum analysis of the impulsive waveform of Figure 1 shows that the arc signal is prevalent between 30 – 120 MHz with a peak of 54 MHz. At a distance of 668 m between the vehicle and the disconnector, it was impossible to detect the signal above the background noise level. SCADA data from the network revealed that the change in current due to the operation of the disconnector was ~6 A, from which it is estimated that the voltage difference across the terminals was of the order of several hundred volts.

Although the propagation distance during the test was very small – in the range between 162 m and 668 m - the voltage change which caused the arc was at least an order of magnitude smaller than would be expected during a genuine arc fault. Consequently, it is hypothesised that genuine arcing faults will radiate signals that can be detected at distances of several km.

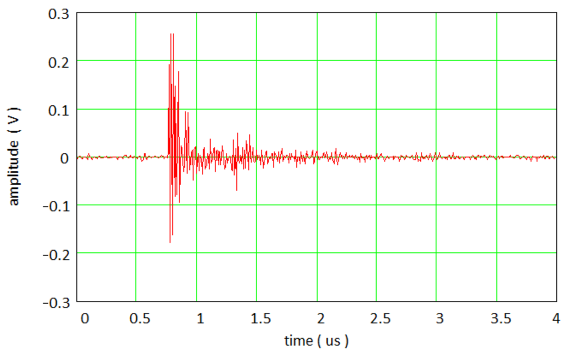

Figure 1 Radiometric switching transient at 11 m

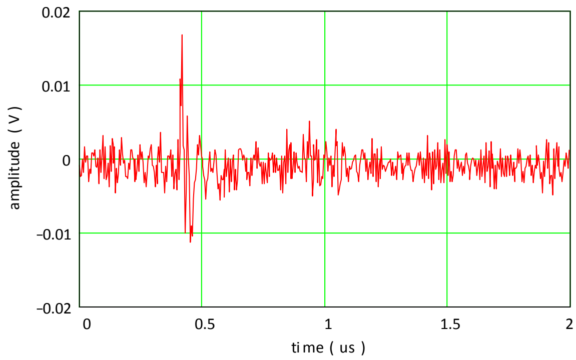

Figure 2 Radiometric switching transient at 162 m

RADIOMETRIC FAULT LOCATION SYSTEM

Fault location

The location of faults using the radiometric approach relies on accurate timing of the arrival of the fault induced arcing signal at several receiving points which are geographically dispersed around the OHL network. When an arcing fault occurs, the radiated signal travels outwards from the fault at the speed of light. By calculating the differences in the arrival times from the receiving stations, the position of the fault point can be calculated mathematically, using a similar system used for lightning location systems [7]. Figure 3 illustrates this effect using 3 receiving stations. The black lines represent the loci of all possible positions of the fault point for a given arrival time difference between 2 of the receiving stations – mathematically these curves are hyperbolae. The intersections of the hyperbolae reveal the fault location. This information will be provided to the utility field staff via a smart phone application.

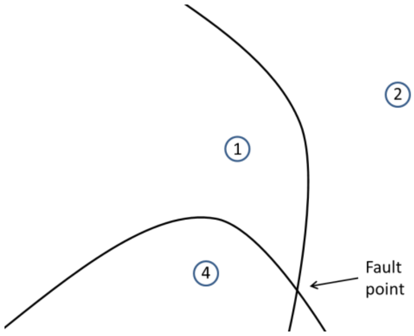

Figure 3 Intersection of hyperbolae reveals fault point

The timing accuracy is derived from the use of GPS technology. Typical GPS equipment can produce timing references which are accurate to ~100 ns: this equates to a free-space distance of 30 m at the speed of light.

Figure 4 shows the arrangement of the trial system that was conducted on a SPEN 11 kV network to the east of Edinburgh. Historically, this circuit has had a greater than average number of fault incidents. The circles numbered 1 – 4 are the receiving stations whereas the red lines represent the OHL network. The grey shape represents the operating area of the system if arcing faults can be detected at a distance of 5 km. The shortest distance between receiving stations 2.34 km (1-2); the longest distance is 4.06 km (1-3). The use of 4 receiving stations was used to avoid ambiguities in the intersection the hyperbolae, and to cope with inevitable errors in the arrival time difference evaluation. The locations of the receiving stations were influenced by the OHL network and the availability of both pole-mounted transformers and good 3G coverage.

Receiving station hardware

The hardware outline of the receiving stations is shown in Figure 5. The hardware is powered from 230 Vac from a pole mount transformer and incorporates a surge arrester to protect against transients, and a battery backed-up dc power supply to allow 30 minutes of operation if the circuit trips. The rf signal is detected using a 1.5 m monopole antenna which bandlimited in the VHF band and amplified before being digitised at 94 MSps. The accuracy of the sampling frequency is controlled by a GPS steered oscillator. A single board computer runs a bespoke monitoring program under Windows to control the rf data acquisition, detect the impulsive fault event, calculate the accurate timestamp and upload this to a server via a 3G modem. Similar to an oscilloscope, an impulsive event is detected by a triggering event, the level of which is manually set above the background noise level.

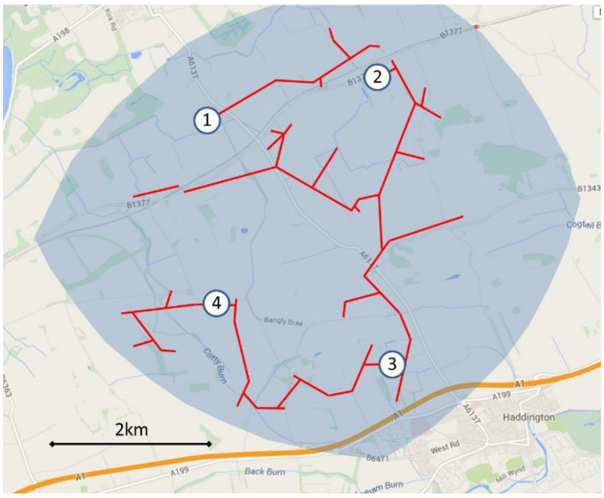

Figure 4 Trial system

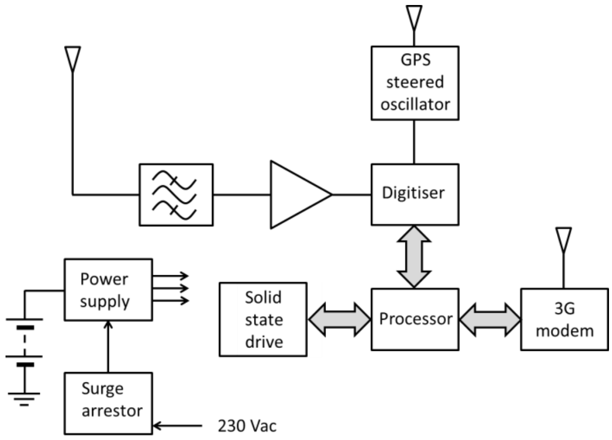

Figure 5 Receiving station hardware

Figure 6 shows a photograph of a receiving station. The hardware is contained within an IP66 stainless-steel cabinet which is fixed onto the pole, above the anti-climb guard, using an earthed steel bracket. The GPS and arc fault rf monitoring (main) antennas are fitted to the top of the cabinet, the 3G antenna is fitted to the bottom. A plastic stabilising bracket is fitted towards the top of the main antenna, which is relatively flexible. A single phase supply from the transformer LV is brought in via cable glands on the bottom of the cabinet.

Once fitted, the receiving stations require no regular attention; any adjustments to the operation of the hardware are made through software adjustments via remote login sessions over the 3G connection.

Figure 6 Receiving station 1 mounted on OHL pole

Trial

The system was installed and commissioned in December 2015 and is still active. To date, the following issues have occurred:

Local impulsive noise

Arcing faults are not the only source of impulsive noise that can cause the receiving stations to trigger. One of the receiving stations was located close to an electric cattle fence which artificially increased the number of impulsive triggers made per day. Similarly, although mostly rural in nature, stations close to residential buildings show elevated levels of triggers caused by the operation of thermostats etc. Although unwanted, the presence of these types of impulsive noise is not detrimental to the operation of the system since, statistically the probability of a single, local impulsive noise event causing an erroneous fault location is extremely low. Furthermore, each receiving station is capable of immediately retriggering, so local events cannot prevent the system from detecting genuine arcing fault signals.

Fuse failure

On one occasion, the internal cabinet fuse in the neutral connection explosively failed, rendering the station inoperative. No other fuses operated. Despite a surprising level of black charring within the fuse holder, no damage to the electronics occurred and the station was promptly returned to service. The cause of the failure remains unknown; no other incidents of this type have occurred.

GPS lockouts

Experience showed that all of the stations experienced regular lockouts of the GPS, despite rigorous factory testing prior to installation. Typically, a station would lose the GPS signal for several hours per day. By far this was the biggest problem experienced during the trial since the software was programmed to wait for the GPS lock before recording data: as a result several fault incidents were missed due to this. Eventually, this problem was traced to a batch of defective cables which were replaced in each station in September 2016: no further GPS problems have been experienced since.

3G modem problems

Any interruption in the operation of the 3G modem jeopardises the operation of the system. Due to the inherent nature of 3G networks – especially in the rural area of the trial - full service is rarely achieved and dropouts of several hours are the norm. However, it was noticed that 2 of the stations experienced dropouts of several days, in one case a dropout of nearly 3 weeks was experienced. Despite the perceived highly reliability of the modems, to alleviate the problem the software was adjusted to recycle the modem power if internet connections could not be made for 2 hours: this has dramatically improved the connection uptime across the system.

RESULTS TO DATE

Despite the historical unreliability of the trial OHL network, there have been relatively few faults during the period of the trial. None of these have been detected by the system, due either to the issues described earlier, or due to incorrect settings in the triggering levels. Figure 8 shows the typical incidence of impulsive triggers on 3 of the receiving stations – it can be seen that the pattern of triggering activity differs between the stations.

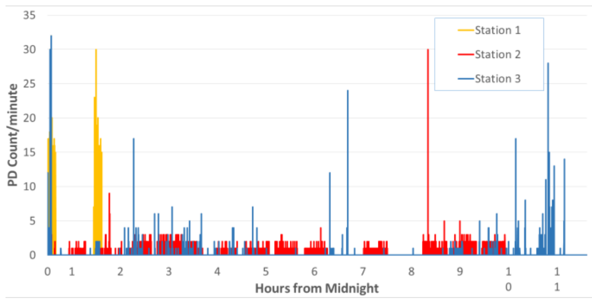

Figure 8 Triggering activity on 11/12/16 am.

Typical impulsive signals recorded by receiving stations 1 and 2 are shown in Figure 9. Although the timestamps are similar, there is a difference of 67.1 µs, which corresponds to a distance of 20.13 km at the speed of light. Since this greatly exceeds the distance between the stations of 2.34 km, these two signals are not related. Events like this are rare – the 67.1 µs difference in the signals is the closest match recorded by the system to date.

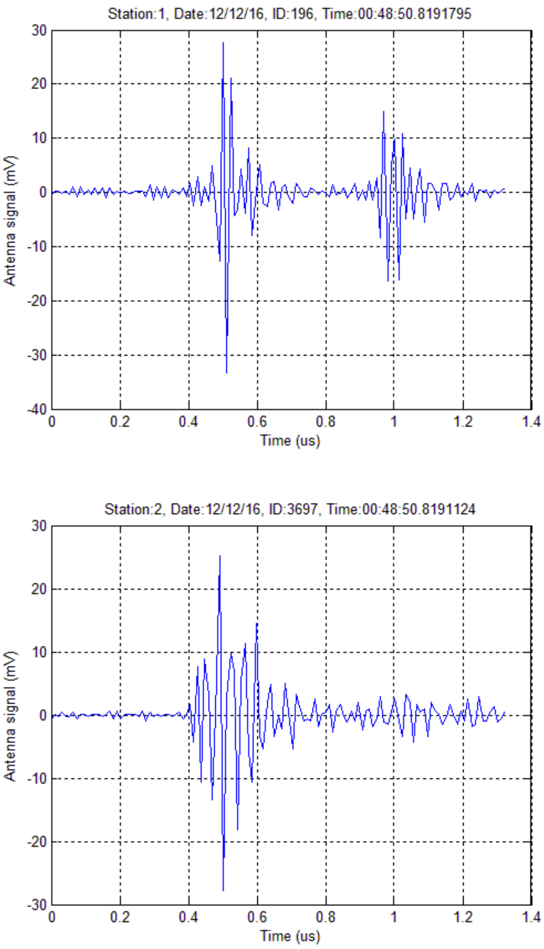

Figure 9 Typical impulsive signals, stations 1 and 2

Data uploaded to the server is scanned for time-delays in the range 8 – 13 us which correspond to the speed of light propagation times between stations.

CONCLUSION

A trial radiometric fault location system for locating arcing faults on distribution OHL circuits has been developed. Early difficulties experienced since the system was commissioned in December 2015 have been resolved and the system is presently stable and operational. Recorded data demonstrates that the system is responsive to impulsive type rf signals, and propagation tests indicate that location should be possible over a range of several km. Further fault events are awaited to prove the accuracy of the system.

The advantages of using a radiometric fault location system include:

- No OHL network data is required for the operation of the system, excepting the geographical route of the circuit.
- The receiving stations do not need any electrical interface to the utility infrastructure.
- The system can be left to monitor over extended time periods – particularly useful where the interval of intermittent faults is measured in days.
- Immune to the presence of non-fault related sources of impulsive noise.

Acknowledgments

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