

ALARM - Automatic Location of Arc-faults through Remote Monitoring

Results and Learning from the Phase One Monitoring Period

September 2020

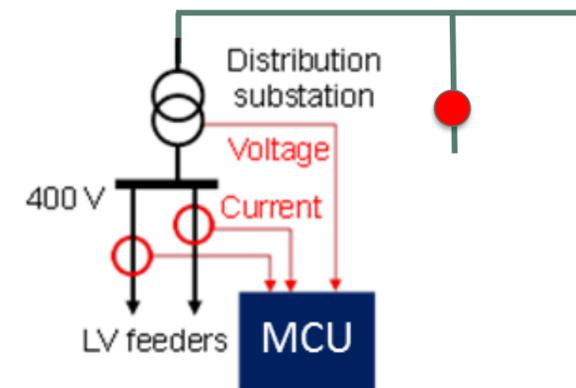


Contents

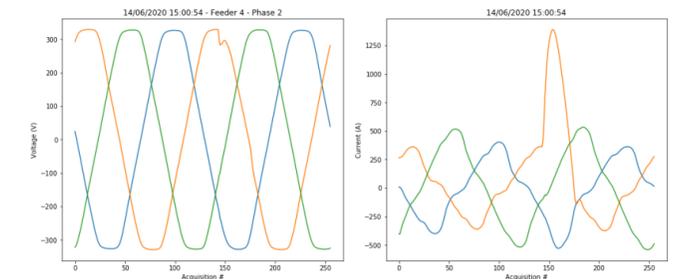
1. [Executive Summary](#)
2. [Equipment and installation](#)
3. [ALARM Phase 1 Overview of Findings](#)
4. [Key Learning Details](#)
5. Individual Feeder Analysis
 - i. [Victoria Road - 4](#)
 - ii. [Fairefield Crescent - 4](#)
 - iii. [Union Street – 4](#)
 - iv. [Ravenstone Road - 1](#)
 - v. [Gulson Road - 2](#)
 - vi. [Gulson Road - 1](#)
 5. Individual Feeder Analysis - continued
 - vii. [Nutfield Road - 2](#)
 - viii. [Ravenstone Road - 2](#)
 - ix. [Rosemary Hill - 2](#)
 - x. [The Grange Ashby - 1](#)
 - xi. [Nottingham Road - 2](#)
 - xii. [Seagrave Road - 3](#)
 - xiii. [Nutfield Road – 4](#)

Exec Summary – Introduction

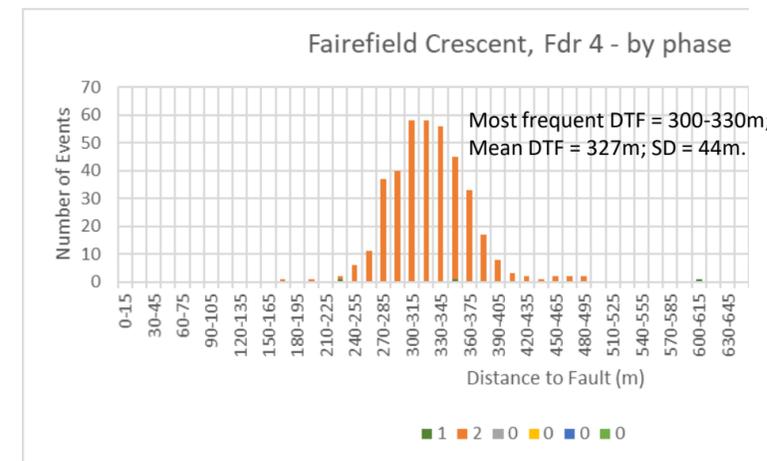
- The project is demonstrating a technically alternative and lower cost approach to identifying the location of transient LV (pecking) faults while the cable is in normal service, before they are presenting multiple fuse operations (and associated customer interruptions), and also before they have developed to a permanent fault requiring immediate location and repair.
- Installed monitors capture voltage and current waveforms from LV feeders when pre-set triggers are activated. The captured waveforms are then forwarded via a GPRS data connection to a data repository. From there, the captured data is processed and impedance values for the monitored network at the time of the event are estimated. This is used as the lead indicator to establish a distance to fault (DTF) estimate. DTF estimates are established for all events conforming to a “pecking fault” characteristic, and a DTF assessment for a feeder is developed from this overall result set. The project’s original scope than manually translates DTF to network position.
- The project will achieve its aims by using monitoring devices at 25 selected sites in the East Midlands region, and assessing the effectiveness of the associated distance-to-fault calculation results on real networks in normal service.
- The partner for this project is Lucy Electric GridKey.
- The project will run from Sep 2019 – Apr 2022 with two distinct phases, and a budget of £493k.



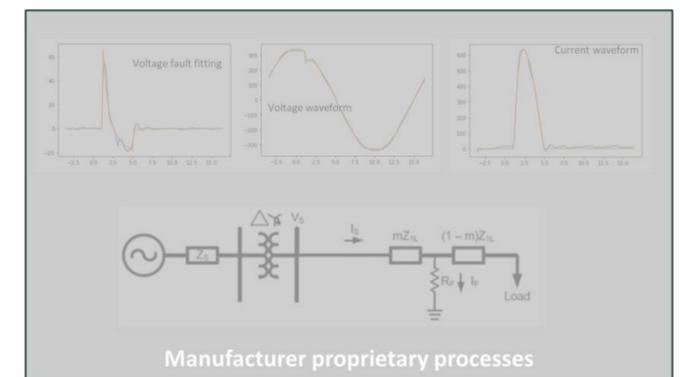
Monitoring



Data capture



DTF assessment



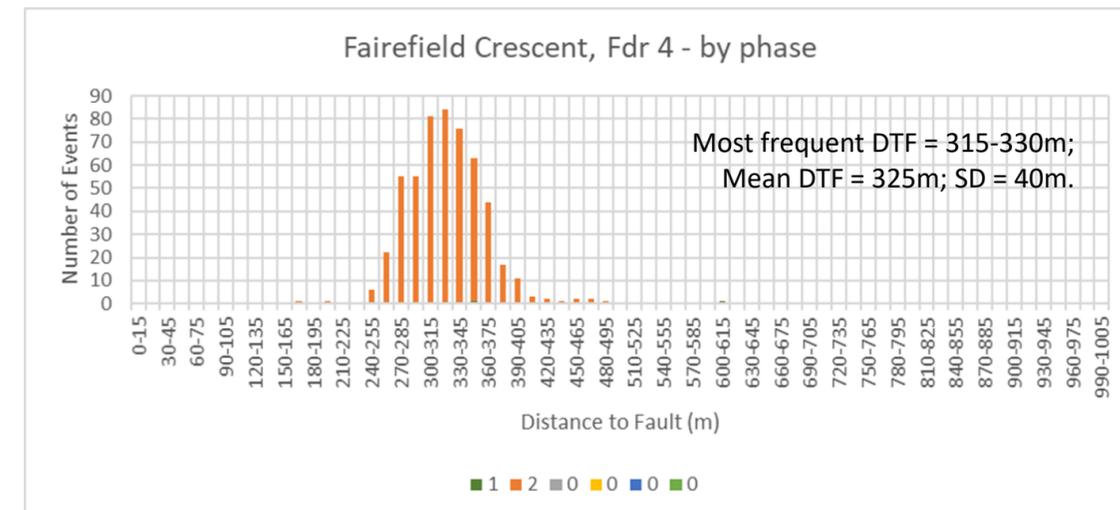
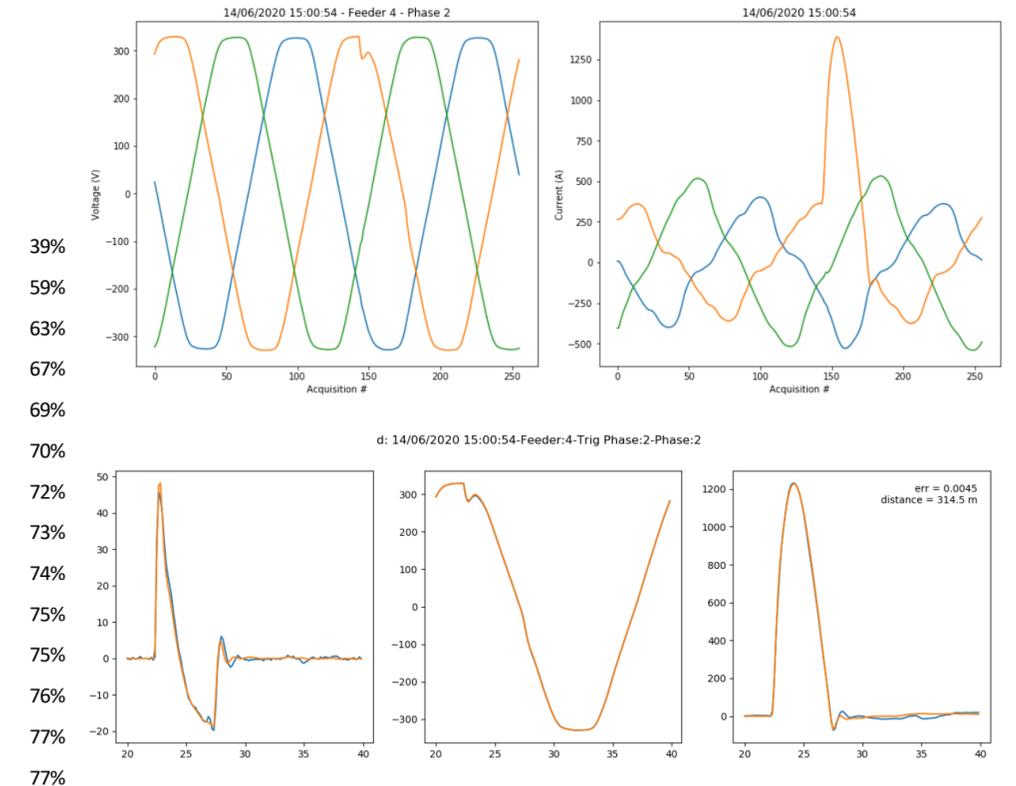
Data processing

Exec Summary - Overview

- The Phase One deployed equipment has successfully captured “pecking” events on all the 26 deployed monitors, consistent with capability expectations of the Phase One installed equipment.
- 7,990 pecking events (including single phase and phase-phase events) have been analysed. 2,647 events have been found to give be good quality fits, compared to the expected electrical behaviour of a feeder with a pecking fault.
- 77% of these 2,647 events from ~six months of monitoring have occurred on 13 of the monitored feeders, these feeders all have 20 or more events per feeder.
- The analysis process for these events has been modified based on collected field data, improving the extent to which the model agrees with measured data.
- Whilst the individual “fits” for events appear good, variation exists in the resulting event DTFs. For three feeders, the histogram of events vs distance could reasonably be interpreted (Victoria Road-4, Fairefield-4, and Union Street-4) These three feeders alone account for 65% of the higher quality assessed events. DTF indications are also emerging for around 10 further feeders, and cautious indications have been offered to local teams for some of these feeders on a “best information available” basis.
- Cross-checks on location for Victoria Road – 4 and Fairefield - 4 are currently underway (this activity was originally expected in Phase 2), to provide additional data and learning.
- Phase One has achieved its fundamental aims of proving the data collection and analysis concept, and informing the development of assessment processes that will be more fully tested in Phase Two of the project, when enhanced hardware becomes available as planned.

Result inclusion filter TRUE

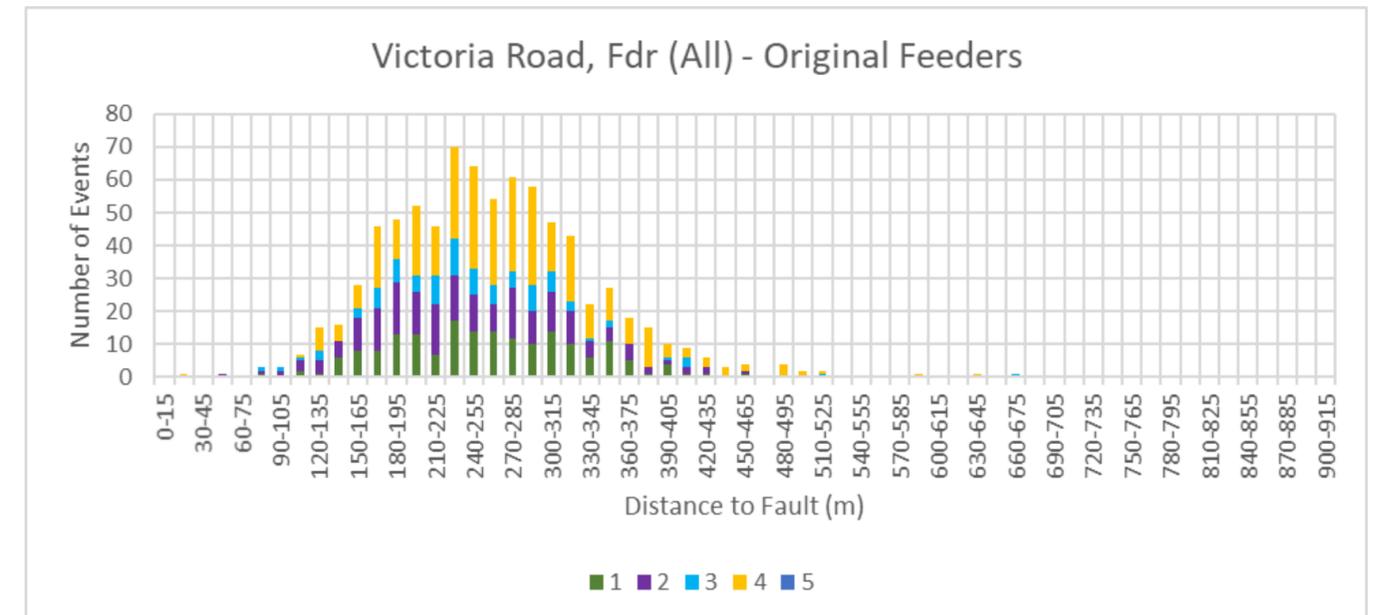
Site	Count of assessed events	
Victoria Road - 4	1040	39%
Fairefield Crescent - 4	528	59%
Union Street - 4	110	63%
Ravenstone Road - 1	89	67%
Gulson Road - 2	50	69%
Gulson Road - 1	42	70%
Nutfield Road - 2	37	72%
Ravenstone Road - 2	30	73%
Rosemary Hill - 2	27	74%
The Grange Ashby - 1	23	75%
Nottingham Road - 2	22	75%
Seagrave Road - 3	20	76%
Nutfield Road - 4	20	77%
Grand Total	2038	77%



Exec Summary – Key Learning

- One significant issue has been identified with the MCU firmware, where mis-identification of the feeder associated with the event was occurring. Firmware has been revised, and a review of existing data has been undertaken to provide a corrected feeder identification where possible. It is concluded that despite the issue, the resulting dataset (including corrected indications) is still credible and reliable.
- Current hardware captures a relatively modest amount of data around each event (single cycle of data before and after the initiation of an event). This limits understanding of suspected subsequent cycle events. Phase 2 hardware will capture higher resolution waveforms per initiating event.
- The current system implements a “lock-out” period post waveform acquisition of 1 minute. During this time no further waveform acquisition occurs. The consequence of this is that events could occur during this lock-out window, but not be captured. The revised Phase 2 hardware is expected to reduce this.
- A small number of other firmware issues and irregularities have been identified (e.g. captured waveforms not re-queued for transmission during periods of low GSM signal strength and consequentially lost; a relatively small number of time periods with missing periodic data). It is expected that changes to firmware with Phase 2 will improve this.
- Installation of flexi-sensors around fuse handles requires precise placement. Contact with a hot fuse can damage the sensor and apply phase voltages to the sensor inputs to the MCU, damaging the MCU.
- The relatively wide range seen within DTF results for any specific feeder may be due to limitations of the passive acquisition hardware for Phase 1 of the project. Phase 2 will have improved waveform acquisition hardware, and a key point of further learning will be the extent to which this improved hardware (e.g. high sampling rate, improved upstream impedance assessment etc.) reduces the range seen in results.

Pre-correction Data



Pre-correction Data

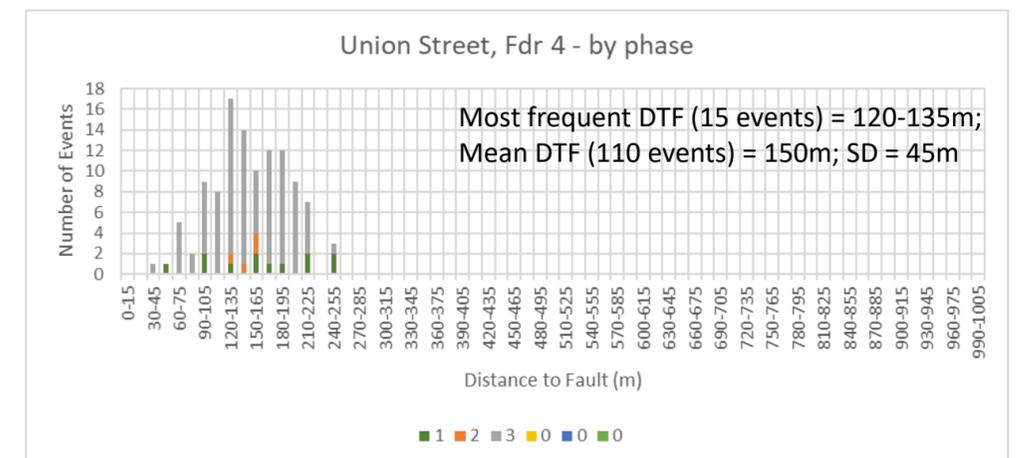
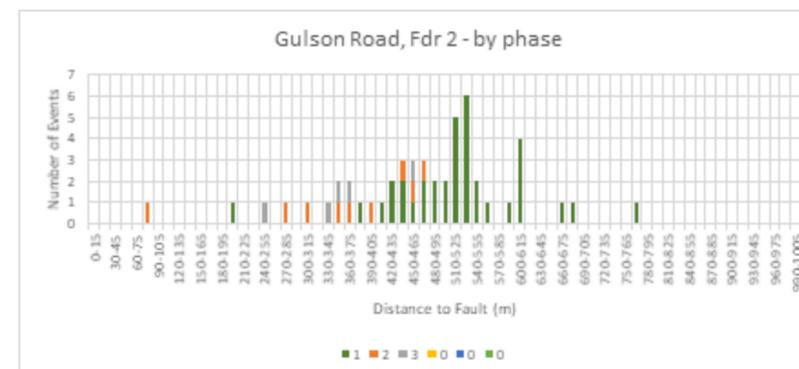
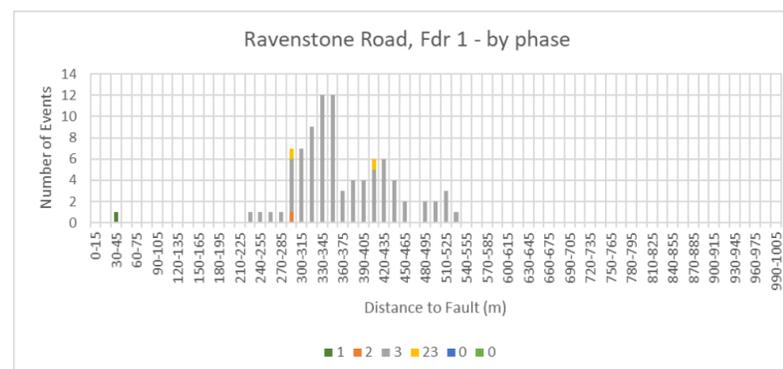
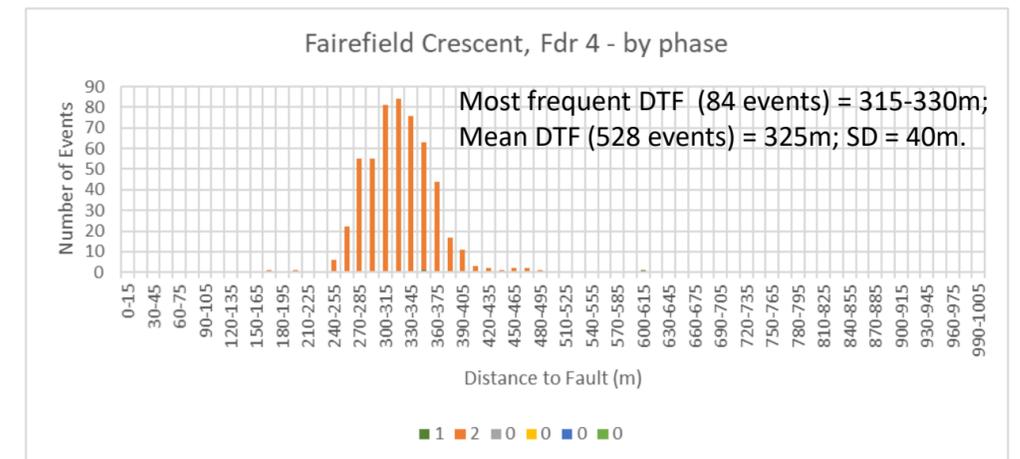
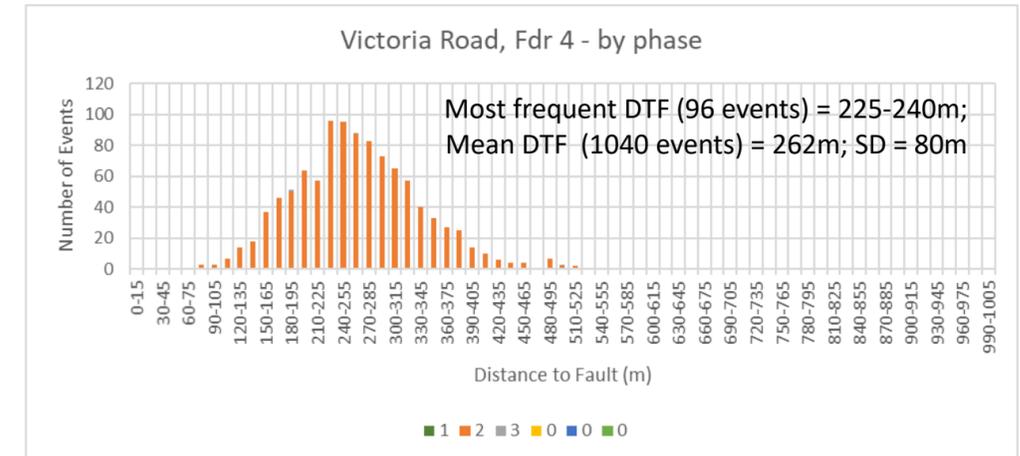
Site	Victoria Road
Result inclusion filter	TRUE
Feeder	Count of Events
1	181
2	185
3	92
4	332
Grand Total	790

Post-correction Data

Site	Victoria Road
Result inclusion filter	TRUE
Reviewed Feeder	Count of Events
1	37
2	46
3	20
4	687
Grand Total	790

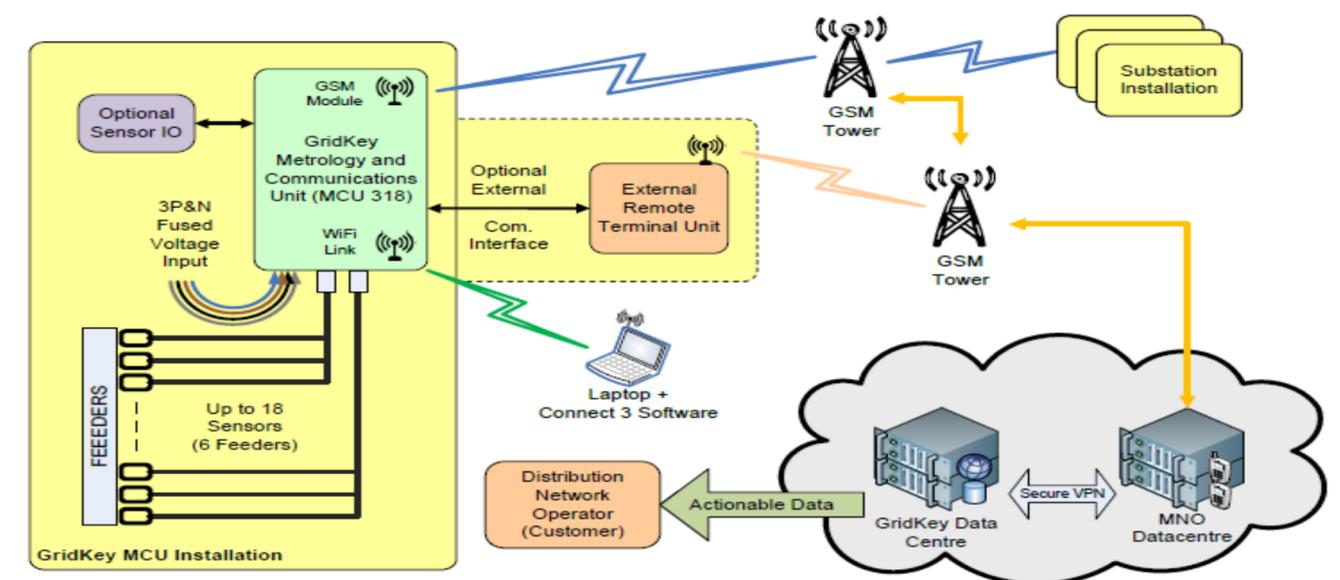
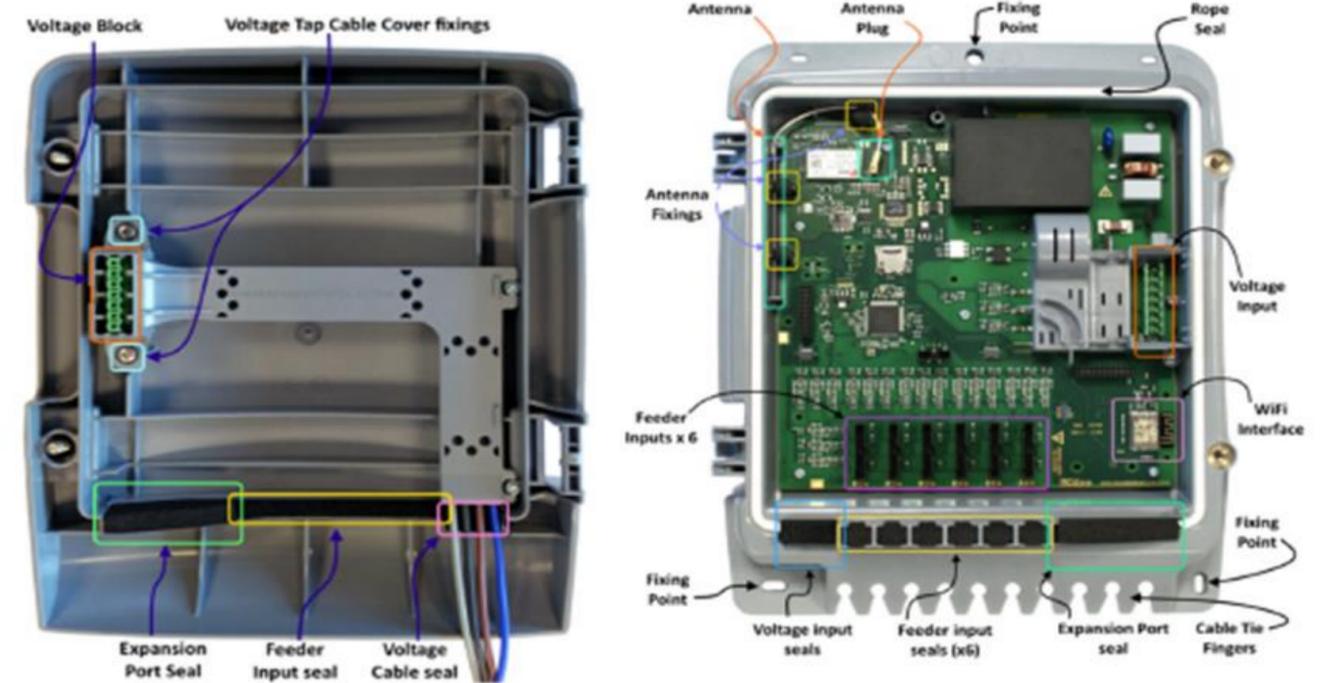
Exec Summary – Headline Feeders

- Three feeders have accumulated 63% of all higher quality events (events with a better fit of actual results to modelled results).
- The DTF result sets for these feeders are now sufficiently credible that cross-checks of the indicated locations will be progressed starting with Victoria Road–4.
- Not all feeders are currently providing such clear indications. In part this is perhaps due to the volume of incidents, and probably due to there being more to understand about events on these feeders. Examples of this are Ravenstone Road Feeders 1 & 2.
- This cross-check activity will initially establish practical details of how non-intrusive validation of results can be achieved within the project context (originally this activity was expected as part of project Phase 2).
- Ultimately the projects aspiration is to physically replace identified components to demonstrate the accuracy of the location process.



Equipment

- The ALARM project is based on the Lucy Electric GridKey MCU318 device.
- The GridKey MCU318 is a continuous monitoring solution for low voltage (LV) networks. It consists of a number of current sensors on each feeder together with common voltage taps, connected to a Metrology and Communications Unit (MCU) which processes the sensor data and generates and logs substation loading and condition parameters. This information is relayed to a cloud based GridKey Data Centre where the data is securely stored, analysed and displayed.
- For Phase One of the project, the MCU318 units have been fitted with an additional passive wide dynamic range attenuator to allow complete fault current waveforms to be captured without clipping. During Phase Two of the project, these passive attenuators will be field upgraded with an active plug-in module to capture a higher resolution unclipped current waveforms



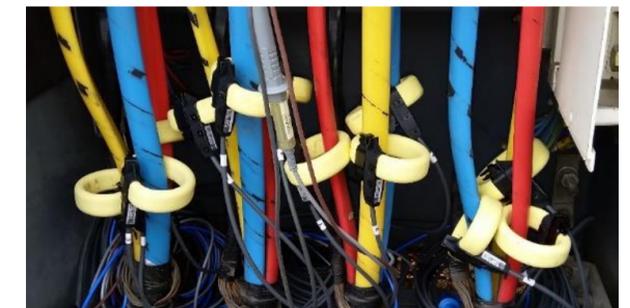
Monitoring Sites

- 25 monitoring sites have been selected across WPD's East Midlands region. Sites have been selected through assessment of previous fault history and in consultation with local field teams
- The intention has been to locate the monitors at sites that have had fuse operations, to test the projects second objective and to mitigating an initial project risk of monitoring at sites that don't provide useful data. There was also the recognition that monitoring at sites where a repair is completed (either just before deployment or following deployment) was also a potential issue, likely to lead to an absence of useful captured data. To date, a monitor has been moved from one site due to a fault repair post initial deployment.



Installation and Commissioning

- Installation of the monitors has been undertaken by WPD Network Service personnel who ordinarily work in the areas that the monitors have been installed in. This has been carried out according to WPD's Standard Technique SP2KD/2, and all other normal working practices.
- The monitors have been installed in a range of LV board arrangements.
- Commissioning of the monitors principally consists of ensuring that correct alignment of phase current measurements with phase voltage measurements (from installation), confirming remote data connection, and applying appropriate substation and feeder names, plus a geographic reference for the site. This is initially checked using a Windows based configuration tool (though an Android version is also available). The type of current sensor used (i.e. SlimSense or FlexiSense) is automatically detected by the MCU.
- Remote collection of routine data measurement was confirmed by checking receipt of data by the GridKey Data Centre.



Captured Events

- Events have been captured from 26 monitoring devices installed at 25 sites (one site has two monitors), providing surveillance of 110 LV feeder.
- Surveillance was fully in place from 06/03/2020, with some units active from 24/02/2020.
- 7,990 events have been assessed, with assessed events occurring at all the installed monitors.
- 2,647 events have a “higher quality” assessment result¹.
- 77% of these higher quality results occur on 13 feeders at 11 Sites. Each of these feeders has 20 or more captured events.
- This presentation focuses on these 13 feeders.

Result inclusion filter (All)	
Site	Count of assessed events
Victoria Road	2287
Ravenstone Road	835
Fairefield Crescent	743
Boundary Road	616
Nutfield Road	440
Seagrave Road	384
St Johns St NP	317
Union Street	293
Nottingham Road	292
Gulson Road	245
Montreal Road	213
White Street Flyover	173
Hazel Close	168
Corporation Street Tx2	165
Rosemary Hill	159
Westfield Rd Bletchley	103
College Fields Wolverton	101
Quaker Rd Sileby	100
Forest St Shepshed	88
Meridian West Mattel	68
The Grange Ashby	66
Warren Green	33
Corporation Street TX1	30
Auburn Road	27
Market Hall Wolverton	26
Templar Av School	18
Grand Total	7990

Result inclusion filter TRUE	
Site	Count of assessed events
Victoria Road	1363
Fairefield Crescent	545
Union Street	130
Gulson Road	121
Ravenstone Road	120
Nutfield Road	73
Rosemary Hill	35
Seagrave Road	35
Nottingham Road	34
The Grange Ashby	24
Boundary Road	22
Corporation Street Tx2	22
Montreal Road	17
Westfield Rd Bletchley	16
White Street Flyover	13
Hazel Close	12
Quaker Rd Sileby	12
Forest St Shepshed	11
Market Hall Wolverton	9
St Johns St NP	8
Auburn Road	6
Warren Green	6
Corporation Street TX1	5
College Fields Wolverton	3
Meridian West Mattel	3
Templar Av School	2
Grand Total	2647

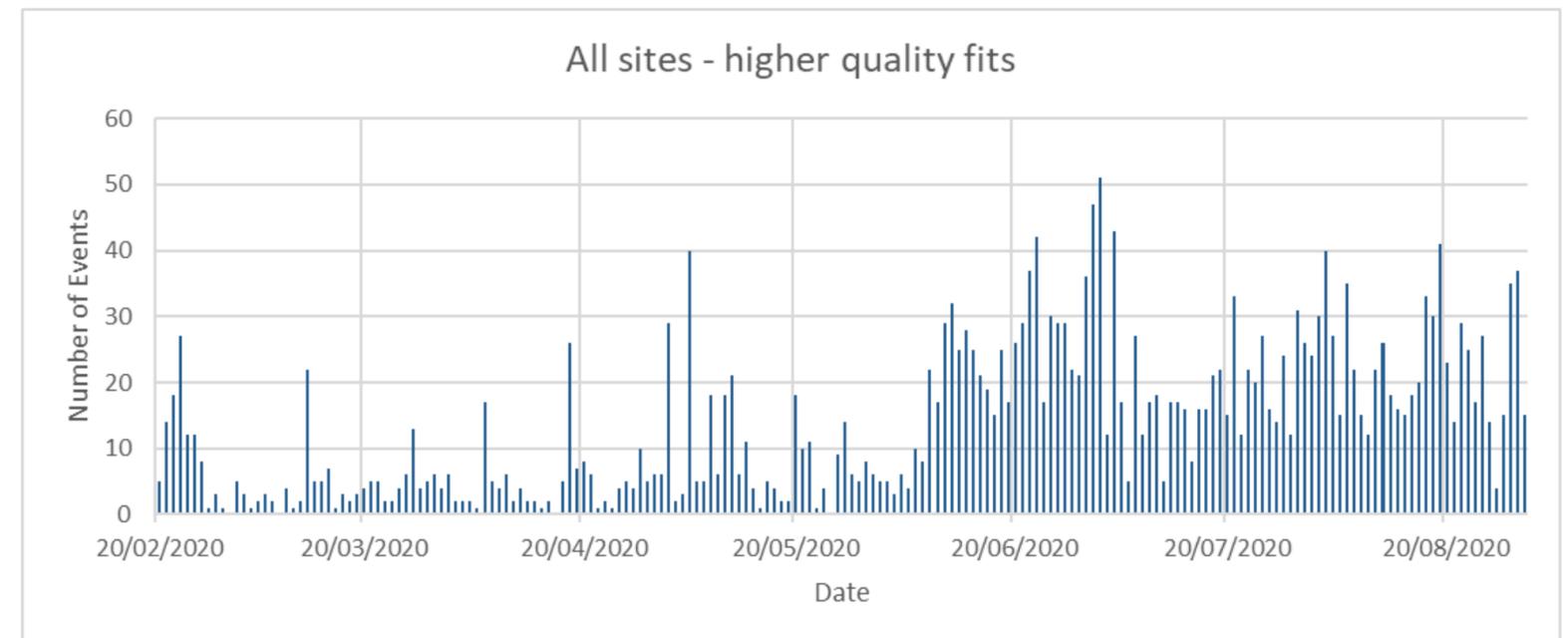
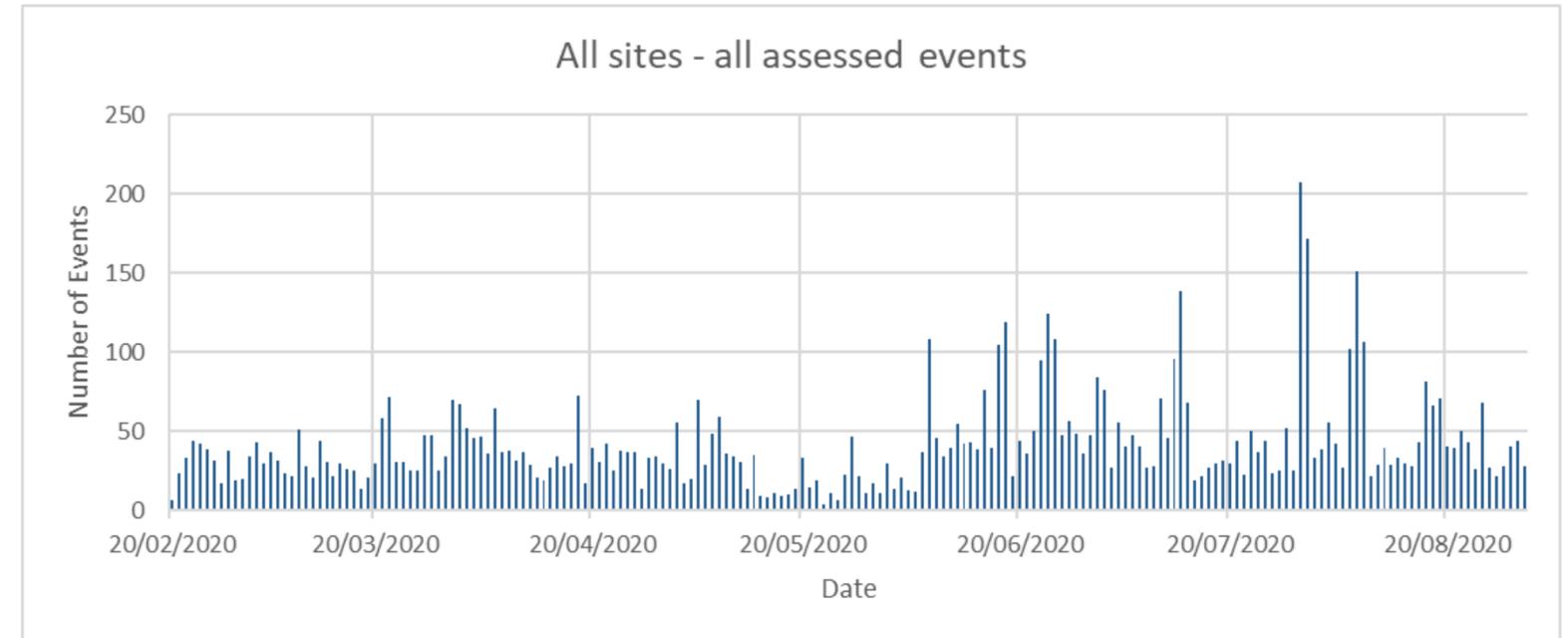
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Notes:

1. A “higher quality” assessment falls within limits set for fitting error, arc voltage value and DTF distance
2. Gulson Road -2 in the above table relates to WPD Feeder 3.

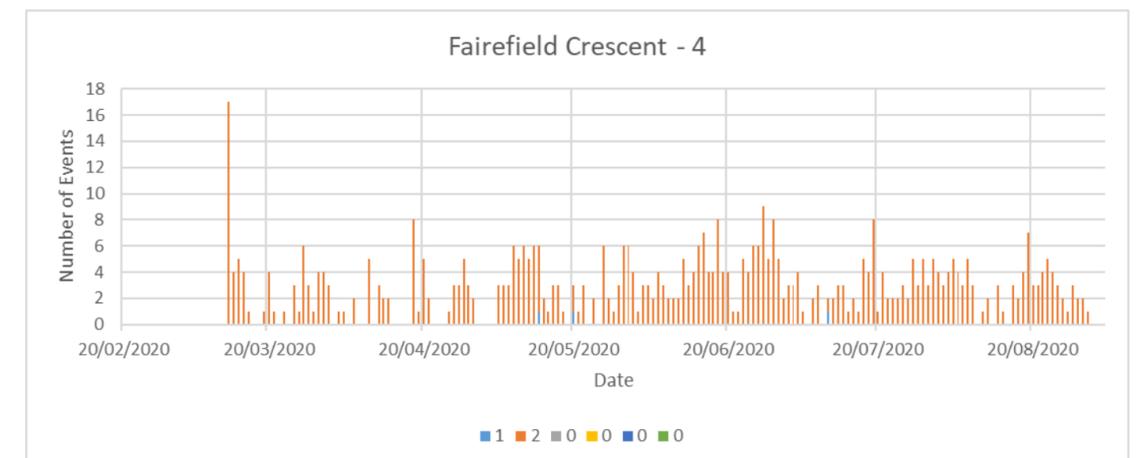
Events over time – 1

- Events have occurred at different daily rates over the monitoring period to date.
- Project focus is on those events that show a high degree of conformance to GridKey modelled pecking faults (lower chart) – higher quality fits. Note the different vertical axis scales.
- Further learning opportunities may exist to initially examine those events that don't conform to the expected pecking fault characteristic.



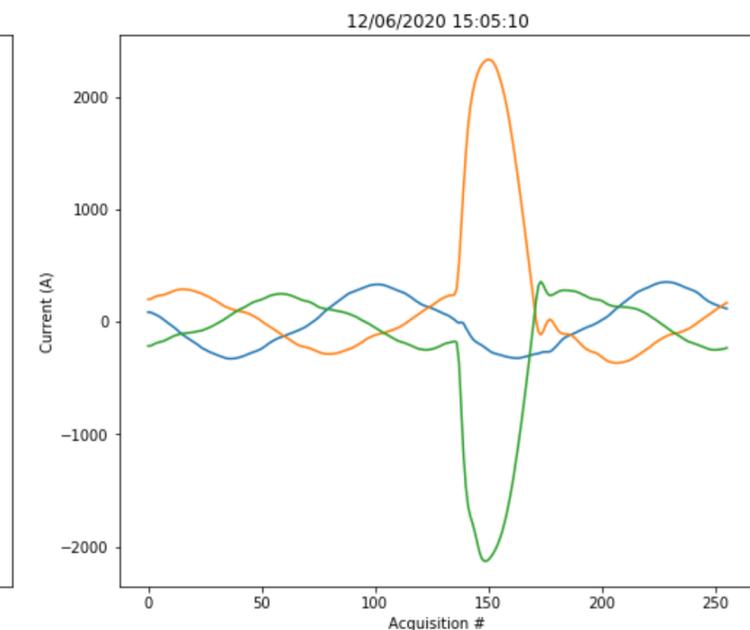
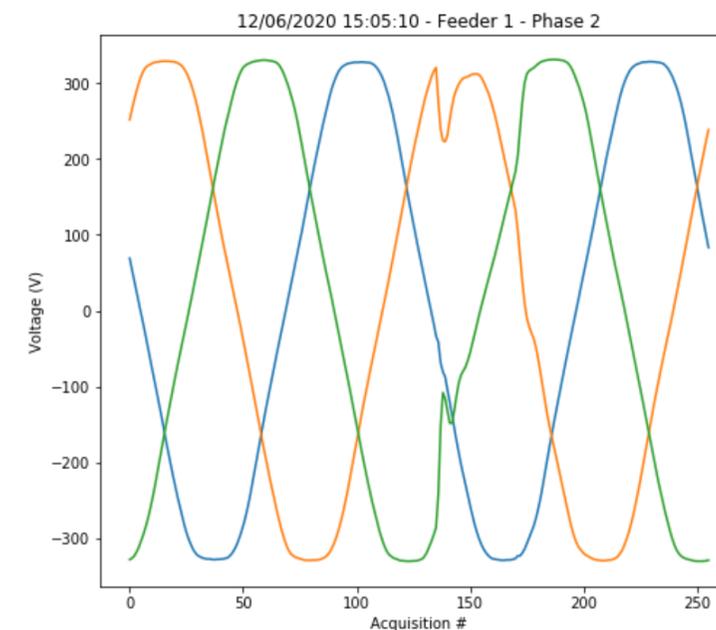
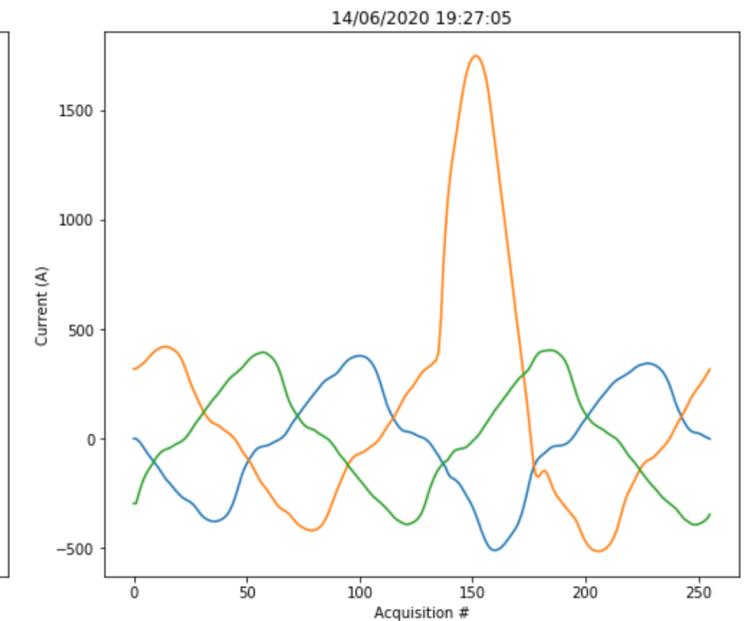
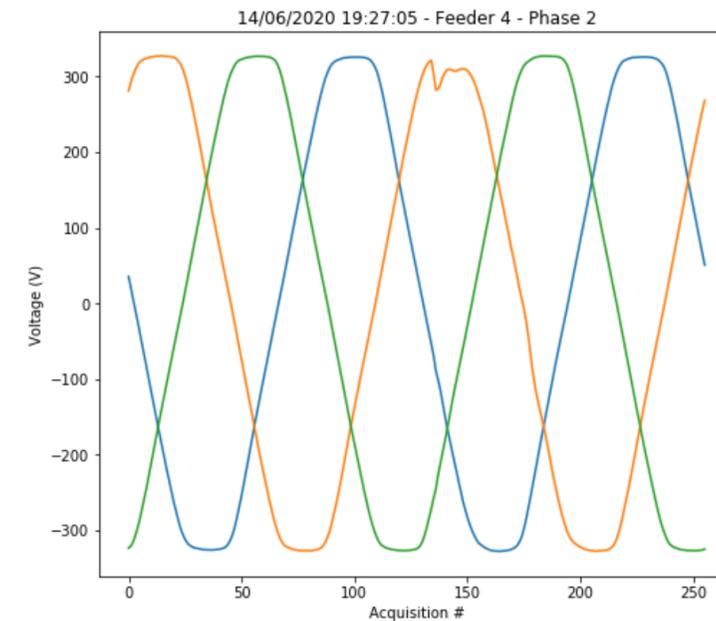
Events over time - 2

- Variations are seen in the level and type of activity for individual feeders
- Victoria Rd – 4 (feeder with the most events) had seen one higher quality event to 06/06/2020 (Note: lower quality events were occurring prior to this, though at a lower rate).
- Fairefield Crescent – 4 (feeder with the second most higher-quality events) has seen relatively consistent levels of higher quality activity.
- Ravenstone Road – 1 (feeder with the fourth most events) has seen a very different pattern of events, a high number of events February, and virtually none since.



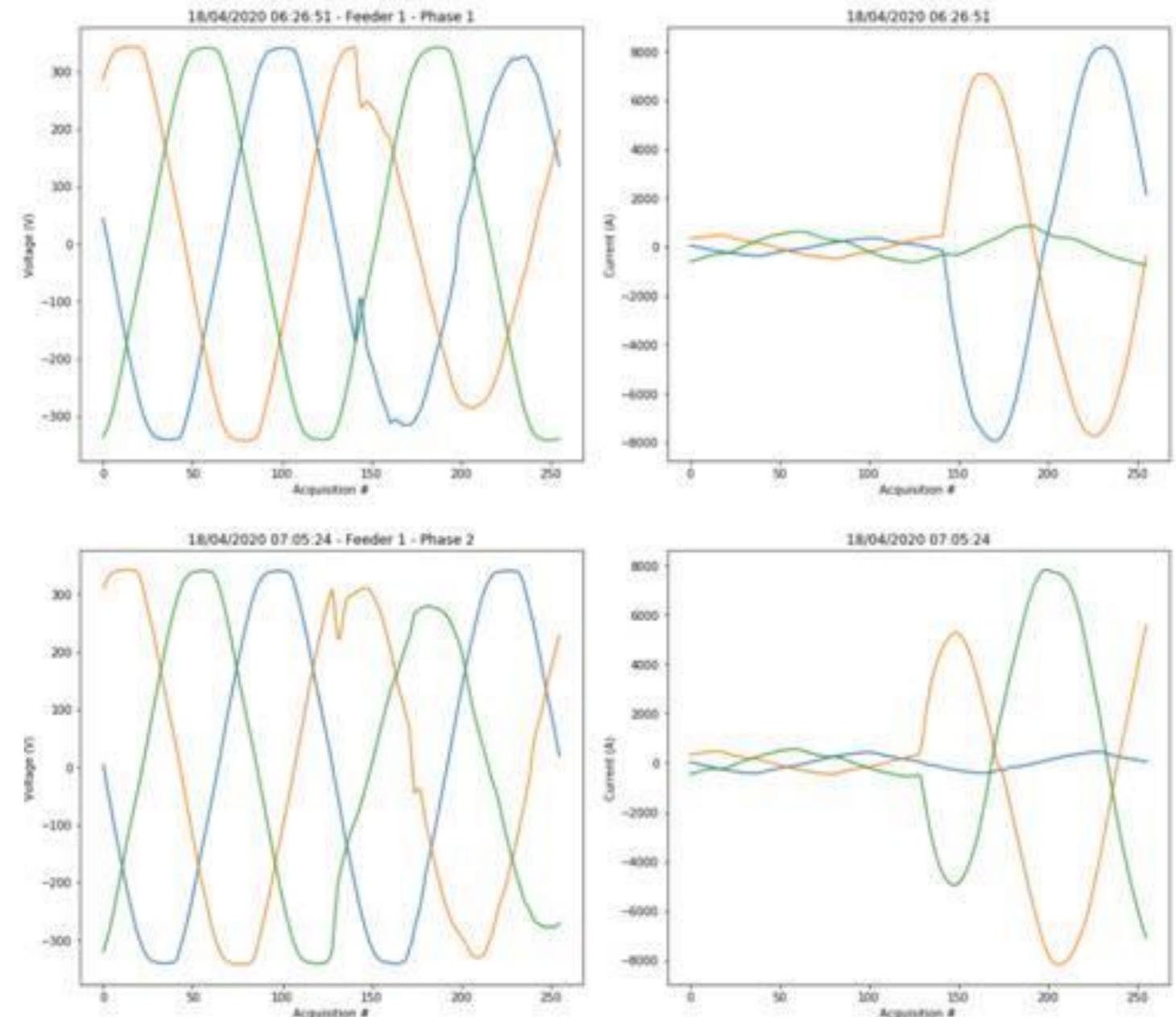
Typical Captured Waveforms

- Two types of event have been assessed.
- The upper chart shows a typical single phase conductor event (Fairefield Crescent - 4)
- The lower chart shows an event involving two phase conductors
- Both events see voltage disturbances corresponding to the triggering current events
- 98.3% of the events have involved a single phase conductor, and 1.7% have involved two phase conductors.



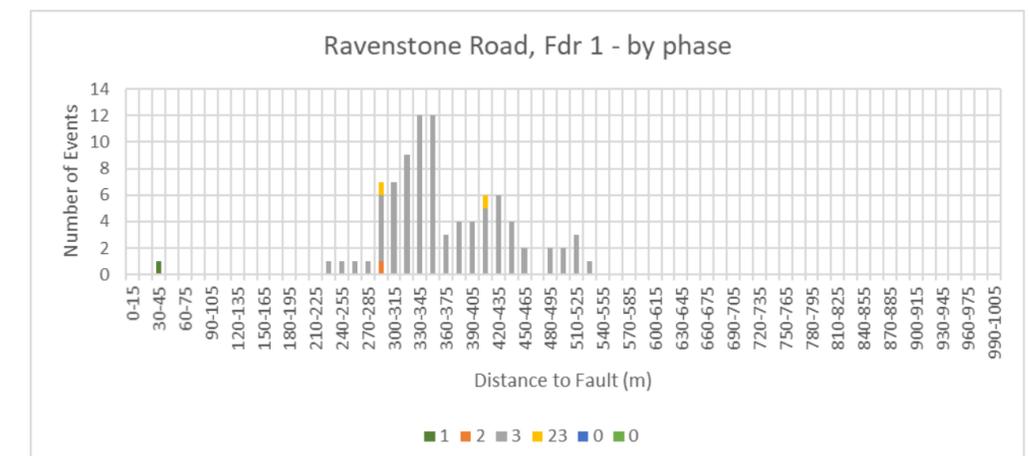
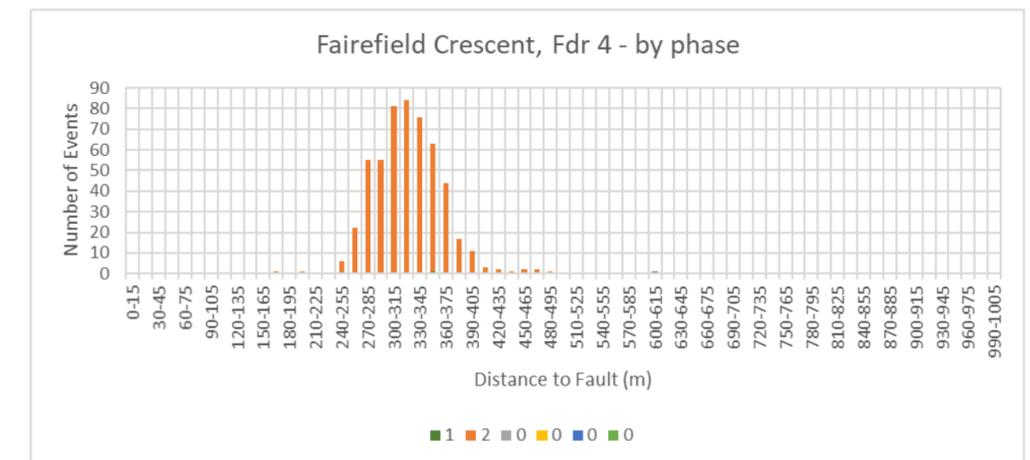
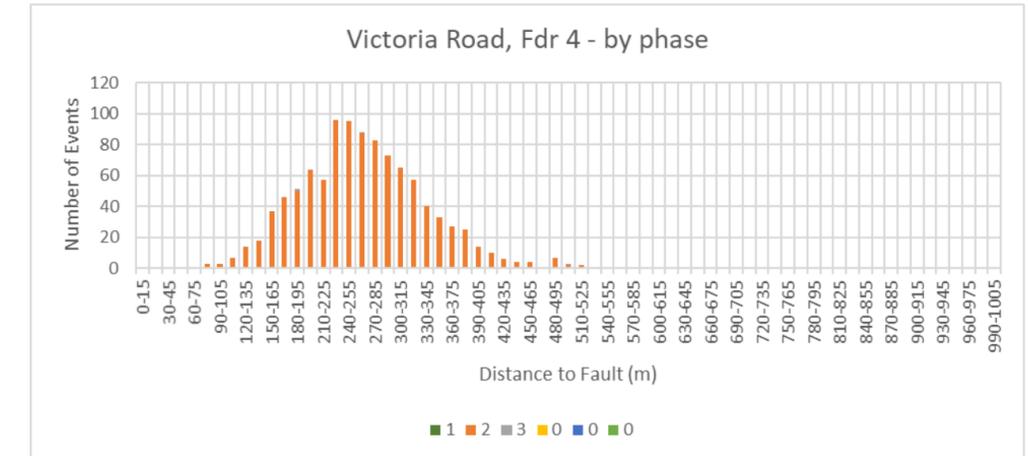
Fuse Operation Waveforms

- A small number of fuse operations have occurred on the monitored feeders, and some data from these has been captured.
- These fuse operating events display a continuing fault current, though with the Phase 1 hardware only one cycle is captured (Phase 2 hardware is expected to capture higher resolution data for longer periods).
- At present, distance to fault is not calculated for these events.

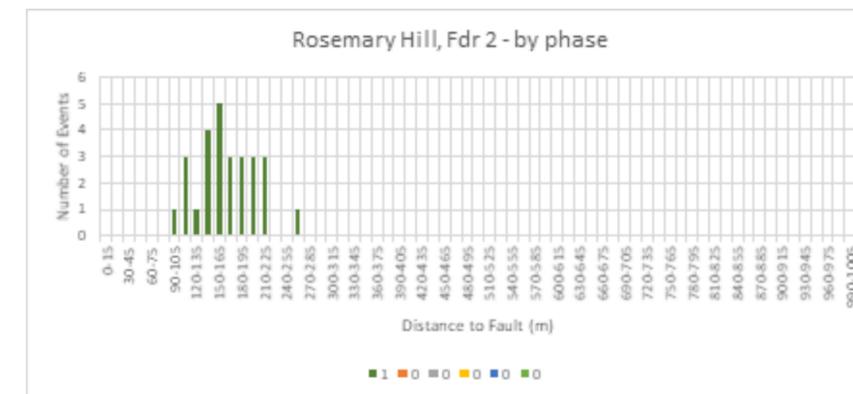
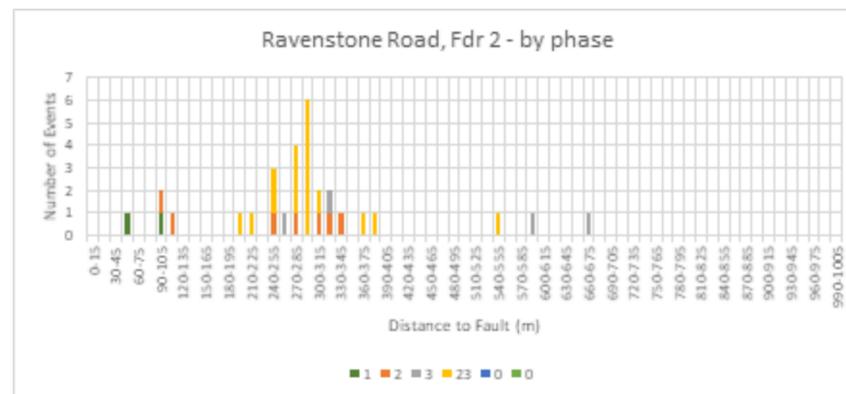
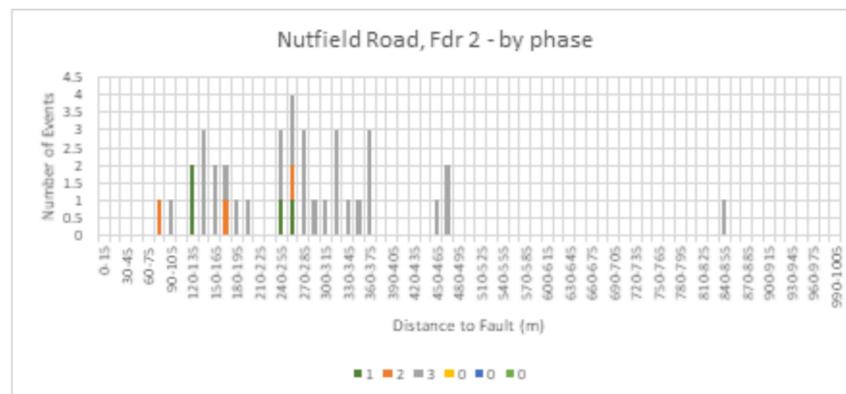
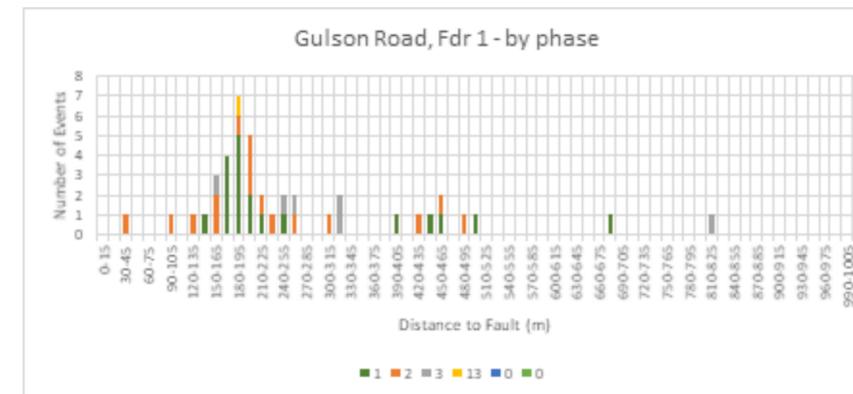
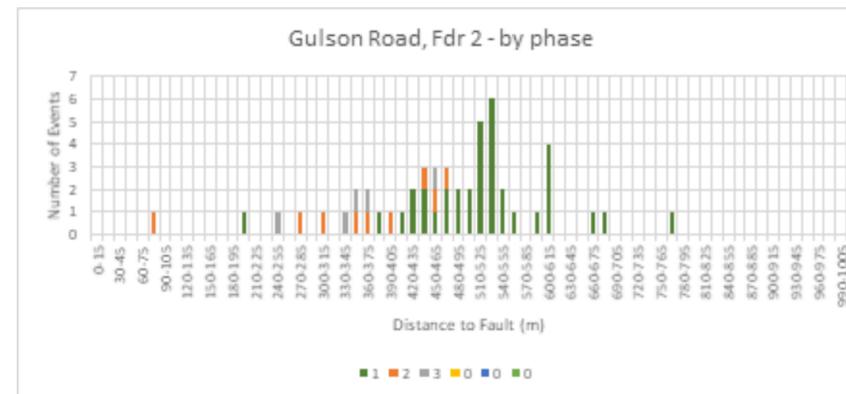
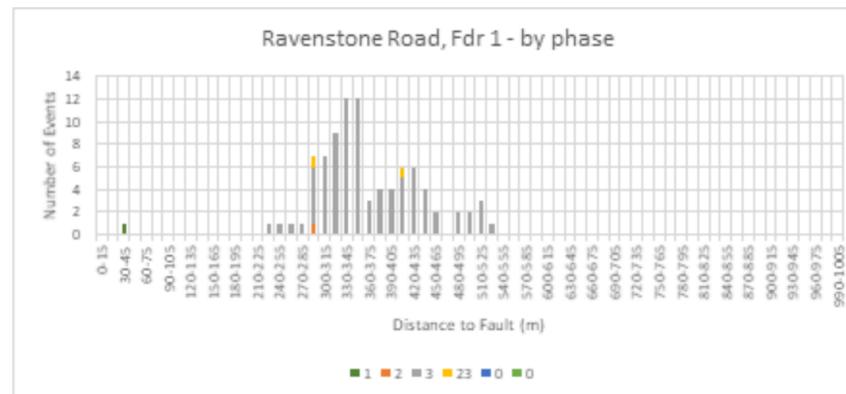
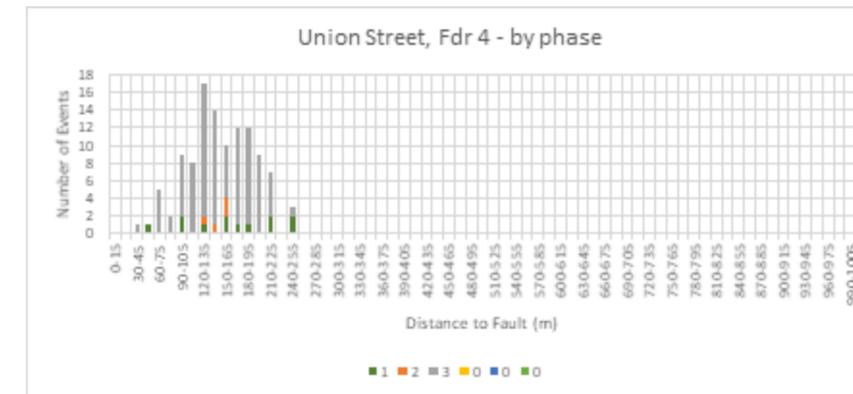
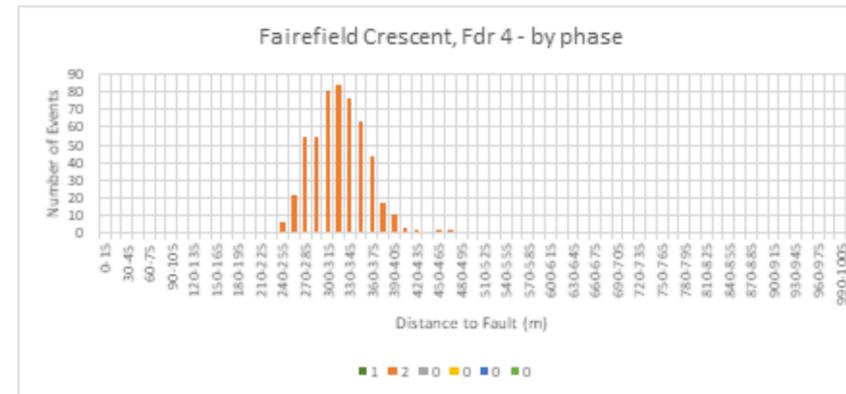


Event location interpretation – 1

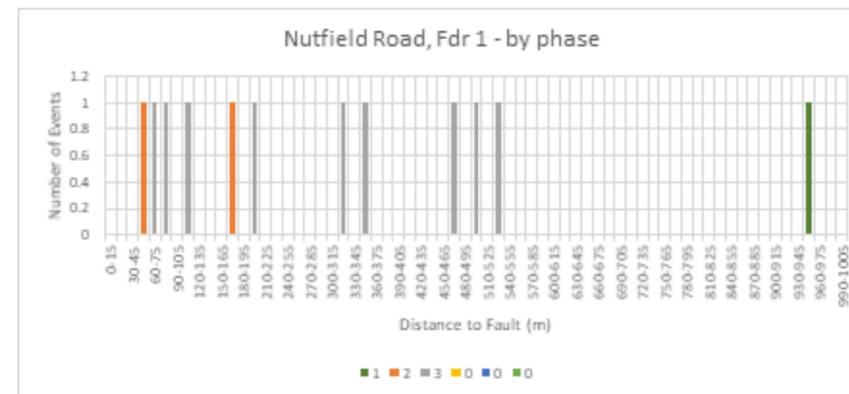
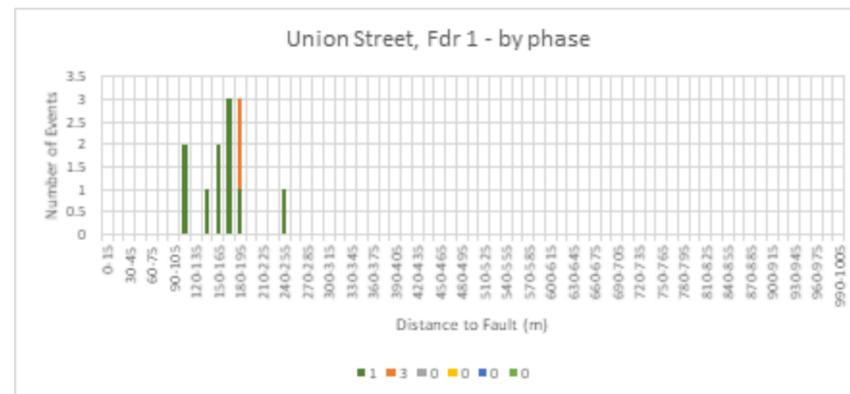
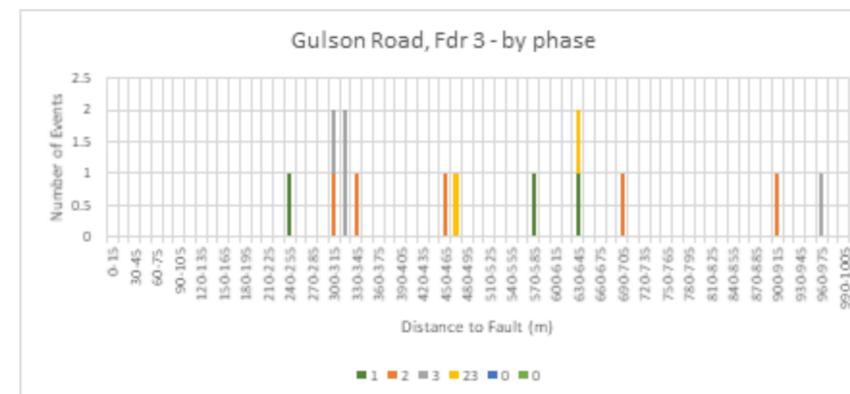
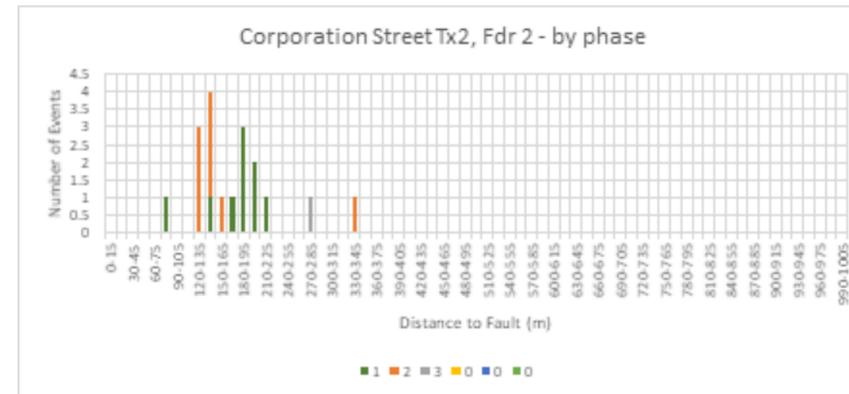
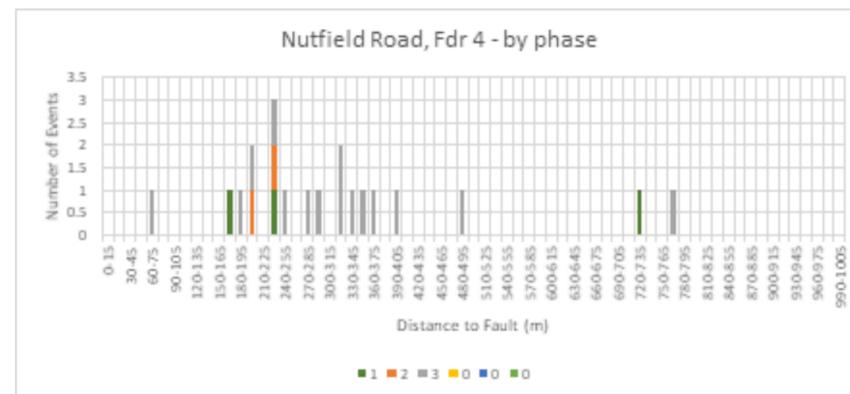
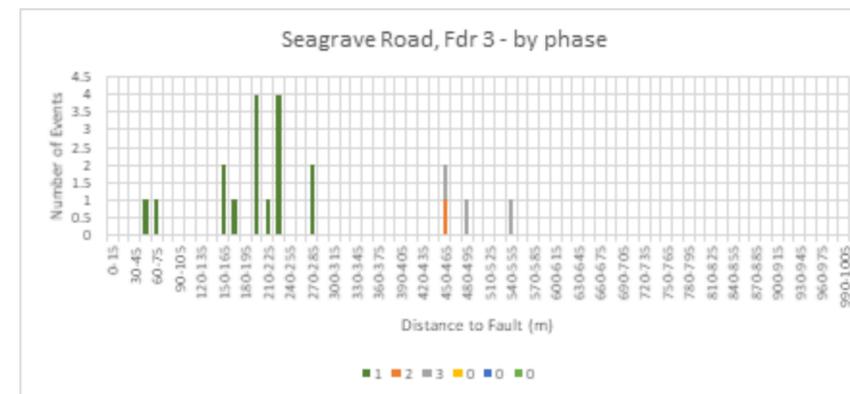
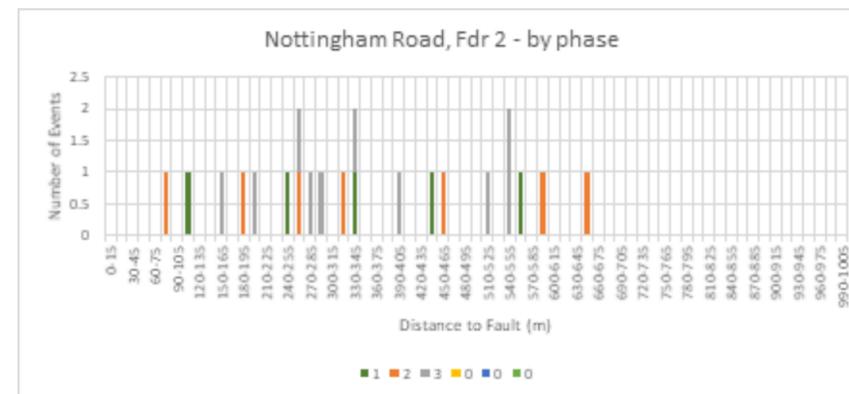
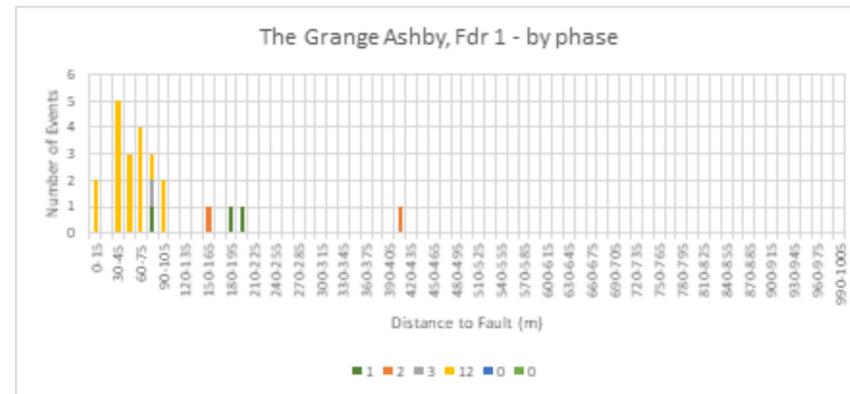
- Interpretation of event location is developing, and is currently mainly based upon a simple statistical view of the most frequent distance and the mean distance arising the assessment results
- In all trial cases, significant variation has been seen in the distance to fault estimates for any given feeder
- Victoria Road – 4 shows a reasonably symmetrical distribution of results with a mean estimate of 266m, though there is a broad range in the results (SD=80m).
- Fairefield Crescent – 4 again shows a reasonably symmetrical distribution of results with a mean of 325m, and a smaller range than Victoria Road – 4 (SD=40m).
- Ravenstone Road – 1 shows a lower number of events, and shows rather less symmetry with a wider range. The possibility of there being more than one defect point has been considered, without a conclusion yet.



DTF histograms - 1 (examples with > 10 events as at 31/08/2020 using revised feeder allocation)



DTF histograms - 2 (examples with > 10 events as at 31/08/2020 using revised feeder allocation)



Key Outputs and Milestones

Type	Description	Due Date	Status	Comments	Completion Date
Milestone	Project Start	Mon 02/09/19	Complete	-	02/09/19
Milestone	LEGK NIA Contract Signed	Fri 18/10/19	Complete	-	18/10/2019
Milestone	Phase 1 LEGK DtF Equipment Deployed (26 locations)	Fri 14/02/20	Complete	Coding of revised firmware associated with Phase 1 monitoring encountered unexpected challenges, and introduced a minor delay. Change Request 001.	06/03/2020
Milestone	End of Phase 1 field work	Fri 28/08/20	Complete	-	28/08/20
Report	LEGK Phase 1 Report Accepted (Phase 1 learning & outcomes)	Fri 18/09/20	Complete	-	18/09/20
Milestone	Phase 2 LEGK Optimised DtF Equipment Deployed (26 locations)	Fri 16/10/20	Not Started	-	-
Milestone	Initial Comparisons and Validation of LEGK DtF Indications	Fri 08/01/21	Not Started	-	-
Milestone	End of Project Field Activities	Fri 06/08/21	Not Started	-	-
Document	Release of WPD St for GridKey DFT Deployment & Utilisation	Fri 12/11/21	Not Started	-	-
Milestone	Final Report Webinar Dissemination Complete	Fri 25/02/22	Not Started	-	-
Report	External issue of Close Down Report	Fri 15/04/22	Not Started	-	-
Milestone	End of Project	Fri 29/04/22	Not Started	-	-

Status of Project Objectives - 1

Objective	Status
<p>Test the feasibility of a technical alternative and lower cost fault locating device.</p>	<p>Phase 1 of the project is now complete, with pecking events captured on all of the 26 deployed monitors.</p> <p>Key findings from Phase 1 - the histogram of events vs distance for three feeders can reasonably be interpreted (Victoria Road-4, Fairefield-4, and Union Street-4). These three feeders account for 65% of the captured higher quality assessed events. Cross-checks on location for Victoria Road – 4 and Fairefield - 4 are currently underway (this activity was originally expected in Phase 2), to provide additional data and learning. DTF indications are also emerging for around 10 further feeders, and cautious indications have been offered to local teams for some of these feeders on a “best information available” basis.</p> <p>Key learning from Phase 1:</p> <ul style="list-style-type: none"> • the DTF analysis model has been modified based collected field data, improving the extent to which the model agrees with measured data; • a significant issue has been identified with the MCU firmware where mis-identification of the feeder associated with the event was occurring, this has been corrected; • Phase 1 hardware captures a relatively modest amount of data around each event (single cycle of data before and after the initiation of an event) which limits understanding of suspected subsequent cycle events, Phase 2 hardware will capture more waveforms per initiating event; • a small number of other firmware issues and irregularities have been identified, which will be addressed during Phase 2; • installation of flexi-sensors around fuse handles requires precise placement, contact with a hot fuse can damage the sensor and apply phase voltages to the sensor inputs to the MCU, revised installation arrangements have been developed; • limitations of the passive waveform acquisition hardware for Phase 1 may contribute the relatively wide range seen within DTF results; Phase 2 will have improved acquisition hardware and a key point of further learning will be assessing the impact of this

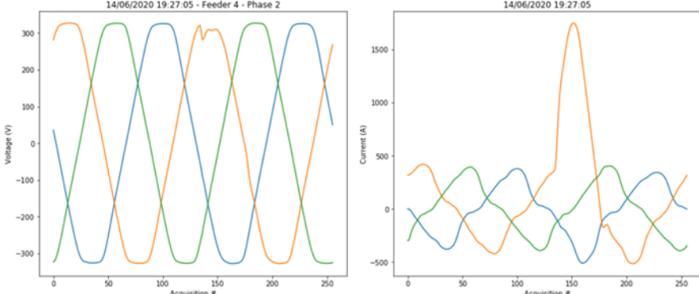
Status of Objectives - 2

Objective	Status
Derive insight into the potential to more widely and cost-effectively deploy such monitoring equipment to feeders showing early indications damage (e.g. transient fuse operations).	Yet to start.

Status of Project Success Criteria - 1

Success Criteria	Status
1) Identification of pecking faults within monitoring data, reliably distinguishing them from other network transients and disturbances.	Within Phase 1 monitoring, captured waveforms are automatically screened to identify those events that confirm to the characteristics of a pecking fault. For example, pecking faults are distinguished from three-phase motor starts even though both event types currently trigger waveform capture. Work is ongoing in this area.
2) Capture of sufficient pecking fault data to estimate confidence in DtF indications for transient arc-faults.	<p>Interpretation of event location is developing, and is currently mainly based upon a simple statistical view of the most frequent distance and the mean distance arising the assessment results.</p> <div data-bbox="1735 977 2718 1431" data-label="Figure"> <p>Fairefield Crescent, Fdr 4 - by phase</p> <p>Most frequent DTF (84 events) = 315-330m; Mean DTF (528 events) = 325m; SD = 40m.</p> </div> <p>Validation of GridKey locations has now started (originally a Phase 2 activity), and this will further inform how to express a level of confidence in a specific DTF indication.</p>

Status of Project Success Criteria - 2

Success Criteria	Status
<p>3) Quality of captured auxiliary data (e.g. upstream and downstream network impedance indications) is sufficient to support reliable distance to fault calculations.</p>	<p>Phase 1 monitoring is currently producing upstream impedance estimates that are comparable to transformer nameplate data. Further refinement of upstream impedance estimates are expected with Phase 2 monitoring. Work is ongoing in this area.</p>
<p>4) Quantitative understanding of the frequency and magnitude of transient arc-faults on monitored feeders</p>	<p>Data is being collated on the number of events that occur on an individual monitor, and is available for all monitors:</p>  <p>The magnitude of individual events can be seen from the waveforms captured for each event:</p>  <p>This quantitative understanding will be summarised towards the end of Phase 2.</p>

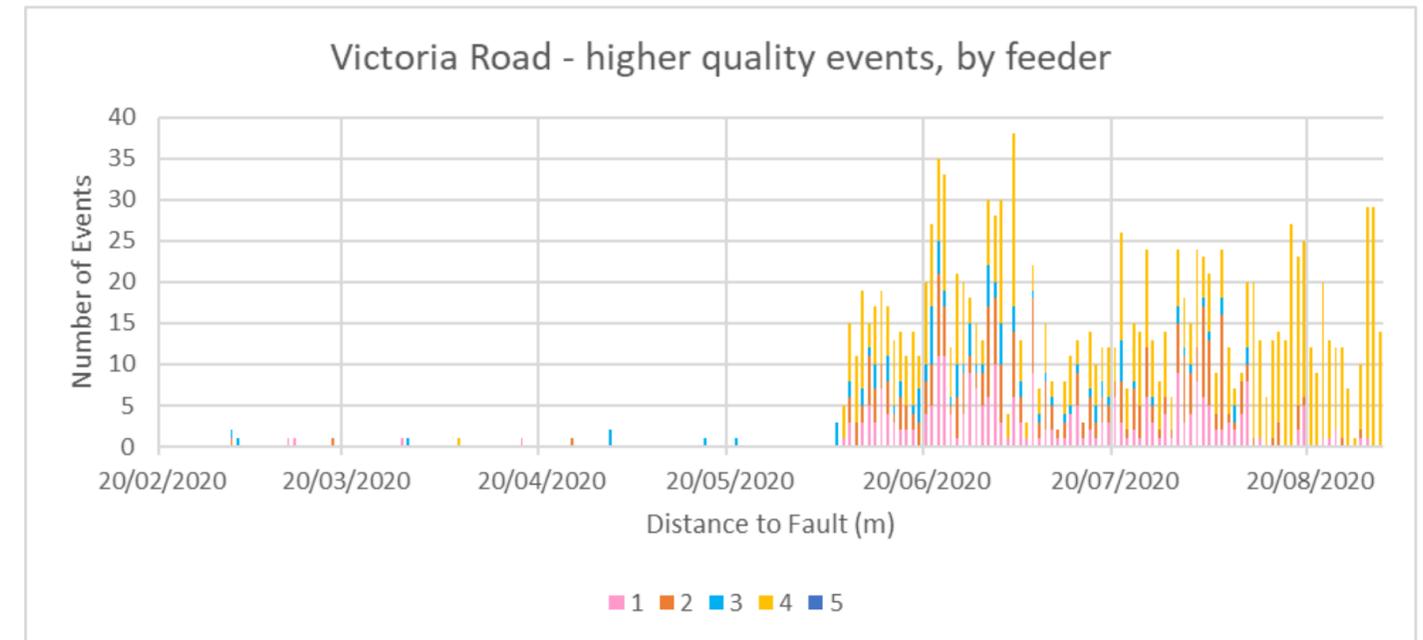
Status of Project Success Criteria - 3

Success Criteria	Status
5) Automatic generation and notification of distance to fault indications	Within the Phase 1 monitoring period, automated scripts are being run to screen and assess captured events. These scripts estimate a distance to fault for an individual event, plus process metrics associated with an individual event. Histograms of numbers of events versus DTF are also automatically generated. Learning from Phase 1 monitoring has refined this assessment process. Further work will be undertaken throughout Phase 2 to automatically generate and appropriately display DTF indications, and provide associated automated notification (e.g. current DTF indications on a regular basis, and upon specific events such as a fuse operation)
6) DtF indications are successfully used by local teams to guide repairs ahead of permanent faults developing	Potential fault locations have been discussed with local teams for a number of sites. Learning has been generated from these experiences which will be further applied to Phase 2 of the project.

Issue with feeder identification - Overview

- An issue has been identified where some captured events were given erroneous feeder allocation.
- The apparent coincidental initiation of pecking faults on all 4 feeders at Victoria Road (see chart) in from ~09/06/2020 prompted a review of input data and data processing. This demonstrated that a large proportion of (and probably virtually all) of the captured events were associated with only one feeder/defect.
- The cause of the issue has been identified, and a fix of applicable software processing has been put in place. A review of existing data has been undertaken to provide a corrected feeder identification where possible. It is concluded that despite this issue, underlying (corrected) indications are still credible and reliable.
- An example of pre- and post-correction event counts by feeder is shown here for Victoria Road. In this example a significant majority of events originally associated with Feeders 1-3 have been positively identified as actually being associated with Feeder 4, and the original identification has an additional corrected association applied.
- It has not been possible to positively identify a minority of events originally associated with Feeders 1-3, these events have been left with their original feeder identification, these feeders are disregarded for now.

Pre-correction Data



Pre-correction Data

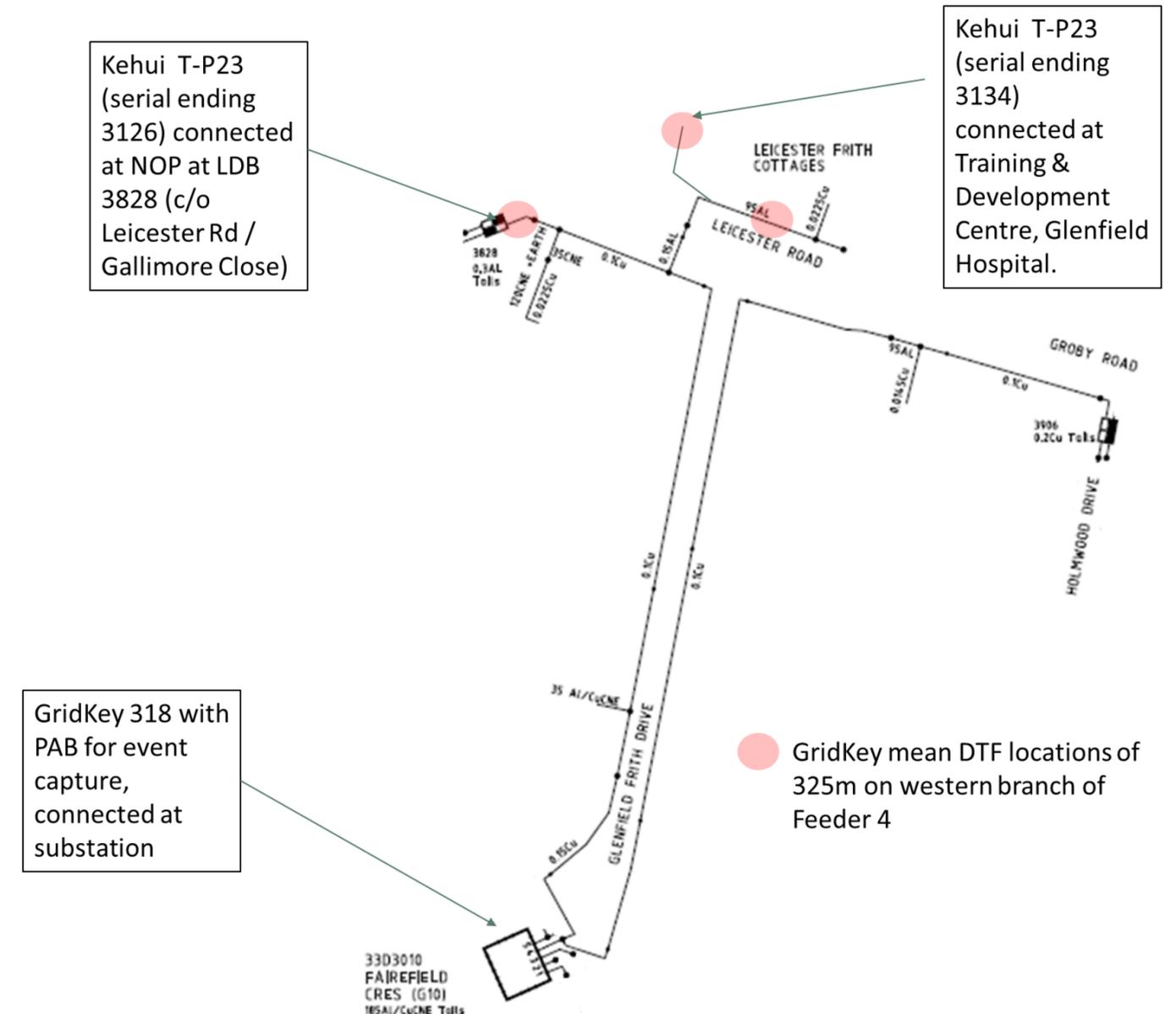
Site		Victoria Road
Result inclusion filter		TRUE
Feeder	Count of Events	
1	181	
2	185	
3	92	
4	332	
Grand Total	790	

Post-correction Data

Site		Victoria Road
Result inclusion filter		TRUE
Reviewed Feeder	Count of Events	
1	37	
2	46	
3	20	
4	687	
Grand Total	790	

Location Results Validation

- Location validation work was originally intended to be undertaken during Phase 2 – Phase 1 results on a few site warrant bringing this work forward.
- Initial validation work has involved the use of an alternative fault location device(s), capable of detecting transient fault conditions, that does not use an impedance method. Time domain reflectometry-based (TDR) monitors are being used.
- It is hoped that later validation work will include the removal of an identified “faulty” component/section and demonstrate the future absence of “pecking” events.
- Early validation activities at a Milton Keynes site proved inconclusive due to TDR monitor placement challenges on the network – this site will be re-visited.
- Validation work at a Leicester site is now underway, with initial results corroborating GridKey indications along the western branch. This work continues.



Individual Feeder Analysis

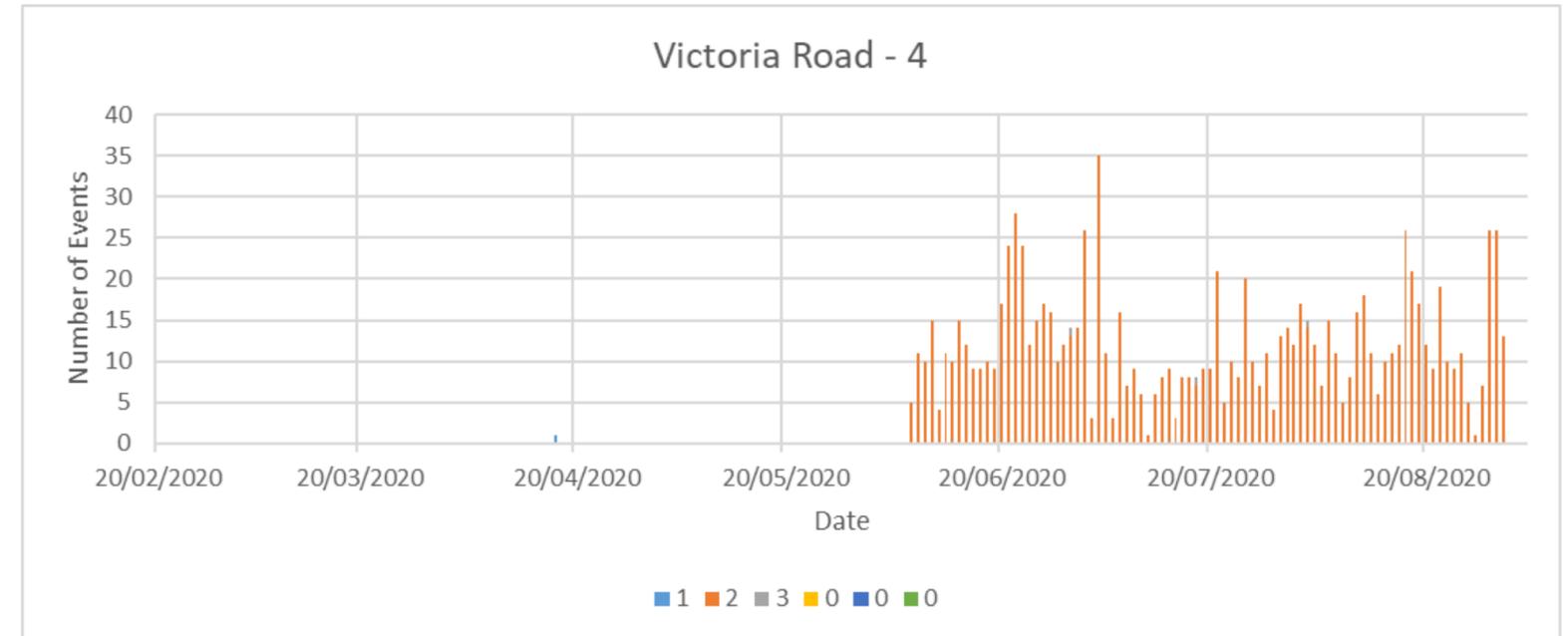
- Details of individual feeder analysis are included for 13 feeders that have captured 20 or more higher quality pecking events.
- The 13 identified feeders account for 2,038 of the 2,647 higher quality events, ~77%.
 - i. [Victoria Road - 4](#)
 - ii. [Fairefield Crescent - 4](#)
 - iii. [Union Street – 4](#)
 - iv. [Ravenstone Road - 1](#)
 - v. [Gulson Road - 2](#)
 - vi. [Gulson Road – 1](#)
 - vii. [Nutfield Road - 2](#)
 - viii. [Ravenstone Road - 2](#)
 - ix. [Rosemary Hill - 2](#)
 - x. [The Grange Ashby - 1](#)
 - xi. [Nottingham Road - 2](#)
 - xii. [Seagrave Road - 3](#)
 - xiii. [Nutfield Road – 4](#)

Result inclusion filter TRUE 

Site 	Count of assessed events
Victoria Road - 4	1040
Fairefield Crescent - 4	528
Union Street - 4	110
Ravenstone Road - 1	89
Gulson Road - 2	50
Gulson Road - 1	42
Nutfield Road - 2	37
Ravenstone Road - 2	30
Rosemary Hill - 2	27
The Grange Ashby - 1	23
Nottingham Road - 2	22
Seagrave Road - 3	20
Nutfield Road - 4	20
Grand Total	2038

Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Victoria Road Dist.	1363	1363
WPD Feeder 1	263	78
WPD Feeder 2	268	172
WPD Feeder 3	105	73
WPD Feeder 4	727	1040



Victoria Road feeder data prior to 11/08/2020 has been reviewed and corrected as far as possible, following the feeder identification issue described above. Event data collected after 10/08/2020 uses revised feeder identification software and is reported as collected.

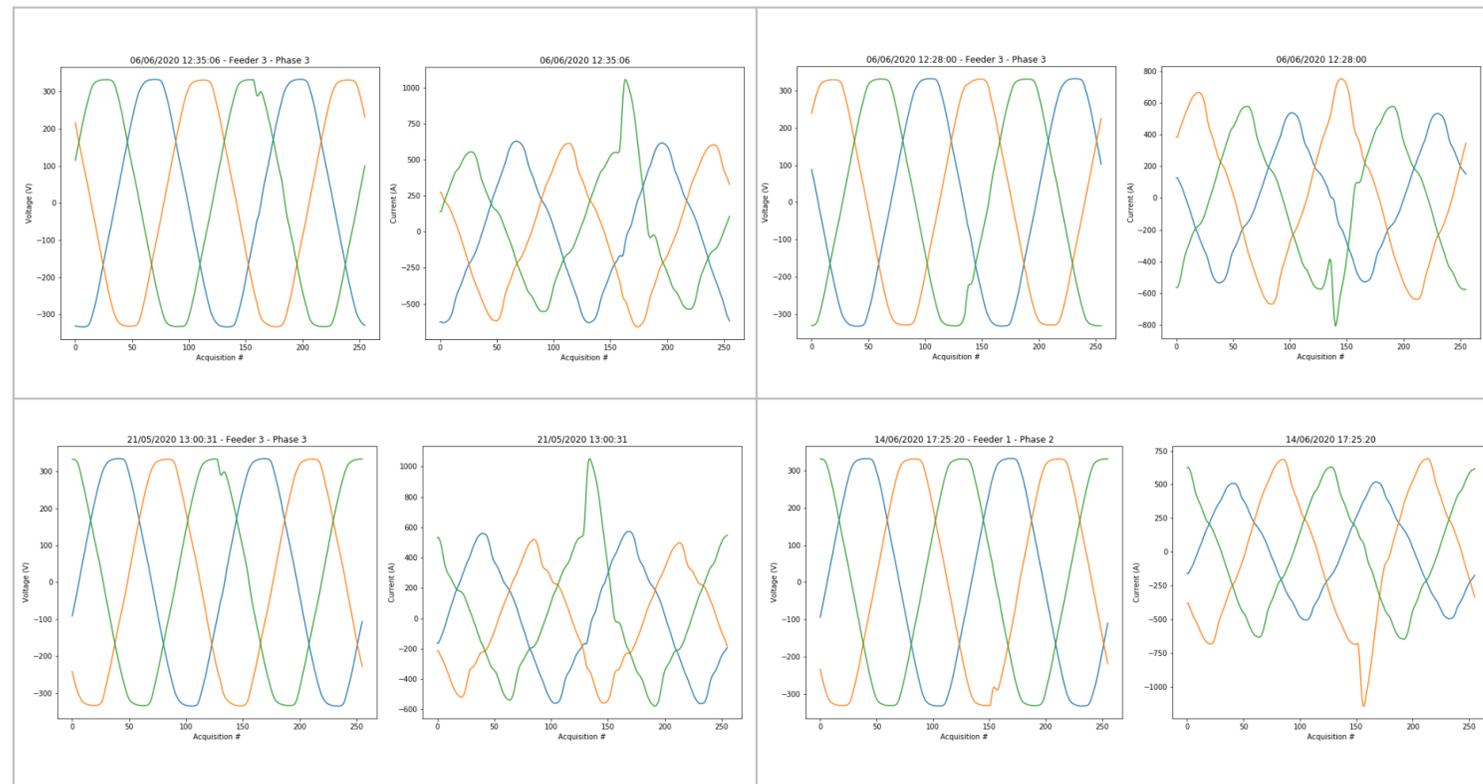
Victoria Road WPD Feeder 4 has shown high activity from June to date, with only one feeder 4 attributed event before this.

The project is not aware of any fuse operations.

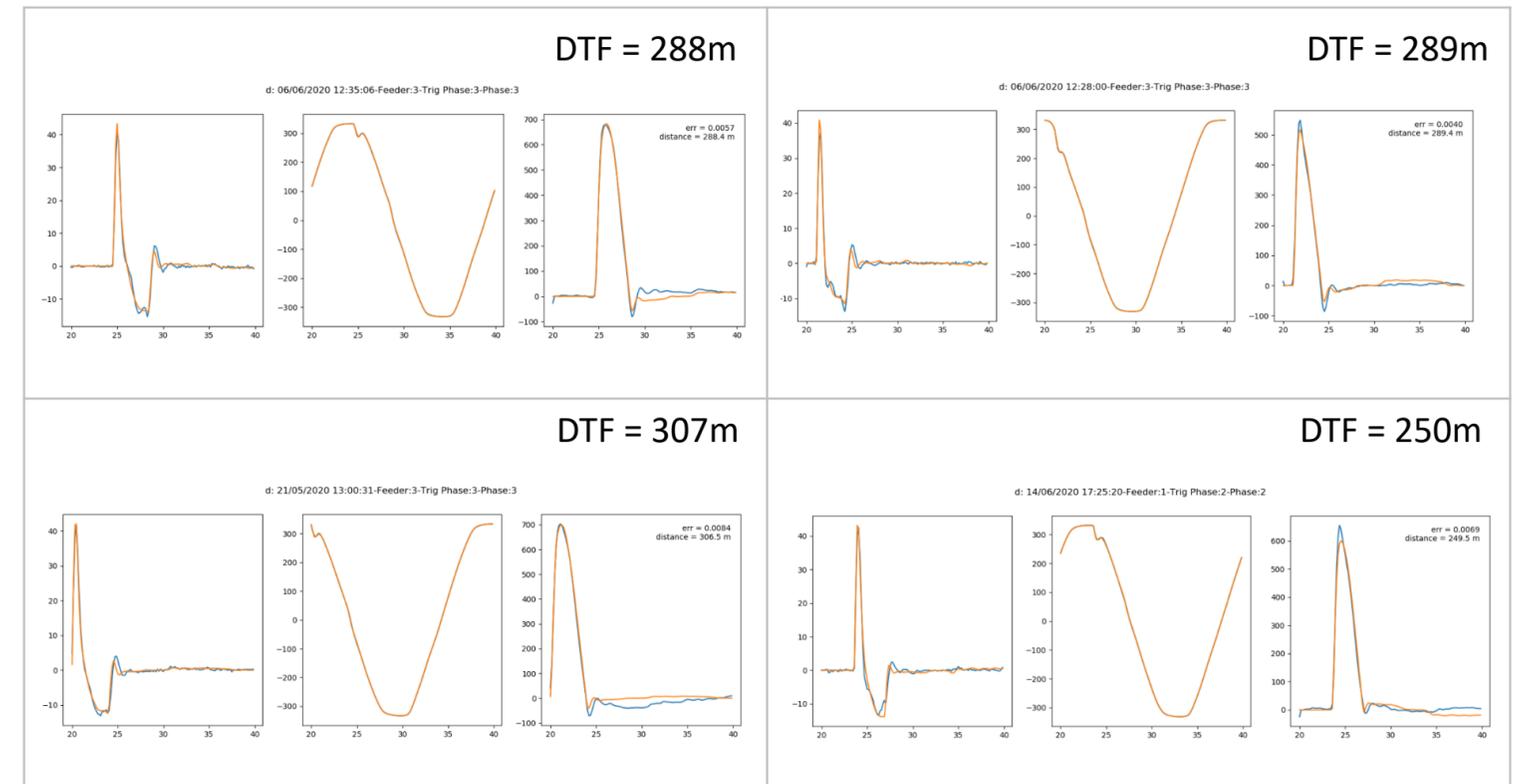
Overwhelmingly events have involved only phase 2.



Waveform and Fault Analysis Data



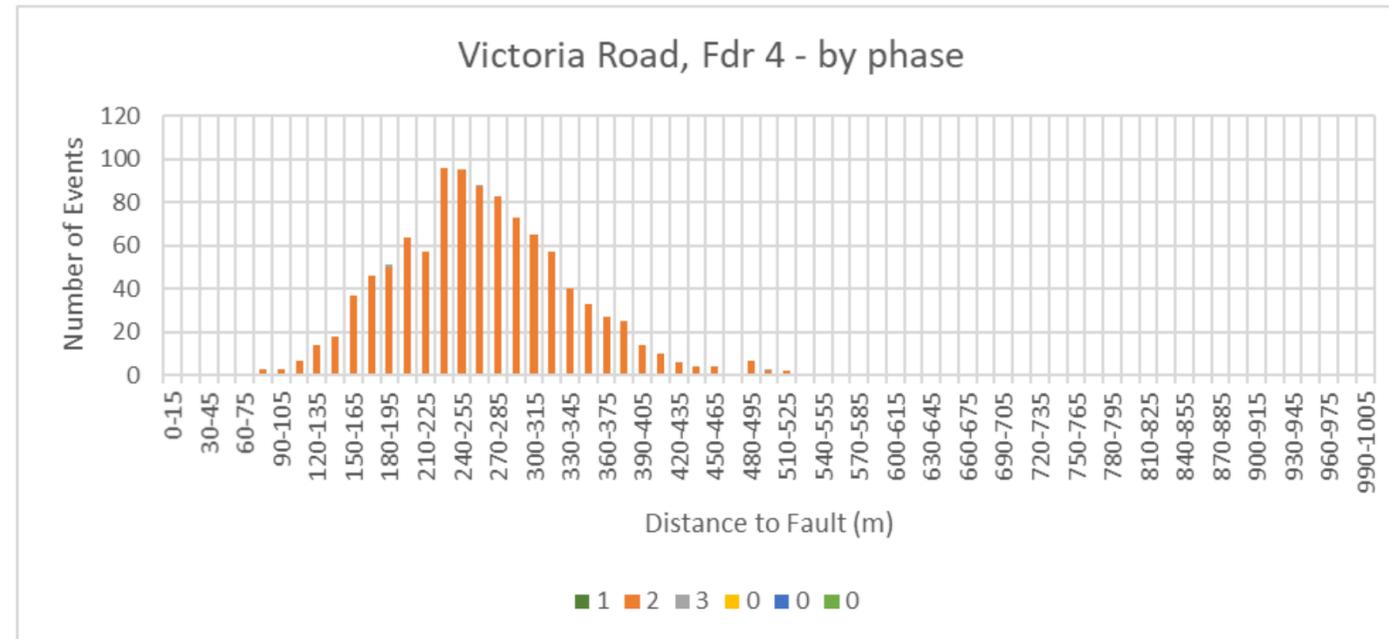
Example captured “pecking fault” waveforms



Example processed waveforms and resulting distances to fault



Indicated Location

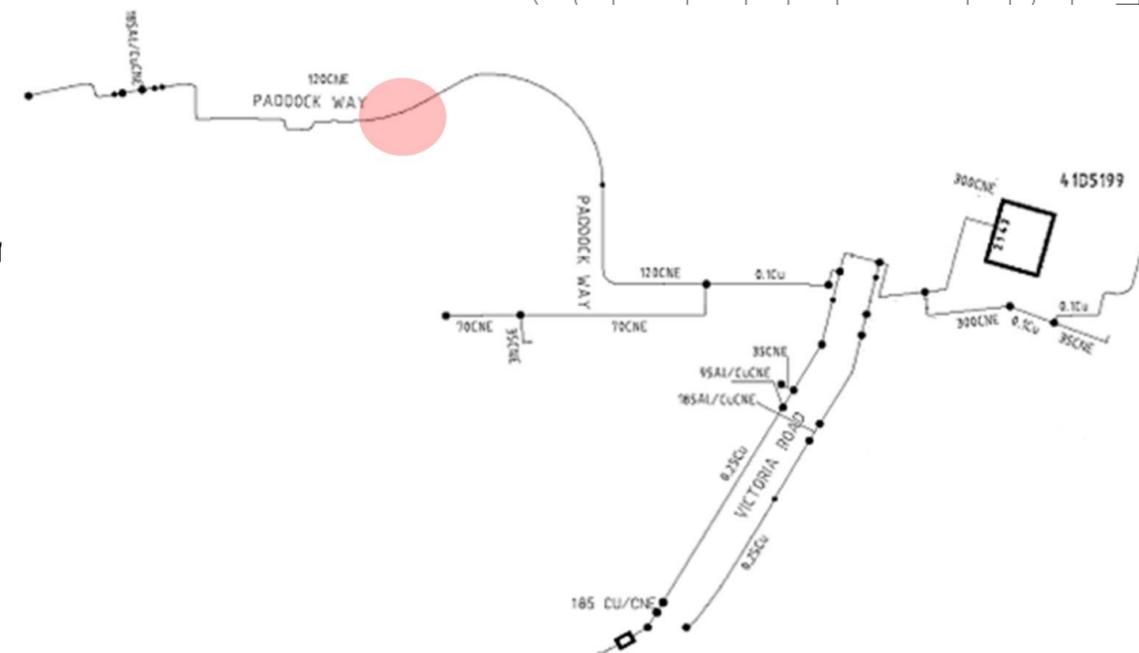
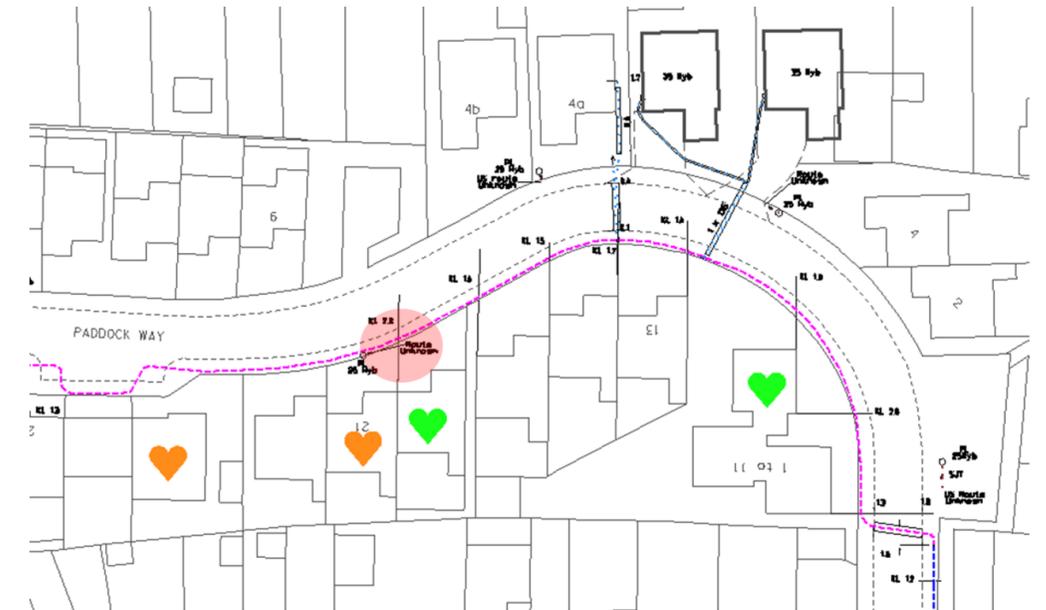


Most frequent DTF (96 events) = 225-240m; Mean DTF (1040 events) = 266m
SD = 80m

Overwhelmingly the events involve L2.

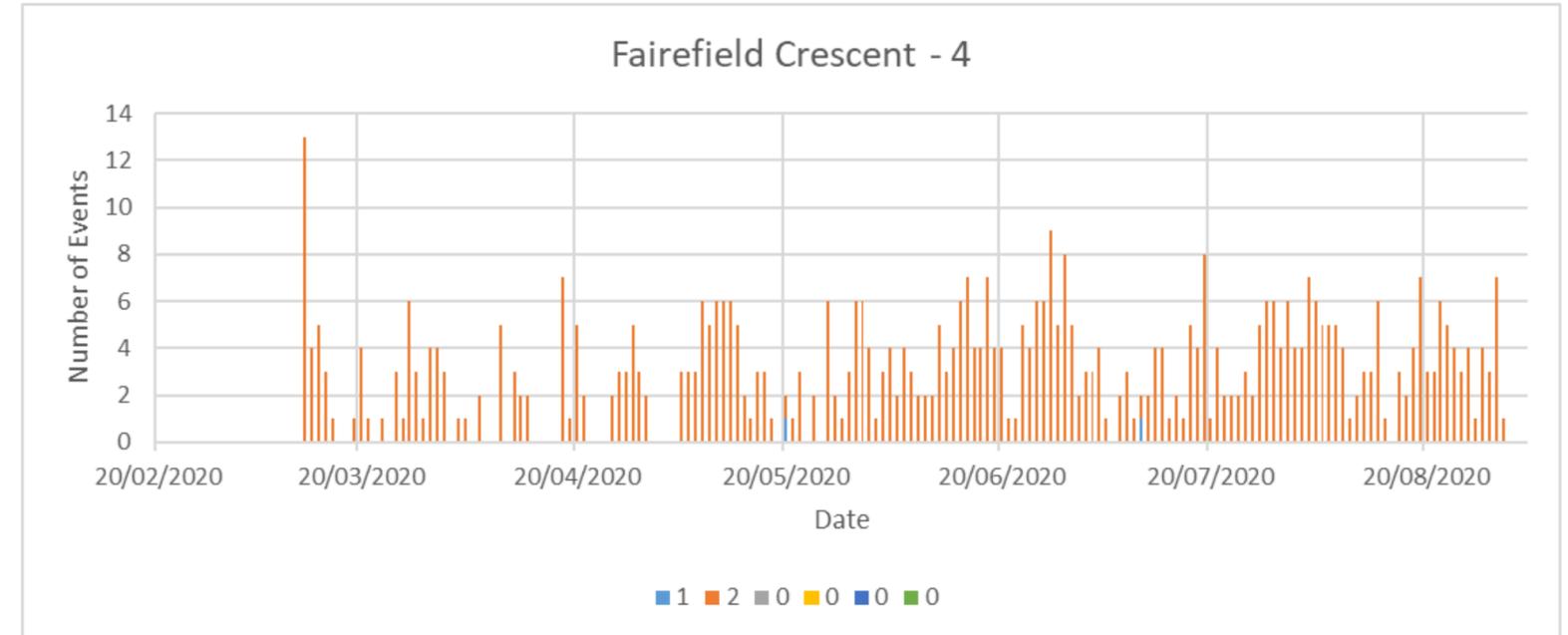
Only one branch is longer than ~210m (branch serving Paddock Way).

These results are currently interpreted as a defect located at ~266m, adjacent to 19-21 Paddock Way.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Fairefield Cresc.	545	545
WPD Feeder 1	72	5
WPD Feeder 2	10	4
WPD Feeder 3	46	7
WPD Feeder 4	400	528
WPD Feeder 5	17	1



Fairefield Crescent feeder data has been reviewed and corrected as far as possible following the feeder identification issue described above.

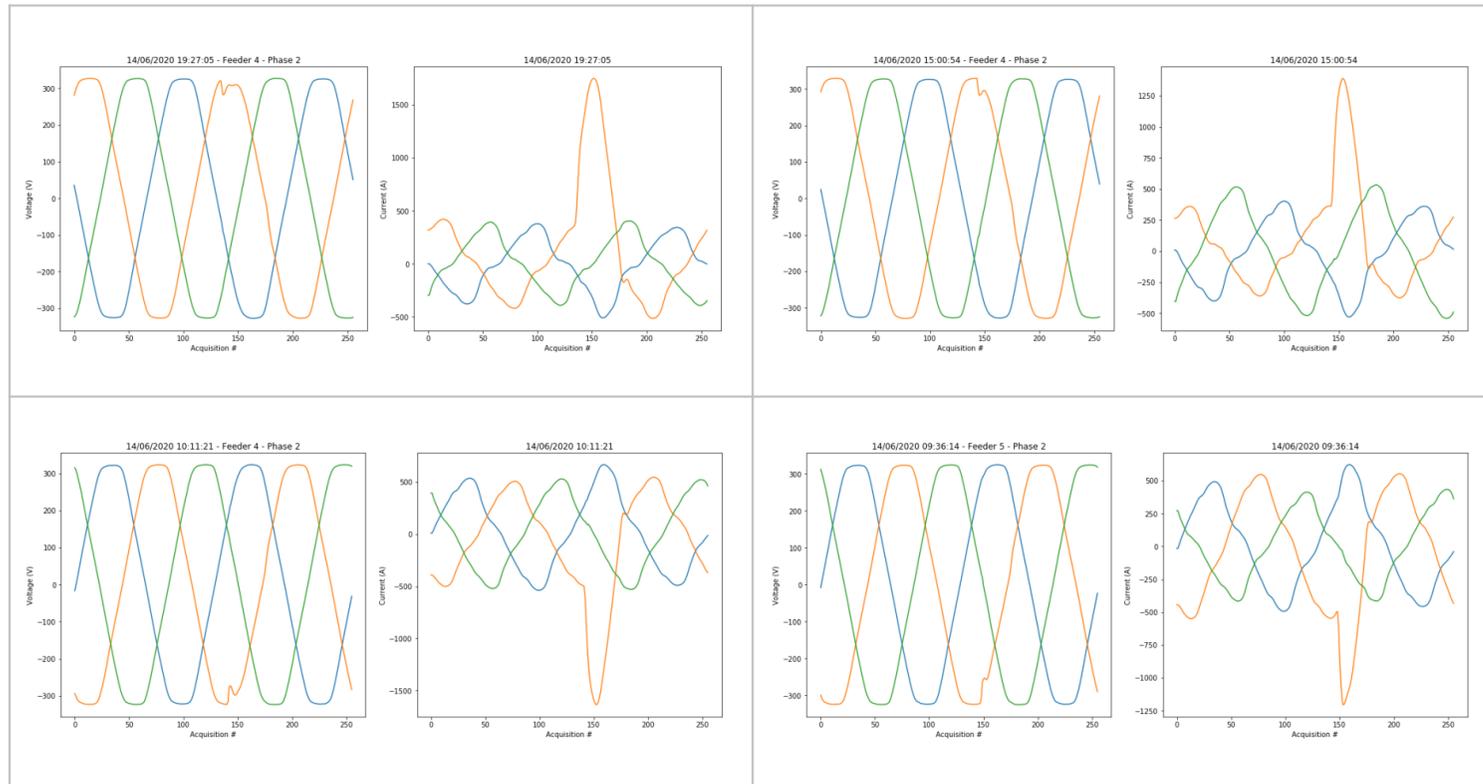
Fairefield Crescent Feeder 4 has been consistently active over the monitoring period.

The project is not aware of any fuse operations.

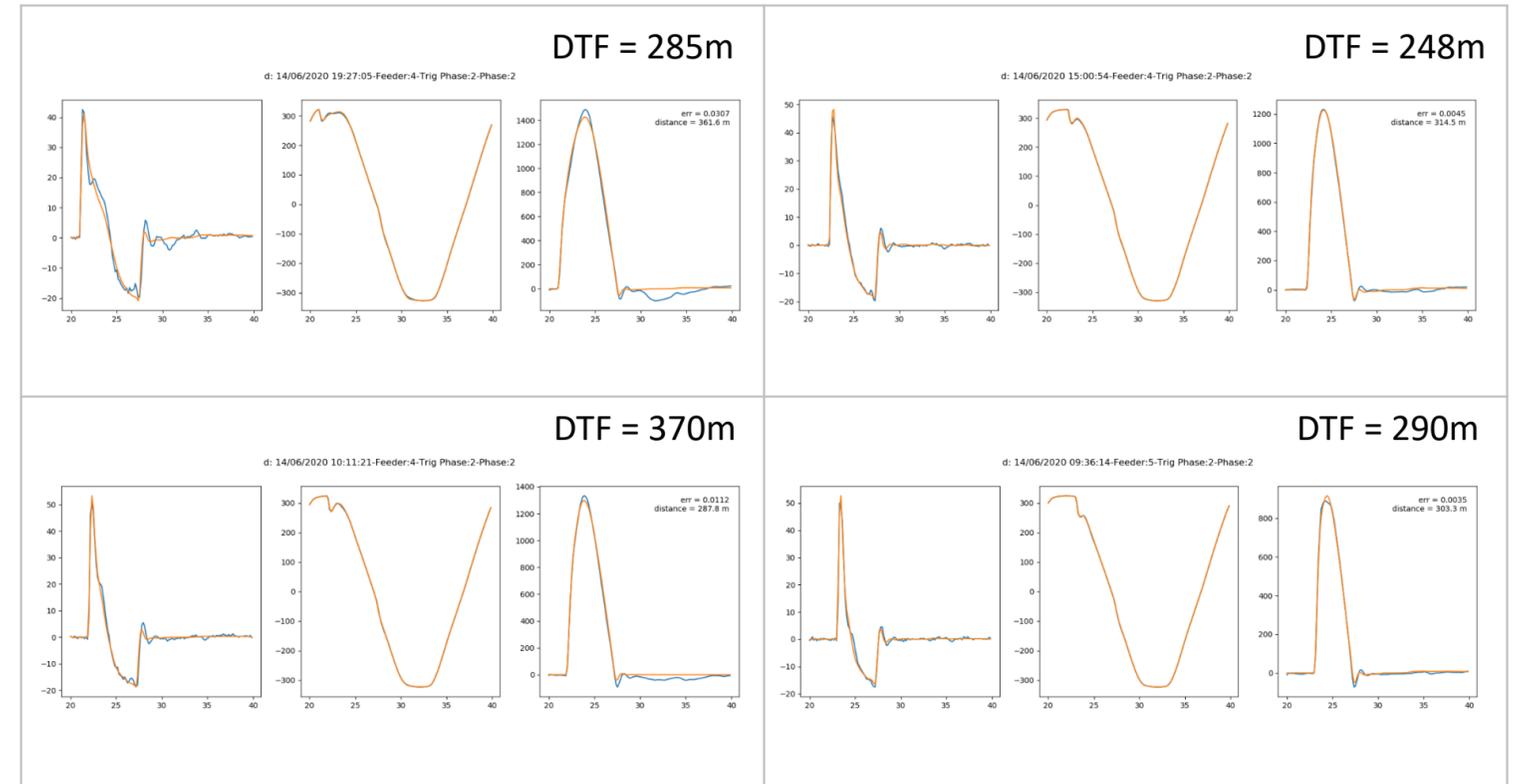
Overwhelmingly events have involved only phase 2.



Waveform and Fault Analysis Data



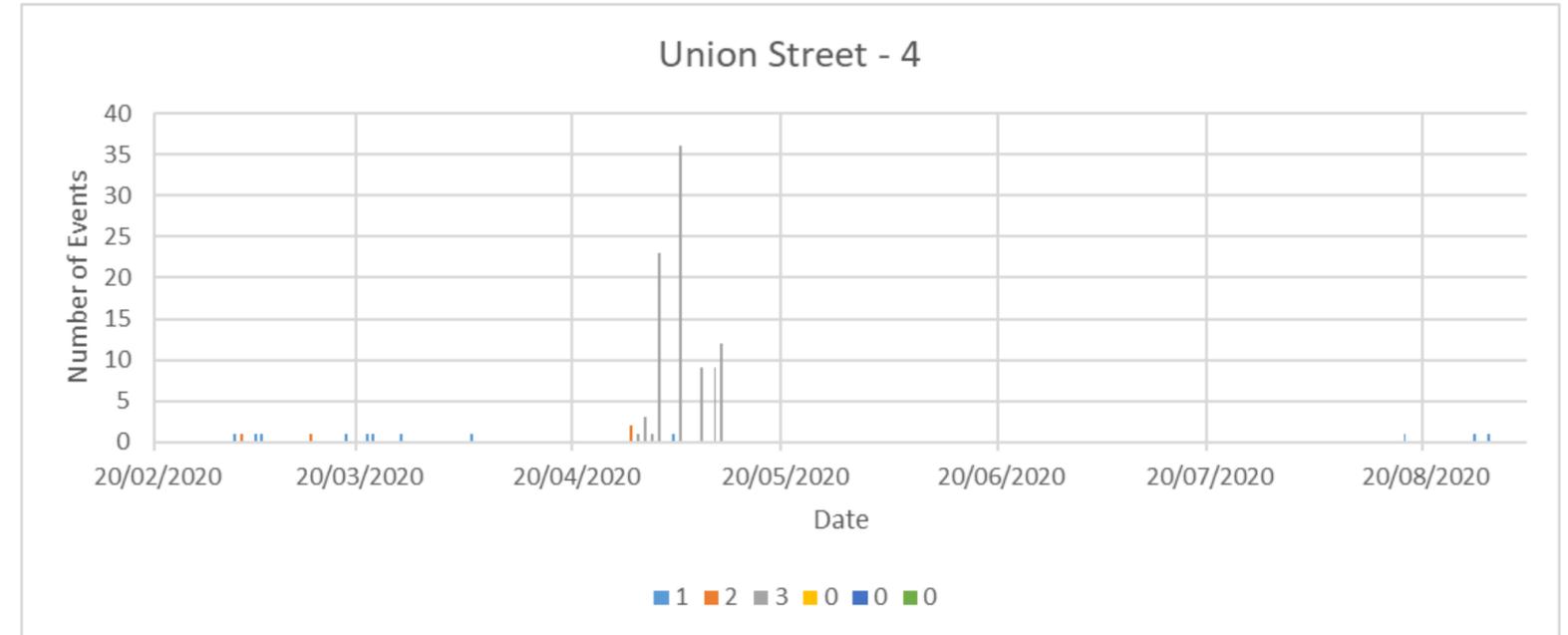
Example captured “pecking fault” waveforms



Example processed waveforms and resulting distances to fault

Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Union Street	130	130
WPD Feeder 1	17	12
WPD Feeder 2	19	5
WPD Feeder 3	11	3
WPD Feeder 4	83	110



Union Street feeder has been reviewed and corrected as far as possible following the feeder identification issue described above, with a relatively small number of changes being made.

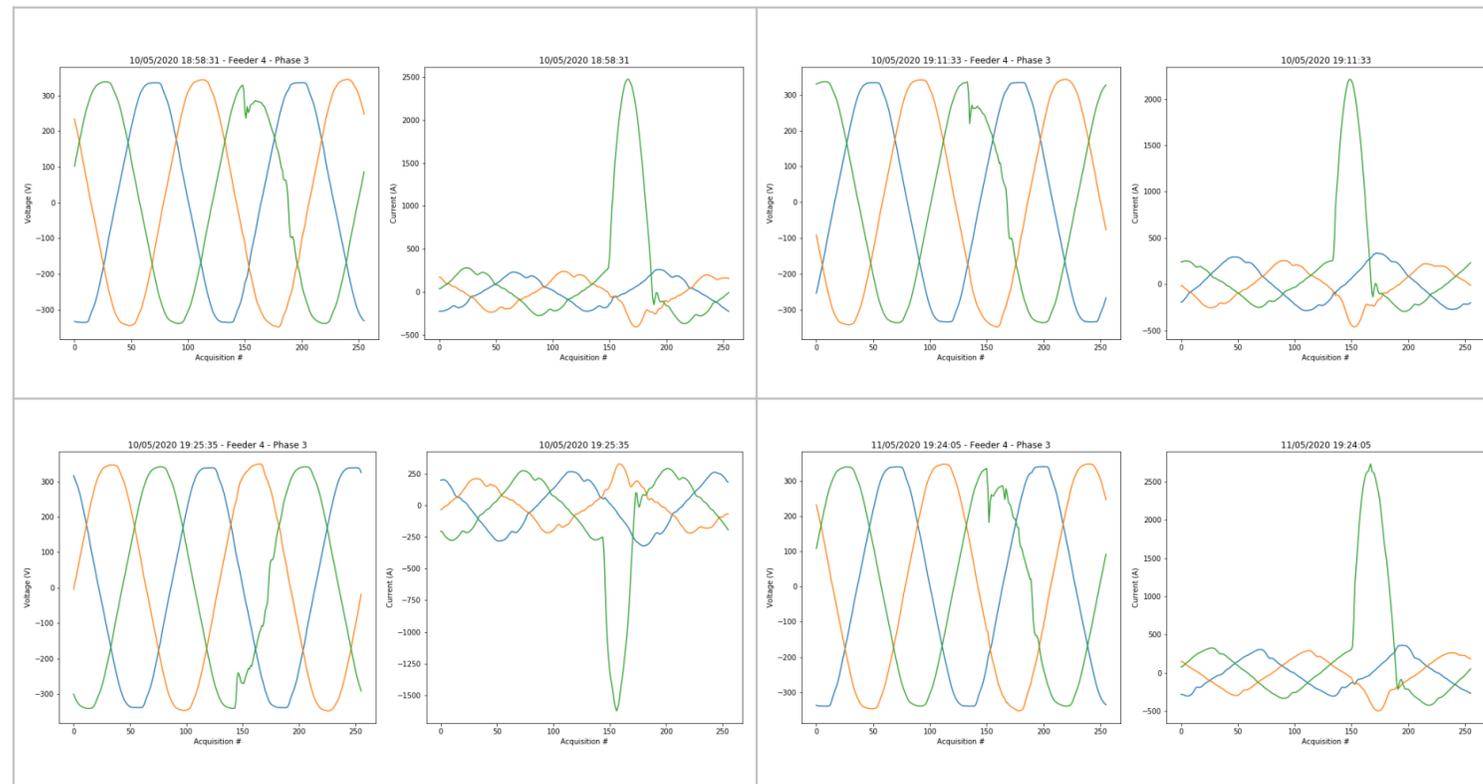
Union Street WPD Feeder 4 was active during the first half of May, and relatively quiet since.

The project is not aware of any fuse operations.

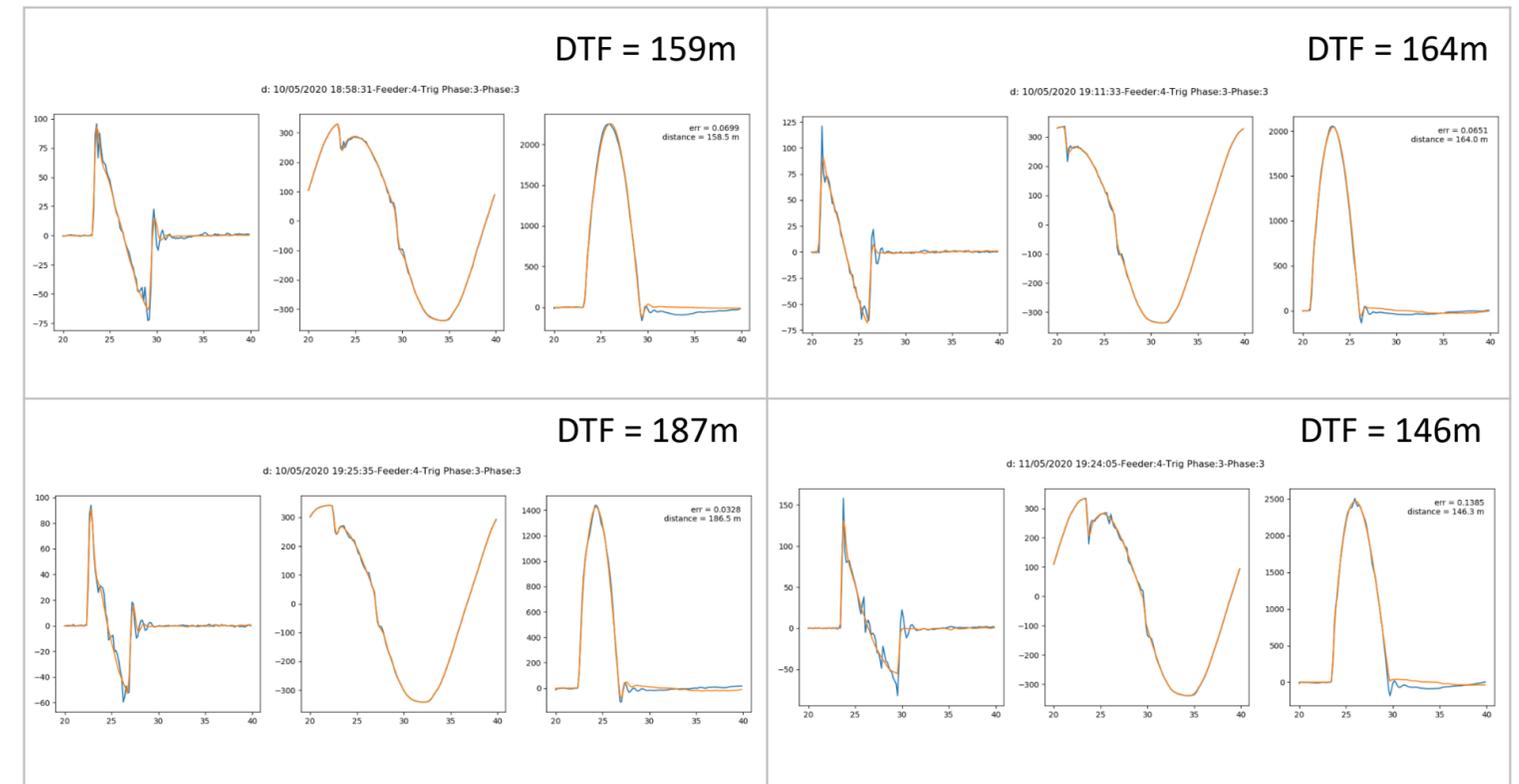
Events have mostly involved only Phase 3.



Waveform and Fault Analysis Data



Example captured “pecking fault” waveforms

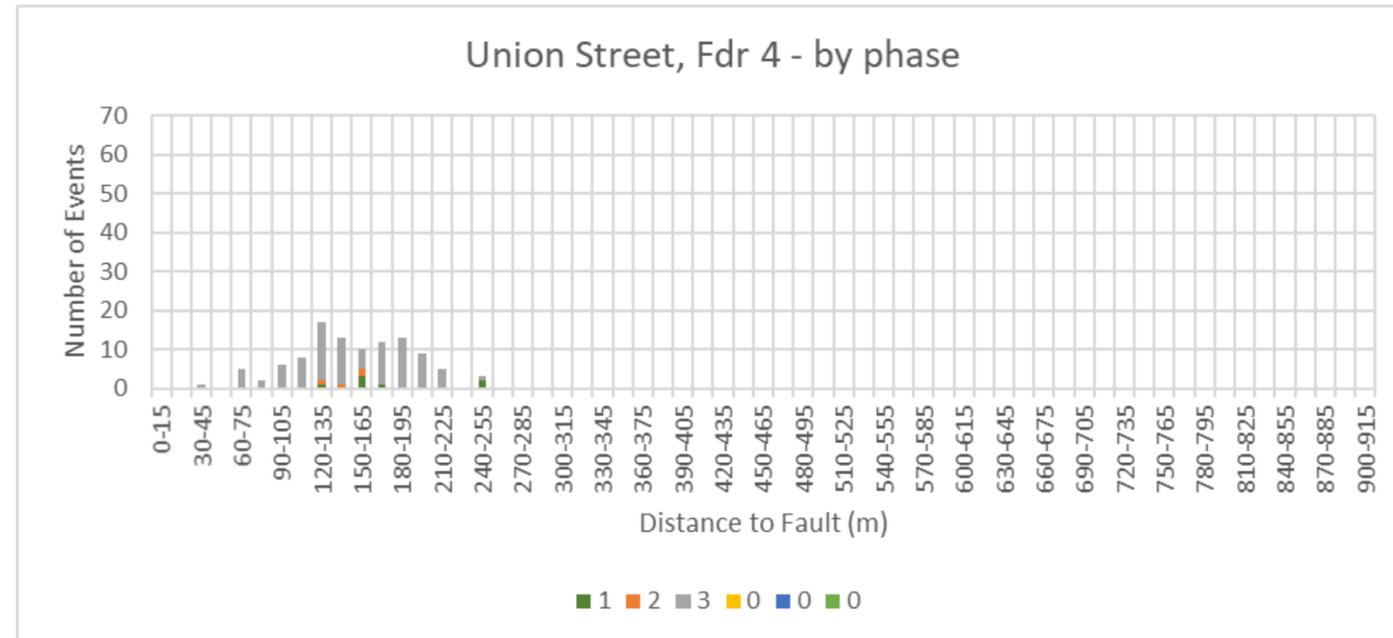


Example processed waveforms and resulting distances to fault

Some speculation has occurred around coincidence of approximate timings of events



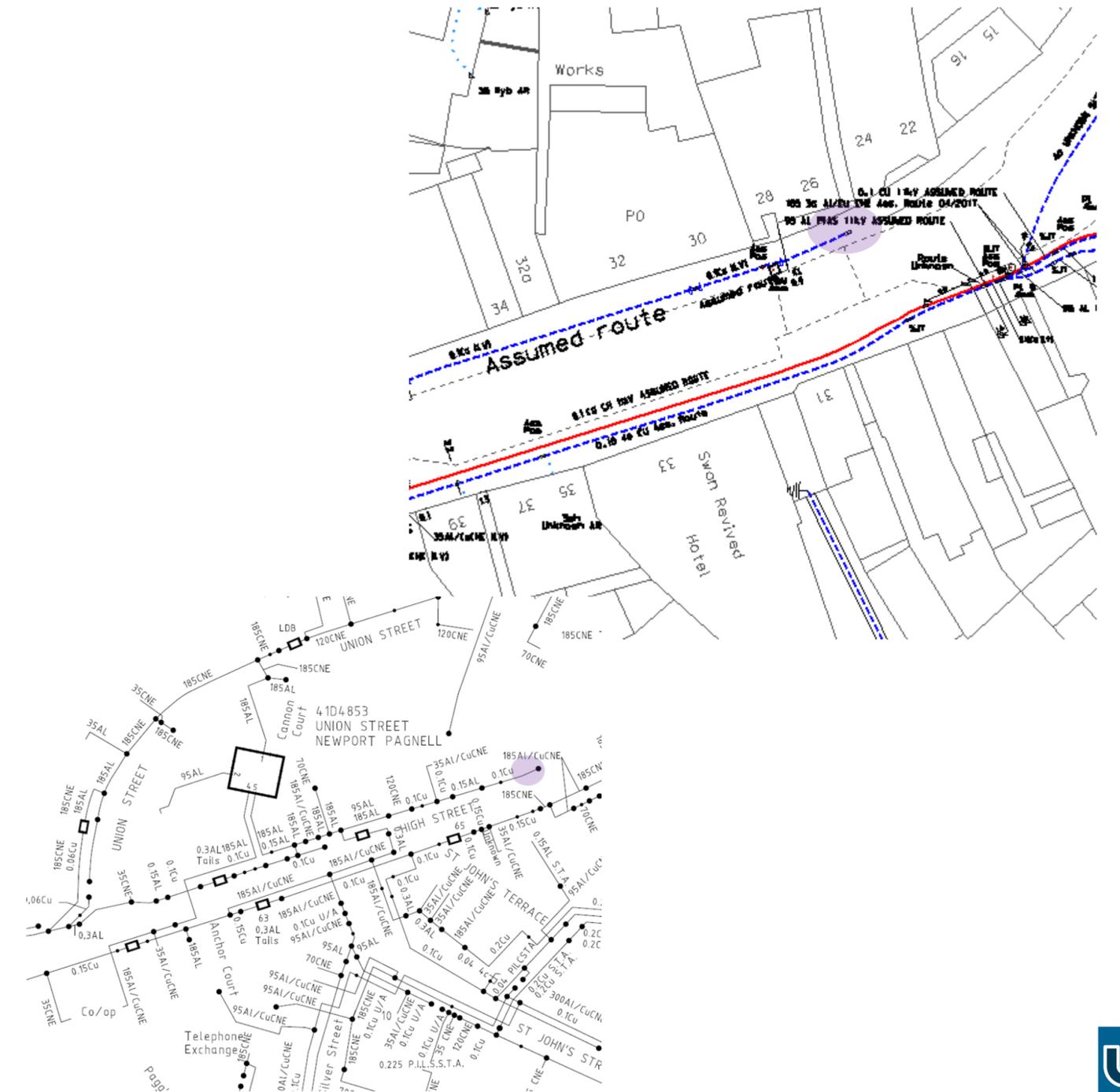
Indicated Location



Most frequent DTF (15) = 120-135m; Mean DTF (130 events) = 150m; SD = 45m

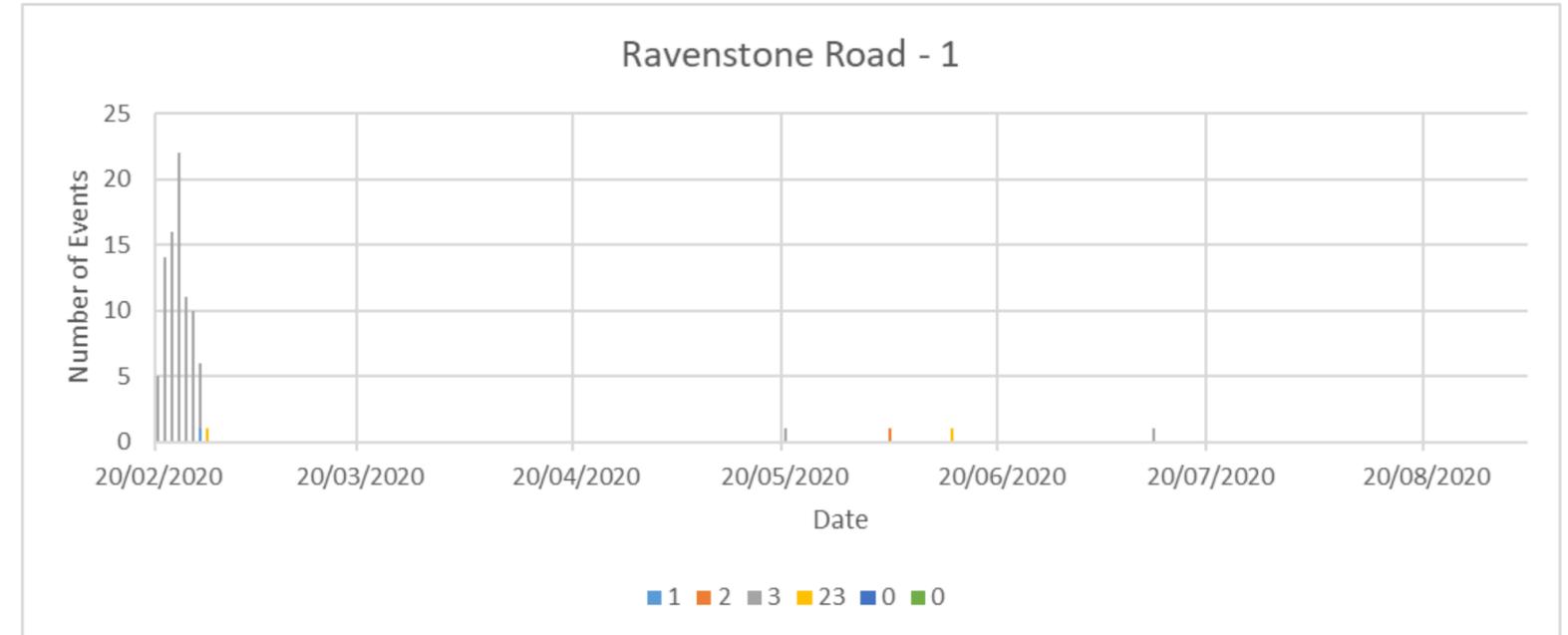
Most events involve L3 alone.

These results are currently interpreted as a defect located at ~153m
~160m is indicated on the network maps (shaded area).



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Ravenstone Rd	120	120
WPD Feeder 1	102	89
WPD Feeder 2	17	30
WPD Feeder 3	0	0
WPD Feeder 4	1	1



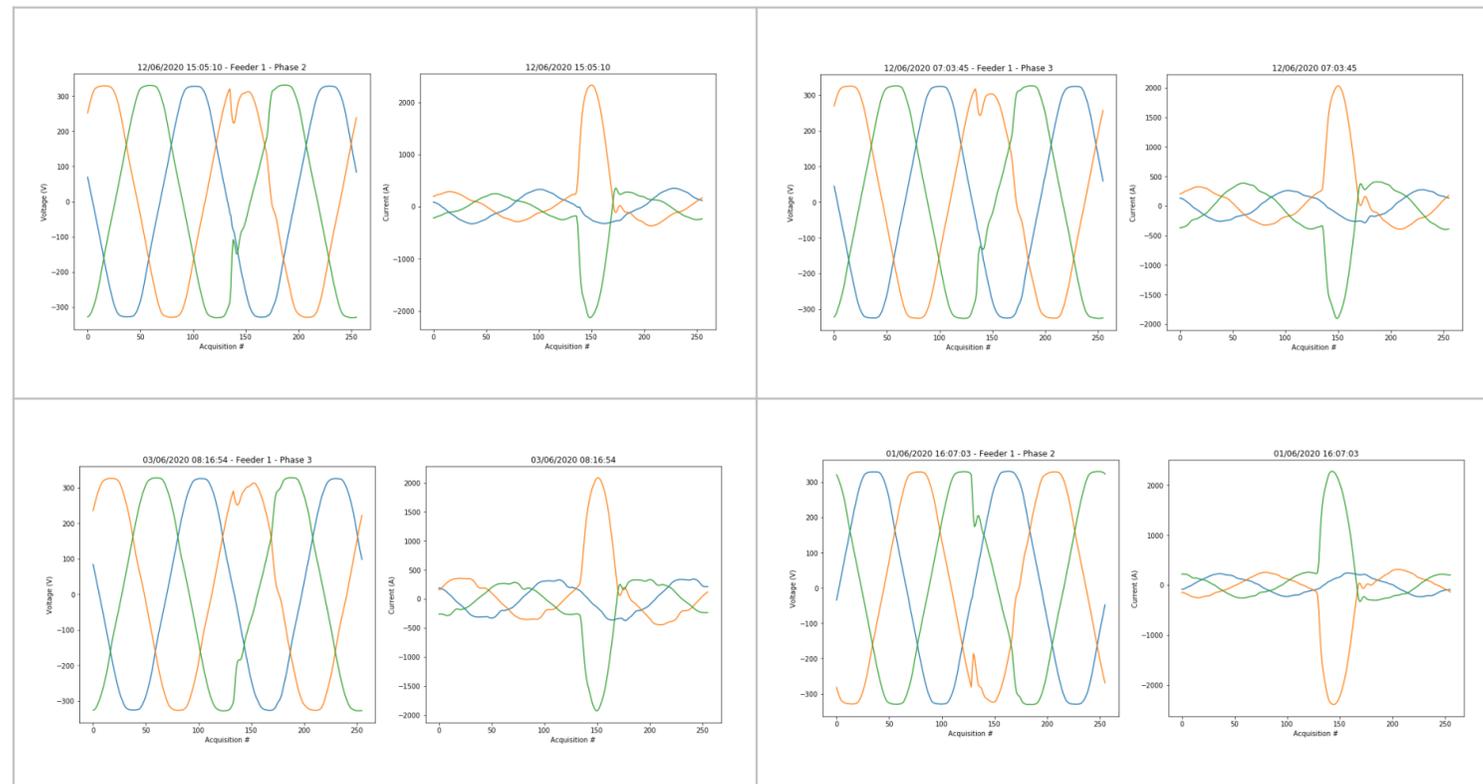
Ravenstone Road feeder data has been reviewed following the feeder identification issue described above, with events from June onwards largely being re-attributed to Feeder 2.

Ravenstone Road Feeder 1 was highly active during the second half of February, and has been quiet since then.

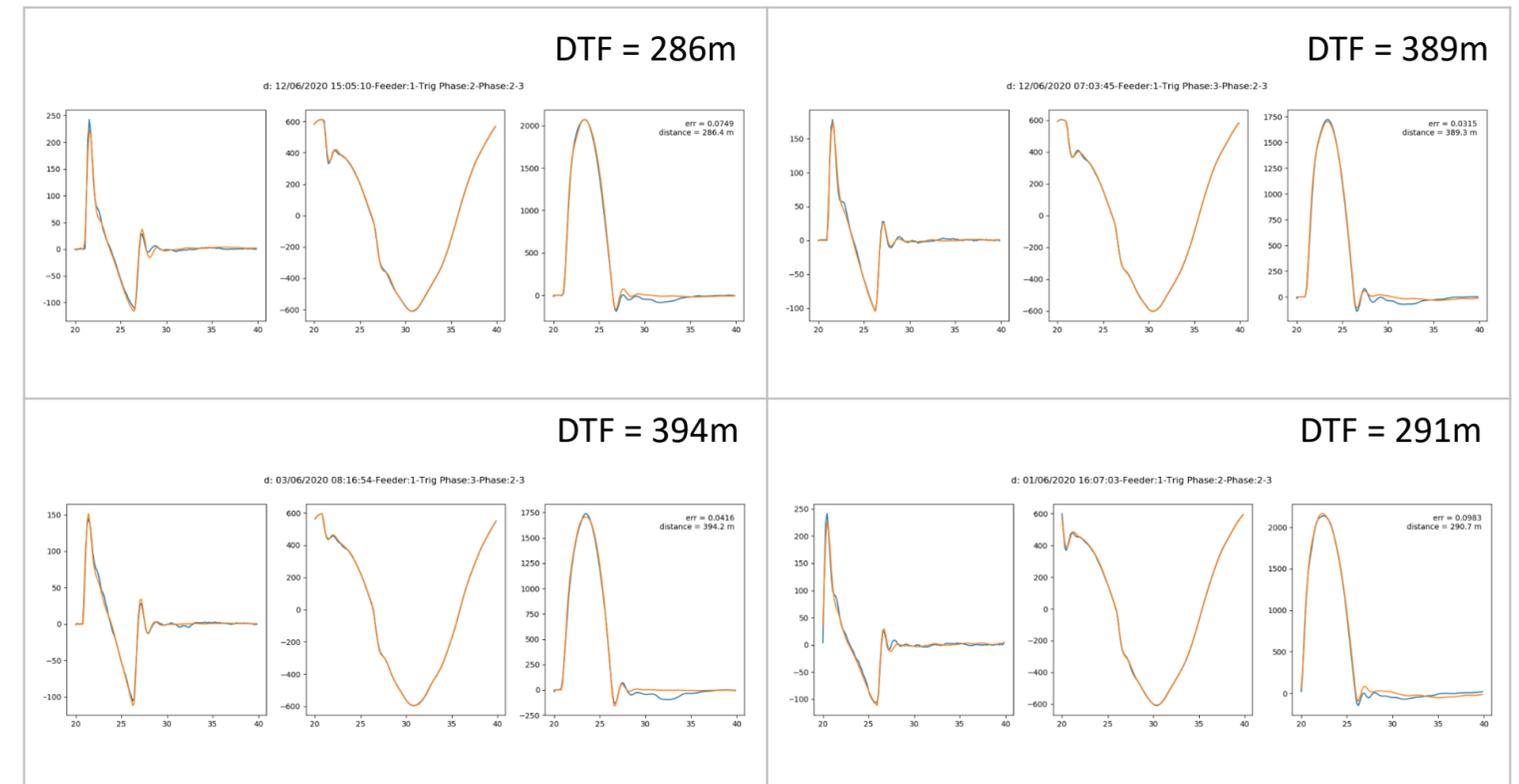
The project is not aware of any fuse operations.



Waveform and Fault Analysis Data



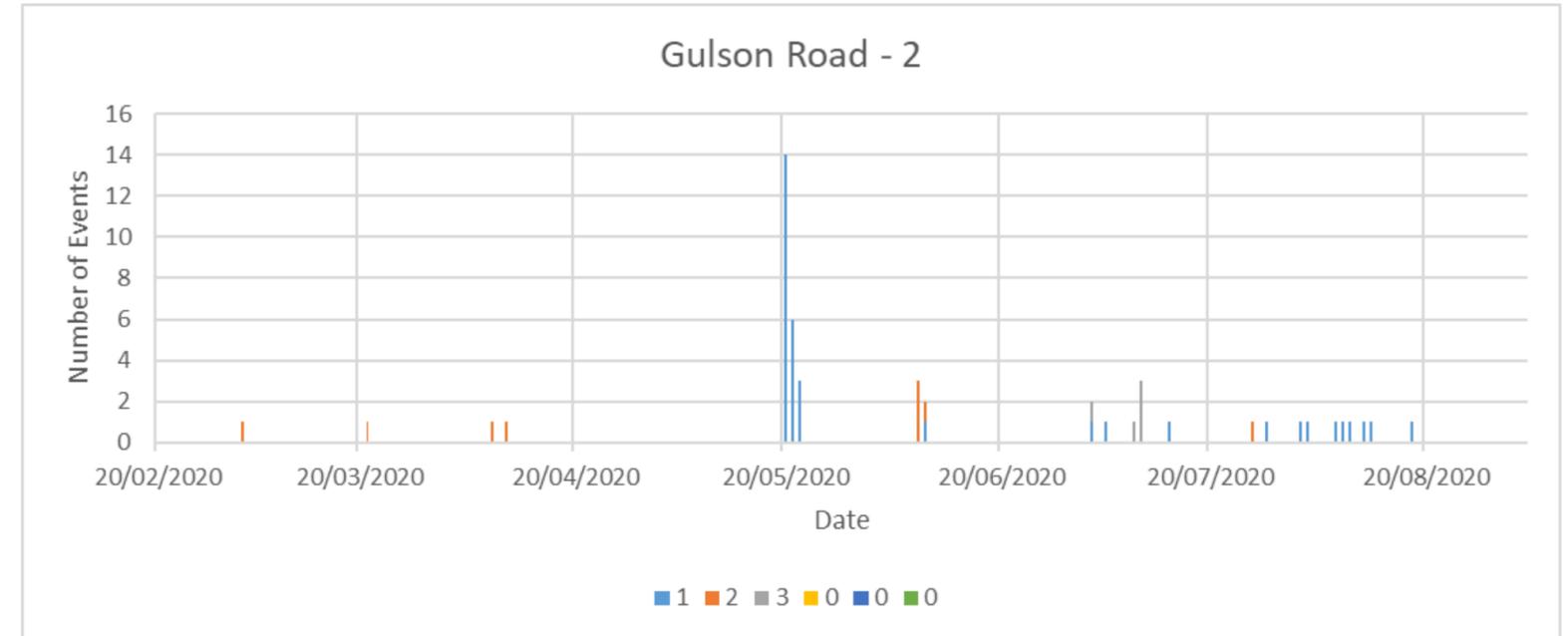
Example captured “pecking fault” waveforms



Example processed waveforms and resulting distances to fault

Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Gulson Rd	121	121
WPD Feeder 1	30	42
WPD Feeder 3	59	50
WPD Feeder 4	11	14
WPD Feeder 9	8	6
WPD Feeder 10	13	9



Note:
1. Gulson Rd – 2 = Gulson Rd WPD Fdr 3

Gulson Road feeder data has been reviewed following the feeder identification issue described above, with some correction of events to Feeder 1.

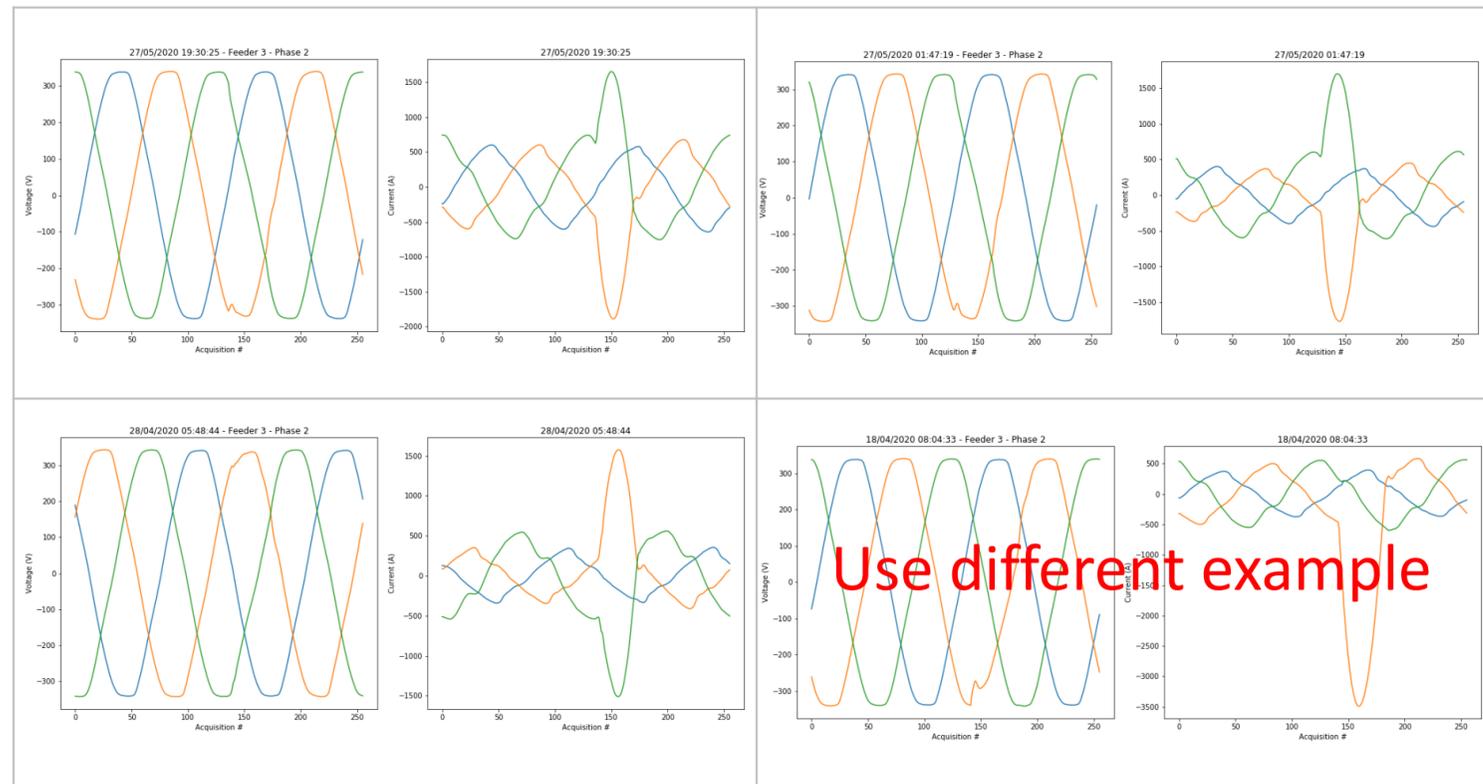
Gulson Road WPD Feeder 3 has shown sporadic activity over Phase One to date, with most events occurring 20-22 May. Events have mostly involved L1 only.

The project is not aware of any fuse operations on this feeder, though a potential location indication was proactively offered to the local team following activity 20-22 May.



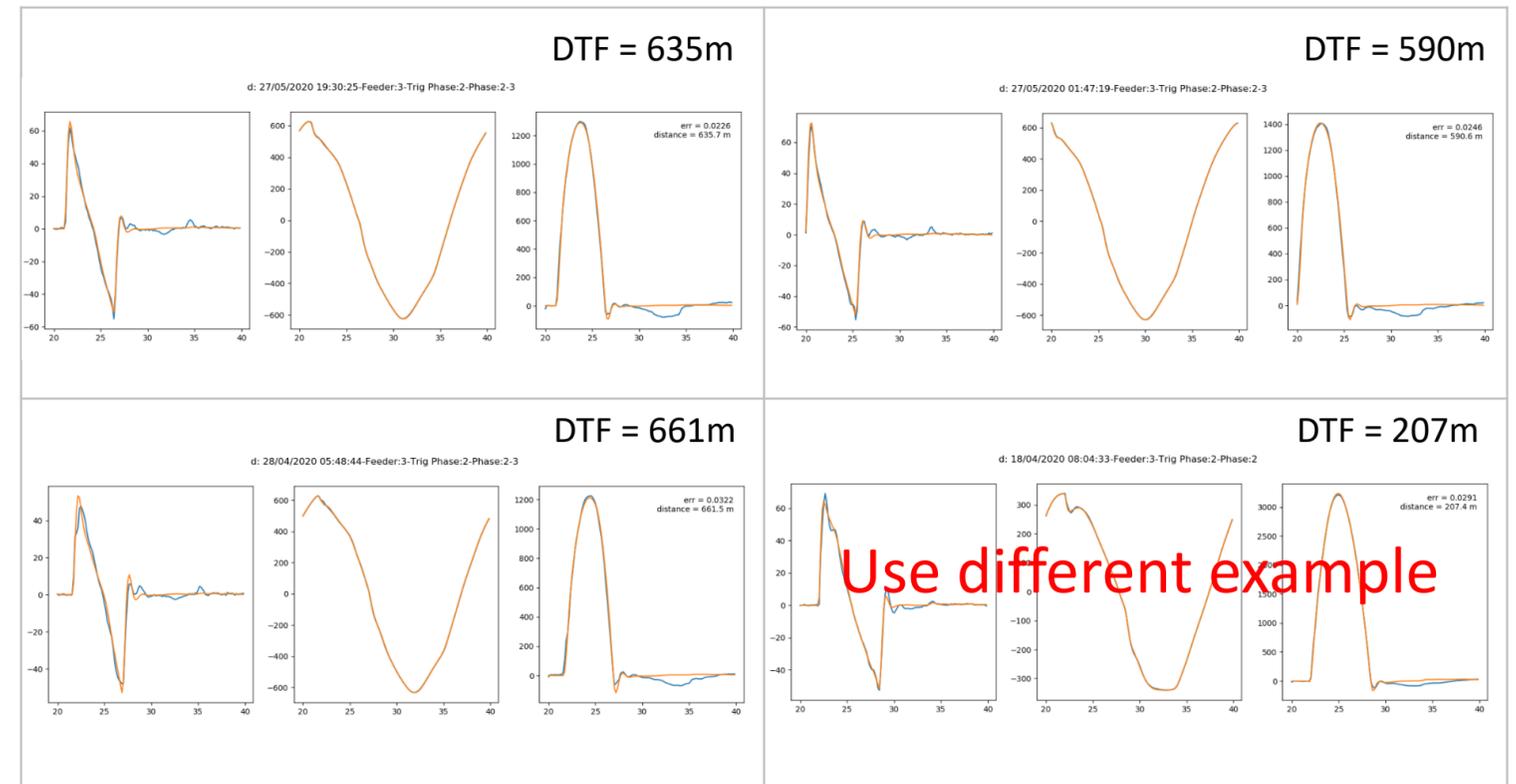
Note: CAUTION – differences exist between monitored WPD feeder references (1,3,4, 9 & 10) and GridKey monitor feeder numbering (1 – 5). This slide shows WPD feeder numbers

Waveform and Fault Analysis Data



Example captured “pecking fault” waveforms

Use different example



Example processed waveforms and resulting distances to fault

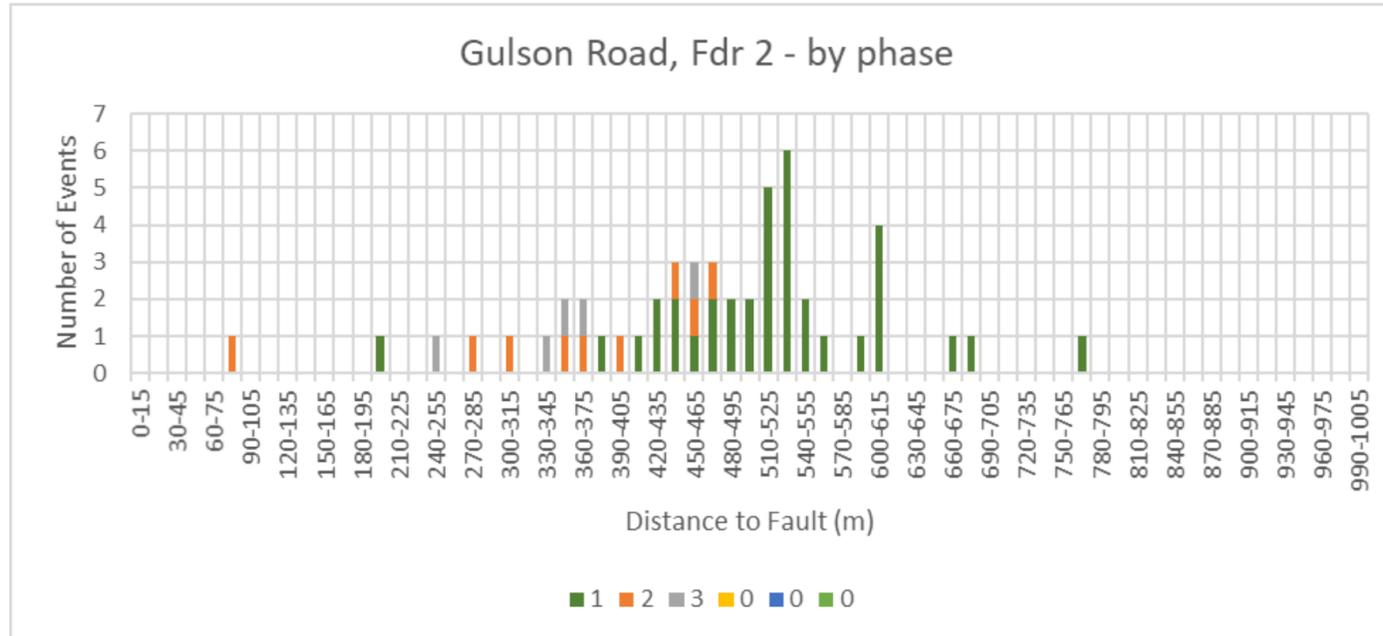
Note:

1. Gulson Rd – 2 = Gulson Rd WPD Fdr 3



Indicated Location

- Note:
1. Gulson Rd – 2 = Gulson Rd WPD Fdr 3

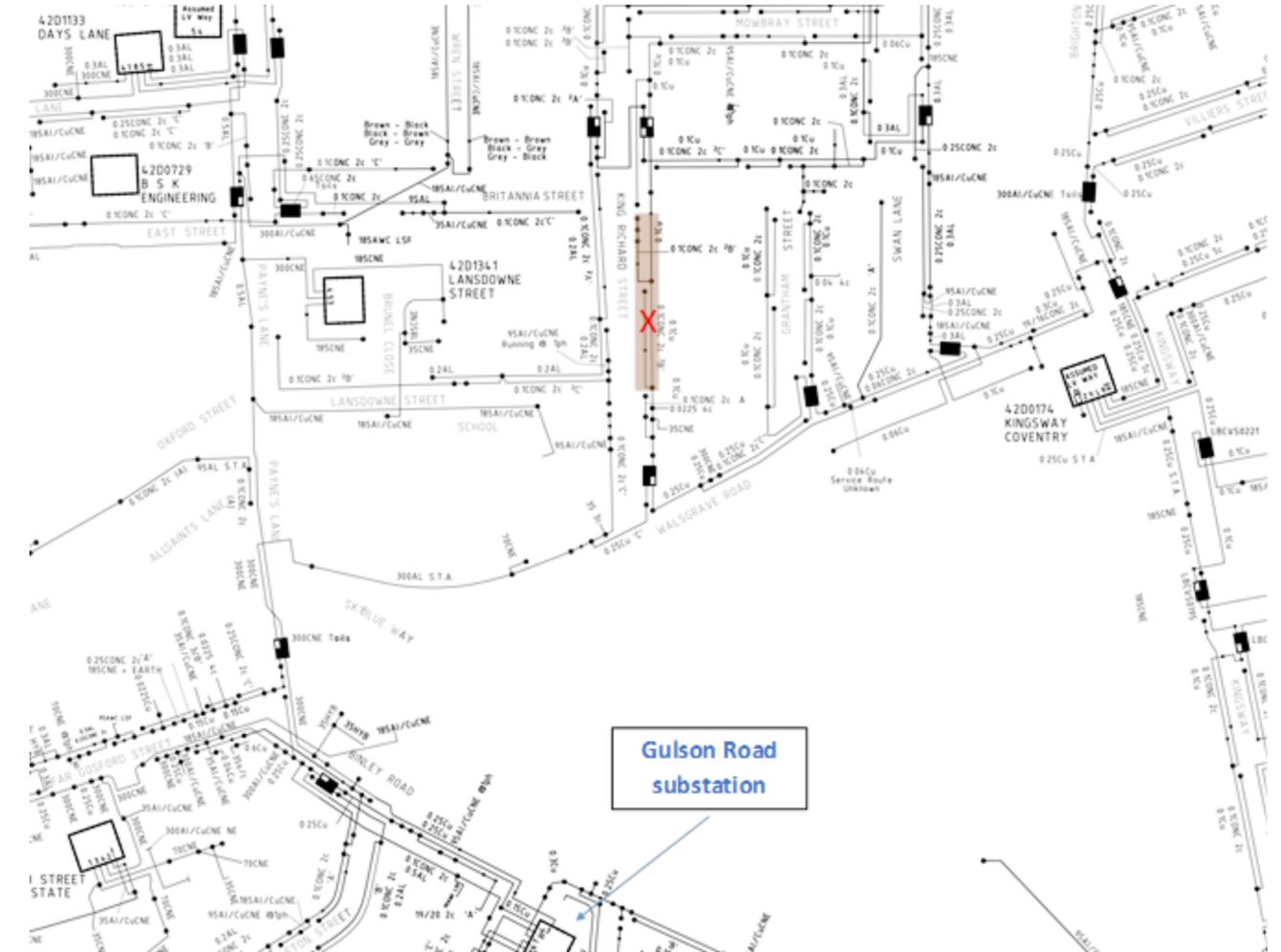


Most frequent DTF (6 events) = 525-540m; Mean DTF (50 events) = 473m; SD = 124m

Most events (31) involve L1 alone.

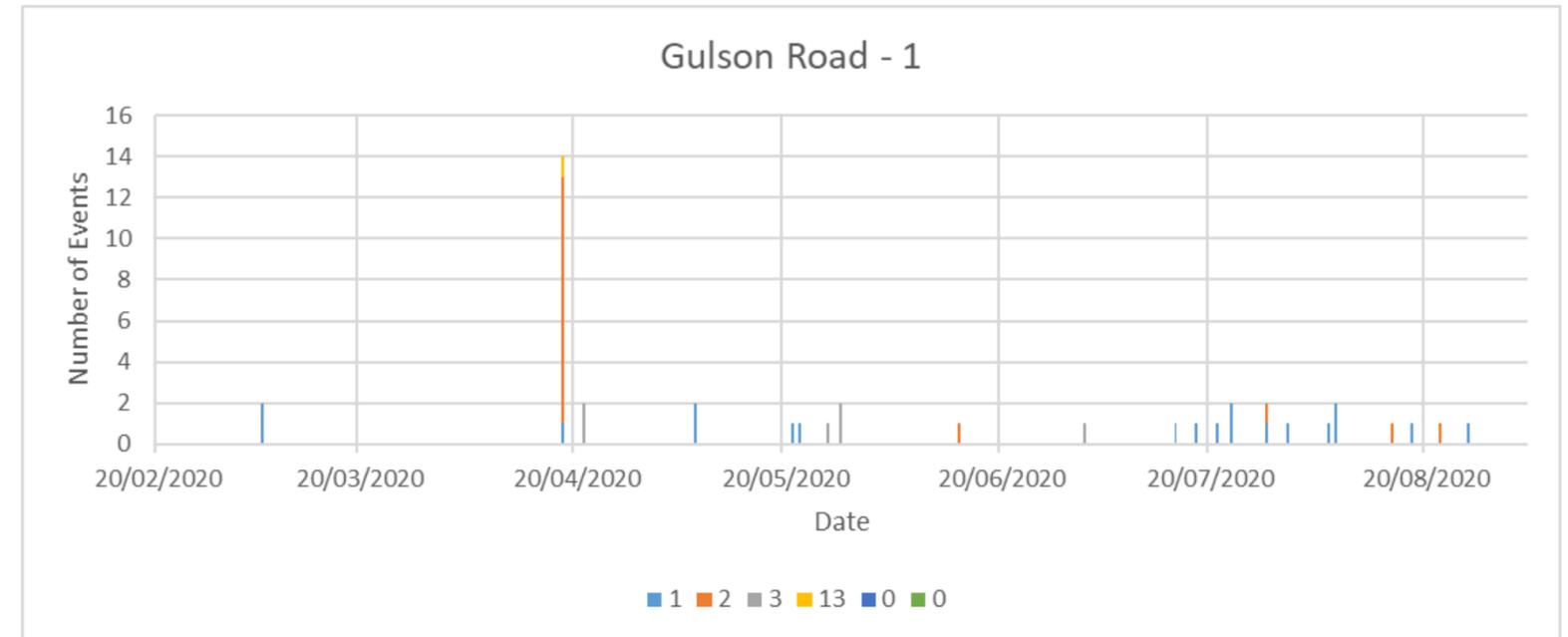
If DTF assessment is limited to events 20-22 May, then Most Frequent DTF (5 events) = 510-540m; Mean DTF (23 events) = 503m; SD = 65m.

A location at around 510m was offered to the local team after 20-22 May events, and this remains a reasonable view. 510m is located adjacent to 28 King Richard Street (red cross). The wider potential location is shown in orange shading, from the branch adjacent to 22 King Richard Street, along to 36 King Richard Street.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Gulson Rd	121	121
WPD Feeder 1	30	42
WPD Feeder 3	59	50
WPD Feeder 4	11	14
WPD Feeder 9	8	6
WPD Feeder 10	13	9



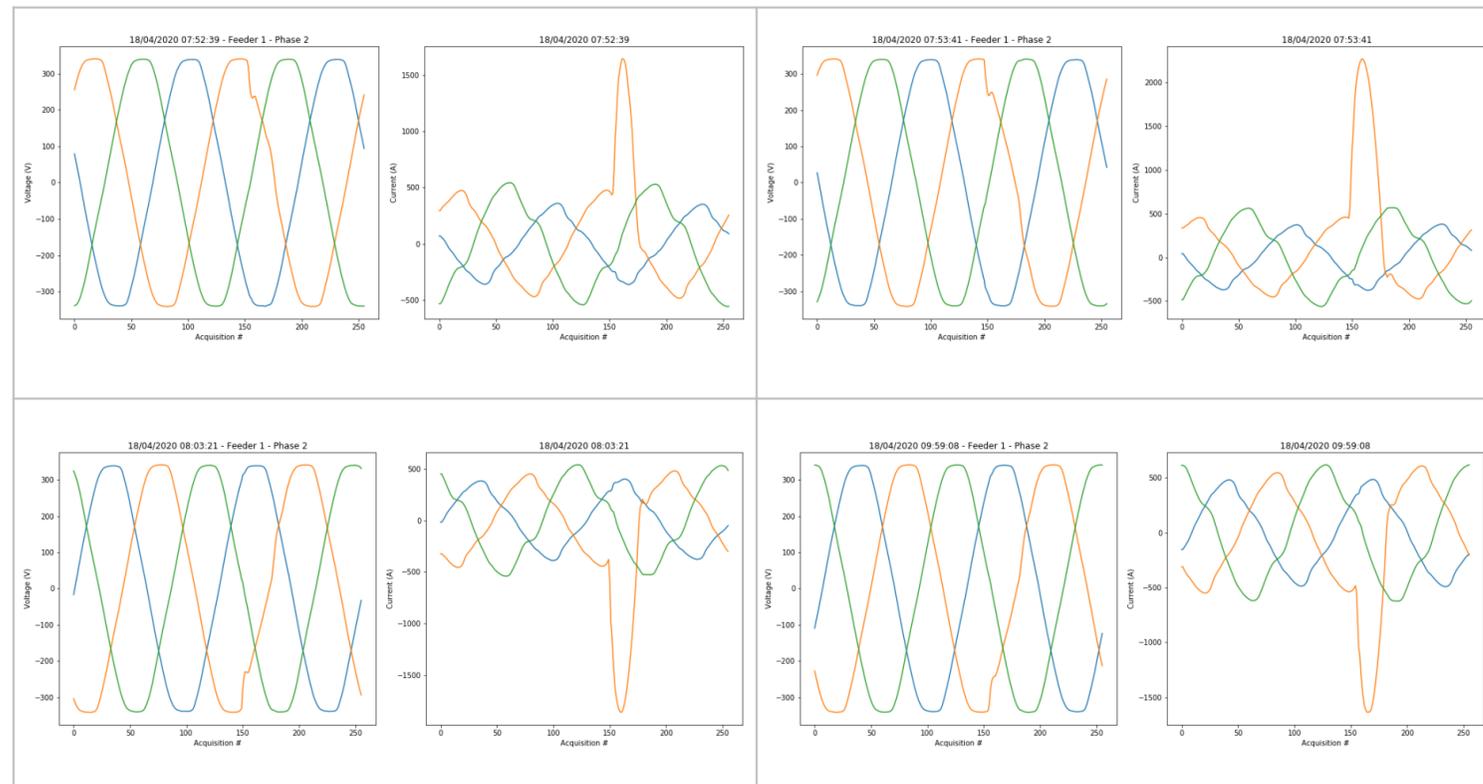
Gulson Road WPD Feeder 1 has shown limited activity other than 18th April, when a fuse operation occurred (07:27). Prior to the fuse operation there had been only three captured and analysed events.

Since 18th April, there have been 26 events, mostly L1 only (16), with L2 only (4) and L3 only (6).

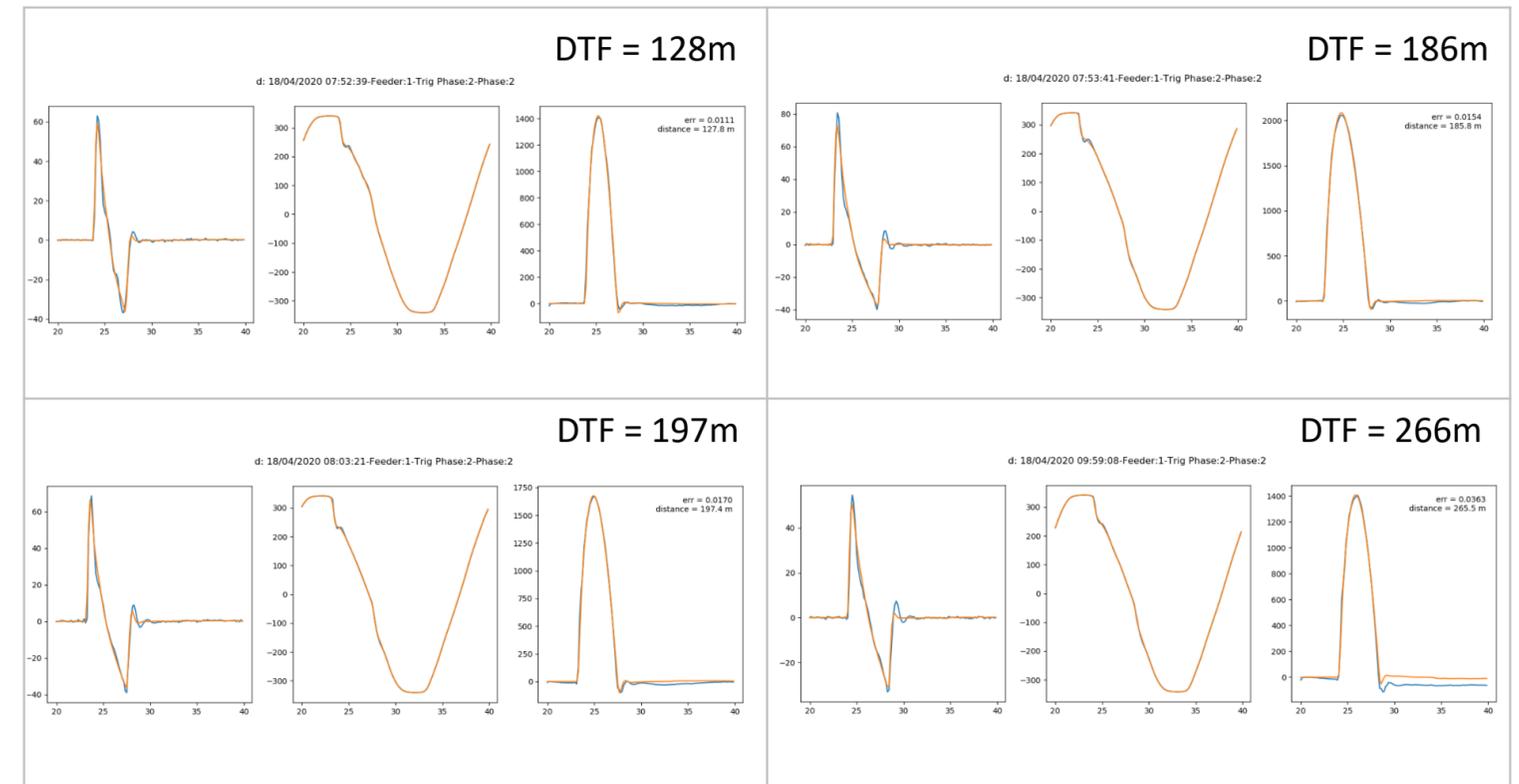
Note: CAUTION – differences exist between monitored WPD feeder references (1,3,4, 9 & 10) and GridKey monitor feeder numbering (1 – 5). This slide shows WPD feeder numbers



Waveform and Fault Analysis Data – “Pecking” events



Example captured “pecking fault” waveforms



Example processed waveforms and resulting distances to fault

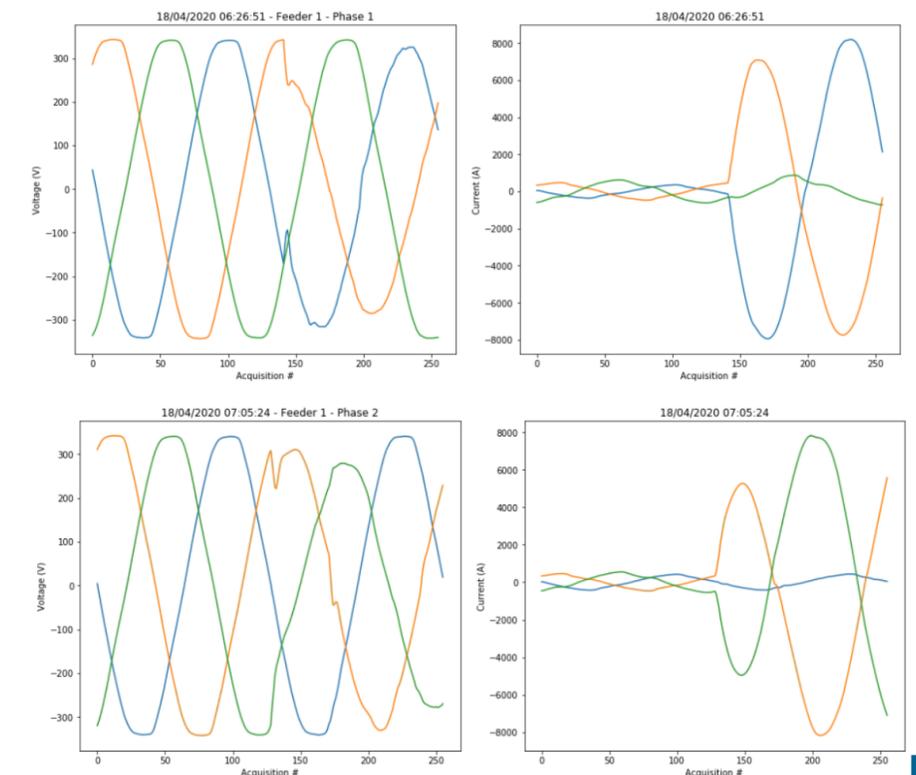
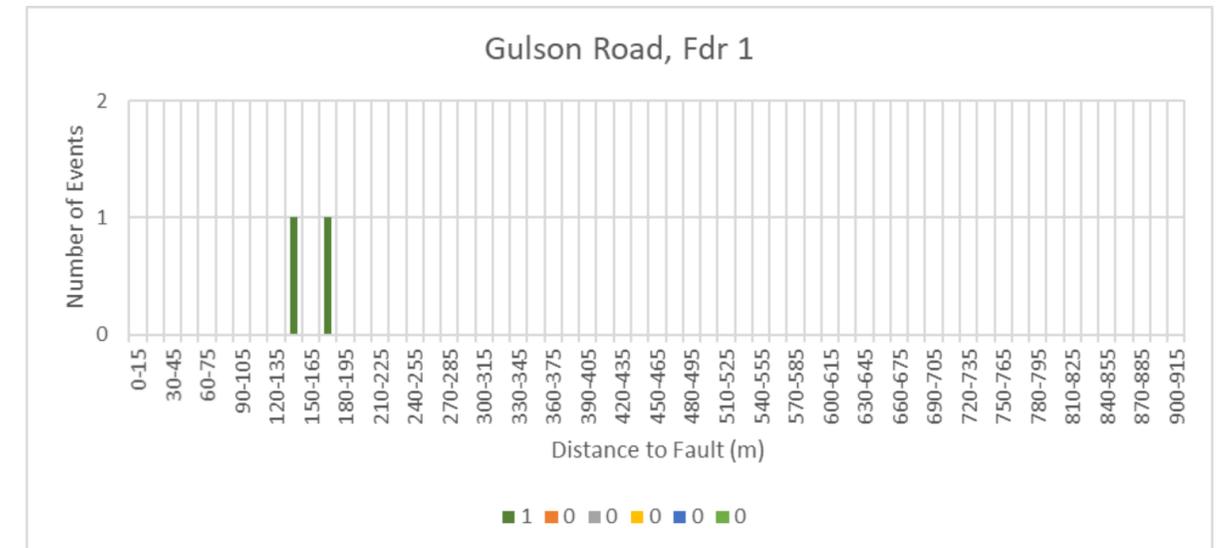
Fuse Op events 18/04/2020 - 1

Prior to the fuse operations on 18/04, there were only two events meeting quality criteria (both 06/03). Therefore previous events provided no significant basis for estimating distance to fault (upper chart).

Waveforms were captured for the two fuse operating events on 18/04:

- 07:26 BST, involving L1-L2 and causing L1 to operate;
- and 08:05 BST, involving L2-L3 and causing L3 to operate

Fuse operating faults have a very different characteristic (see lower two charts) to typical pecking faults and are not yet routinely analysed. In addition, the current hardware-related limited sample period (1 cycle after the event start) does not necessarily allow for stable fault current to have established, and for a reliable DTF assessment



Fuse Op events 18/04/2020 - 2

Field fault location and repair took place on Sat 18th April, before any ALARM location data was analysed.

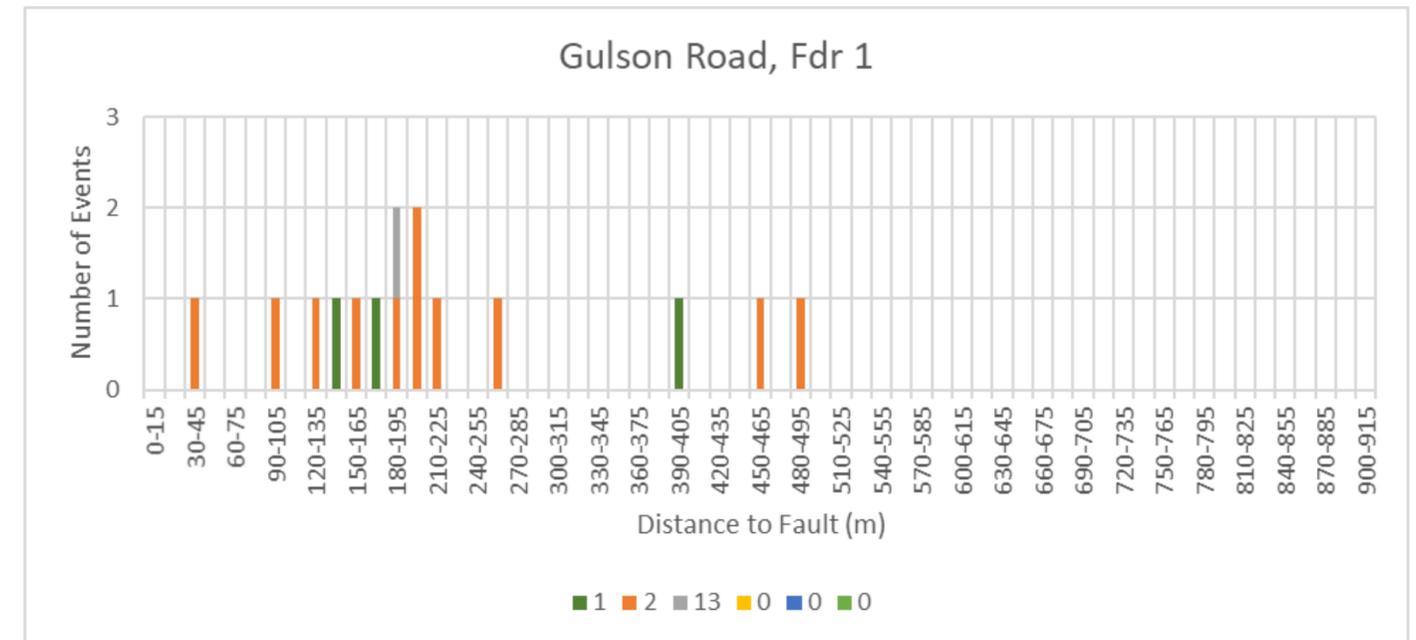
Retrospectively, distance assessment was undertaken using available data from before the 18/04, and for 18/04. This included a best-effort analysis of the fuse operation events.

This suggested:

- a most frequent pecking fault analysis distance of 180-210m, with significant noise/variation (see upper chart), however different phase conductor involvement clouds interpretation; and
- ~ 120m based on assessment of the fuse operation events (with limited cycles/data).

Given limited indication from the pecking fault analysis the fuse-op assessment ~120m was offered.

The actual repair location was ~200m (average of all pecking events up to and including 18/04 was 183m)

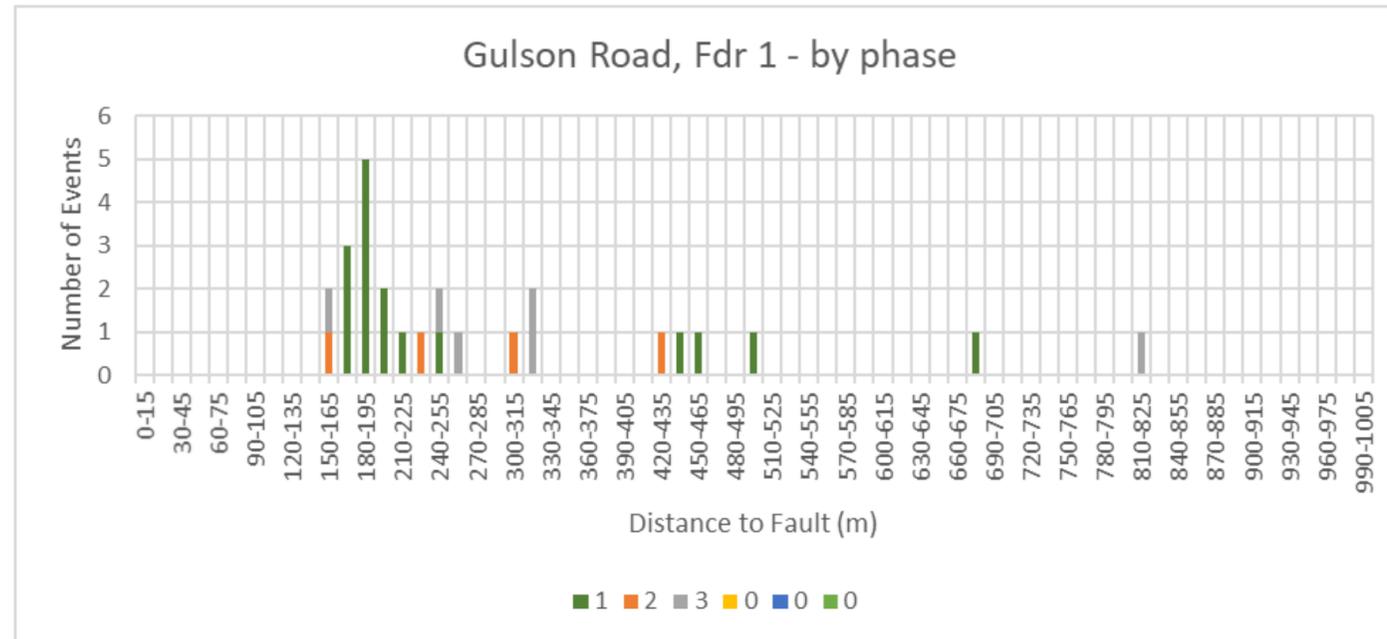


Learning:

1. Currently, only limited reliance should be placed on assessments of waveforms from fuse op events
2. Fullest picture should be offered (e.g. including conflicting indications if they exist, e.g. fault vs pecking, variable phases, range of pecking fault indications etc)
3. Interpretation of “pecking” fault data is still in an early stage, there is much still to be learned (e.g. average vs most frequent vs spread).
4. Any faulted joints or cable sections should be collected for possible later investigation



Indicated Location (post 18/04/2020)



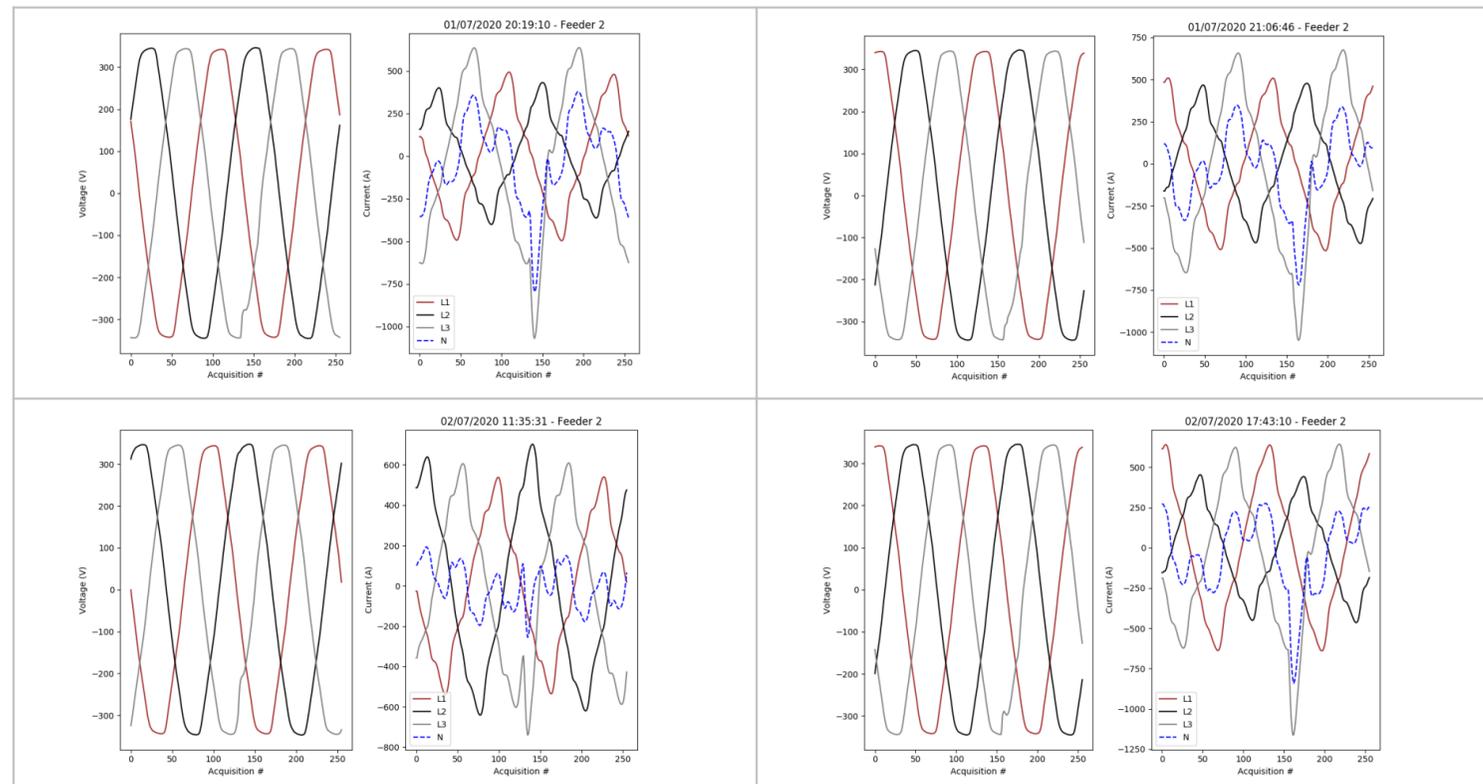
Based on 26 events since 18th April when a repair was completed on Feeder 1 at ~200m:

Most frequent DTF (5 events) = 180-195m; Mean DTF (26 events) = 295m; SD = 169m

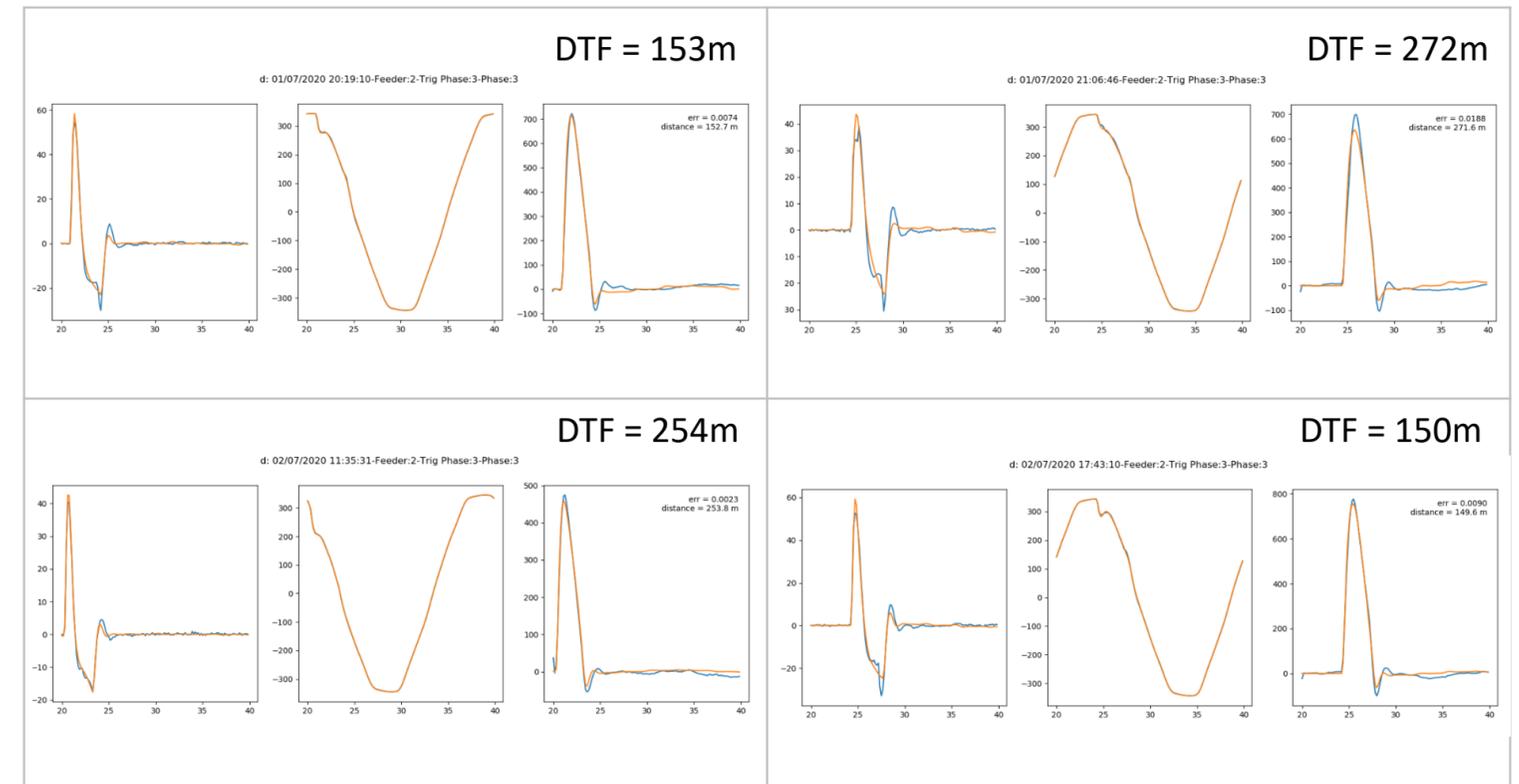
At present, this does not appear to be a credible indication, having a mean DTF indication that is considerably beyond the physical length of the feeder (~208m). Further assessment of this feeder will be undertaken in Phase 2 with the enhanced hardware.



Waveform and Fault Analysis Data

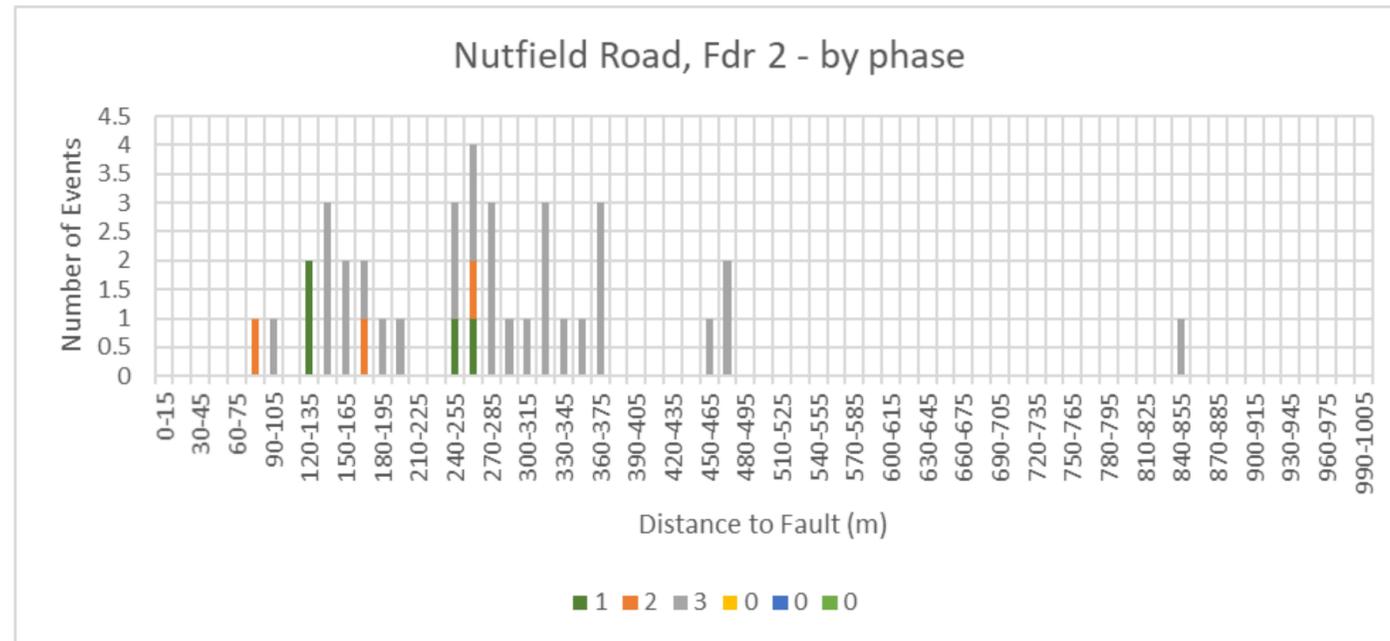


Example captured “pecking fault” waveforms



Example processed waveforms and resulting distances to fault

Indicated Location



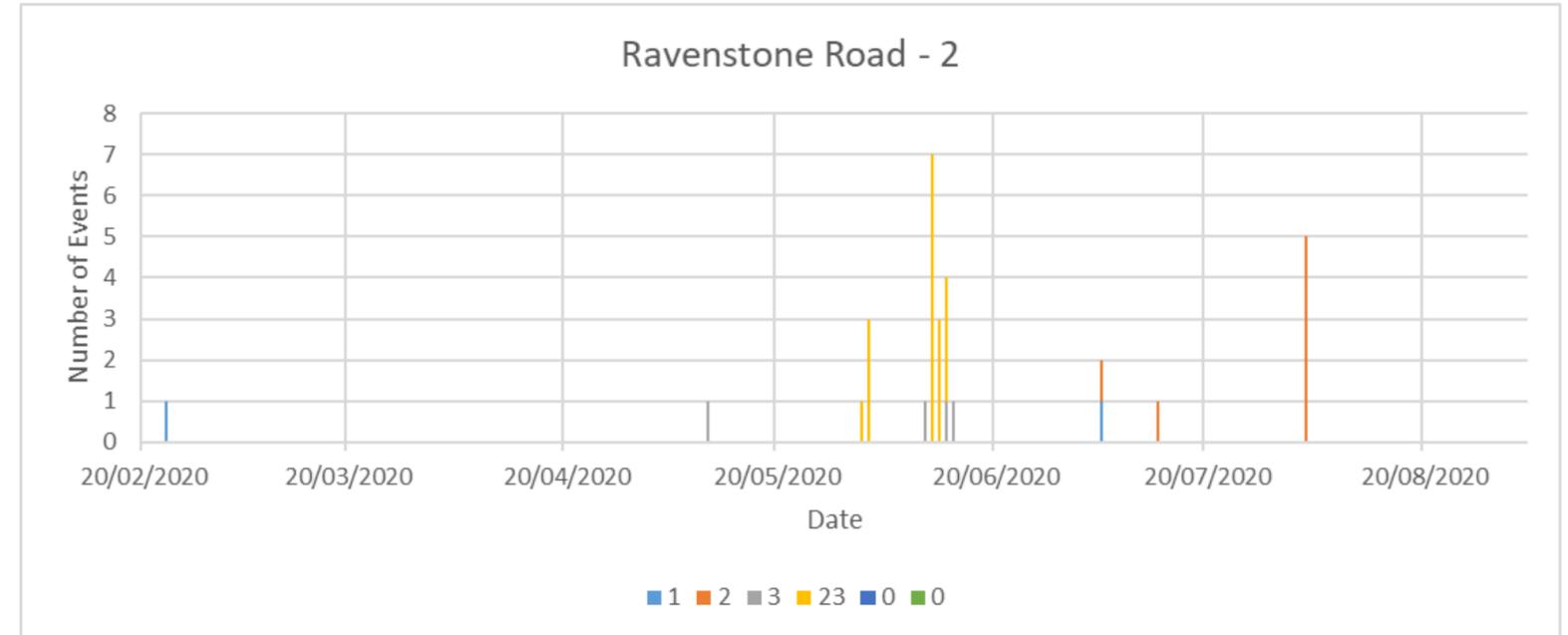
Most frequent DTF (4 events) = 255-270m; Mean DTF (37 events) = 274m; SD = 139m

At present, this data does not present a clear indication. It could be interpreted that there are two distinct indications: at 135-150m and somewhere around 255-270m. Further assessment of this feeder will be undertaken in Phase 2 with the enhanced hardware.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Ravenstone Rd	120	120
WPD Feeder 1	102	89
WPD Feeder 2	17	30
WPD Feeder 3	0	0
WPD Feeder 4	1	1



Ravenstone Road feeder data has been reviewed following the feeder identification issue described above, with events from June onwards largely being re-attributed to Feeder 2.

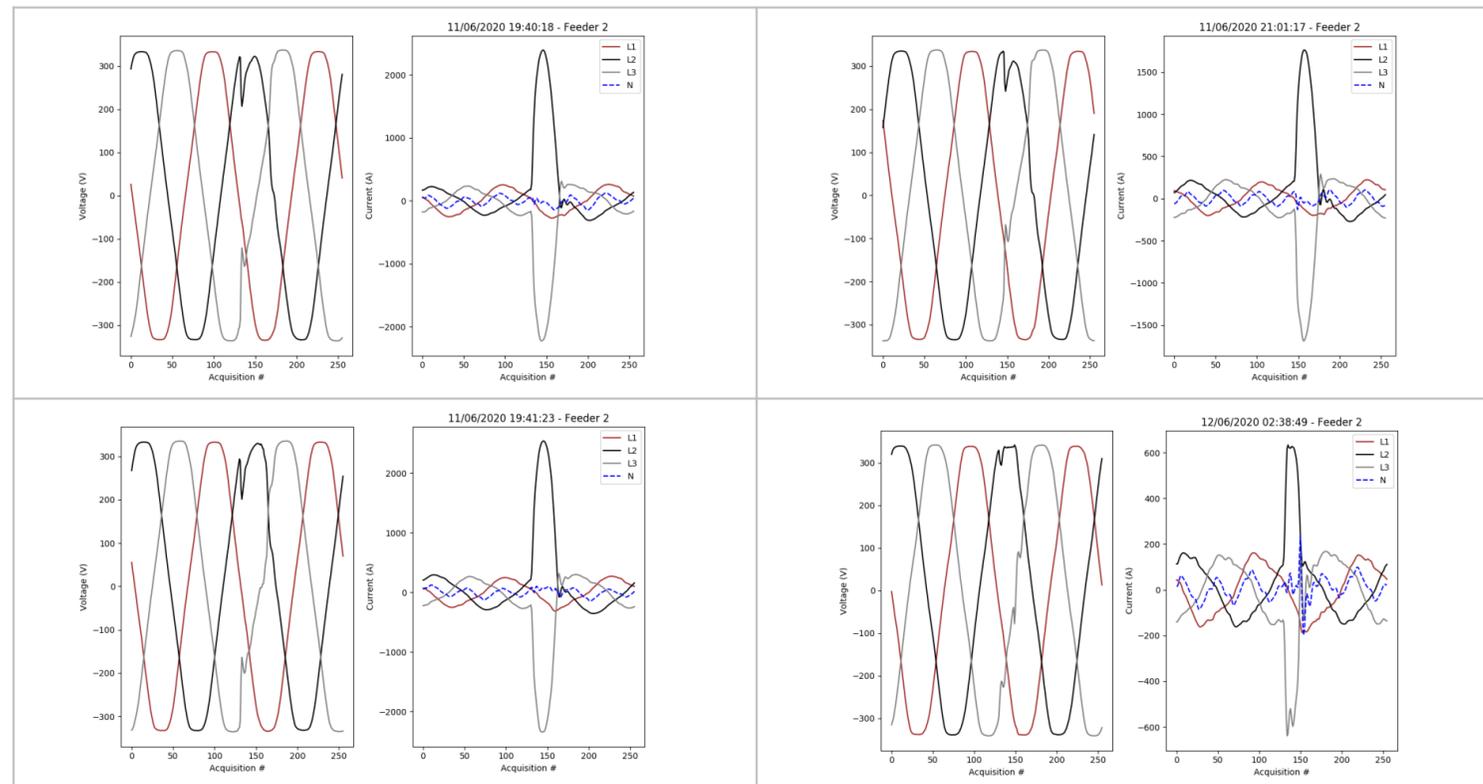
Ravenstone Road WPD Feeder 2 activity has been quite sporadic.

There has been one known transient fuse operation on 13/07/2020.

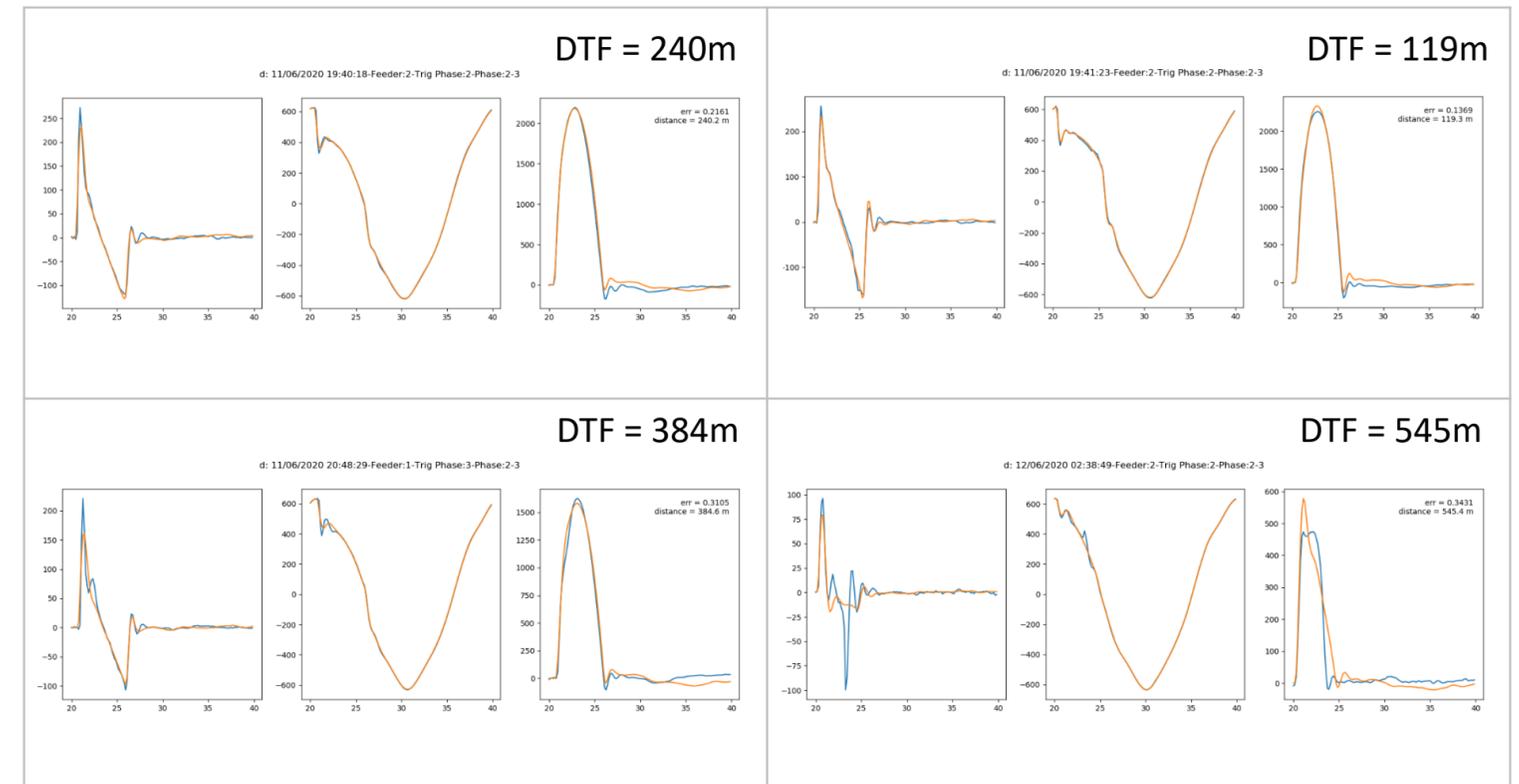
Most events have involved only phases 2-3.



Waveform and Fault Analysis Data – “Pecking” events

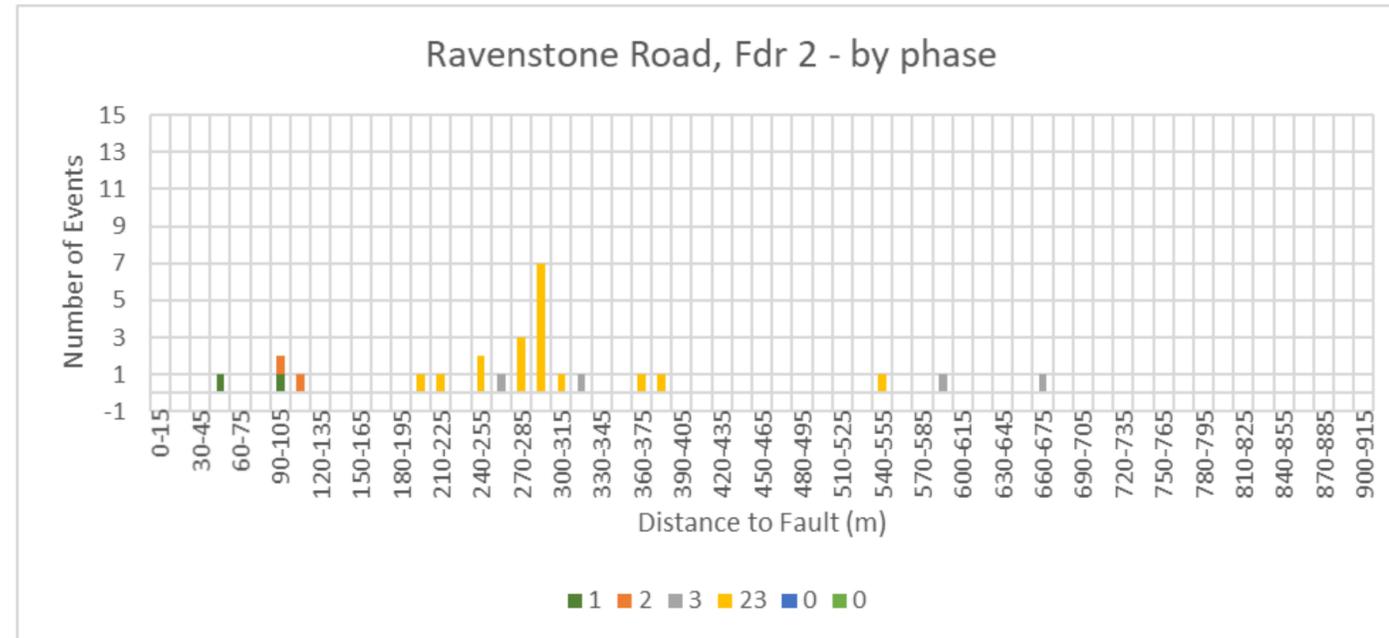


Example captured “pecking fault” waveforms



Example processed waveforms and resulting distances to fault

Indicated Location



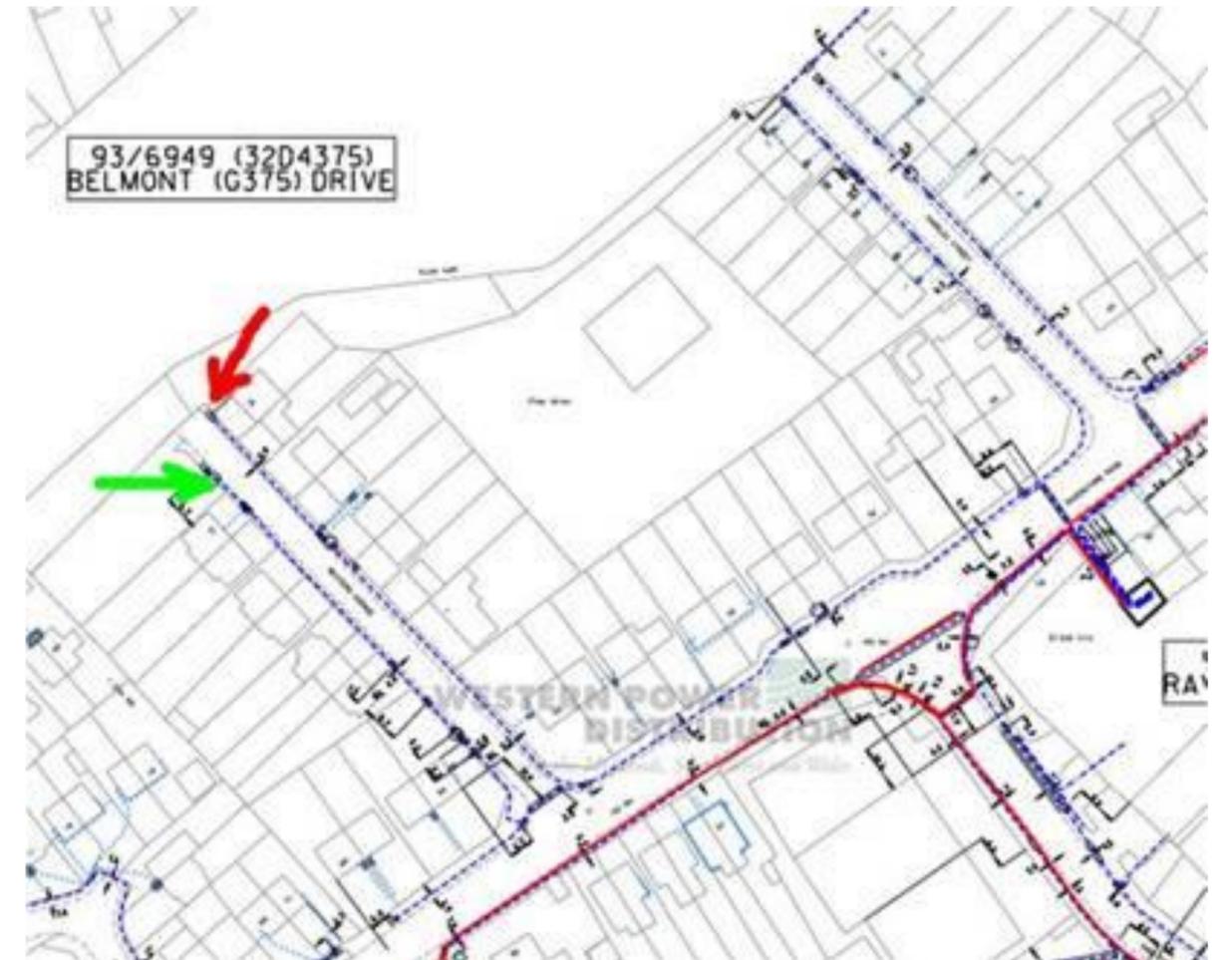
Most frequent DTF (6 events) = 285-300m; Mean DTF (30 events) = 292m; SD = 140m

Most events involve L2-L3.

Current interpretation is tentative, recognising a relatively low number of events and that the data suggests involvement of L1-only and L2-only events at quite different distances to L2-L3 events (there are also 4 L3-only events occurring across a range of distances). Analysis of only the L2-L3 events shifts the mean DTF marginally to 300m.

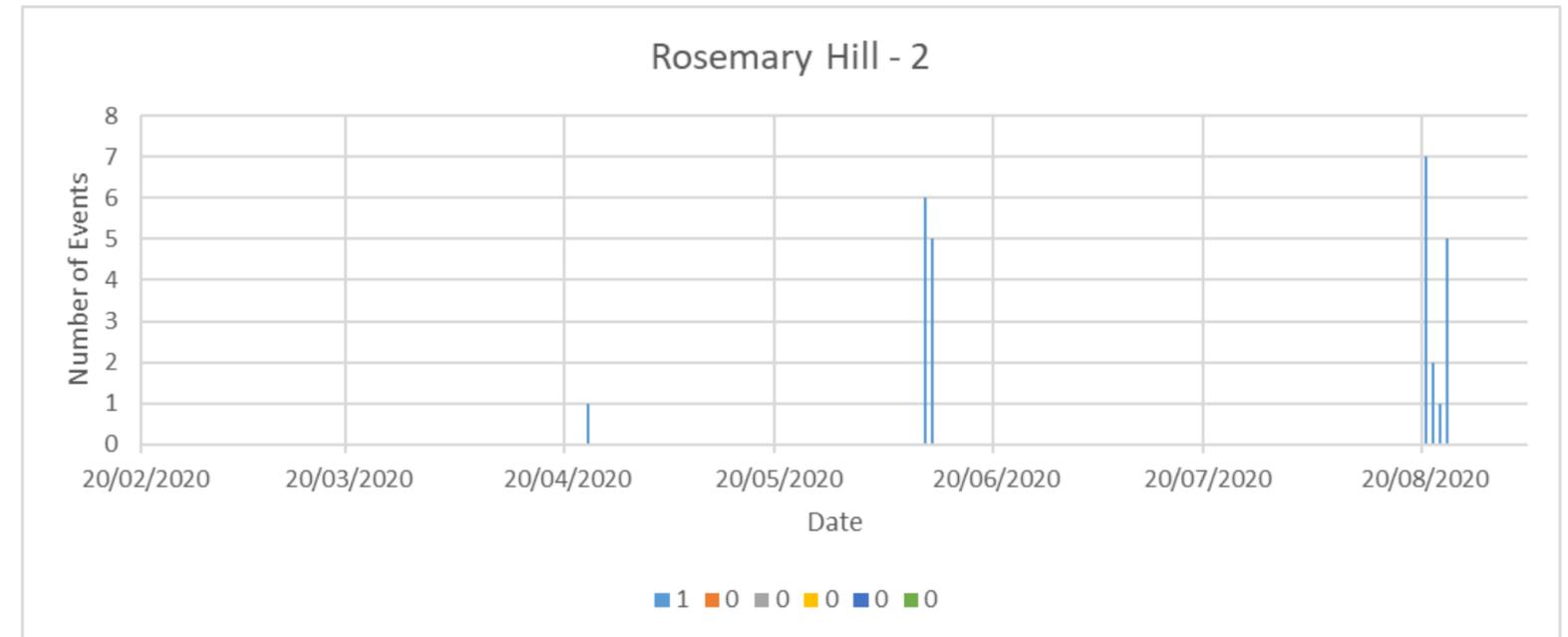
Applying this DTF indication to the branched structure of Ravenstone Road Fdr 2 (Western Ave.), 292m suggests that the fault is at the end of one of the branches running down Western Avenue (red and green arrows in the drawing below, red arrow=264m, green arrow=271m).

These potential locations have been shared with the local team, following the fuse operation on 13/07/2020.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Rosemary Hill	35	35
WPD Feeder 2	7	3
WPD Feeder 3	23	27
WPD Feeder 4	2	4
WPD Feeder 5	3	1



Note:

1. Rosemary Hill – 2 = Rosemary Hill WPD Fdr 3

Rosemary Hill feeder data has been reviewed following the feeder identification issue described above, with a small number of corrections applied.

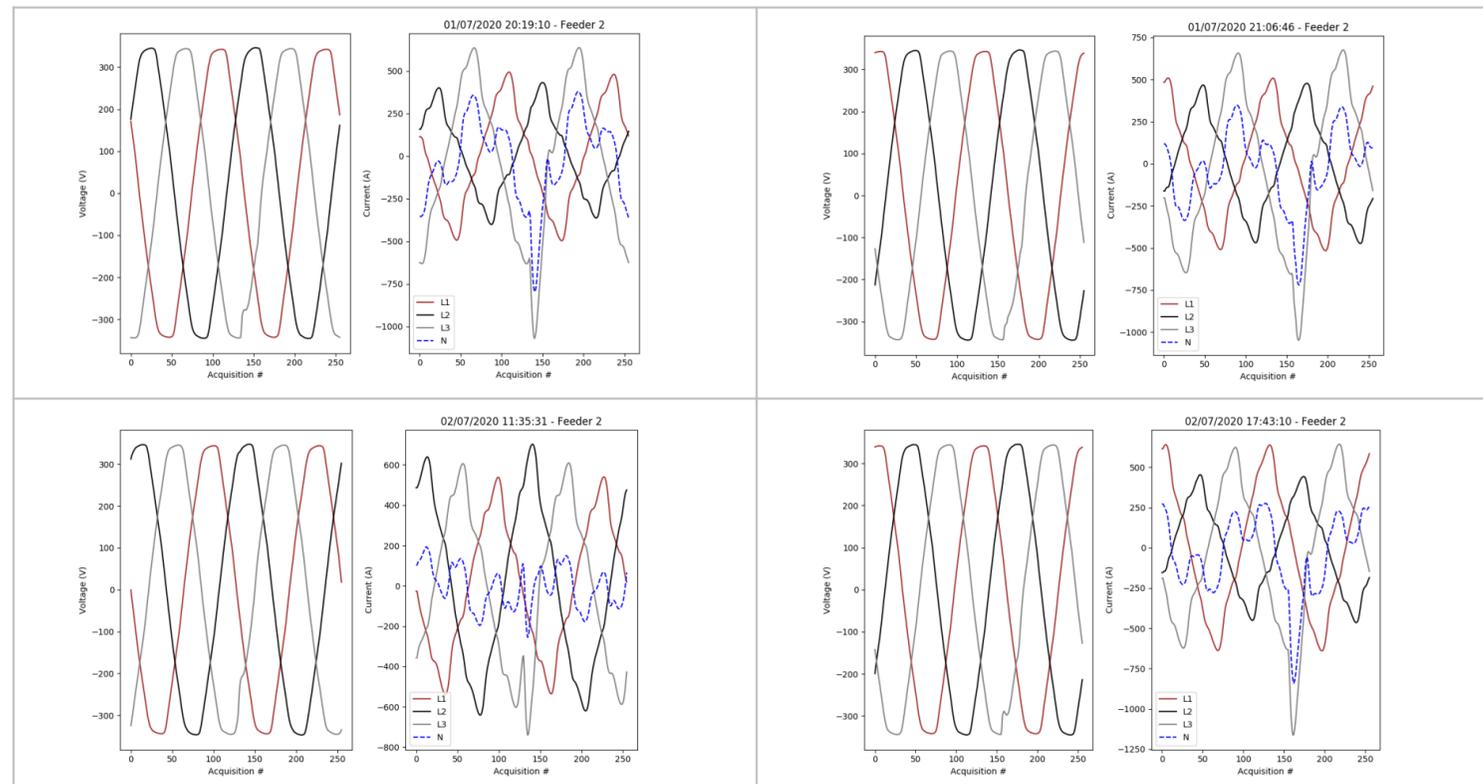
Available data suggests sporadic flurries of activity for Feeder 2. All the events are associated with L1.

The project is not aware of any fuse operations on this feeder during the monitored period.

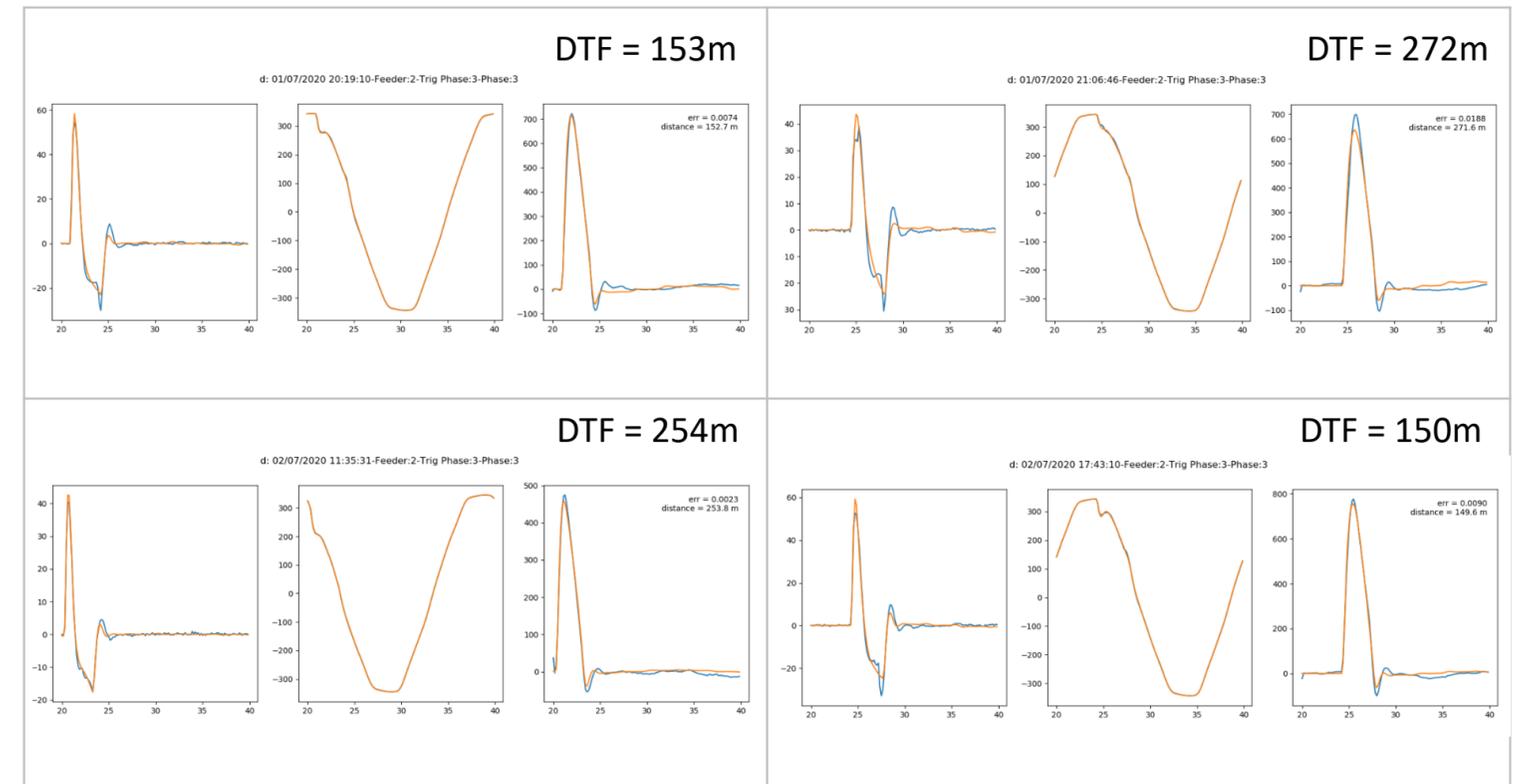


Note: CAUTION – differences exist between monitored WPD feeder references (2,3,4 & 5) and GridKey monitor feeder numbering (1 – 4). This slide shows WPD feeder numbers

Waveform and Fault Analysis Data

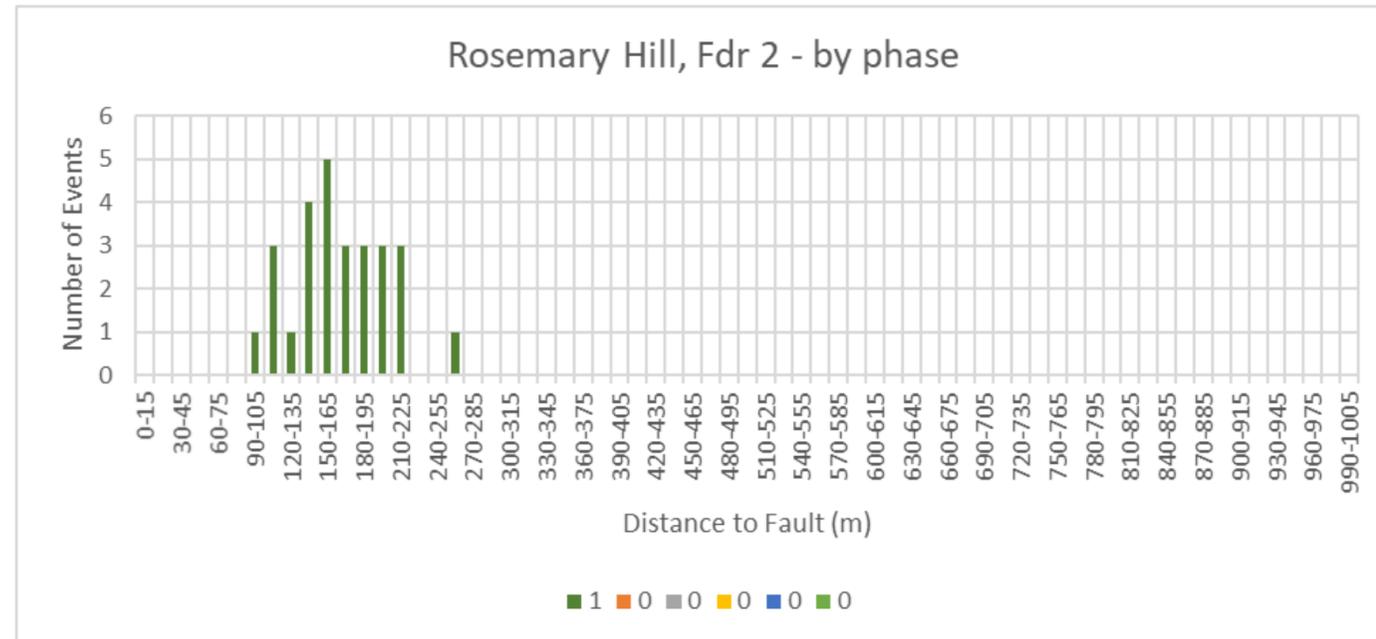


Example captured “pecking fault” waveforms



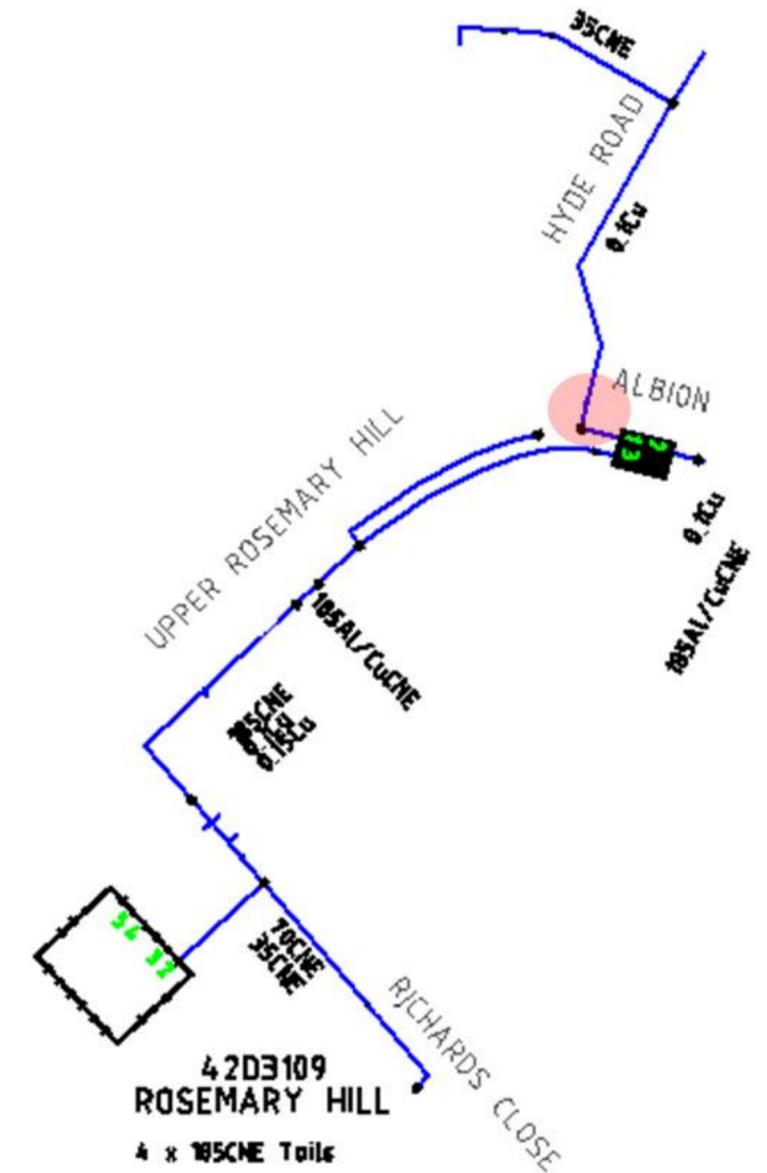
Example processed waveforms and resulting distances to fault

Indicated Location



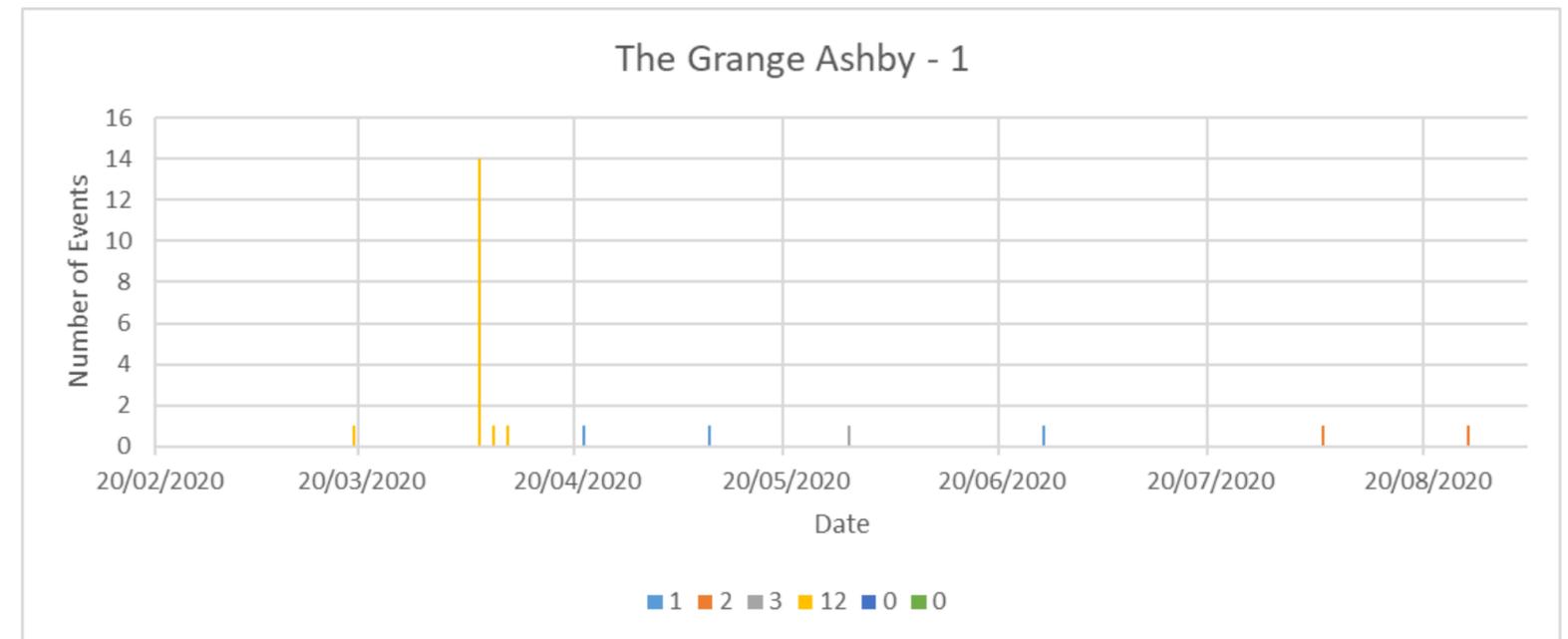
Most frequent DTF (5 events) = 150-165m; Mean DTF (27 events) = 168m; SD = 39m

These results are currently interpreted as a possible defect located at ~168m. The joint at ~161m is shown on the network schematic.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
The Grange	24	24
WPD Feeder 1	22	23
WPD Feeder 2	1	1
WPD Feeder 3	1	0



The Grange feeder data has been reviewed following the feeder identification issue described above. One change of feeder association has been made.

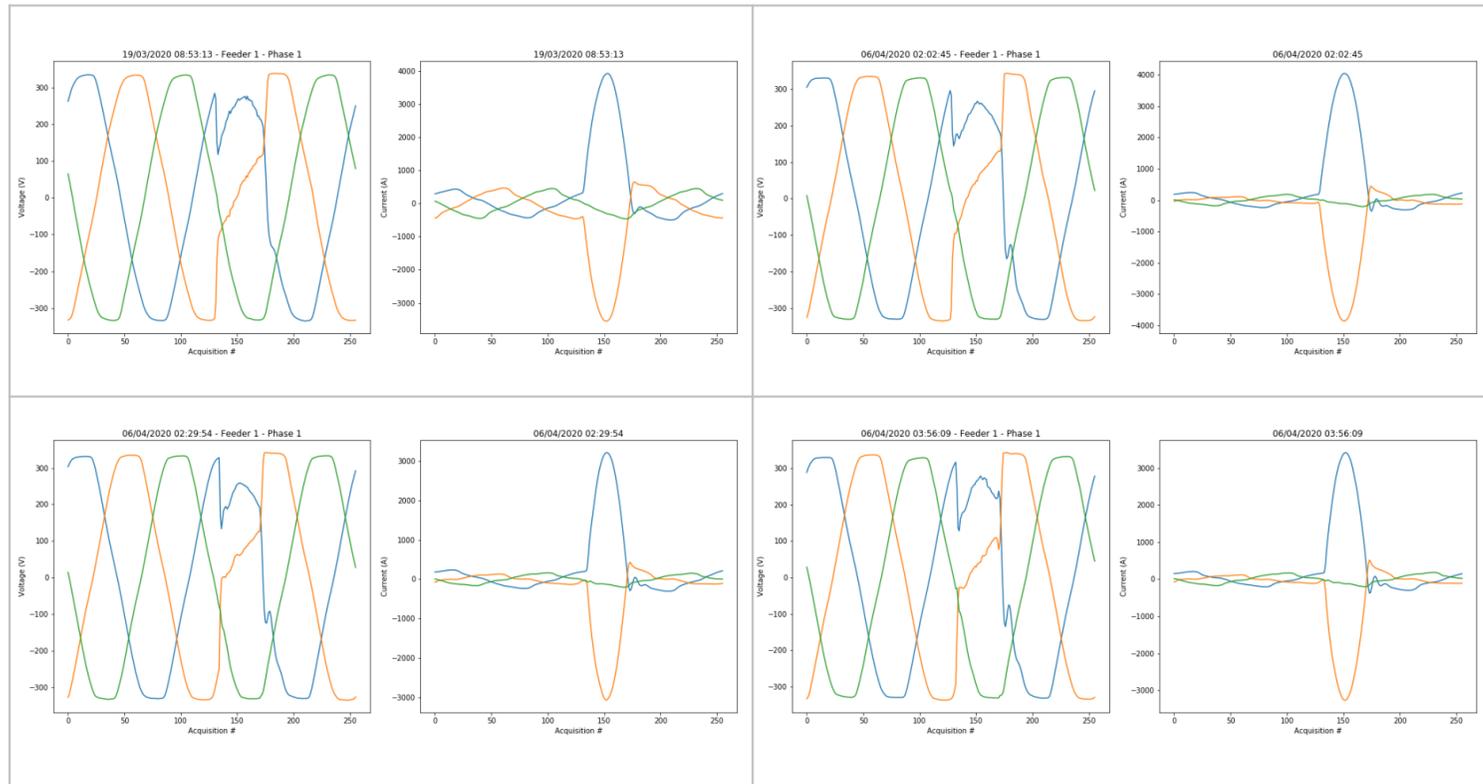
The Grange WPD Feeder 1 showed high activity on 06/04/2020, with limited numbers of events before and after this.

Fuse operations occurred on: 08/04/2020 @14:41 L1; 11/04/2020 @20:31 L3 & 21/04/2020 @08:46 L2. New fuses have re-energised the feeder each time.

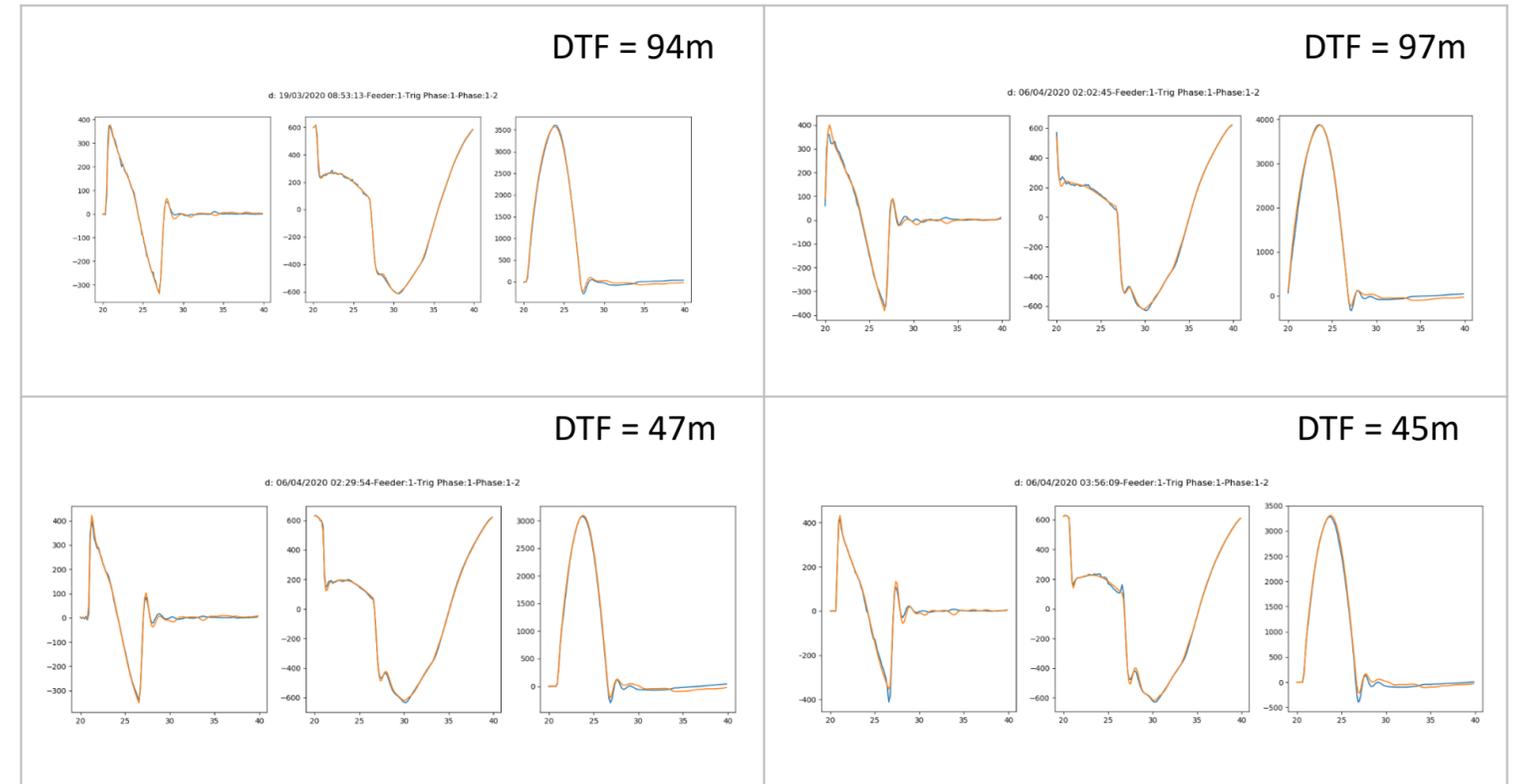
Mostly events have been L1-L2.



Waveform and Fault Analysis Data



Example captured “pecking fault” waveforms

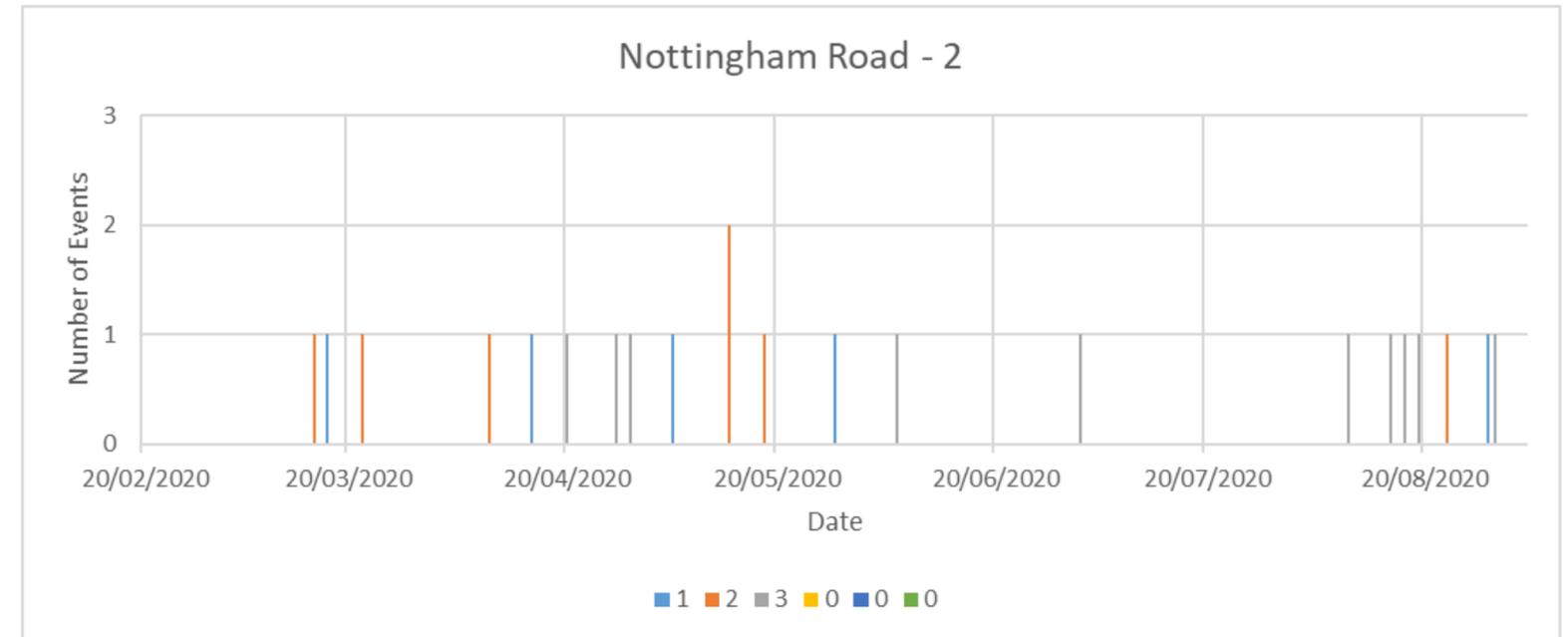


Example processed waveforms and resulting distances to fault



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Nottingham Rd	34	34
WPD Feeder 1	0	0
WPD Feeder 2	25	22
WPD Feeder 3	4	10
WPD Feeder 4	3	1
WPD Feeder 5	2	1



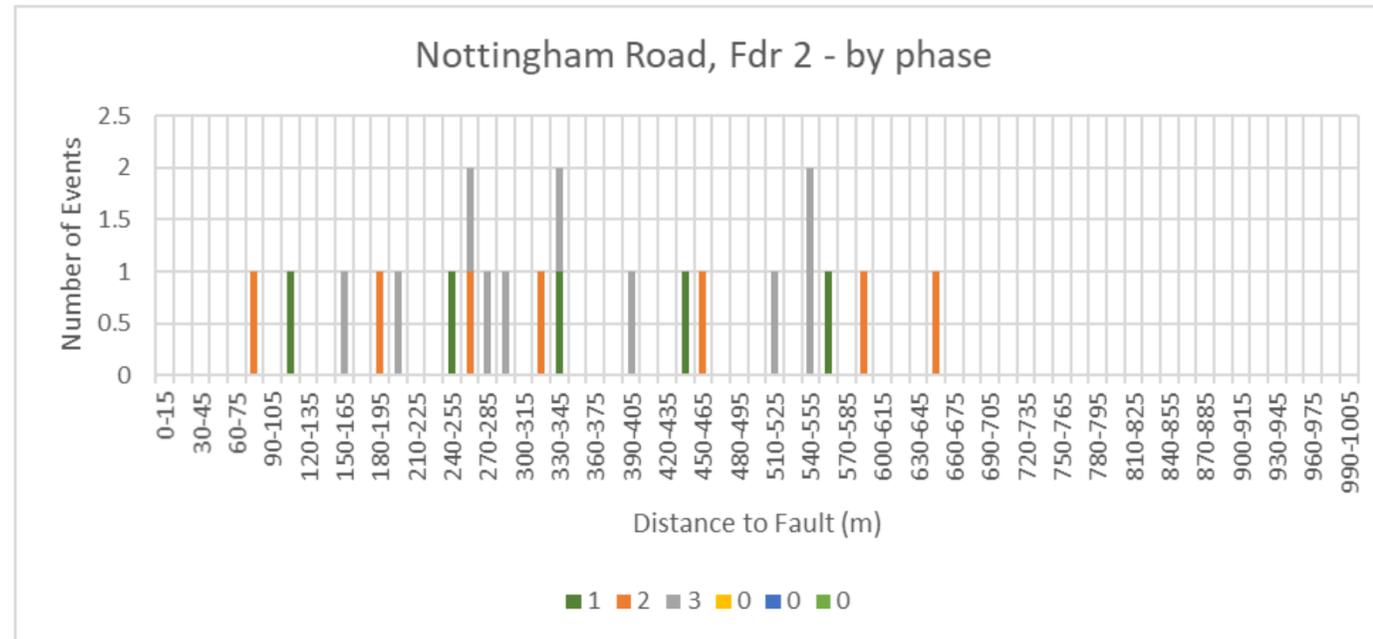
Nottingham Road feeder data has been reviewed following the feeder identification issue described above. Some events have been corrected to Feeder 3.

Nottingham Road Feeder 2 showed shown low levels of activity broadly through the monitoring period. Indications are that these events have occurred across all three phases.

The project is not aware of any fuse operations on this feeder during the monitored period.



Indicated Location

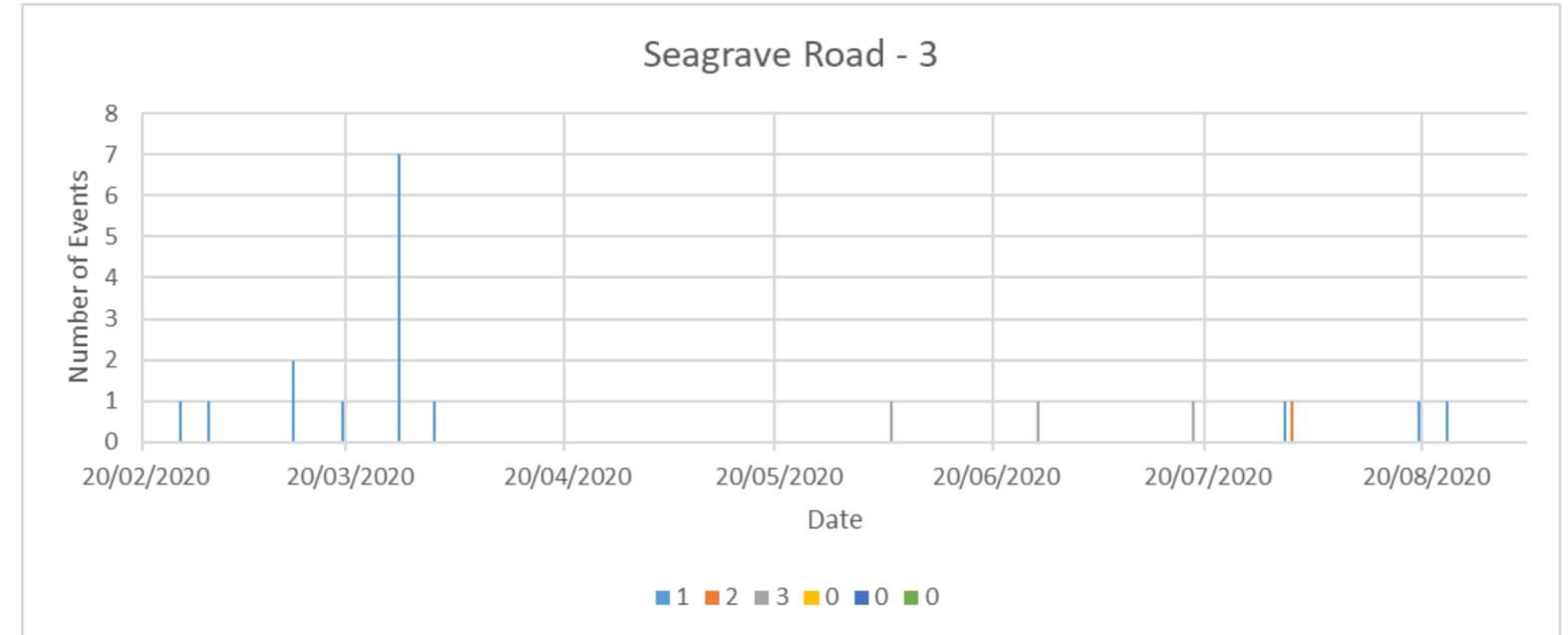


At present, this data does not provide a clear indication. Further assessment of this feeder will be undertaken in Phase 2 with the enhanced hardware.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Seagrave Rd	35	35
WPD Feeder 1	9	3
WPD Feeder 2	9	7
WPD Feeder 3	12	20
WPD Feeder 4	4	5
WPD Feeder 5	1	0



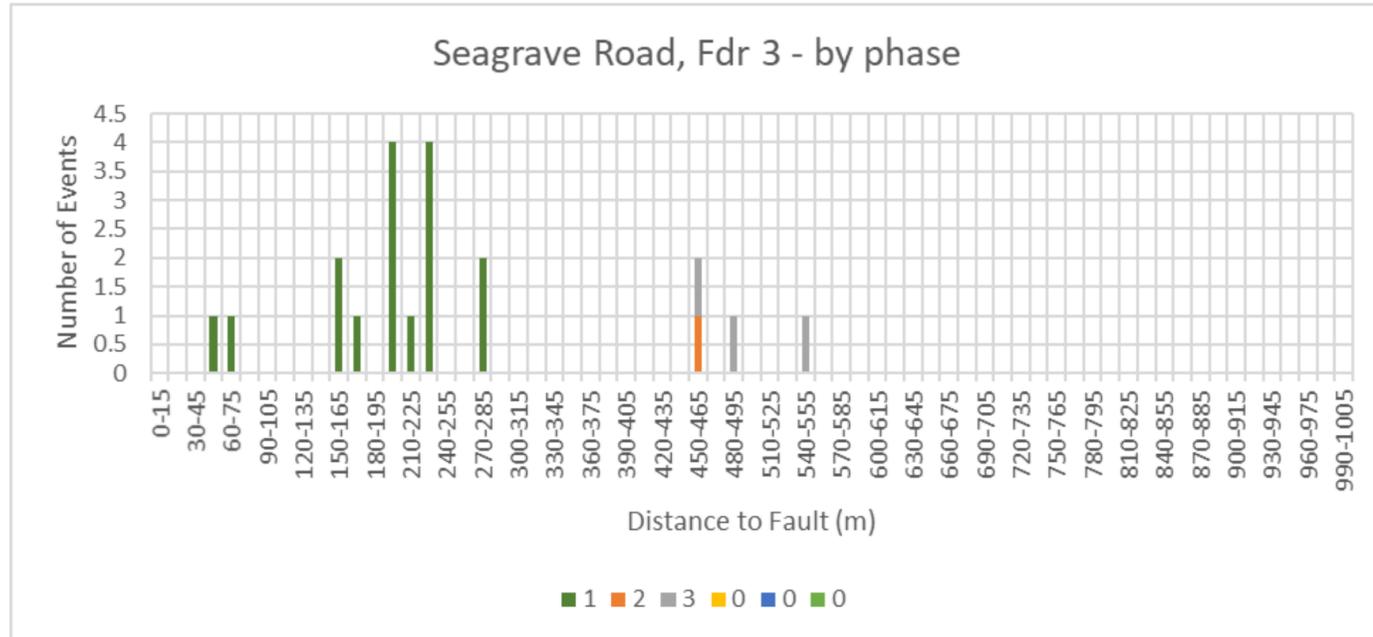
Seagrave Road feeder data has been reviewed following the feeder identification issue described above. Some events have been corrected to Feeder 3.

Seagrave Road Feeder 2 showed shown low levels of sporadic activity through the monitoring period.

The project is not aware of any fuse operations on this feeder during the monitored period.



Indicated Location

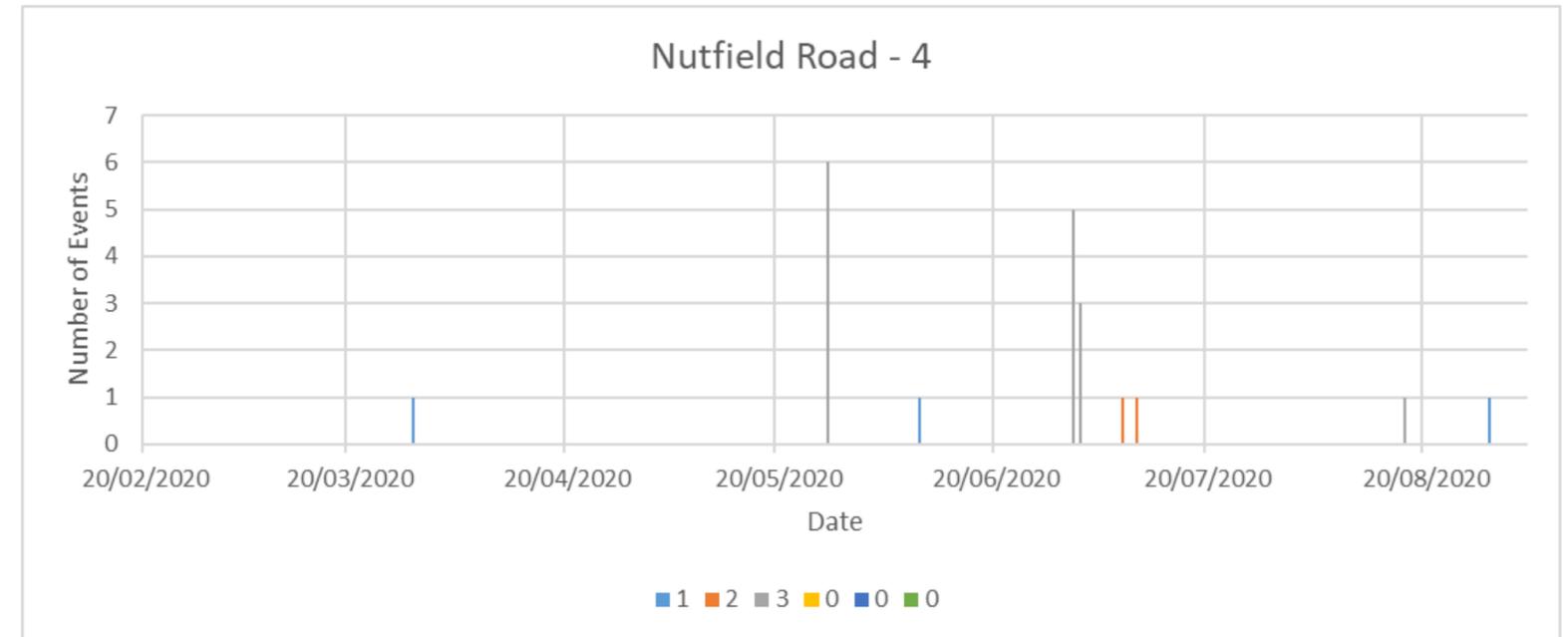


At present, this data does not provide a clear indication. Further assessment of this feeder will be undertaken in Phase 2 with the enhanced hardware.



Captured Events (as at 31/08/2020)

Site	Number of events – no feeder correction	Number of events – with feeder correction
Nutfield Rd	73	73
WPD Feeder 1	12	12
WPD Feeder 2	49	37
WPD Feeder 3	1	4
WPD Feeder 4	11	20



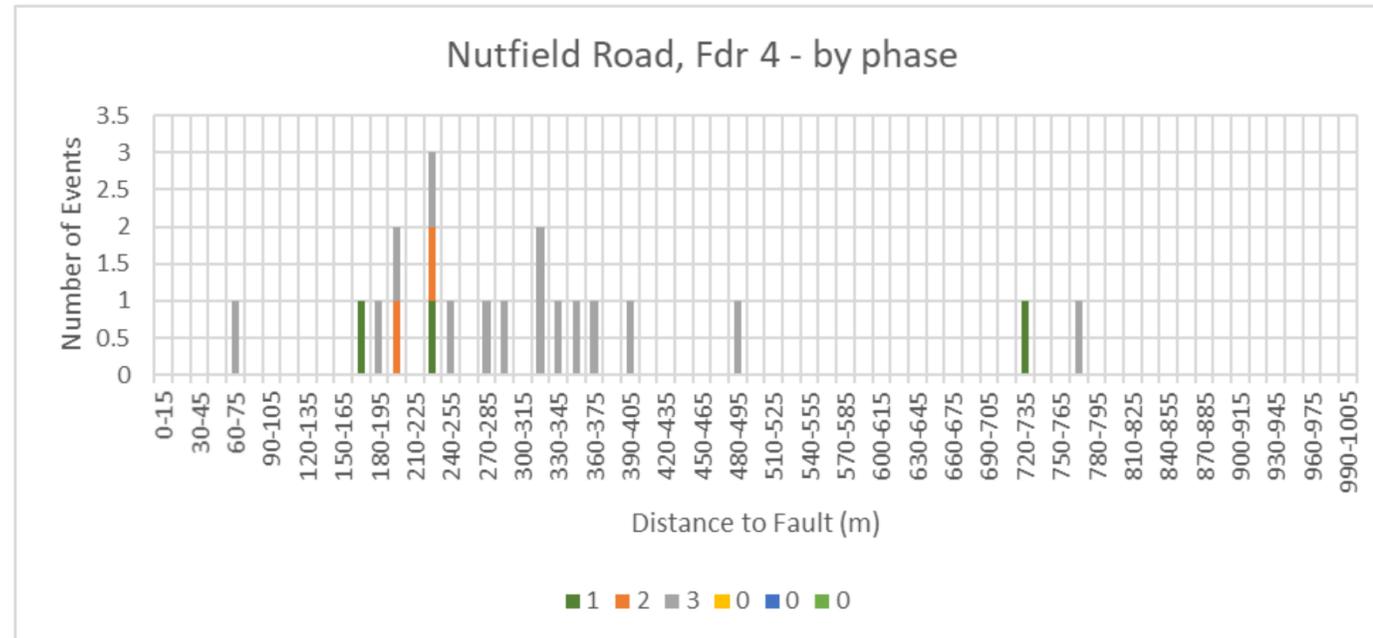
Nutfield Road feeder data has been reviewed following the feeder identification issue described above, with some correction of events to from Feeder 2 to Feeder 4.

Available data suggests intermittent levels of activity for Nutfield Road Feeder 4. 15 of the events are associated with L3.

The project is not aware of any fuse operations on this feeder during the monitored period.



Indicated Location



At present, this data does not provide a clear indication. Further assessment of this feeder will be undertaken in Phase 2 with the enhanced hardware.

