WPD INNOVATION
Transforming the electricity network

Pre-Fix

Requirements Specification

November 2021

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Version Control

Issue	Date
1	08/02/2022

Publication Control

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1. Introduction

1.1. Background

Pre-Fix will develop and demonstrate a Common Disturbance Information Platform (C-DIP), allowing equipment from different vendors to be utilised for pre-fault detection and more accurate fault location on HV overhead line and underground cable circuits. The outputs from this project are expected to deliver game-changing performance benefits for the operation of distribution systems across GB in RIIO-ED2 and beyond.

1.2. Business Case

The business case from Project Pre-Fix comes from building two capabilities, these capabilities should be thought of as value cases.

1. **Broadcasting of fault location**

In the event of a HV feeder protection operation, there is a typically a period of time where the fault location has to be identified before the faulted circuit section can be switched off the system. Fault location often only occurs after line patrols and iterative fault switching. Pre-fix intends to trial a capability to estimate where the fault is through system measurements. By broadcasting an estimated fault position in the moments after a protection operation, customer benefits could be accrued.

2. **HV Pre-Fault management**

If HV protection operations can be avoided through pro-active defect mitigation, then significant customer value can be obtained. Pre-Fix seeks to enable a HV Pre-Fault process that can answer the following questions:

- Is there a defect at a pre-fault stage on a HV feeder?
- What is the location of the pre-fault?
- How long might there be until the pre-fault develops into a protection operation?

1.3. Concept

To achieve the required price points that are discussion in 1.2, WPD wishes to develop a data platform architecture that can deliver the two value cases.

1.3.1. Hardware basis.

The enabling hardware for Pre-Fix would be a variety of Pre-Fix compatible devices that could be procured from different manufacturers. Different devices would have different use cases within the Pre-Fix system, as described in Table 1

Table 1: Pre-Fault device hierarchy

Device Category	Description	Examples
Category I	Devices that can capture three phase current and voltage waveforms (at a suitable sampling rate) and broadcast the information in operationally useful timescales.	Protection Relays Power Quality Monitors
Category II	Devices that can capture three phase current waveforms (at a suitable sampling rate) and broadcast the information in operationally useful timescales. (note, in the future, this could be expanded to devices that capture three phase voltage, but not current, waveforms such as LV monitors)	Smart FPI's such as Smart Navigator 2.0 and the NX44 devices
Category III	Devices that are sensitive to current passage, voltage presence or circuit status, but do not capture waveforms, but can broadcast information in operationally useful timescales.	LV monitors Connected FPI's HV Autoreclosers

The above devices will be specified in a series of functional specifications. This will specify the minimum set of functional requirements needed for Pre-Fix, but also the handling of different devices with different capabilities. These will be classified as 'must haves' (minimum required functionality) and 'nice to haves' (extended capability that would deliver more benefit to Pre-Fix, if available).

1.4. User Requirements Document Structure

The User Requirements Specification document is structured as follows:

1.4.1. System Concept and Integration Requirements

The concept of the Pre-Fix solution is described in Section 2

1.4.2. Data Processing Requirements

Data processing requirements (for enabling works as well as pre-fault and post-fault event scenarios) are described in Section 3.

1.4.3. User Interface Requirements

User interface requirements (for both DM and Control/Field staff) are described in Section 4.

1.4.4. Device Functional Specifications

The functional specifications for Pre-Fix field devices are given in Section 5.

1.4.5. Network Application Requirements

The application of devices to the network (for example, deciding on equipment quantities and locations) is described in Section 6.

1.4.6. Cyber Security Requirements

Cyber security requirements to which Pre-Fix must conform are given in Section 7.

1.4.7. BaU Adoption Requirements

BaU adoption requirements, captured as part of initial stakeholder engagement activities, are given in Section 8.

2. Architecture

2.1. Architecture

The conceptual architecture for Pre-Fix is given in Figure 2-1. Data from various field devices (such as trip alarms, analogue measurements and wave form captures) needs to be fed into a Common Disturbance Information Platform (C-DIP). C-DIP needs to support interfaces to other systems (such as PowerOn/TSDS, INM/CROWN and GIS) and data needs to be processed accordingly to deliver the required outcomes of Pre-fix (determining HV pre-fault and fault locations, quantifying pre-fault activity metrics and informing the priority of preventative actions).

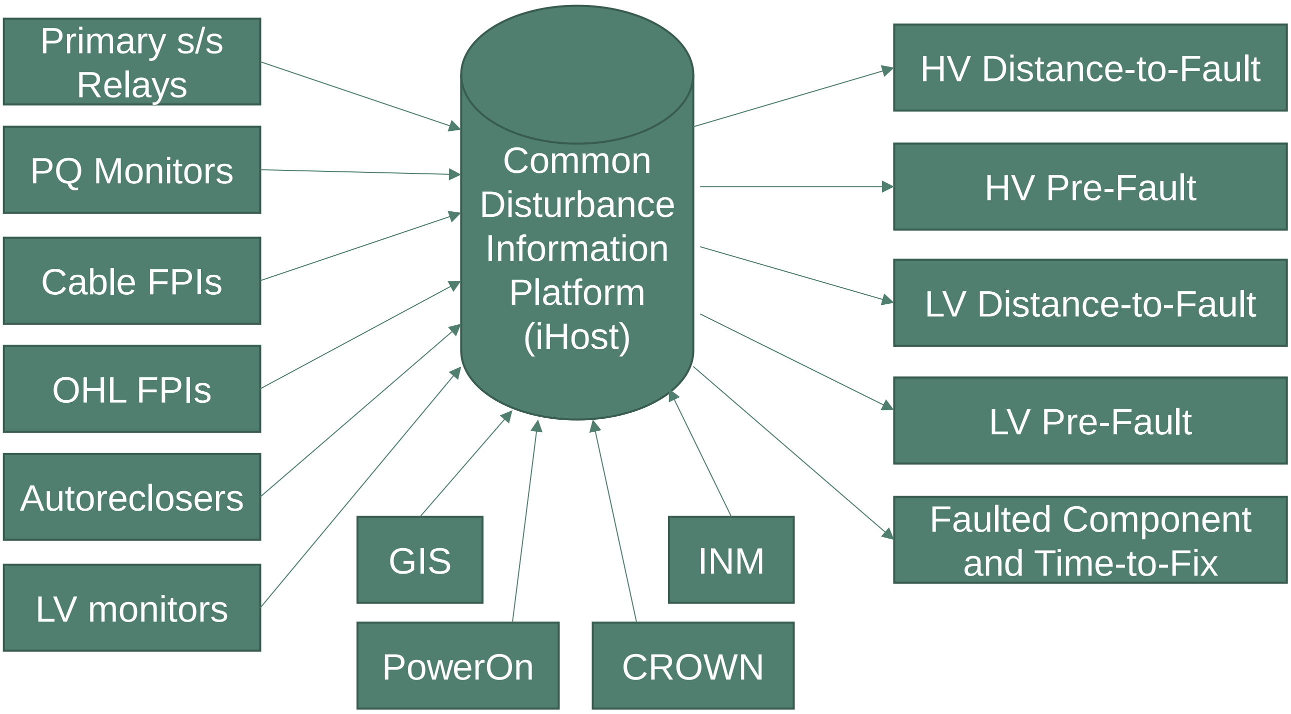


Figure 2-1 – Pre-Fix Conceptual Architecture

The Pre-Fix solution will need make use of WPD's iHost system for data gathering from field devices and Nortech's hosted iHost system for platform feature development (such as creation of dashboards and development of algorithms for data processing). The main trial hardware (FPIs and Power Quality Monitors) will need to be integrated to WPD's iHost system. Samples of each equipment type (FPIs, Power Quality Monitors and Relays) need to be available to Nortech to integrate into the iHost Develop system for development and testing purposes. Reflecting this, the embodiment architecture is given in Figure 2-2. The project will make use of SINCAL models (as these already exist) for impedance and topology as a proxy for INM models (which are still undergoing development and validation) but will look to show that INM models can be utilised as and when these are developed, validated, available and maintained.

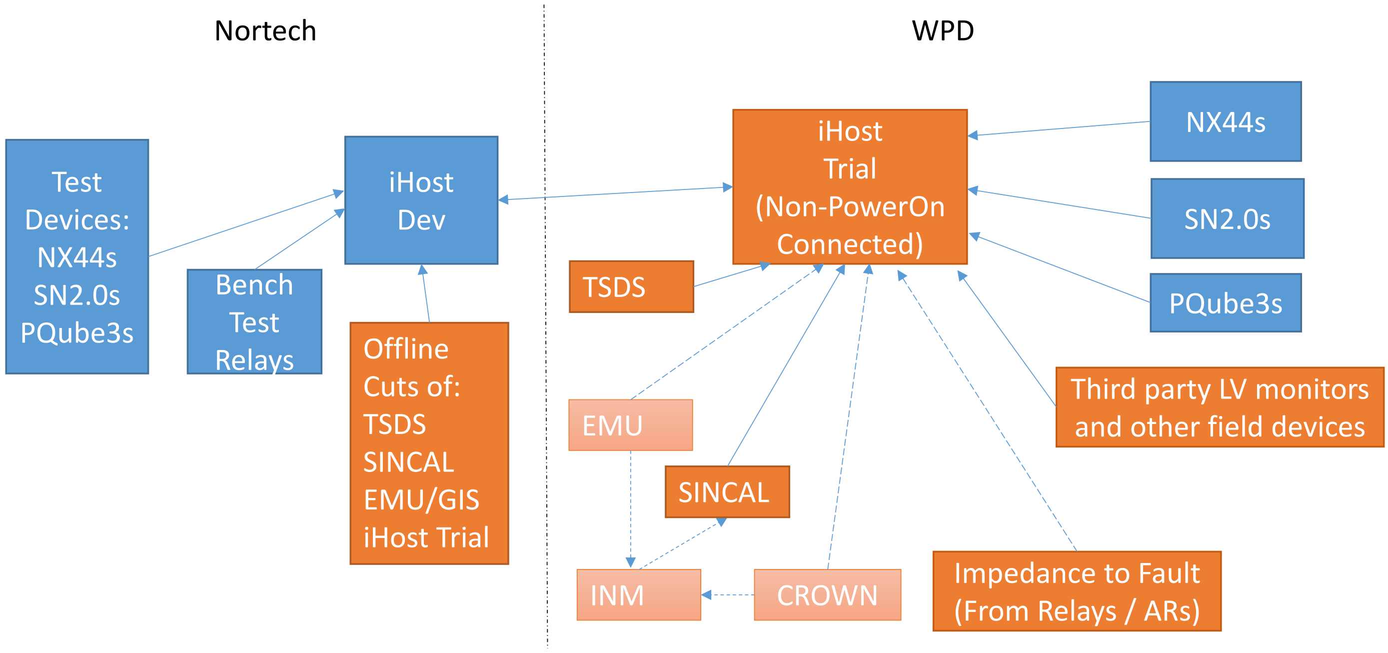


Figure 2-2 – Pre-Fix Embodiment Architecture

2.2. Hardware Component Descriptions

2.2.1. Power Quality Monitors

Power quality monitors (PQMs) need to be retrofittable to existing 11kV panels within the Primary substation to monitor the 11kV data feed from 33/11kV transformers.

PQMs need to trigger on network disturbances to record wave forms associated with fault and pre-fault activity.

Wave forms need to be generated and transferred in COMTRADE format. The project will help inform the scalability and sustainability of generating COMTRADE files for every pre-fault event as this will impact on the size of the servers that WPD will need to specify and procure for BaU operations.

For the purposes of the trial, wave form data can be transferred as a 24-hour roll up. For BaU adoption, the fault wave forms will need to be transferred by exception, immediately following the conclusion of the network disturbance (or when the recording duration is completed).

For the purposes of the trial, the voltage and current analogues from PQMs, and the events they record, will be used to estimate impedance to fault.

2.2.2. Cable Fault Passage Indicators

Cable FPIs (such as NX44s) need to be retrofittable (for trial purposes) to existing 11kV Ring Main Units within Secondary Distribution substations to monitor the 11kV data feed from 11kV feeders.

Cable FPIs need to detect, locally indicate and remotely communicate the passage of fault and pre-fault current through the network location where the FPI is installed. Cable FPIs need to trigger on network disturbances to record waveforms associated with fault and pre-fault activity.

Waveforms need to be generated and transferred in COMTRADE format.

For the purposes of the trial, waveform data can be transferred as a 24-hour roll up. For BaU adoption, the fault wave forms will need to be transferred by exception, immediately following the conclusion of the network disturbance (or when the recording duration is completed).

2.2.3. Overhead Line Fault Passage Indicators

Overhead Line FPIs (such as Smart Navigator 2.0s) need to be retrofittable to existing 11kV overhead line circuits to monitor the 11kV data feed from 11kV feeders.

Overhead line FPIs need to detect, locally indicate and remotely communicate the passage of fault and pre-fault current through the network location where the FPI is installed.

2.2.4. LV Monitors

LV monitors (such as Gridkey MCUs) need to be retrofittable to existing LV boards within Secondary Distribution Substations.

LV monitors need to detect and remotely communicate the presence of voltage on the LV side of the Secondary Distribution Substation.

2.2.5. Relays (Future Requirement)

IED relays need to fit into (or replace) existing 11kV panels within the Primary substation to monitor the 11kV data feed from 33/11kV transformers.

IED relays need to trigger on network disturbances to record wave forms associated with fault and pre-fault activity.

Wave forms need to be generated and transferred in COMTRADE format.

For BaU adoption, the fault wave forms will need to be transferred by exception, immediately following the conclusion of the network disturbance (or when the recording duration is completed).

IED relays need to generate and remotely communicate to PowerOn impedance to fault information. The project will help to inform the methods by which impedance-to-fault information can be operationally presented.

2.2.6. Auto-reclosers (Future Requirement)

Communicating Auto-reclosers (ARs) need to trigger on network disturbances to record wave forms associated with fault and pre-fault activity.

Wave forms need to be generated and transferred in COMTRADE format.

For BaU adoption, the fault wave forms will need to be transferred by exception, immediately following the conclusion of the network disturbance (or when the recording duration is completed).

If possible, ARs also need to generate and remotely communicate to PowerOn impedance to fault information.

2.3. Software Component Descriptions

2.3.1. iHost Trial

The iHost Trial system needs to support interfaces to the various systems and hardware components as given in Figure 2-2.

2.3.2. iHost Development

The iHost Development system needs to support interfaces to the various systems and hardware components as given in Figure 2-2 including offline cuts of datasets from the Trial iHost system, INM (or SINCAL as a proxy), TSDS and EMU/GIS.

2.4. System Storage Requirements

The iHost systems for development and trialling should be sufficiently sized for the storage and processing of data for the Pre-Fix solution. Nortech's development iHost will be used as the testbed to determine the storage and processing requirements for BaU adoption of the Pre-fix solution.

3. Platform Processing (Algorithms)

3.1. Application Logic

3.1.1. Systems Integration

The Pre-Fix solution must include software interfaces to support integration to the various systems as defined in Figures 2-1 and 2-2. The intention is implement the iHost 'mating half' of software interfaces within Phase 1 of Pre-Fix such that the BaU integration to other WPD systems can be completed as part of RIIO-ED2 (post-March 2023).

SFTP file transfers of database cuts (such as WPD's iHost system for LV monitors, INM (SINCAL) for impedance data and TSDS for circuit switching data), will be used to capture representative dataset samples for the purpose of developing the Pre-Fix solution.

3.1.2. Enabling Works

The following enabling works must be delivered as a pre-requisite to delivering the data processing aspects of the Pre-Fix solution. (The 'how' will be described and explained in the Algorithm Functional Design Specification documentation.)

1. Linkage to INM or Sincal/Open points
2. Tracking Open point changes
3. List of Pre-Fault observations into Pre-Fault indicator Flags (flexible table to allow for evolving knowledge) & thresholds (Magnitude of peck, duration of peck, evolution of phase to earth to become phase to phase)
4. Data structure
5. What is the defect signature?
6. Signal co-ordination (i.e. device X saw this, did anything else see this?
7. Thresholding and triggering
8. Maintenance of data (Customer numbers, INM, open point moves)
9. All tables to allow growth of data
10. How often the algorithms run or what triggers an algorithm run
11. Demonstrate that the platform can Integration with weather data (To allow weather correlation, rain, lighting, wind, ambient), but does not run 24-7 on the project
12. (seek to pair waveforms evolution with known defective equipment, with aim of spotting future defect spiral)
13. Algorithm to manage low powered smart navigators (limited waveform buffer)
14. Lining up waveforms
15. Allowance for CT performance of fixed installations & Did something saturate or not during an event

3.1.3. Pre-Fault Data Processing

The following outputs must be determined as part of the Pre-Fault data processing of the Pre-Fix solution. (How this will be achieved will be described and explained in the Algorithm Functional Design Specification documentation.)

1. Determined whether or not a pre-fault is present within a particular part of the network
2. Use a combination of high resolution and low resolution datasets from the range of network devices listed in Table 1 and Section 2
3. Determine which pre-fault flags are present
4. Determine the pre-fault search zone , using zones of probability, updated for incoming information (during fault location)
5. Determine where the pre-fault is (following location and verification activities)
6. Be capable of differentiating zones of probability for two pre-faults
7. Determine the type of fault (for example, earth fault / phase-to-phase fault)
8. Determine the type of component that is failing (for example, insulation shed / branch faulting an overhead line conductor / cable/ cable joint/ partial discharge)

9. Correlate the pre-fault to prevailing weather conditions (for example, did it occur within ‘n’ days of rain, did it occur when the wind speed was greater than ‘X’)
10. Determine how many pre-fault flag events have occurred within the particular network location to date
11. Determine rate-of-change of flags
12. Determine the most probable number of concurrent pre-faults present within a particular network location
13. Determine how many customers would be affected if the pre-fault were to develop into a fault
14. Report the number of customer CMLs and CIs in the recent period
15. Predict and quantify time-to-fail (based on data to date, classified by asset type, influenced by weather)
16. Provider to users a framework for classifying pre-fault observations into criticality banding
17. Filter out events that are not pre-fault indicators

In addition, in future, the Pre-Fix platform should be capable of being expanded to deliver:

18. Rolling update of weather impact on expected pre-fault activity

3.1.4. Post-Fault Data Processing

The following outputs must be determined as part of the Post-Fault data processing of the Pre-Fix solution. (How this will be achieved will be described and explained in the Algorithm Functional Design Specification documentation.)

1. Determine what type of fault has occurred
2. Determine the search area / the faulted section of network (together with % certainty)
3. Align HV faults with voltage output from LV monitoring
4. Determine the distance to fault (into the search area) and establish how many search areas are required

In addition, in future, the Pre-Fix platform should be capable of being expanded to deliver:

5. Alignment with call-ins from WPD’s customers
6. Correlation with previous switching activity (CB and autorecloser locations and frequency of trip occurrences)

3.1.5. Sensitivities

The algorithm Functional Design Specifications must make allowance for the effect of the following factors on Pre-Fix solution outputs:

1. CT performance (understanding and handling scenarios when CTs could be driven into saturation)
2. Fault current linearity (understanding how this could impact assessments such as distance-to-fault and distance to pre-fault)
3. Communications reliability (tolerating drop-outs and restorations in communications from field devices)
4. Sensitivities relating to the impedance data underpinning the distance-to-(pre-)fault calculation (and the impact this has on locating the fault with a % degree of certainty)
5. Configuration of network devices (for example, if data from one PQube is being used to represent the operation of two transformers in parallel)

3.2. Algorithms

3.2.1. Network Event Correlation

The Pre-Fix system must be able to correlate network disturbance events recorded and communicated by the trial field devices.

Correlated network events need to be accessible and displayed to the user for further analysis as part of the Pre-Fix project.

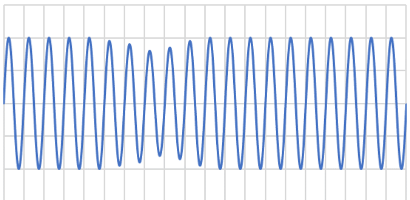
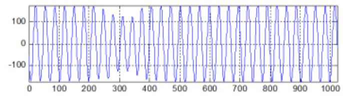
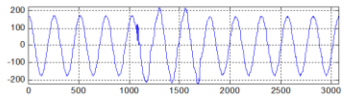
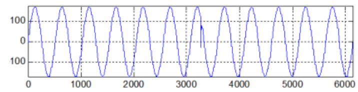
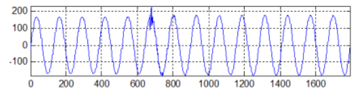
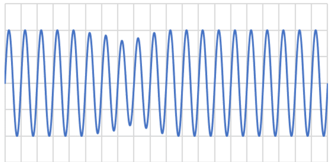
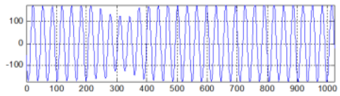
3.2.2. Distance to Fault

The Pre-Fix system must be able to determine HV fault / pre-fault location with an associated degree of certainty and geographical bounding of the probability zone.

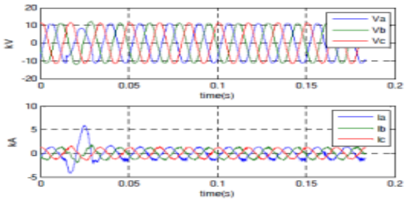
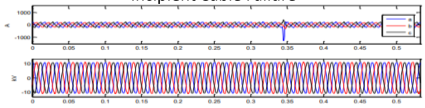
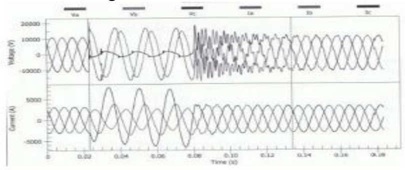
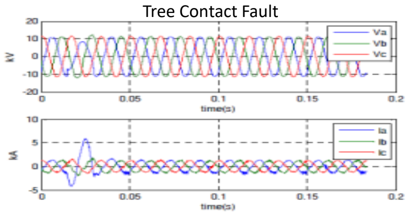
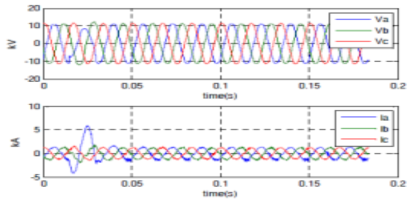
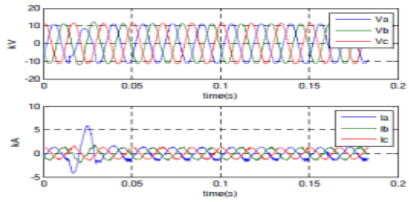
3.2.3. Electric Signature Detection and Categorisation

Using IEEE Technical Report PES-TR73 as the basis for templates for electric equipment failures, the Pre-Fix system must be able to categorise electrical fault signatures with a degree of certainty of match to template electrical disturbances and power system component failures.

Example Disturbance Classification for sags/swells etc.:

Input	Processing	Output
An input Fault/Pre-Fault Waveform is collected from a device on the network. Example Power Quality Waveform: 	Fault/Pre-Fault Waveform is classified based on potential Fault/Pre-Fault Waveform Templates Example Power Quality Categorizations: Sag Disturbance  Swell Disturbance  Impulse Voltage Transient  Impulse Oscillatory Transient 	"The Input Fault/Pre-Fault Waveform most closely matches a Sag Disturbance, with a match of X%" Input Waveform:  Output Waveform: Sag Disturbance 

Example Power System Component Failure Classification (for tree contact to overhead line in this example):

Input	Processing	Output
An input Fault/Pre-Fault Waveform is collected from a device on the network. Example Waveform: 	Fault/Pre-Fault Waveform is classified based on potential Fault/Pre-Fault Waveform Templates Example Categorizations: Incipient Cable Failure  Underground Cable Termination Failure  Tree Contact Fault 	"The Input Fault/Pre-Fault Waveform most closely matches a Tree Contact Fault, with a match of X%" Input Waveform:  Output Waveform: 

An expected output of the Pre-Fix project is that a similar database will be generated for signatures of components that are about to fail. This database will build up over time (following the installation of network monitoring that can gather the pre-fault failure signatures) and, once in place, a similar approach to fault classification will be used for pre-fault classification.

3.3. Time synchronisation

Wherever possible, field devices and Pre-Fix systems handling real-time data should use GPS as their definitive time source. Field devices and central systems should synchronise to a GPS clock at least once every 24 hours and exhibit a clock drift of no more than 3 seconds within a 24-hour period.

If GPS is unavailable / unviable, the field device should synchronise with a GPS-connected time server at least once every 24 hours and exhibit a clock drift of no more than 3 seconds within a 24-hour period.

As part of Pre-Fix, it is anticipated that BaU specifications for devices that form part of the Pre-Fix solution (e.g. LV monitors) may evolve to include the time synchronisation requirement specified above. Pre-Fix will help to inform the decision about the criticality of GPS-synchronised devices and the effect that GPS time synchronisation has on aligning event data from dispersed field devices.

3.4. Other factors

3.4.1. Weather

The Pre-Fix system must be able to correlate network disturbance events with other sources of information such as weather datasets (for example, to determine if rainfall, prior to the network event, is a factor that causes underground cables to fail).

In the Pre-Fix project, this will be delivered via a series of offline weather datasets that are processed together with pre-fault / fault activity to determine if correlations exist.

This will be further expanded as part of BaU adoption to incorporate the use of real-time weather datasets with real-time pre-fault / fault activity.

3.5. Testing and Acceptance Criteria

For the purpose of algorithm development and testing, the Development iHost system must support the ability to 'play through' datasets using simulators of the various components and interfaces.

As part of the FDS documentation and subsequent Test Books, the various requirements defined in this document will be translated into a series of quantitative acceptance criterion.

4. Platform Visualisation (User Interface)

4.1. Criticality Framework and indicator flags

A criticality framework shall be established that will allow circuits to be allocated to a risk of trip banding based key indicator flags. Within the Pre-Fix project, Nortech shall establish data structures that will enable them to test what are likely indicator flags for circuits that are about trip and investigate the time to fail relationships associated with any such flags.

It is acknowledged that Pre-Fix is a short duration project and that the analysis behind the indicator flag system and time to fail will need to continue after this project. For this reason, the data structures established within the C-DIP must offer the following functionality:

- To enable further research into indicator flags, the C-Dip platform must allow back office interrogation and export of all gathered data for research purposes.
- There must be a method to enable different groups of circuits to have different blends of indicator flags allocate a circuit into a common criticality banding
- There must be methodology to add or update what indicator flags decide a particular criticality band

Within each criticality band, it must be possible to rank circuits on the basis of:

- Customer numbers
- Recent experience of power cuts

4.2. Dashboards Overview

The project shall provide a set dashboards to satisfy the following user requirements

4.2.1. User Story – Depot managers and Team managers

Depot managers and team mangers are responsible for managing the CML and CI performance of the depot. They will be responsible for scheduling work and managing the risk of unplanned outages. The user stories for these individuals are as follows:

1. As a depot manager, I need to know how many customers within my depot area are in each criticality band; of which, how many have experienced more than “X” unplanned outages in “Y” time period so that I can understand how many power cuts I could plan to avoid and prioritise immediately available resources.

2. As a depot manger, I need to know , that if I instigate no pre-fault repairs actions, how many CML and CI am I likely to have in the upcoming time period of “Z” weeks or months; of which, how many have already experienced more than X unplanned outages in Y time period. This is so that I can plan resources in the upcoming weeks, days or months.

3. As a depot manager/team manager, I need to be able to drill down through the dashboard data from the total customer view, down through primary substations and onto HV feeders to understand which circuits are driving my risk profile, so that I can decide where best to invest my pre-fault resources.

4. As a depot manager/team manager, I need to be able to understand what works I should instruct to help me successfully prevent or mitigate an unplanned outage.

5. As a depot manager/team manager, I need to be able to accurately direct staff to locations on a circuit that has just tripped. This is so that I can minimise the customer restoration time.

4.2.2. User Story – Pre-fault practitioners

Pre-fault practitioners are persons responsible for locating and planning the repairs of defects that have not tripped yet. The user stories for these individuals are as follows:

1. As a pre-fault practitioner, I need to able understand where are the likely locations of a pre-fault defect and how long have I got before the defect is likely to escalate into an unplanned outage. I would prefer these to be heat mapped. This is so that I can implement repairs or mitigations before customer disturbances.
2. As a pre-fault practitioner, I need to be able to understand the variability and confidence in the predicted pre-fault location. This is so that I can interpret the reliability of the predictions that I am reviewing.
3. As a pre-fault practitioner, it is essential that I can review locational predictions on a geographical and schematic basis. This is so that I can understand the system impact and inspect the potential locations.
4. As a pre-fault practitioner, I need to be able to understand which defects are likely to need additional interventions to ensure that locational certainty can be developed and what these interventions could be. This is so that I can become more certain of locating a defect before it becomes an unplanned outage.
5. As a pre-fault practitioner, I need to be able to monitor the success of a repair. This is so that I can be sure that I have successfully cleared a defect from the system.
6. As a pre-fault practitioner, I will need this information to be available to me in the office and to retain some of this functionality in the field.

4.2.3. User Story – Fault responders and control engineers

Fault responders are team members and control engineers who restore customers after an unplanned outage. Within Pre-Fix there are no plans to use the system in real time fault location, so these requirements are future needs, but the C-DIP platform must be capable of offering this in the future.

1. As a fault responders I need to have information as to the circuit sections where the fault is most likely situated and are not situated. This is so that I can restore customers faster.
2. As a control engineer, I would prefer this information to be presented within PowerOn advantage. This is so that I can concentrate on one computer system only.
3. As a fault responder, I need to ensure that I do not become confused by conflicting or incorrect information. This is so that I can make the correct decisions.

4.3. Wire-frame Dashboard Mock-Ups

In parallel to the development of this User Requirements Specification, a series of wireframe dashboards are being developed by the Innovation Team in conjunction with key WPD stakeholders (DM end users). A work-in-progress draft of Dashboard wireframes is included in Appendix 1.

4.4. Wave form visualisation

The Pre-Fix system must allow COMTRADE wave forms from field devices to be displayed to the system user through the User Interface.

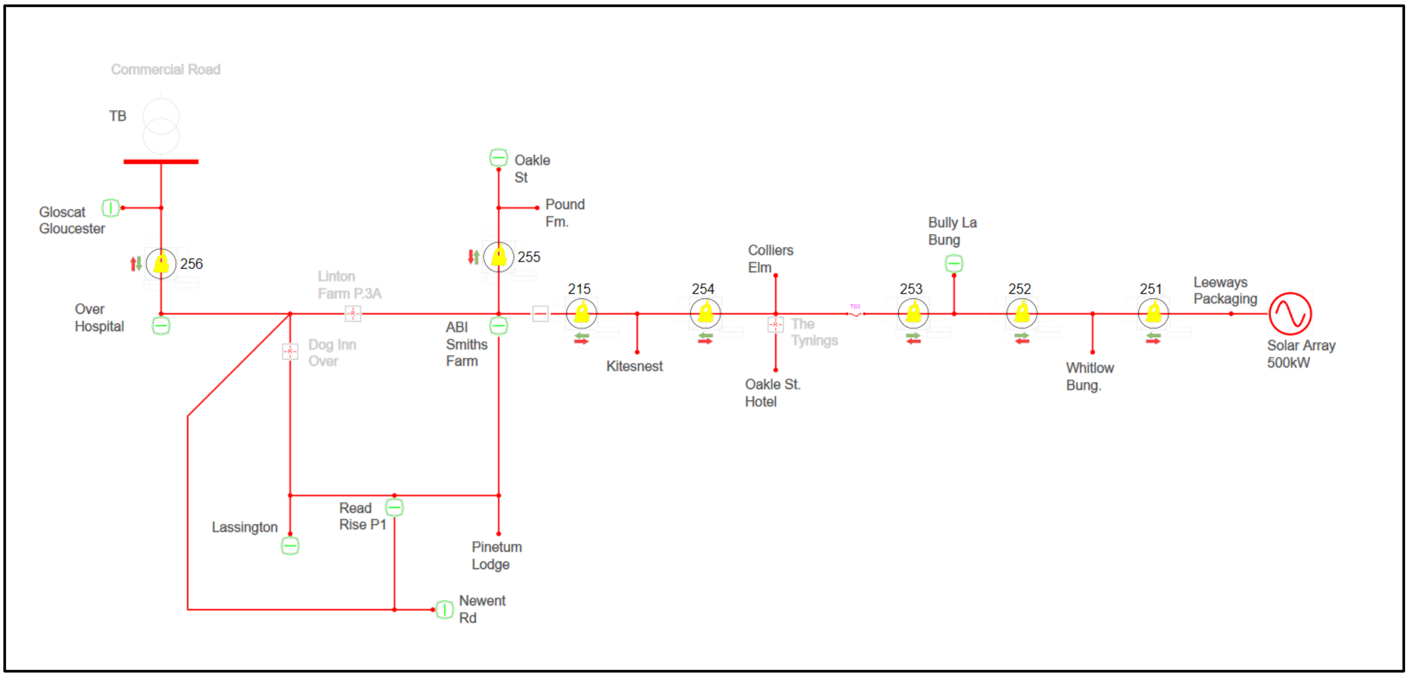
The viewer is to show the number and frequency of pre-fault events for a presumed defect i.e. bring together data generated by lots of events. This should include metrics such as how often did a defect “peck” and how often did a peck exceed ‘X’ kA.

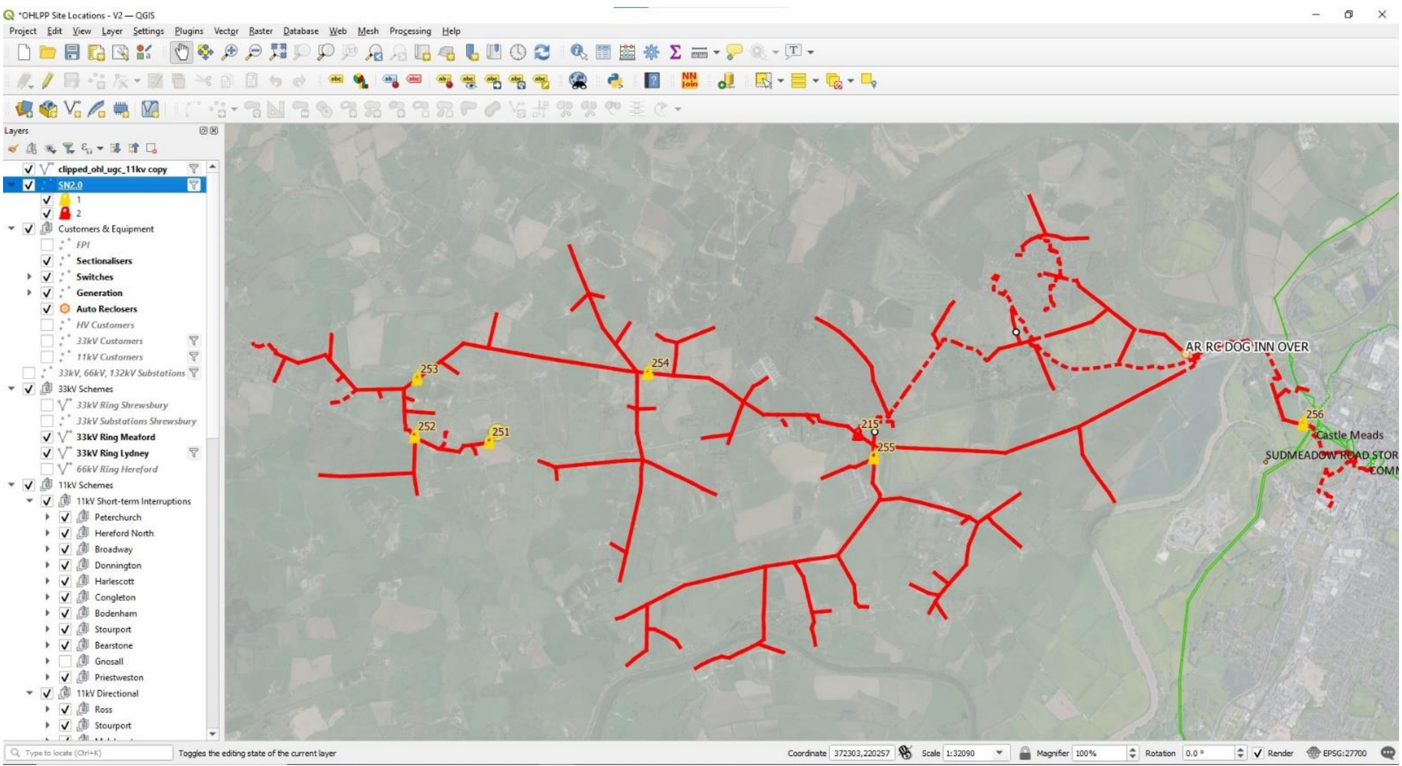
e.g. how often did a defect “peck” how often did a peck exceed x kA.

4.5. Distance to fault location (network diagram representation, SLD and map view)

The Pre-Fix system must allow fault and pre-fault locations (geographical search zones and degree of certainty) to be displayed to the system user on a network schematic through the User Interface both in SLD/network diagram view and geographical map view.

In the future, the system must be capable of informing Power on of the circuit sections within the search zones.





4.6. Reports and Notifications

In addition to User Interfaces and Dashboards defined above, the Pre-Fix solution must be capable of providing user-defined reports to interested stakeholders and fault report notifications.

The content of these reports and notifications will be developed as part of Phase 1 of the Pre-Fix project.

5. Functional Specification of Pre-Fix Devices

5.1. Protection Relays

Protection relays within the Pre-Fix project will be required to act as a Category I device. Within the Pre-Fix trial, protection relays will only be trialled in a bench test environment to prove general capability.

5.1.1. Trial and application requirements

The Pre-Fix project will seek to use relays that would likely be specified by WPD in the future to deliver a standard HV feeder protection function on rural and urban feeders. It is assumed that protection devices will normally be applied on a “per feeder” basis.

5.1.2. Relay data requirements

The selected relays will initially align with WPD standard setting policy for HV feeder protection schemes. The Pre-Fix project will amend the standard relay specification to obtain the following functional enhancements

1. Ability to output a calculated impedance to fault for a given protection operation.
2. Capture of current and voltage waveforms upon a nominated trigger, preferably with an common system timestamp
3. Ability to share current and voltage waveforms via a Comtrade file
4. Ability to share Comtrade files within a substation over an IEC61850 protocol

In addition to the above items, engagement will reveal whether the relays can supply a distance to Pre-fault calculation in addition to the comtrade file, in which case the C-DIP platform should take account of this.

WPD will select, supply suitable protection relays to Nortech for the purpose of bench testing.

5.1.3. Pre-Fix trial application

During the Pre-Fix trial, HV feeder protection relay application will be trailed on a bench test basis only. These bench tests will be hosted on Nortech premises.

WPD will select, supply suitable protection relays to Nortech for bench testing and ensure that they have been programmed and tested ready for application testing by Nortech. This will include verification of protection settings, disturbance settings and IEC61850 communications

Nortech will deliver relay bench-testing infrastructure and testing sequences. During the testing campaign, Nortech shall be available to make minor changes to the relay settings file to help refine learning from the bench testing (such as changing individual settings fields where agreed with WPD).

The relay bench-testing campaign will:

1. Pass known pre-fault and fault current and voltage waveforms through the protection relays to verify the use of protection relays as a Category I device on the C-DIP platform.
2. Demonstrate that parameters calculated by the relay (distance to fault/distance to pre-fault) can be shared with the C-DIP.
3. Provide design intent and verify the options for gathering data into the C-DIP from the relays, to include
    a. Fully digital substation communications, assuming IEC61850 protocol for all relay input/output
    b. Partial digital substation communications, assuming a serial data connection to the relay for Comtrade file operations but a hard-wired connection for all other input/output
    c. As per b, but with additional local computation to reduce need for a full Comtrade file to be shared.
4. To enable the future use of this methodology, Nortech should provide a methodology for how relays can be mapped onto feeders.

It is assumed that the bench test will emulate hard-wired RTUs and IEC61850 RTUs, hence no actual RTU is to be supplied.

It is assumed that demonstration of the communication links from WPD RTU's to the C-DIP platform is out of scope, but demonstration of comtrade file transmission over Envoy devices (as per item c.b) is required.

5.2. Autoreclosers

Within the Pre-Fix trial, autoreclosers will be classified as a Category III device

5.2.1. Trial and application requirements

1. Nortech will demonstrate a methodology for retrofit integration of WPD standard specification autoreclosers onto the C-DIP. This can be limited to a bench test basis. WPD and Nortech may pursue real system demonstrations, but only by prior arrangement.
2. Nortech's design must prescribe a design methodology to integrate "Pre-Fix ready" autoreclosers onto the C-DIP in the capacity of a Category III device. The Pre-Fix trial must record a set of specifications that future manufacturers would need to be tested against adhere to before their auto-reclosers could be allowed to connect to the C-DIP. The Pre-Fix trial is not expected to certify any new devices against this specification, but a recorded set of requirements will be needed to show how these future devices can be integrated into the C-DIP. WPD will seek to obtain feedback from the potential supply chain with regard to feasibility of these requirements, after which WPD and Nortech shall review implications on the design of the C-DIP.
3. To accommodate future growth, the C-DIP architecture must enable the functionality of autoreclosers to deliver Category I device performance, hence there must be demonstration of a design intent that could enable auto reclosers to deliver the data listed in **Error! Reference source not found.** onto the C-DIP.

5.2.2. Autorecloser data requirements

It is initially assumed that autoreclosers will be a category III device, therefore they must provide the following data onto the C-DIP

1. To fulfil its role as a Category III device, autoreclosers will provide the following data to the C-DIP:
   a. Changes in circuit breaker status (Open/Closed)
   b. Changes in voltage presence (Voltage/not Voltage), but only in cases of VT's being present
   c. Sensitivity of any fault passage indication function (in amps)
   d. Fault passage indication (True/False) (if configured in that manner)
   e. Geographic and electrical location
   f. Communications status

5.3. Power Quality Monitors

Within the Pre-Fix Trial, power quality devices will be classified as a Category I device. It is assumed that these units will be assigned on a "per primary" basis, unless the substation busbars are run split in normal operation.

5.3.1. Trial and application requirements

It is assumed that that the same PQube and Envoy configuration that was used on WPD's PNPQA project will be the starting point for this project. It is assumed that that these devices can be assigned a voltage or current trigger to capture a set of waveforms.

1. The PQube devices shall capture three phase voltage and current waveforms associated with the incoming transformer circuits onto the primary substation. These waveforms shall be captured at a sufficient resolution to enable meaningful application of algorithms. Disturbance recording shall be triggered on events likely to be a pre-fault event or actual fault event.
2. These devices must be able to publish the information to the C-DIP in operationally useful timescales. For the purpose of the trial, the PQube shall need to demonstrate that it can deliver information to the C-DIP at a speed that would enable publication and exploitation of the estimated location for a protection cleared fault that has occurred. For the purposes of the trial, this shall be assumed to between within [minutes] of the disturbance
3. Nortech will be responsible for supplying hardware and settings for the PQube/Envoy combinations. The device settings shall aim to deliver simultaneous delivery of harmonic monitoring and pre-fault/fault disturbance capture. Regard to be made for ensuring the data flows do not overwhelm users specific Ihost pages.
4. Nortech will be responsible for ensuring that within the trial, the PQube/Envoy devices can upload data in a suitable format for ingestion by the C-DIP. It is assumed that this will be done at the trial stage by sharing of Comtrade files. It should be noted that Comtrade files from these Category III devices are expected to be used for the protection relay bench testing also.
5. It would be preferable, but not essential, for each device to be able to use a common timing signal to help compare Comtrade files across the platform.
6. It is assumed that within the trial, the Envoy devices will communicate via 4G. WPD will be responsible for supplying communication sim cards to be fitted into the Envoys
7. Nortech will develop a set of device settings to ensure that the PQubes can deliver concurrent harmonic measurement, disturbance capture services and device memory management.
8. Nortech will train WPD staff on how to set up and install the PQube/Envoy devices
9. WPD will install the PQube/Envoy devices within the selected substations and Nortech will witness onsite installation
10. As part of the end of trial learning, Nortech should illustrate opportunities for how local computation and processing might enable reduced data transmission (in comparison to sending all Comtrade files)
11. Nortech's design must prescribe a design methodology to integrate "Pre-Fix ready" power quality monitors onto the C-DIP in the capacity of a Category III device. The Pre-Fix trial must record a set of specifications that future manufacturers would need to be tested against adhere to before their devices could be allowed to connect to the C-DIP. The Pre-Fix trial is not expected to certify any additional devices against this specification
12. PQubes will need to be connected to CT secondary's and VT secondary's. When developing pre-Fix algorithms, Nortech shall hold suitable regard for the performance limitations of CT's and VT's that these units are connected to.
13. Users will need to be able to record the geographic and electrical location of individual devices on the C-DIP platform. Users will need to be able to verify that the correct location has been recorded on the platform. This functionality should be deliverable on-site next to the device. This process needs to be applied to devices that could be fitted permanently or temporarily.
14. Devices should be capable of being updated remotely.
15. Faulty devices should be automatically logged to a WPD database.
16. Nortech will provide advice on the minimum requirements for the application of power quality monitor to fulfil C-DIP duties, including guidance on an acceptable play off between coverage of the incoming circuits versus increased uncertainty within the distance to fault algorithm. At present, the working hypothesis is that monitoring of a single GT incomer (where transformers are operated in parallel) will provide a sufficiently representative waveform for distance to fault and electric failure signature characterisation.

5.3.2. Power Quality monitor data requirements

1. The Power Quality monitors must provide the following data to the C-DIP:
    a. Three phase voltage and current disturbance records via a Comtrade file. These disturbance files to be captured upon the system reaching a trigger setting.
2. Whilst delivering item **Error! Reference source not found.Error! Reference source not found.**, Power quality monitors must continue to deliver the harmonic disturbance monitoring as demonstrated on the PNPQA project.

3. The Pre-Fault platform must provide a methodology to enable the electrical and geographic location of PQube devices to be declared on the C-DIP during commissioning. It would be preferable for this to be done through WPD on-site resources.
4. Provision must be made in the future output to local computation facilities before onward data transmission.

5.4. Secondary substation devices

In the Pre-Fix trial, Nortech NX44 devices will be used to investigate the use of category II devices located on ring main units.

5.4.1. Trial and application requirements

1. When acting as a category II device, the devices shall be capable of:
    i. Capturing three phase current waveforms in the form of a Comtrade file and sharing that file with the C-DIP.
    ii. Indicating the whether a pre-fault or fault is beyond or behind the device (relative to the primary)
    iii. Each device shall be capable of having a user specified current trigger that decides when a waveform is captured
2. When instructed to act as a category III device, the device shall be capable of
    i. Capturing and reporting the RMS current that has passed through the unit, the direction of this current and whether it was a phase to phase event, phase to earth event or open circuit event (i.e. broken conductor) [Can they provide a plot of the RMS behaviour during the peck?]
    ii. Capturing whether there is voltage presence and reporting that back
3. Each device shall be capable of having a user specified current trigger (and logic) that decides when a device reports only a fault passage event (presence of fault passage and phases) (i.e acting in Category III mode)
4. It would be advantageous, but not essential, for each device to be able to use a common timing signal to help compare Comtrade files across the platform.
5. Devices shall correctly replicate a waveform up to the ‘x’ kA capability of RMU CTs (where ‘x’ kA is dependent on the equipment class of the CTs. Beyond ‘x’ kA, the CT will saturate and the output waveform will be clipped).s
6. Users will need to be able to record the geographic and electrical location of individual devices on the C-DIP platform. Users will need to be able to verify that the correct location has been recorded on the platform. This functionality should be deliverable on-site next to the device. This process needs to be applied to devices that could be fitted permanently or temporarily.
7. Devices should be capable of being updated remotely.
8. Faulty devices should be automatically logged to a WPD database.
9. Nortech and WPD will provide user training for the installation of these units for the purpose of the Pre-Fix trial.
10. These devices will initially need to be connected to CT secondary’s that monitor the HV circuit. When developing Pre-Fix algorithms, Nortech shall hold suitable regard for the performance limitations of CT’s that these units are connected to. As a result of algorithm development work, Nortech will signpost what performance opportunities would be offered if WPD were to begin specifying ring main units/primary switchgear with higher specification CT’s or Rogowski coils.
11. Devices shall be capable of being powered by both 230V AC or any RTU DC power associated with WPD automation schemes.
12. These systems will use a WPD Sim card for trial purposes and local radio (if available) for BaU adoption.
13. Nortech will write a device requirements specification that will enable devices from other suppliers to contribute information to the C-DIP platform. This specification will establish a minimum performance baseline for category II and category III devices to contribute and to the C-DIP. To ensure that the aims of interoperability between suppliers can be met, WPD will arrange for some engagement with other devices suppliers to ensure to confirm that they would be able to offer “Pre-Fix” ready devices on the basis of the specification (i.e. new package substations etc.)

5.5. Overhead Line Fault Passage Indicators

Within the Pre-Fix trial, it is assumed that overhead line power devices will be used as a category II device, but at BAU scale, overhead line devices could be a category II or category III device

5.5.1. Trial and application requirements

It is assumed that the overhead line devices used to be used on Pre-Fix will be the same specification as those used on the Overhead line power pointer project, but with the ability to deliver the following additional requirements:

1. When acting as a category II device, the devices shall be capable of:
    a. Capturing three phase current waveforms in the form of a Comtrade file and sharing that file with the C-DIP.
    b. Indicating the whether a fault is beyond or behind the device relative to the primary
    c. Voltage presence
2. Each device shall be capable of having a user specified current trigger that decides when a waveform is captured
3. Each device shall be capable of having a user specified current trigger (and logic) that decides when a device reports only a fault passage event (presence of fault passage and phases) (i.e acting in Category III mode)
4. When acting as a category II device, the devices shall be capable of:
    a. Reporting the magnitude of the pre-fault or fault current, preferably as part of a time series, after a measurement of a current above a trigger threshold on a per phase basis
    b. Reporting the presence or not of voltage on a per phase basis
5. Devices shall correctly replicate a waveform up to the ‘x’ kA capability of overhead line monitoring devices (where ‘x’ kA is dependent on the equipment class of the CTs. Beyond ‘x’ kA, the CT will saturate and the output waveform will be clipped).
6. Users will need to be able to record the geographic and electrical location of individual devices on the C-DIP platform. Users will need to be able to verify that the correct location has been recorded on the platform. This functionality should be deliverable on-site next to the device. This process needs to be applied to devices that could be fitted permanently or temporarily.
7. Devices should be capable of being updated remotely.
8. Faulty devices should be automatically logged to a WPD database.
9. Nortech and WPD will provide user training for the installation of these units.

5.6. LV Substation Monitors

Within the Pre-Fix trial, no LV monitors are being placed upon the network. There will be an integration test to demonstrate whether LV monitors can be used to act as category III devices as part of the bench test activities.

5.6.1. Trial and application requirements

1. The C-DIP shall be capable of determining whether there is instantaneous voltage presence upon an LV monitor.
2. The C-DIP shall be capable of utilising voltage presence from LV disturbance monitors to help locate HV locations
3. In the future, the C-DIP shall be capable of comparing voltage disturbance recordings from LV monitors to gather information on the voltage profile.

6. Site Selection for Trials

6.1. Equipment availability

Within the Pre-Fix trial, there will be equipment provision for

- 20 Category I devices (PQube devices that connect to the incoming 33/11 KV circuits)
- 76 Sets of Category II devices that can be fitted to overhead lines
- 170 sets of Category III devices that can be fitted to ring main units (with existing three phase line CT's)

An additional data resource will be any disturbance recorders on the existing protection relays in the primary substation, but this data will need to be manually downloaded and reviewed by field staff if they think there is justification.

6.2. Selection of Primary Substations

The Pre-Fix project needs to demonstrate application of the Pre-Fix platform and capture Pre-fault behaviour in the lead up to a protection operation. It is expected that this behaviour will be different depending on a number of factors including weather and also the network type (i.e. underground or overhead) and age. The list of substations proposed to be used in Pre-Fix are summarised in Table 2.

Table 2: Pre-Fix locations

Name	Number	Voltage (kV)	Depot	Context	Feeders
Holbrook Lane	930038	6.6	Coventry	Urban (underground cable) Three bus sections, two infeeds.	12 (a further 8 are N.O.P or feed auxillaries)
Sandy lane	930040	6.6	Coventry	Urban (underground cable) Two bus sections, two infeeds	12 (a further 3 are N.O.P)
Spon Street	935791	6.6	Coventry	Urban (underground cable)	12
Courthouse Green	930035	11 (6.6. appears decomd)	Coventry	Urban (underground cable)	6
Cox Street	930031	6.6	Coventry	Urban (underground cable)	13 +1 NOP
London Road	930027	6.6	Coventry	Urban (underground cable)	7 +2 NOP
Dillotford Avenue	930623	11	Coventry	Urban (underground cable)	8 + Aux
Walsgrave	930047	11	Coventry	Urban (underground cable)	12 + 1 NOP + 2 Parallel
Whitley	930045	11	Coventry	Urban (underground cable)	13 +2 Parallel

Name	Number	Voltage (kV)	Depot	Context	Feeders
Gulson Road	930043	6.6	Coventry	Urban (underground cable)	9
Okehampton	350050	11	Exeter	Rural (Mainly overhead line with some UGC sections)	7 + capacitor
Crediton	310015	11	Exeter	Rural (Mainly overhead line with some UGC sections)	4 (first leg are NEXUS)
Witheridge	310011	11	Exeter	Rural (Mainly overhead line with some UGC sections)	3
Folly Bridge	310016	11	Exeter	Rural (Mainly overhead line with some UGC sections)	5
Chudleigh Knighton	340011	11	Exeter	Rural (Mainly overhead line with some UGC sections)	5

If applicable, further locations will be determined as the Pre-fix project evolves.

6.3. Trial location selection

Once the Pre-Fix trial sites have been selected, Category II and Category III devices need to be allocated using the following rules:

6.3.1. Feeder identification

There must be at least one category III device fitted to each feeder in the primary substation that is within the network before any branches along the feeder. The purpose of this rule is to be able to align the impedance measurements from the category 1 devices (i.e. PQube) to the feeder that has the defect.

Under BAU arrangements it is hoped that a capability will have been developed that will allow intelligent relays connected to the top of this relay to avoid this rule.

6.3.2. Feeder installations location, permanent fit.

Class II and Class III devices can be used to localise the location of defects and faults that have operated. For the purposes of the trial, The Nexus44 units can be placed on ring main units with suitable CT's. Smart Navigator units can be placed on overhead lines, it should be noted though that when then are connected on overhead lines with less than 20 Amps of continuous load, they act as the more limited class II device mode (i.e. communicate transients on an RMS basis, but not on a wave form basis.

When Class II or Class III pre-fault detection devices are to be placed on a feeder, where possible they should be placed to remove the greatest amount of uncertainty by firstly allocating to locations as high up the feeder as possible and then covering significant tee points. Situations where the first category II device is to be located beyond the second distribution substation on the feeder shall be flagged for technical review.

Category II and III devices can be placed on circuits where there is no Category I device as a means to help locate a fault that is difficult to locate, but this process will have to work without the aid of any impedance to fault based algorithms.

6.3.3. Feeder installations location, temporary fit.

The Pre-Fix project will have a stock of roaming smart Navigator units that can be deployed to increase monitoring on feeders that are known to have a defect that is brewing towards a fault. These units may be placed at the discretion of the field staff limited by the rules already expressed in 6.3.2.

7. Cyber Security

All equipment and systems utilised in Pre-Fix should comply with Standard Technique IR1/B (the document that defines the minimum cyber security requirements expected of third parties who process, store or have access to WPD information).

Where not already compliant, systems and equipment will be penetration tested in conjunction with the cyber security team.

Cyber security team guidance will be sought on a case-by-case basis relating to the requirements for equipment that has previously been penetration tested and is being modified as part of Pre-Fix (such as Smart Navigator 2.0s and substation relays).

8. BaU Adoption

8.1. Policies and Standard Techniques

Pre-Fix will either develop appendices to existing Standard Techniques (in the case of existing equipment installation and additional device settings) or, if required, develop entirely new Standard Techniques (for new equipment installations and the selection of sites for installation of Pre-fix solution equipment).

8.2. Future Integration with WPD Systems

Where possible dashboards should be accessible from the Oracle (i.e. in the future, build a link from Oracle to iHost)

In the future, Pre-Fix should be integrated with Power On and WPD field staff tablets to allow users to view data (such as search zone maps and fault impedance).

8.3. System Ownership

The enduring ownership of the Pre-Fix solution will be established as part of Phase 1 of the Pre-Fix project.

8.4. System Maintenance

It is anticipated that the Pre-fix solution, once adopted and operational as a BaU system, will be maintained as part of BaU processes (for example, Pre-Fix module will be deployed onto WPD's iHost system(s) for which there is already enduring support agreements in place).

Glossary

Abbreviation	Term
AR	Auto recloser
BaU	Business-as-Usual
C-DIP	Common Disturbance Information Platform
CI	Customer interruption
CML	Customer minutes lost
CT	Current transformer
DNP3	Distributed Network Protocol (Evolution 3.0)
FPI	Fault passage indicator
GB	Great Britain
GIS	Geographical information system
HV	High voltage
INM	Integrated network model
LV	Low voltage
NOP	Normally open point
OHL	Overhead line
PQ(M)	Power quality (monitor)
RIIO-ED2	Revenue = Incentives + Innovation + Outputs, Electricity Distribution Price Control Period 2
RTU	Remote terminal unit
TSDS	Time series data store
UGC	Underground cable

Appendices

Appendix 1 - Work-in-Progress Draft of Dashboard Wireframes

Western Power Distribution (East Midlands) plc, No2366923
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Western Power Distribution (South West) plc, No2366894
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