APPLYING MACHINE LEARNING TO POWER QUALITY SIGNALS TO DETECT COMPONENT FAILURE SIGNATURES AND PREVENT UNPLANNED HV OUTAGES

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ABSTRACT

This paper presents the application of machine learning, using a dynamic library of template electric failure signatures (built up from power quality waveforms), to detect component failures in HV distribution networks. By the early identification of pre-fault power quality signal disturbances and understanding the likely component to fail, unplanned customer outages can be avoided and the reliability performance of the HV distribution network can be maintained or improved.

INTRODUCTION

Project Pre-Fix is funded through Ofgem's Network Innovation Allowance (NIA) funding mechanism and is running from Autumn 2021 to March 2024 [1].

Pre-Fix is being delivered by National Grid Electricity Distribution (NGED) in partnership with Nortech Management Limited.

NGED is conducting this project with the intention of being able to improve customers' experience of power cuts. This will be achieved by enabling faster restoration and potentially intercepting defects before they occur. Pre-Fix seeks to overcome the barriers to wide-spread High Voltage (HV) pre-fault capability represented by developing alternatives to a vendor tie model in that is associated with proprietary software. Overcoming vendor tie in will mean that NGED can interoperate pre-fault sensitive devices. This interoperability will translate into a lower unit cost to deliver this capability.

This project utilises HV pre-fault capture capable devices from different manufacturers to demonstrate how they can all contribute into a Common Disturbance Information Platform (C-DIP). Further information on the C-DIP can be found in complementary Paper # 10751 "Delivering the benefits from a Common Disturbance Information Platform to prevent unplanned outages".

This project also demonstrates how existing network devices, such as power quality monitors and protection relays can contribute to HV pre-fault detection in addition to their base functionality. The project is in the process of developing operational dashboards and reports that will facilitate a consistent policy-driven approach to be implemented across NGED's organisation and other GB DNOs.

Key activities during Pre-Fix include:

- Use of trial data from other DNOs to inform platform design and support testing
- Architecture specification for the Common Distribution Information Platform (C-DIP)
- Interoperability specification and setting of pre-fault gathering devices
- Design of common operational user interfaces
- Live trial of devices, platform and reports

The key outputs of Pre-Fix will be:

1. A Common Disturbance Information Platform (bringing information from multiple sources together into a single place);
2. Development and demonstration of Distance-to-Defect algorithms (localising the location of the fault or pre-fault in the HV network); and
3. Development and demonstration of artificial intelligence algorithms to classify faulted components via their electrical signatures at the time of fault and during the build up to the fault.

This paper focuses on Key Output #3. Further information on the C-DIP and Distance-to-Defect can be found in complementary Paper # 10751 "Delivering the benefits from a Common Disturbance Information Platform to prevent unplanned outages" (focusing on Key Outputs #1 and #2).

BACKGROUND

Whilst significant developments and advances have taken place at LV for fault detection and location, at present NGED does not have a distance-to-fault or distance-to-pre-fault solution for HV networks. To overcome this, the Pre-Fix project was conceived.

Any solutions that do exist in the current marketplace are tied into specific vendors (hardware and software platforms) and their Distribution Management System (DMS). It is not financially or practically viable for NGED to make use of such systems without embarking on a potential replacement programme for the DMS itself.

Even if a platform were available, as it is vendor-specific, it would not allow data from multiple devices at multiple locations to be brought together to extra information in a coordinated and corroborative way. Therefore, the development of such a platform is required and, for game-changing performance in RIIO-ED2 (NGED's second regulatory price control period in RIIO), the way to business-as-usual (BaU) adoption needs to be paved in RIIO-ED1 via development and demonstration.

WAVEFORM CAPTURE DEVICE TYPES

To demonstrate interoperability, the waveform classifier presented in this paper is based on three different device types:

Power Quality Monitors (PQMs): These devices are located on the low voltage (LV) side of 33kV / 11kV transformers and have voltage transformer (VT) and current transformer (CT) inputs. The PQMs were initially configured to trigger waveform captures based on voltage waveform distortions, rapid voltage changes, voltage dips and swells and spikes in load current.

Cable Fault Passage Indicators (FPIs): These devices utilise CT inputs and can be located within source circuit breaker panels, at the headend of HV circuits, within the Primary Substation. Cable FPIs can also be installed at HV Ring Main Units (RMUs) at strategic locations along HV cable circuits. The cable FPIs were configured to trigger waveform captures based on pre-set current-time thresholds as well as current waveform distortion.

Overhead Line (OHL) Fault Passage Indicators (FPIs): These devices utilise CT inputs and can be placed at strategic locations along HV overhead line circuits. The OHL FPIs were configured to trigger waveform captures based on pre-set current-time thresholds as well as current waveform distortion.

As part of Pre-Fix, the Common Disturbance Information Platform will be expanded to make use of other devices capable of capturing fault signature waveforms (such as auto-reclosers and protection relays.)

METHODOLOGY

The classification methodology is given in Figure 1. The classification algorithm was set up on the basis of using a convolutional neural network (CNN) pre-trained on a large quantity of verified time-series data that show a wide range of common fault signatures. The prototype CNN was created in python using the TensorFlow Keras module. Pre-training the model allowed for a faster user experience when it came to classifying a particular waveform automatically.

Outputs of the CNN give the user the closest match between the input fault signature data and a known fault signature type, along with a % certainty score. An initial set of electric fault signatures was used to train the CNN fault classifier based on the IEEE Power Engineering Society Technical Report 73: “Electric Signatures of Power Equipment Failures”.

In the C-DIP, the user has the option to view the input data and the matched waveform as graphs, to allow for manual verification before continuing. Clearly, on occasions it could be possible for no match to be found (or to be found with a confidence outside of configured tolerances). In this case, these classifications are displayed as “no classification match”, to allow for these exceptions.

A key novel feature of the classifier within C-DIP is that the CNN classifier is capable of being retrained in order to add new fault/pre-fault categories as real-life fault data is captured during the course of Pre-Fix.

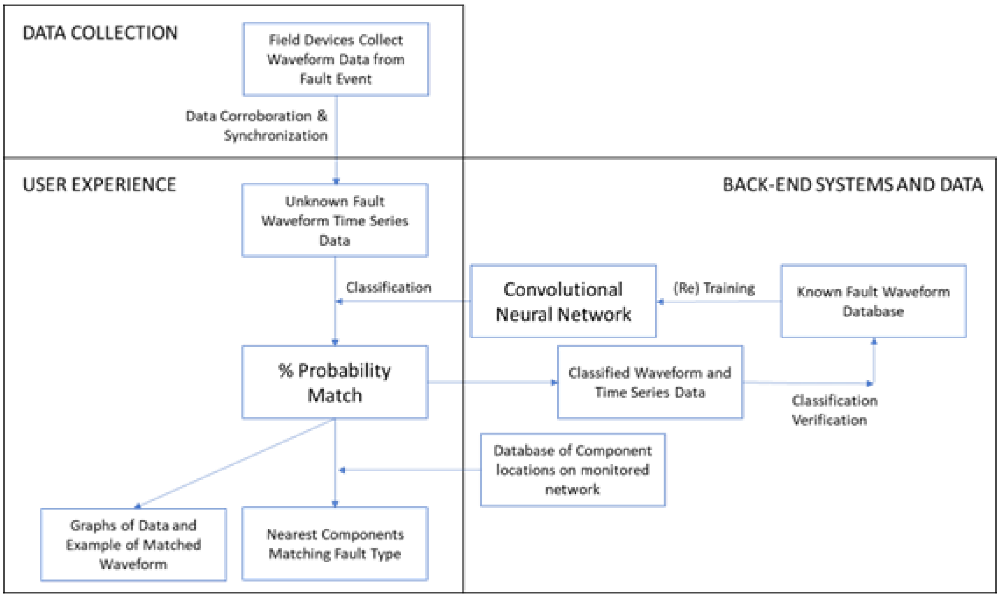

Figure 1: Classification of faulted components using electric failure signature templates

RESULTS

Incipient Cable Fault (Pre-Fault Defect)

The template signature for an incipient cable fault from the IEEE PES Technical Report 73 is given in Figure 2. Two incipient cable faults captured during Pre-Fix are given in Figures 3 and 4 respectively.

The defect shown in Figure 3 was classified with 95.4% confidence as phase-phase incipient cable fault based on the waveform capture from a pre-fault enabled cable fault passage indicator (FPI) device located at the source circuit breaker of the faulty HV circuit.

The defect shown in Figure 4 was classified with 82.1% confidence as phase-earth incipient cable fault based on the waveform capture from a pre-fault enabled cable fault passage indicator (FPI) device located at the source circuit breaker of the faulty HV circuit.

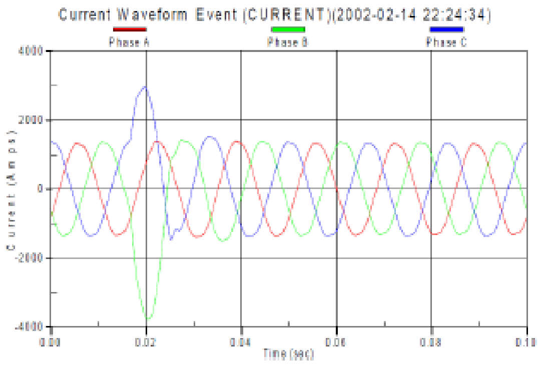

Figure 2: Incipient cable fault template signature

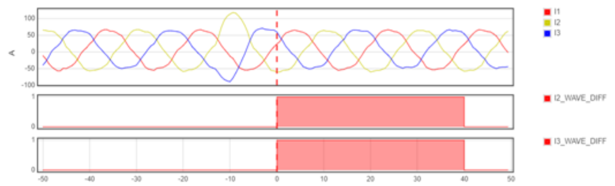

Figure 3: Waveform classified as incipient phase-to-phase cable fault

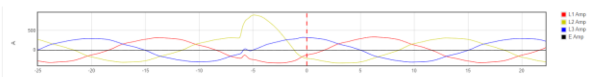

Figure 4: Waveform classified as incipient phase-to-earth cable fault

Underground Cable Fault

The template signature for an underground cable fault from the IEEE PES Technical Report 73 is given in Figure 5. An underground cable fault captured during Pre-Fix is given in Figure 6.

The waveform given in Figure 6 was classified with 69.2% confidence as a phase-earth cable fault based on the waveform capture from a power quality monitoring device located at the Primary Substation (on the 11kV side of the 33kV / 11kV transformer feeding the HV network).

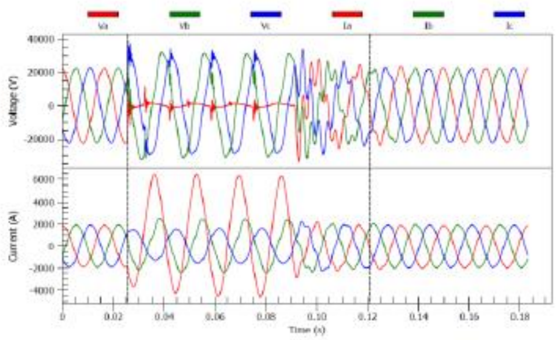

Figure 5: Underground cable fault template signature

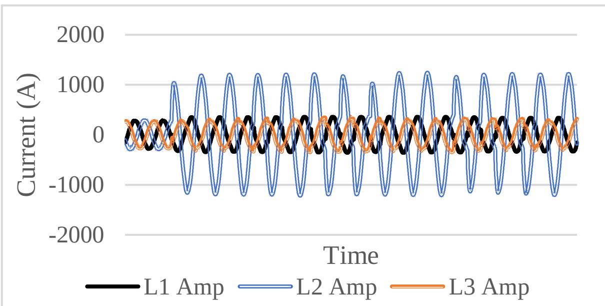

Figure 6: Waveform classified as underground cable fault

Fuse Blown Fault (forming new fault template signature)

A new template signature is given in Figure 7 for blown fuses at a pole-mounted transformer based on the waveform capture from a power quality monitoring device at the Primary substation and validation by NGED field staff of the cause of the defect.

As given in Figure 8, this learning has already been taken forwards to classify the waveforms from pre-fault enabled overhead-line fault passage indicator (FPI) devices located between the Primary Substation and faulty HV circuit section.

The waveform given in Figure x-8 was classified with 87.9% confidence as a three-phase fault due to foreign object on a pole-mounted transformer (PMT) (causing fuse operations) based on the waveform capture from OHL FPI devices.

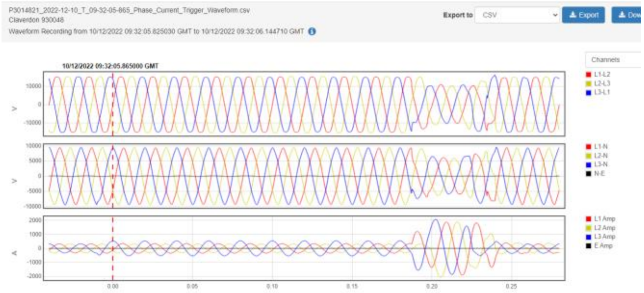

Figure 7: Fuse operation template signature (due to foreign object on a HV/LV pole-mounted transformer)

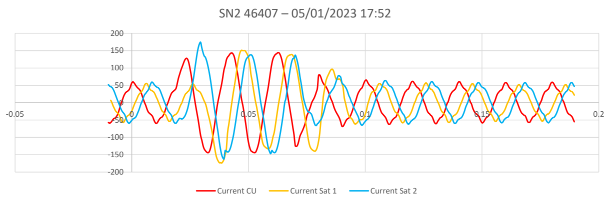

Figure 8: Waveform classified as fuse operation due to foreign object on HV/LV pole-mounted transformer.

DISCUSSION

If there are two fault signatures with similar characteristics, there is potential for overlap between faults that are classified. This can be mitigated by analysing other waveform parameters (such as use of both voltage and current rather than just current) and bringing in data from corroborative sources.

The classification system currently has some capacity to filter out noise in input waveforms. However, if noise is too extreme, it can lead to the system classifying the input waveform incorrectly.

In initial trials, the classification system is able to accurately classify fault waveforms with a signal-to-noise ratio of 20dB or higher. This allows faults, which are characterised by extreme noise (such as arcing faults), to be differentiated from a noisy fault of a different component. This boundary will be further refined based on trial data collection and performance.

The classification system requires a robust database of known fault waveforms in order to correctly classify incoming data. If the database used to train the system is too limited, there will be accuracy issues and a risk that waveforms are misclassified or not able to be classified at all.

This can be partially mitigated in the future with the retraining of the system using new (pre-)fault waveforms collected. There is currently an extensive dataset of post-fault data to use during training, and pre-fault data is currently being collected as part of Pre-Fix to inform the classification of network defects observed in the future.

CONCLUSION

This paper has presented the application of machine learning, using a dynamic library of template electric failure signatures (built up from power quality waveforms), to detect component failures in HV distribution networks. By the early identification of pre-fault power quality signal disturbances and understanding the likely component to fail, unplanned customer outages can be avoided and the reliability performance of the HV distribution network can be maintained or improved.

REFERENCES

[1] National Grid, 2021, "Pre-Fix", Available on-line at: https://www.nationalgrid.co.uk/projects/pre-fix [last accessed 19/01/2023]

[2] IEEE Power and Engineering Society, 2019, *Technical Report 73 Electric Signatures of Power Equipment Failures*, IEEE, USA, 1-78