REPORT

UltraTEV Monitor Analysis for RESPOND Project

Private and confidential

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15/09/17	Issue 1	Vittawat Dolbandarnchoke	
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Executive summary

EA Technology's proposal P9123 Issue 3 was submitted to Electricity North West limited (ENWL) in July 2014 offering both equipment and consulting services to support ENWL's RESPOND project. The equipment (4 x UltraTEV Monitors) was purchased in December 2015 and installed in early 2016.

The consulting element of the proposal was requested as a provisional piece of work. As part of the RESPOND project ENWL has committed to carrying out increased asset condition monitoring of assets on the network which may be affected by the RESPOND project.

The RESPOND project is now approximately half way through the trial phase and ENWL has asked EA Technology to supply a price for performing analysis on the UltraTEV Monitor results to date, to see if there is any identifiable change in Partial Discharge activity on assets where the RESPOND solutions have been exercised.

As such EA Technology has performed partial discharge (PD) analysis on switchgear in the following substations:

- Atherton Town Centre Substation
- Blackbull Substation
- Broadheath Substation
- Denton West Substation
- Irlam Substation
- Littleborough Substation
- Mount St Substation
- Offerton Substation

Where possible, the PD analysis has been compared with fault history in the past year provided by the ENWL to qualify or quantify any relationship between faults and changes in observable PD.

Conclusions

C1. Ten faults occurred within five substations between 31/05/2016 to 08/05/2017, those substations were Atherton Town Centre, Blackbull, Broadheath, Littleborough, and Offerton.

C2. Respond Fault Level Monitor (FLM) equipment was engaged on five fault occasions in Atherton Town Centre, Blackbull, and Littleborough substations.

C3. A correlation between fault history and captured data was completed for Atherton Town Centre, Broadheath, and Littleborough substation. Monitoring session data from Blackbull, and Offerton did not cover the date of the faults.

C4. Three substations had no faults registered during the same period; those substations were Denton West, Irlam, and Mount St.

C5. Analysis has shown that there is no correlation between faults and TEV activity, regardless of the engagement of Respond FLM equipment as the magnitude and pattern of TEV activity remains similar before and after the faults.

Recommendations

R1. An UltraTEV Monitor should be installed in Blackbull, and Offerton substations for at least one week after the completion of the project in order to monitor and trend TEV activity.

R2. Should any faults occur, an UltraTEV Monitor should be installed in the Denton West, Irlam, and Mount St. substations to monitor and trend TEV activity.

R3. The UltraTEV Monitor data from eight substations should be reviewed at the end of project, June 2018, to investigate the effects of faults and the engagement of Respond FLM equipment.

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1. Background & Introduction

EA Technology's proposal P9123 Issue 3 was submitted to Electricity North West limited (ENWL) in July 2014 offering both equipment and consulting services to support ENWL's RESPOND project. The equipment (4 x UltraTEV Monitors) was purchased in December 2015 and installed in early 2016.

The consulting element of the proposal was requested as a provisional piece of work. As part of the RESPOND project ENWL has committed to carrying out increased asset condition monitoring of assets on the network which may be affected by the RESPOND project.

EA Technology developed Condition Based Risk Management (CBRM) and now Common Network Asset Indices Methodology (CNAIM) Models for ENWL and has been asked to outline a strategy for how the data, gathered as part of RESPOND can be used to assess the effects of the new fault level management techniques on existing assets.

In March 2016, the following approach to achieve ENWL's objectives was recommended by EA Technology:

1. Finalise which substations the active fault management will be installed in, with consideration given to the asset types, ages and health indices of assets in those substations.
2. Carry out a condition assessment before the beginning of the trial and update the Health Index.
3. Define monitoring or data collection intervals during the trial (where applicable) or how additional data can be obtained during operation.
4. Analyse and compare asset condition information at regular defined intervals during the trial period, taking into account the impact of the fault management equipment.
5. Recalculate health indices based on condition information during the trial and at the end of the trial.

A budget of £40,000 was allocated for this work.

The RESPOND project is now approximately half way through the trial phase and ENWL has asked EA Technology to supply a price for performing analysis on the UltraTEV Monitor results to date, to see if there is any identifiable change in Partial Discharge activity on assets where the RESPOND solutions have been exercised.

As such EA Technology has performed partial discharge (PD) analysis on switchgear in the following substations:

- Atherton Town Centre Substation
- Blackbull Substation
- Broadheath Substation
- Denton West Substation
- Irlam Substation
- Littleborough Substation
- Mount St Substation
- Offerton Substation

Where possible, the PD analysis has been compared with fault history in the past year provided by the ENWL to qualify or quantify any relationship between faults and changes in observable PD.

2. Results

Four UltraTEV Monitors were installed and monitored eight substations in the past year, with the length of survey lasting from one week to one year. This was to provide a datum of PD activity in each of the substations. Sections below detail and discuss analysis for each substation.

2.1 Installation in Atherton Town Centre Substation

An UltraTEV Monitoring system with 4 nodes was installed in Atherton Town Centre substation and monitored activity in the substation between 25/04/2016 to 20/06/2017. Figure 1 below is a plot containing all the TEV activity captured from Atherton Town Centre substation. Elevated TEV activity was detected on all channels. The patterns mostly correlated to measurements from the aerials, which suggest that the source is external interference. Five faults occurred during this monitoring period, where the date is shown as an overlay on Figure 1. The date and brief information of five incidents are the following:

1. 09/06/2016: Collier Brook Feeder, no engagement of Respond FLM.
2. 13/07/2016: ENA Mill, no engagement of Respond FLM.
3. 29/07/2016: Collier Brook, Respond FLM was engaged.
4. 28/08/2016: Thomas St/Holland St, Respond FLM was engaged.
5. 16/09/2016: York St SW STN, Respond FLM was engaged.

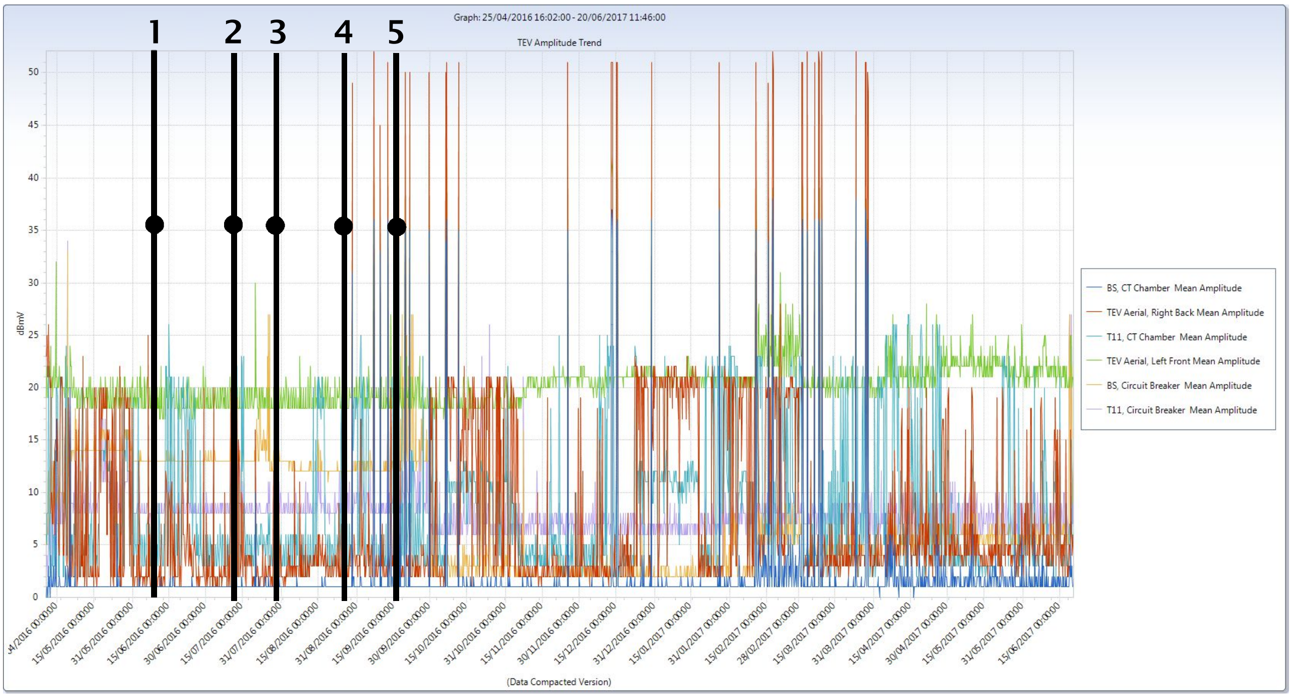

Figure 1 TEV Activity Plot with Date of Faults Overlay for All TEV Channels in Atherton Town Centre

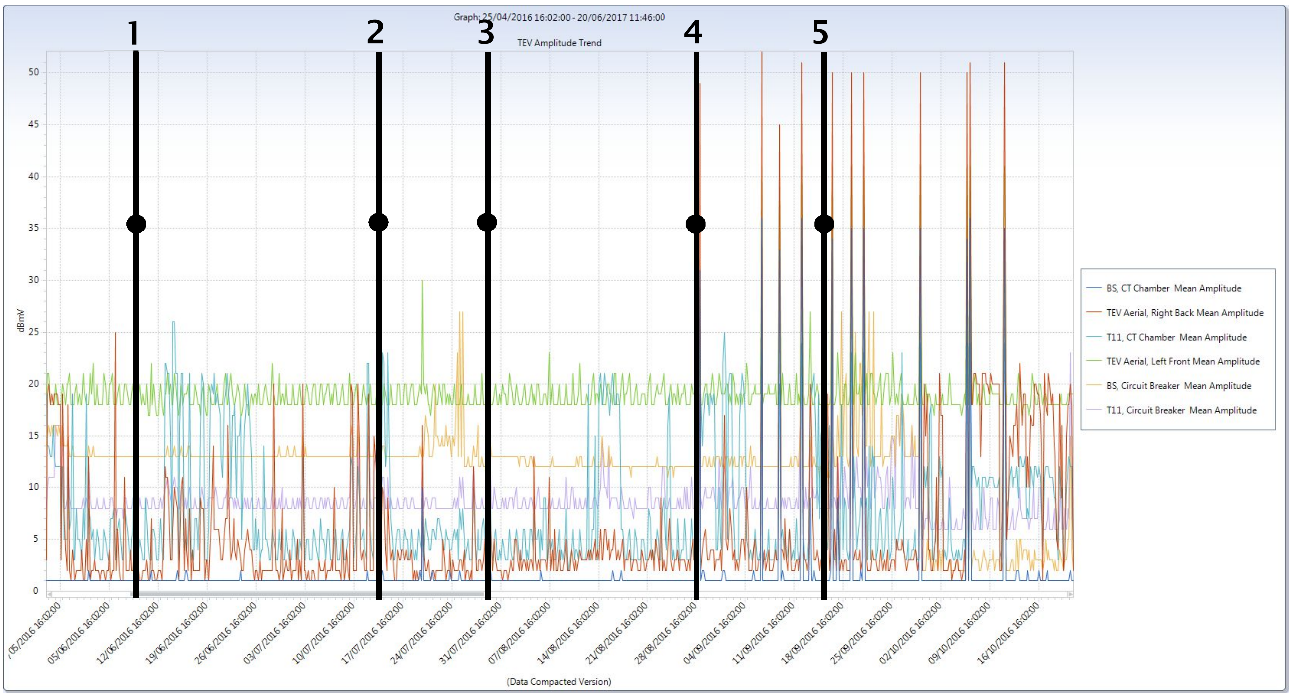

Figure 2 TEV Activity Plot for All TEV Channels in Atherton Town Centre between 05/06/2016 to 16/10/2016

Figure 2 above illustrates TEV activity captured on all channels in Atherton Town Centre substation between the period of 05/06/2016 to 16/10/2016, which covers all the faults that occurred in this substation. According to the activity shown in Figure 2, the faults on five occasions did not significantly affect the TEV magnitude or patterns observed from all six channels. The base level of TEV activity stayed at a similar level prior to and after the fault occurred. Respond FLM was engaged on fault number 3, 4, and 5, yet, the TEV activity remained similar after the engagement of the equipment. Figure 3 and Figure 4 below are a six-week close-up of TEV activity covering the occurrence of fault number 3, and number 5. The magnitude and pattern of TEV activity from these two figures remained the same despite three faults occurring between the two-time periods. Note that the multiple high amplitude spikes in Figure 4 were caused by external interference, as the most dominant signal came from the two aerials. This suggests that faults and the use of Respond FLM do not affect the TEV activity within these assets.

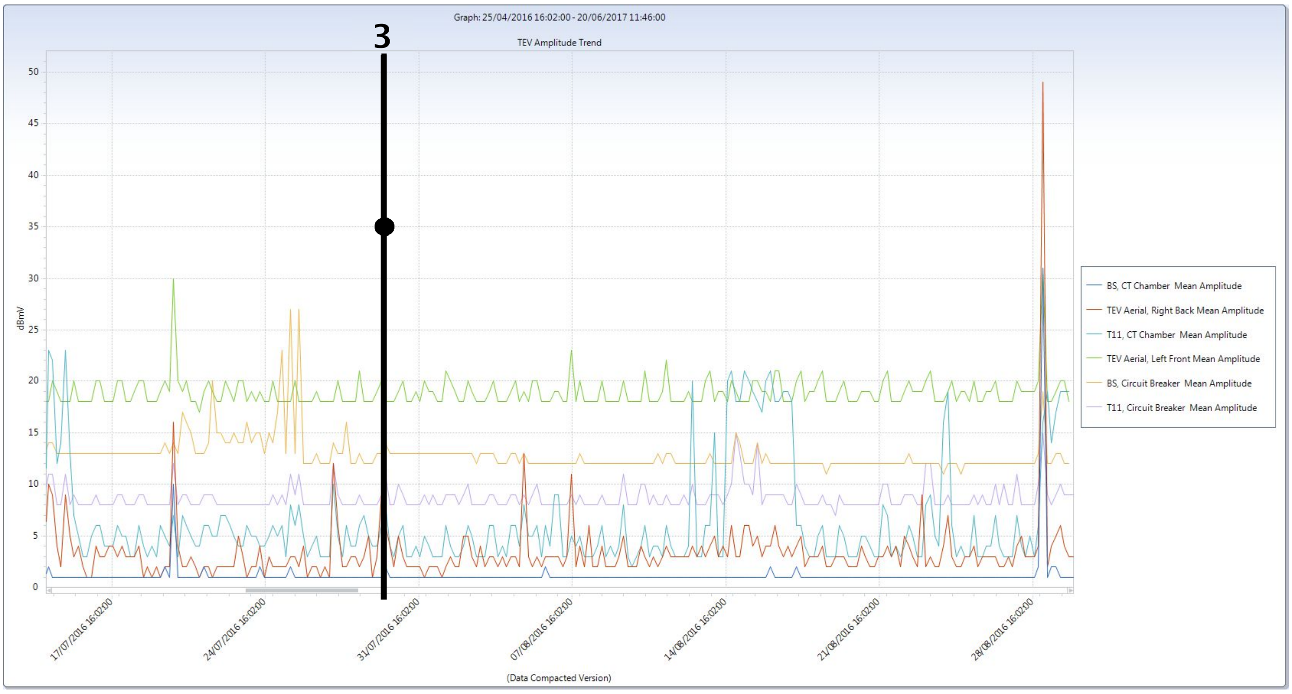

Figure 3 **Close-Up of TEV Activity Plot for All TEV Channels in Atherton Town Centre Covering Fault Number 3**

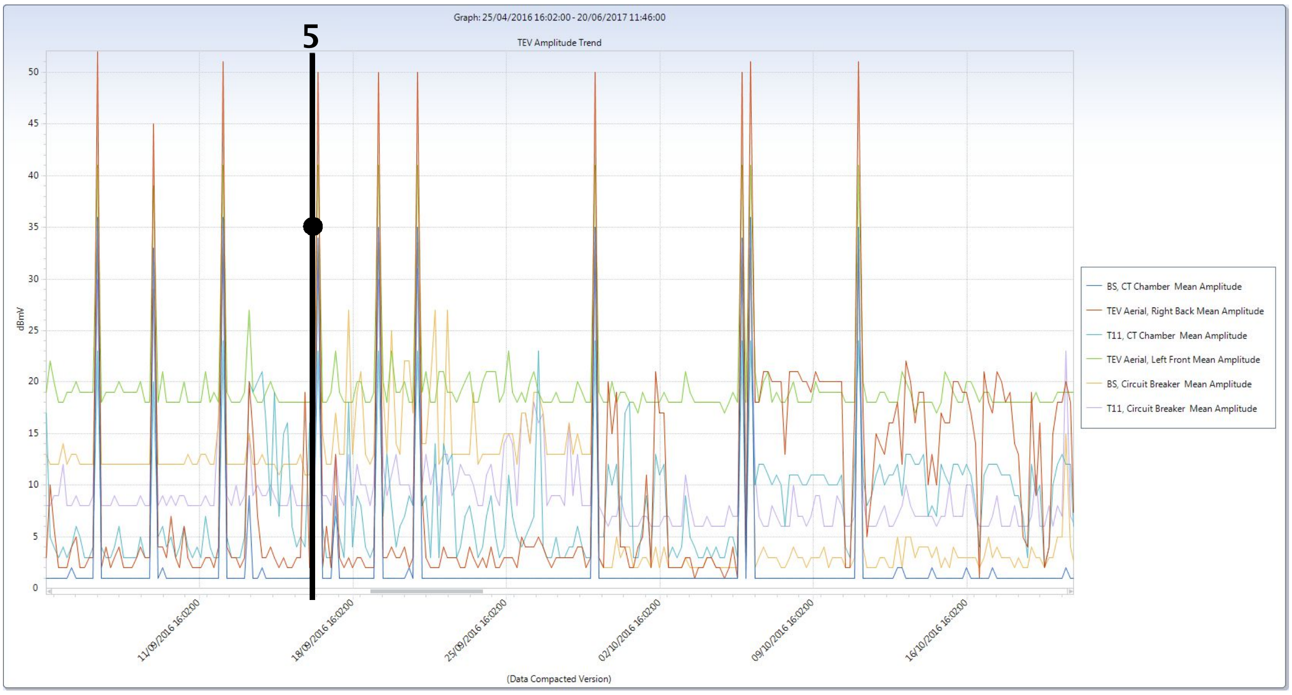

Figure 4 **Close-Up of TEV Activity Plot for All TEV Channels in Atherton Town Centre Covering Fault Number 5**

2.2 Installation in Blackbull Substation

An UltraTEV Monitoring system with 2 nodes was installed in Blackbull substation and monitored activity in the substation between 29/04/2016 to 06/05/2016. Figure 5 illustrates captured TEV activity on all the channels in Blackbull substation. Activity captured from the two aerial channels dominated the TEV plot, and signals from the remaining channels are well below the PD threshold, which suggests that there was no partial discharge activity detectable in this session.

According to a fault log, there was a fault that occurred on 06/04/2017, however, the obtained data only captured activity between 29/04/2016 to 06/05/2016. Hence, the fault history of this substation cannot be correlated to the captured activity.

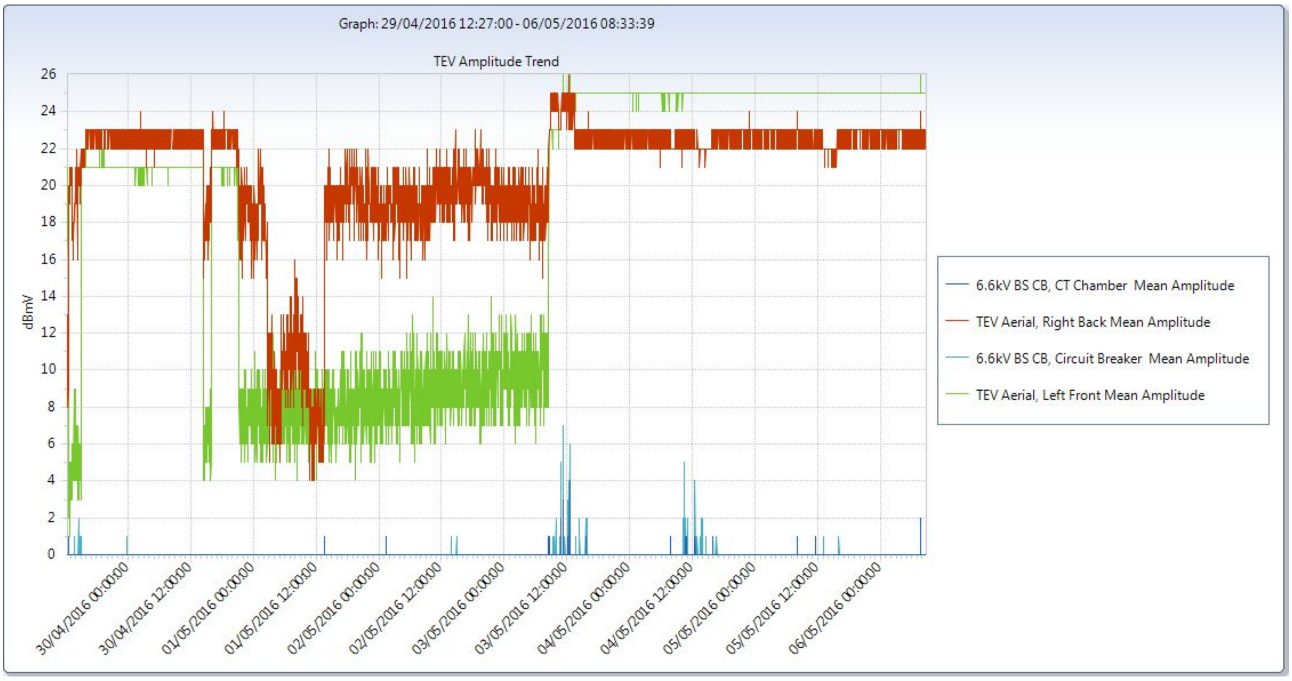

Figure 5 TEV Activity Plot for All Channels in Blackbull

2.3 Installation in Broadheath Substation

An UltraTEV Monitoring system with 3 nodes was installed in Broadheath substation and monitored activity in the substation between 22/04/2016 to 16/05/2017. Figure 6 displays all TEV activity captured from the monitoring session. Activity captured from the two aerial channels are the strongest in this session, and activity from the three remaining TEV channels have a pattern that follow signals from the aerials closely. This suggests that there was no partial discharge activity detectable during this measurement period.

There were two faults that occurred during the monitoring session, which are detailed below:

1. 31/05/2016: L2239 LINOTYPE/BUNDENBERG HSE, no engagement from Respond FLM
2. 05/04/2017: L2245 ALTRINCHAM RET PK NO 1, no engagement from Respond FLM

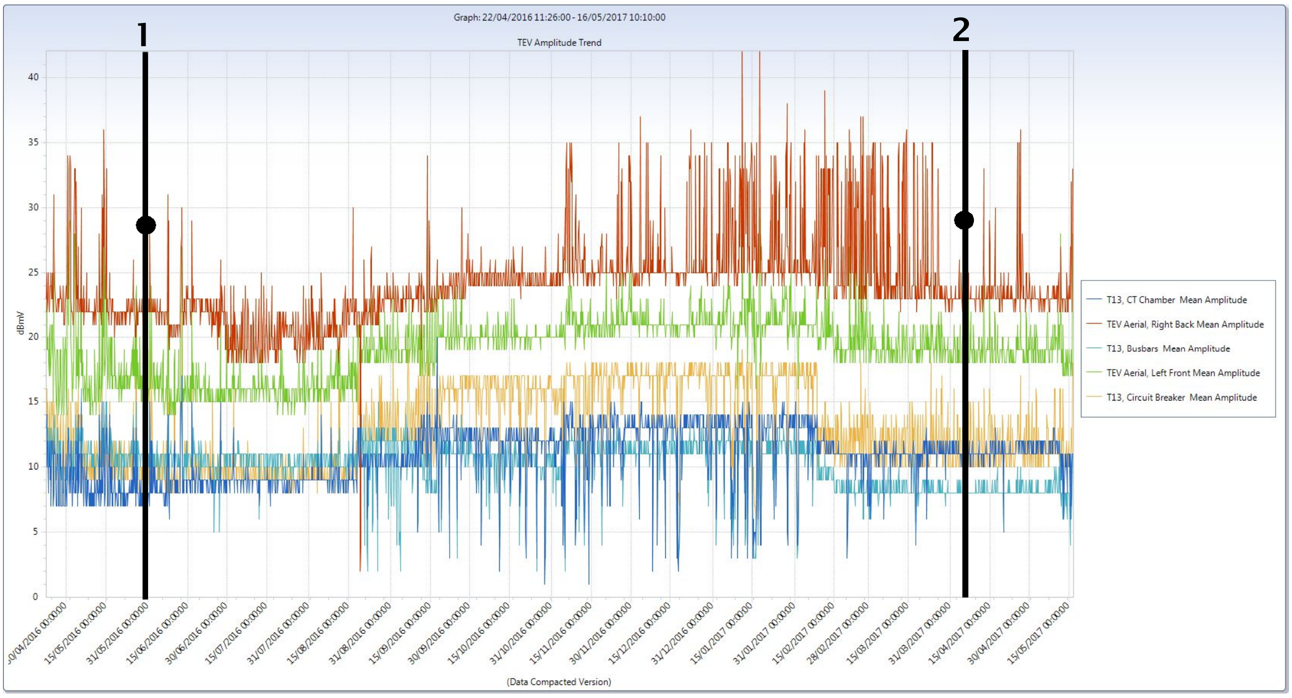

Figure 6 TEV Activity Plot with Date of Fault overlay for All TEV Channels in Broadheath

Figure 7 and Figure 8 below are a close-up of TEV activity focusing around the dates of incidents. The plots focus on the period one week before the fault, and four weeks after to capture activity after the re-energization of assets.

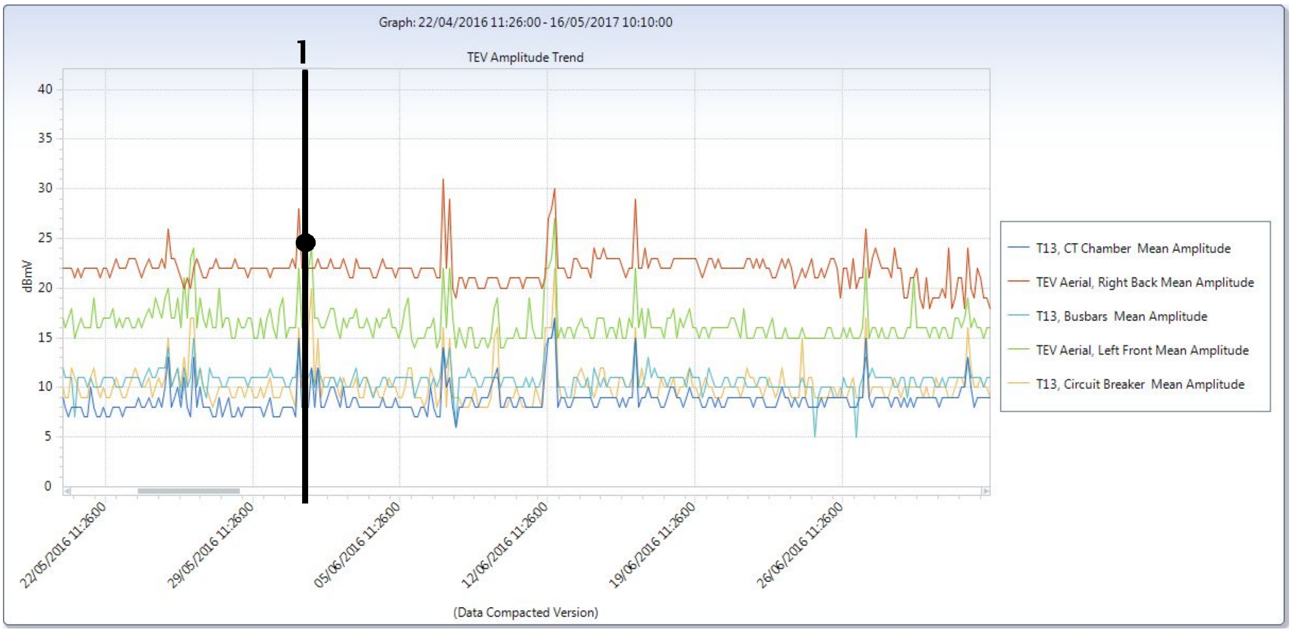

Figure 7 **TEV Activity Plot with Date of Fault overlay for All TEV Channels Covering Fault Number 1**

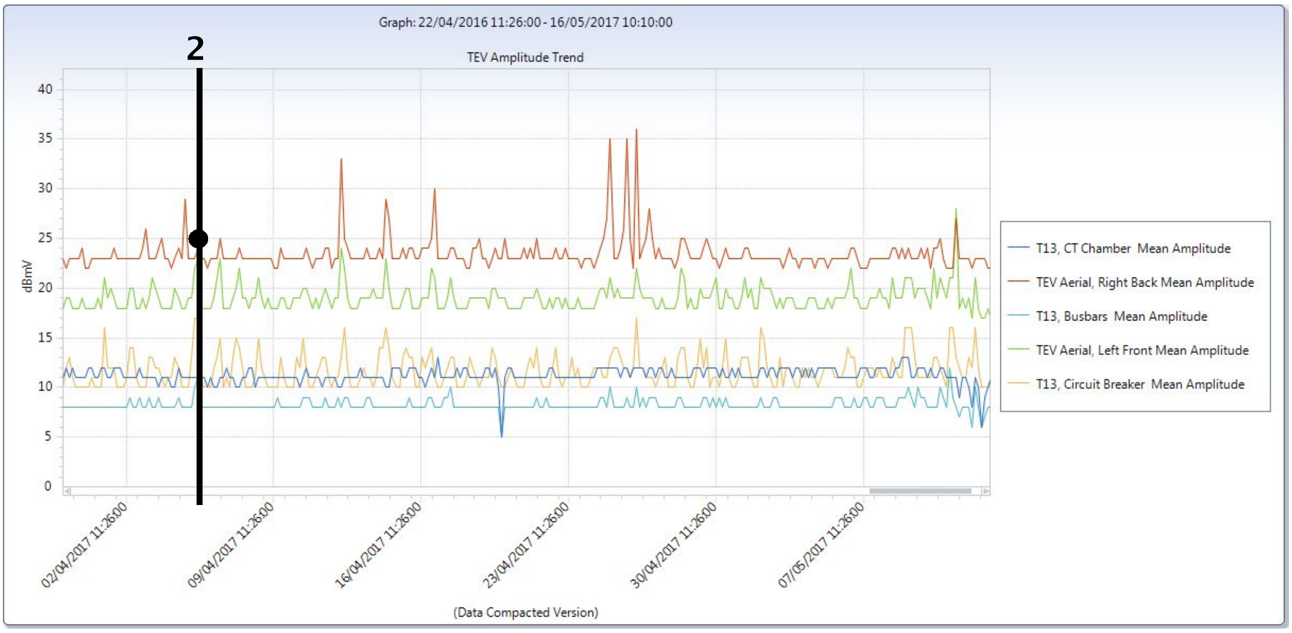

Figure 8 **TEV Activity Plot with Date of Fault overlay for All TEV Channels Covering Fault Number 2**

From the two diagrams above, there is no change of base level for TEV activity before or after the date of the incidents. Additionally, despite the occurrence of multiple faults, TEV activity still follows interference captured from the aerials. These confirm that; only external interference was captured on this measurement, and the faults had no effects on TEV activity.

2.4 Installation in Denton West Substation

An UltraTEV Monitoring system with 3 nodes was installed in Denton West substation and monitored activity in the substation between 18/04/2016 to 29/04/2016. Figure 9 illustrates all TEV activity captured during the monitoring session. The most dominant activity captured in this session are from the two aerials, and the activity on the remaining TEV channels have patterns that are following closely throughout the period. Hence, it is reasonable to conclude that no partial discharge activity was detected in this session.

No faults occurred at Denton West substation during the monitoring period, hence, a correlation between fault data and monitored data cannot be completed.

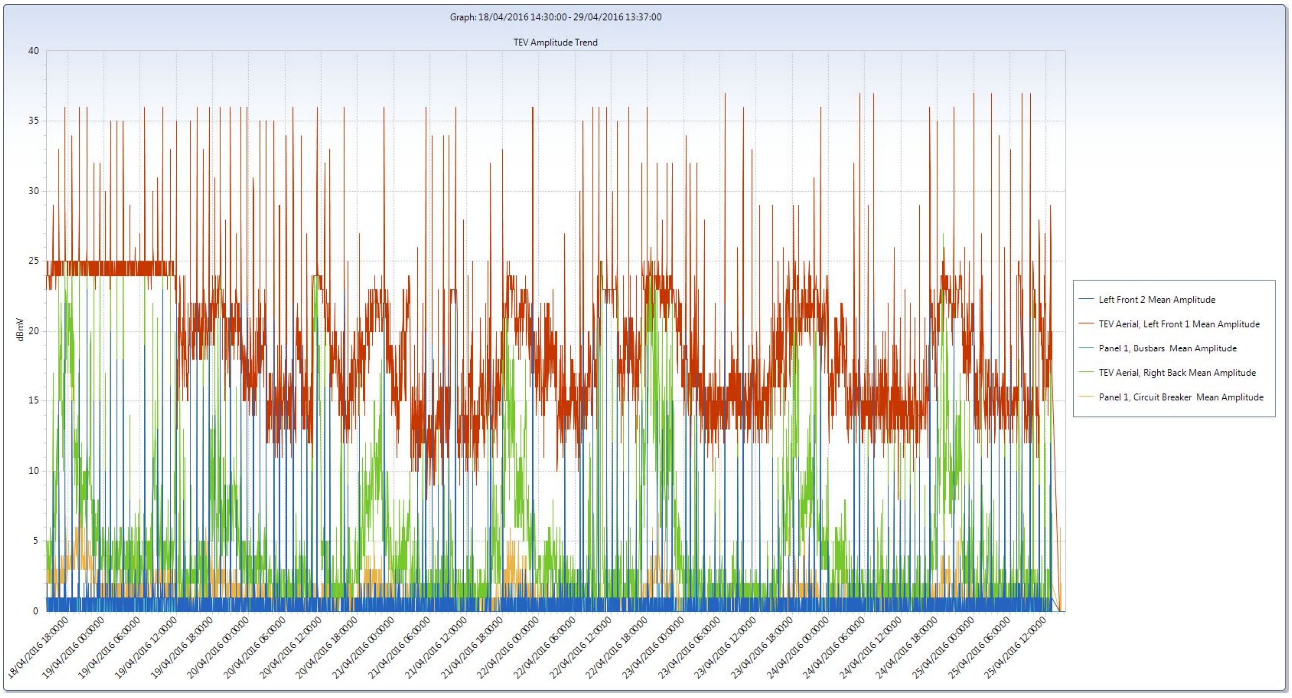

Figure 9 TEV Activity Plot for All TEV Channels in Denton West

2.5 Installation in Irlam Substation

An UltraTEV Monitoring system with 2 nodes was installed in Irlham substation and monitored activity in the substation between 13/05/2016 to 06/06/2017. Figure 10 displays all TEV activity captured in Irlam substation. In this period, activity captured from the two aerial channels are the most dominant, and the activity from the remaining TEV channels follow the pattern of the aerials closely. Hence, it is reasonable to conclude that external interference is the main cause of all the captured activity, and no partial discharge activity was detected.

No faults occurred at Irlam substation during the monitoring period, hence, a correlation between fault data and monitored data cannot be completed.

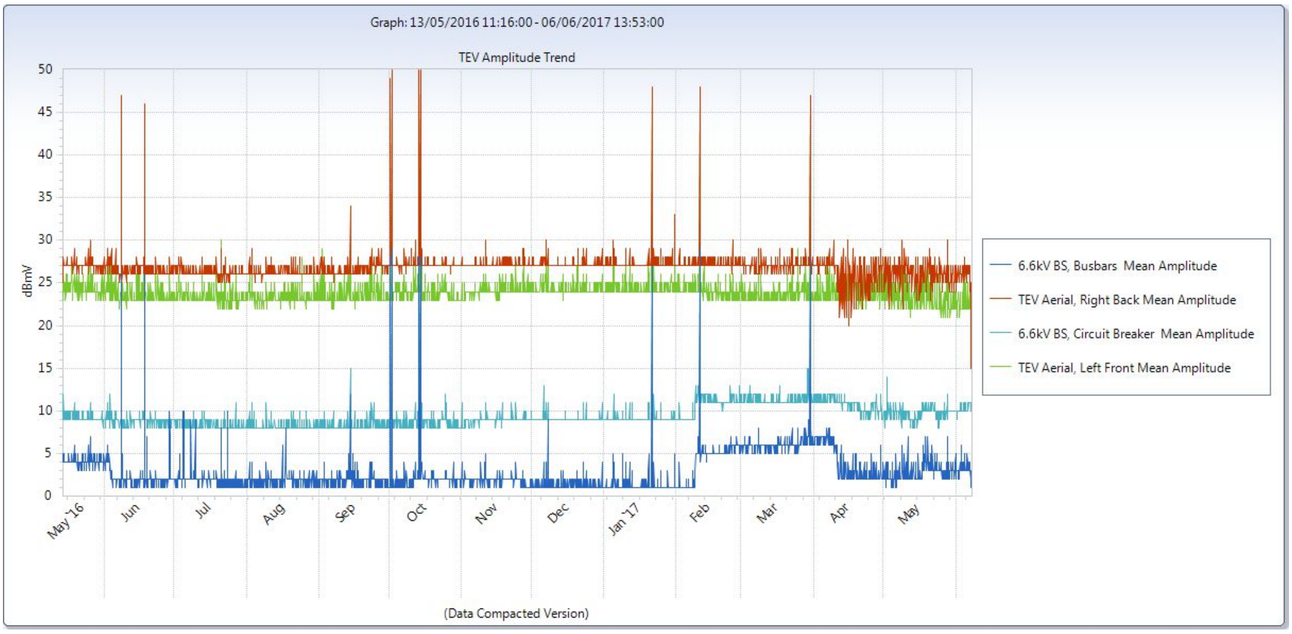

Figure 10 TEV Activity Plot for All TEV Channels in Irlam

2.6 Installation in Littleborough Substation

An UltraTEV Monitoring system with 3 nodes was installed in Littleborough substation and monitored activity in the substation between 27/04/2016 to 06/06/2017. Figure 11 displays all TEV activities captured in Littleborough substation. In this period, activity captured from the two aerial channels was the most dominant, and the activity from the remaining TEV channels remained dormant with minimal elevation below the signals from the aerials. This suggests that external interference caused the captured activity, and no partial discharge activity was detected.

A fault occurred in Littleborough substation on MIDGEHOLES/DEARNLEY feeder on 08/05/2017, and the Respond FLM equipment was engaged. An overlay is placed on Figure 11 to indicate the date of incident.

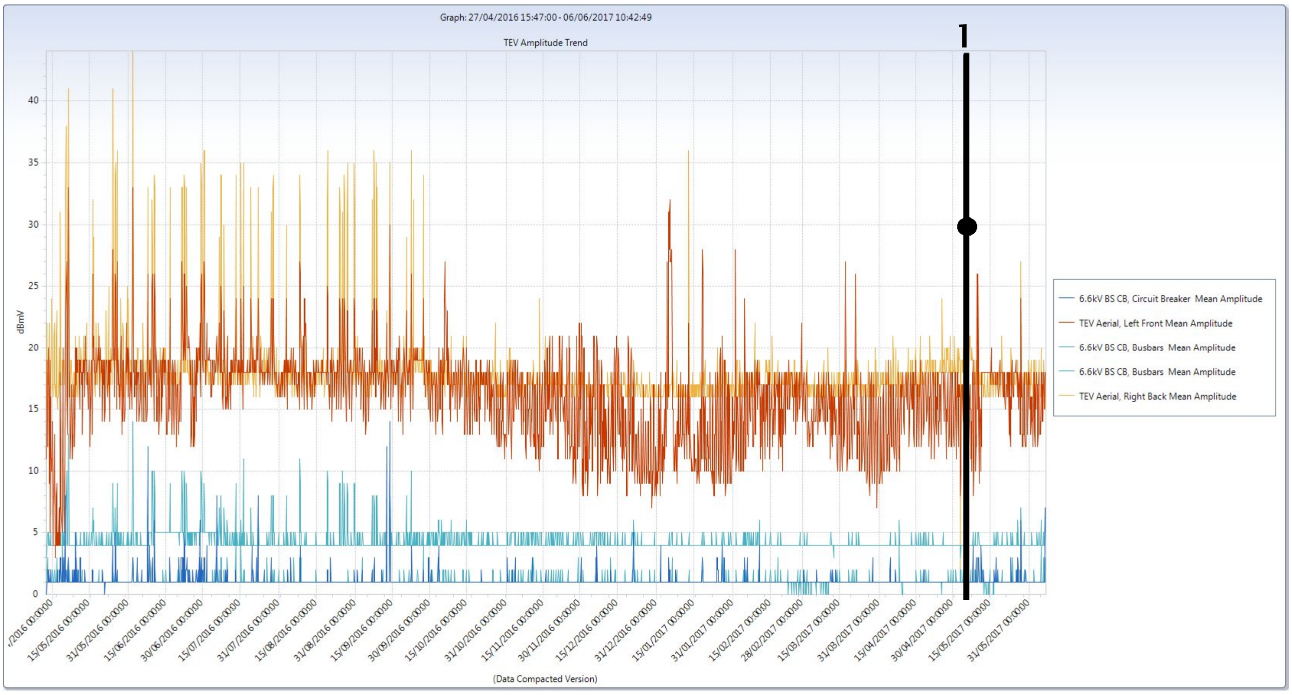

Figure 11 TEV Activity Plot for All TEV Channels in Littleborough

Figure 12 below displays a close-up of TEV activity in all channels two weeks before the date of the incidents, and four weeks after to capture TEV activity after the re-energization of assets. According to Figure 12, TEV activity remained at a similar level both before and after the fault. Furthermore, there is no change in the pattern of activity in any of the channels. This suggests that the faults and the engagement of Respond FLM equipment did not affect TEV activity in terms of magnitude and patterns. This also confirms that only external interference was detectable during this monitoring session, and no partial discharge activity was detected.

Figure 12 TEV Activity Plot with Date of Fault overlay for All TEV Channels Covering Fault in Littleborough

2.7 Installation in Mount St Substation

An UltraTEV Monitoring system with 3 nodes was installed in Mount St substation and monitored activity in the substation between 06/05/2016 to 13/05/2016. Figure 13 illustrates all the captured TEV activity in Mount St substation. During this monitoring session, the activity captured from the two aerial channels had the strongest magnitude. Additionally, activity in the remaining TEV channels had patterns that followed closely to the pattern of aerials. Hence, it is reasonable to conclude that external interference is the main cause of all the captured activity, and no partial discharge activity was detected during this measurement period.

No faults occurred at Mount St substation during the monitoring period, hence, a correlation between fault data and monitored data cannot be completed.

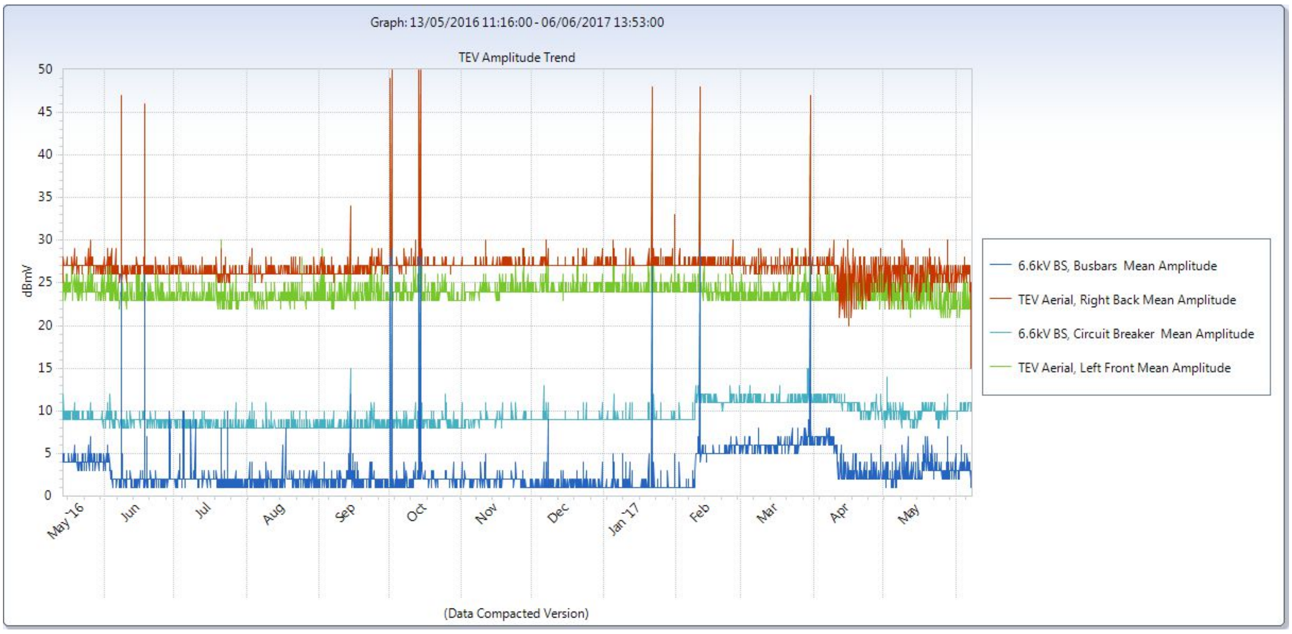

Figure 13 TEV Activity Plot for All TEV Channels in Mount St

2.8 Installation in Offerton Substation

An UltraTEV Monitoring system with 2 nodes was installed in Offerton substation and monitored activity in the substation between 20/04/2016 to 27/04/2016. Figure 14 illustrates all the captured TEV activity in Offerton substation. During this monitoring session, the activity captured from the TEV Aerial, Right Back exhibited a pattern with the strongest magnitude. Additionally, activity in the remaining TEV channels had patterns that followed closely to the pattern of the aerials. Hence, it is reasonable to conclude that external interference is the main cause of all the captured activity, and no partial discharge activity was detected during this measurement period.

According to a fault log, a fault occurred on 14/06/2016, however the obtained data only captured activity between 20/04/2016 to 27/04/2016. Hence, fault history of this substation cannot be correlated to the captured activity.

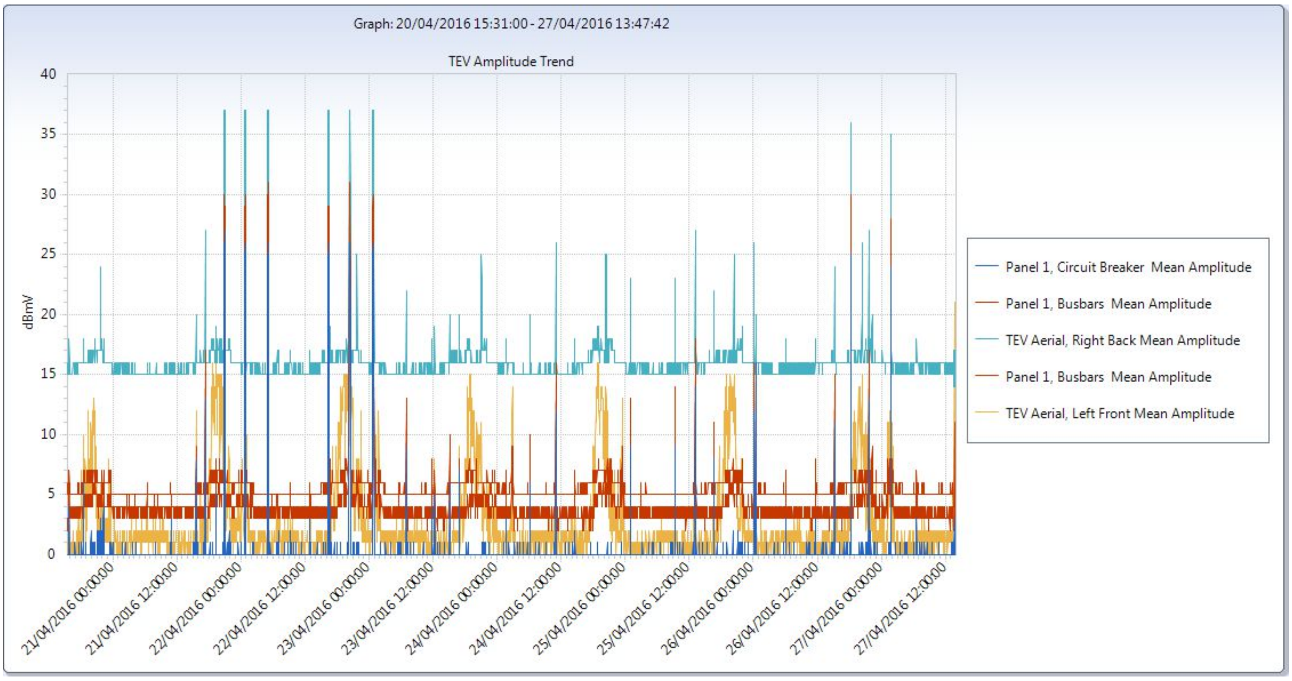

Figure 14 TEV Activity Plot for All TEV Channels in Offerton

3. Conclusions

C1. Ten faults occurred within five substations between 31/05/2016 to 08/05/2017, those substations were Atherton Town Centre, Blackbull, Broadheath, Littleborough, and Offerton.

C2. Respond Fault Level Monitor (FLM) equipment was engaged on five fault occasions in Atherton Town Centre, Blackbull, and Littleborough substations.

C3. A correlation between fault history and captured data was completed for Atherton Town Centre, Broadheath, and Littleborough substation. Monitoring session data from Blackbull, and Offerton did not cover the date of the faults.

C4. Three substations had no faults registered during the same period; those substations were Denton West, Irlam, and Mount St.

C5. Analysis has shown that there is no correlation between faults and TEV activity, regardless of the engagement of Respond FLM equipment as the magnitude and pattern of TEV activity remains similar before and after the faults.

4. Recommendations

R1. An UltraTEV Monitor should be installed in Blackbull, and Offerton substations for at least one week after the completion of the project in order to monitor and trend TEV activity.

R2. Should any faults occur, an UltraTEV Monitor should be installed in the Denton West, Irlam, and Mount St. substations to monitor and trend TEV activity.

R3. The UltraTEV Monitor data from eight substations should be reviewed at the end of project, June 2018, to investigate the effects of faults and the engagement of Respond FLM equipment.

Appendix I Detection of Partial Discharge Activity

Detection of Partial Discharge Activity

General

Partial discharges are electric discharges that do not completely bridge the electrodes. The magnitude of such discharges is usually small; however, they can cause progressive deterioration of insulation that may lead to eventual failure.

Non-intrusive partial discharge detection provides a fast and simple to use method for identifying potential sources of insulation failure, that could result in the loss of supply to customers and a serious health and safety issue to staff and other personnel.

A partial discharge emits energy in the following ways:

Electromagnetic:

- Radio
- Light
- Heat

Acoustic:

- Audio
- Ultrasonic

Gases:

- Ozone
- Nitrous oxides

The most practical techniques for non-intrusive testing are based on the detection of the radio frequency part of the electromagnetic spectrum and ultrasonic emissions.

Airborne Ultrasonic Discharge Activity

Acoustic emission from surface discharge activity occurs over the whole acoustic spectra. Audible detection is possible but depends on the hearing ability of the individual. Using an instrument to detect the ultrasonic part of the acoustic spectra has several advantages. Instruments are more sensitive than the human ear, are more directional, are not operator dependent and operate above the audible frequency.

A sensitive method of detection is uses an airborne ultrasonic microphone centred at 40kHz.

This method is very successful at detecting surface discharge activity provided there is an air passage between the source and the microphone.

Electromagnetic Discharge Activity

When partial discharge activity occurs within high voltage switchgear insulation it generates electromagnetic waves in the radio frequency range which can only escape from the inside of the switchgear through openings in the metal casing. These openings may be air gaps around covers, or gaskets. The signal can travel through other insulating materials or components; however, the signal attenuation increases with each surface or medium that it traverses. When the electromagnetic wave propagates outside the switchgear it also impinges on the metal casing of the switchgear producing a transient voltage on the external metal cladding of the switchgear. The Transient Earth Voltage (TEV) is a few millivolts to a few volts and lasts only a short time with a rise time of a few nanoseconds.

The partial discharge activity may be detected non-intrusively by placing a capacitive probe on the outside of the switchgear whilst the switchgear is in service.

Description of Partial Discharge Instrumentation

UltraTEV Monitor (UTM)

The UltraTEV Monitor is a main operated instrument which can record TEV, Ultrasonic and Cable Partial Discharge. The System consist of a computer based monitoring “hub” and multiple sensor nodes. These nodes are attached to the switchgear magnetically and have an integrated capacitive TEV sensor plate. The nodes are connected using a single power and communication cable which provides communication back to the “hub”.

The UltraTEV Monitor records and locates TEV signals on the metal casing of high voltage switchgear. Aerials can be attached to an input on each node to provide a screen from external electromagnetic sources; the aerial input can also be used to provide an additional TEV measurement through the use of extra sensors. Each node can accept up to two ultrasonic sensors (airborne or contact). The node can also accept one cable PD measurement when required. Cable PD measurements are taken by attaching radio frequency current transformer (RFCT) to the earth strap of a cable. This can only be done if an appropriate cable termination exists. The UltraTEV Monitor system is also capable to acquire local temperature and humidity data during monitoring exercise using the environmental probe connected to a node.

The UltraTEV Monitor is normally left in its logging mode for a week or longer in each substation. For permanent installations hub with a network access option is available, this is allowing instant remote access to the data via local network or internet.

In order to detect intermittent partial discharge sources, it is important to monitor switchgear for a period of time sufficient to cover changes in load, ambient and switching. The UltraTEV Monitor is recommended for this purpose and partial discharge activity is only considered to have been detected if:

1. Average Overall Severity ≥ 2

2. Maximum Short-Term Severity ≥ 50

3. There is no correlation between the probes and the aerials

Interpretation of Results

The interpretation of results is aided by the use of EA Technology's partial discharge measurements database that contains over 20000 records of surveys of switchgear using partial discharge detection equipment. A judgement has been made that the top 5% of the switchgear requires further investigation. It is possible to interrogate the database to determine the criteria for further investigation of different subsets within the data e.g. for particular types of switchgear, different voltage ratings, particular manufacturers etc.

The level for further investigation of ultrasonic measurements is determined more by the knowledge that a source has been found than by the amplitude of the measurement. This is because the amplitude is very dependent on the size of the opening through which the airborne ultrasonic signal can pass and a clear direct line path between the source and the opening. A source is deemed to be found if movement of the ultrasonic microphone across the opening and angling the probe towards and away from the opening shows that the source is within the switchgear.

It is important that the following additional criteria are taken into consideration. Any one of these factors may result in a further investigation being carried out at levels below the general criteria.

- Switchgear component
- History of failures
- Circuit importance
- Level of Risk

Appendix II Substation Environment Recommendations

Introduction

It is known that the internal environment of a substation, especially high humidity, can have a significant effect on the development of partial discharge in polymeric components. The environmental specification (IEC 62271-1 High-Voltage Switchgear and Control gear – Part 1: Common specifications) is probably not adequate in harsh locations of switch rooms and where appropriate it is recommended that some type of environmental control be considered.

Recommended conditions

The recommended level for normal service conditions according to IEC 62271-1' is:

The ambient air temperature does not exceed 40°C and its average value, measured over a period of 24 h, and does not exceed 35°C.

The conditions of humidity are as follows:

- The average value of the relative humidity, measured over a period of 24 h, does not exceed 95 %
- The average value of the water vapour pressure, over a period of 24 h, does not exceed 2.2 kPa
- The average value of the relative humidity, over a period of one month, does not exceed 90 %
- The average value of the water vapour pressure, over a period of one month, does not exceed 1.8 kPa.

Some switchgear manufacturers describe ideal conditions for relative humidity (RH) as less than 40%, and standard / normal conditions as RH less than 60%.

Where the average RH is greater than 60% they normally recommend that some form of environment control is used in the switch room.

Research at EA Technology Ltd has shown that existing partial discharge levels increase as the RH increases. High RH is known to promote the initial development of partial discharge. The most important factor is to avoid rapid variations in temperature, which in conditions of high humidity may drop below the dew point causing condensation. It is also known that the air inside switchgear is at the same temperature and RH as the ambient air in the substation. Condensation would therefore occur within and outside the switchgear, leading to corrosion that would not be apparent until invasive maintenance.

Sources of humidity

The three most common sources of humidity within substations are:

1. Ambient air with high humidity
2. Water leaks into the substation
3. Water in cable trenches

Primary methods of controlling the environment

There are several measures that address the control of the environment in the switchgear and substations. The primary methods of controlling the environment are listed below:

1. The substation building should be of sound construction and adequately water tight. Where the substation is in a location of extreme weather or flooding extra measures to prevent water ingress may be required.
2. The substation building should be adequately insulated to prevent large temperature variations.
3. Ventilation should be kept to the minimum required to dissipate heat and allow ventilation. It should not be oversized or generate large temperature variations within the substation. Forced ventilation increases the likelihood that the dew point will be reached and condensation formed. Forced ventilation should be limited to exceptionally hot conditions i.e. above 40C. Ventilation should be located as far away from switchgear as possible and should be positioned so that it is not passing air across the switchboard.
4. Cable trenches should be sealed to prevent water ingress to the trench, or the trench sealed to prevent transfer of humid air into the substation.

It is recommended that temperature and humidity surveys be carried out in the switch rooms to see if any of the above actions improve the environment. If action is required, then subsequent surveys should also be carried out to see if the environmental improvements have been effective.

Secondary methods of controlling the environment

The following secondary measures can be implemented to improve the substation environment, these can be implemented where substation environmental conditions fall outside of the above bounds:

1. Fitting heaters in the switchgear (e.g. in the cable compartments) in cases where humidity is high over a long period of time.

2. Installation of substation heating.

3. Installation of dehumidifiers or air conditioning.

Anti-condensation heaters

Anti-condensation heaters can be fitted inside the cable compartments and must operate continuously to prevent condensation forming. They are designed to prevent condensation in that chamber but they do have several disadvantages:

1. They can only be checked during invasive maintenance requiring a circuit outage.

2. They do not remove moisture from the air, but keep the temperature of the compartment above the dew point, thus preventing condensation.

3. They have little beneficial effect on other chambers in the switchgear.

4. If they fail this may lead to condensation and rapid failure of the switchgear.

Substation heaters

Substation heaters can be installed to reduce temperature swings within the substation. If fitting heaters in the substation they should be temperature regulated to avoid large temperature swings or be left on continuously. The heating should be checked regularly as if they fail it may lead to condensation and rapid failure of the switchgear. If the switch room is wet with standing water in a cable trench, then substation heaters can contribute to humidity rather than getting rid of it. It is better to use heaters within the switchgear to keep the equipment dry or dehumidifiers.

Dehumidifiers and Air Conditioning

Dehumidifiers is the best option for reducing the humidity, air conditioning can be used to control the temperature and humidity within the substation. If installing these devices, they should be controlled by a thermostat or humidistat. The substation should be sealed to minimise the exchange air exchange to outside.

Any environmental control should form part of the scheduled maintenance and the frequency should be determined by the severity of the local conditions. Regular maintenance on the switchgear and any environmental controls should help prolong the life of the switchgear.

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We provide products, services and support for customers in 90 countries, through our offices in Australia, China, Europe, Singapore, UAE and USA, together with more than 40 distribution partners.

Our Expertise

We provide world-leading asset management solutions for power plant and networks.

Our customers include electricity generation, transmission and distribution companies, together with major power plant operators in the private and public sectors.

- Our products, services, management systems and knowledge enable customers to:
- Prevent outages
- Assess the condition of assets
- Understand why assets fail
- Optimise network operations
- Make smarter investment decisions
- Build smarter grids
- Achieve the latest standards
- Develop their power skills

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