REPORT N$^{O}$ 62104988

# RESPOND POST FAULT ANALYSIS

CONFIDENTIAL

16 NOVEMBER 2017

WSP | PARSONS BRINCKERHOFF

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**Electricity North West Ltd**

**Type of document (version)**
**Confidential**

Project no: 62104988
Date: 16 November 2017

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# QUALITY MANAGEMENT

| ISSUE/REVISION | FIRST ISSUE | REVISION 1 | REVISION 2 | REVISION 3 |
|---|---|---|---|---|
| Remarks | Draft | | | |
| Date | 16 November 2017 | | | |
| Prepared by | P Watson | | | |
| Signature |  | | | |
| Checked by | G Williamson | | | |
| Signature pp |  | | | |
| Authorised by | S Elliott | | | |
| Signature |  | | | |
| Project number | 62104988 | | | |
| Report number | 62104988-10 | | | |
| File reference | | | | |

# PRODUCTION TEAM

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# 1 INTRODUCTION

The Electricity North West's Respond, second tier Low Carbon Network funded project, is investigating active fault level management techniques as a cost beneficial alternative to traditional reinforcement of network assets.

Three fault level mitigation techniques are being trialled as part of the Respond project. Performance of these techniques is assessed by examining the systems' behaviour in response to a fault. This report presents the analysis of a fault event occurring during the Respond trial in accordance with Successful Delivery Review Criteria, SDRC 9.3.3, as shown below.

| CRITERIA | EVIDENCE |
|---|---|
| 3. Implement monitoring and post fault analysis procedures in Trial period | 3. Publish on Respond website a summary of each fault event three months after each event, with the expectation that a minimum of 18 faults will be reported on |

# 2 EVENT DETAILS

| | |
|---|---|
| **Substation** | Irlam Primary |
| **Fault Mitigation Technique** | Adaptive Protection |
| **Voltage** | 6.6 kV |
| **Date/Time** | 17 August 2017 / 00.12.32 |
| **Faulted Circuit** | F3145 Tramway Rd 6.6 kV circuit |
| **Fault Location** | At GVR 7269 Astley Rd - between Whittle St and Starring Way |

# 3 SITE AND INSTALLATION INFORMATION

## 3.1 NETWORK DATA

The pre-fault Irlam Primary network configuration is shown in Figure 3-1. For the Respond trials, the 6.6 kV transformer incomer CTs are connected in parallel. The individual phase current inputs to the Adaptive Protection high-set instantaneous overcurrent relay (50) receives the sum of the respective phase currents in each transformer incomer. Operation of the Adaptive Protection initiates the tripping of the 6.6 kV bus section circuit breaker, increasing the impedance to the fault and reducing the initial fault current.

Pre-fault loading information is shown in Table 3-1.

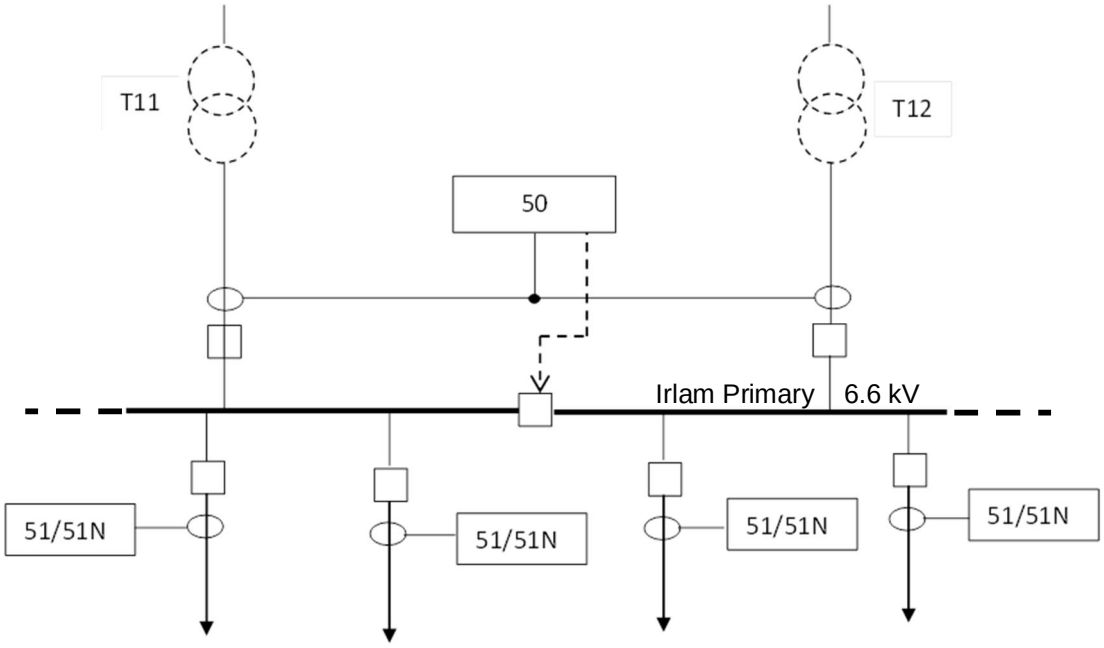


**Figure 3-1: Irlam Primary Substation Network**

**Table 3-1: Pre-fault Load Conditions**

| Pre-fault load data (1/2hour) | |
|---|---|
| Irlam Primary | 591 A |
| Tramway Rd Feeder | 47 A |

## 3.2 PROTECTION DATA

The Adaptive Protection has the facility to be remotely switched in and out of service, however in this case it is permanently enabled.

The settings of the Irlam Primary Adaptive Protection relay and Tramway Rd 6.6kV feeder protection relay are provided in Table 3-2 and Table 3-3 respectively.

**Table 3-2: Irlam Primary Adaptive Protection Settings**

| | |
|---|---|
| **CT** | 4000/5 |
| **Relay** | MiCOM P40 Agile P145 |
| **I>1 Function** | Disabled |
| **I>2 Function** | Disabled |
| **I>3 Status** | Enabled |
| **I>3 Direction** | Non-Directional |
| **I>3 Current Set** | 4520A |
| **I>3 Time Delay** | 0 s<br>(The manufacturer's declared accuracy for definite time (DT) operation is ±2% or 50ms, whichever is greater.) |
| **I>4 Status** | Disabled |
| **Comment** | The setting of 4520 A is well below the short circuit capability of the Irlam Primary 6.6 kV switchgear (26.3 kA), but this value is selected for these trials to ensure operation for 6.6 kV phase faults. |

**Table 3-3: F3145 Tramway Rd 6.6 kV Feeder Protection Settings**

| | |
|---|---|
| **CT** | 400/5 |
| **Relay** | MCGG 52 (2 Phase Overcurrent and Earth Fault) |
| **I>** | 1 x In (400 A) |
| **t>** | 0.1 - Standard Inverse |
| **I>>** | Disabled |
| **Io>** | 0.3 x In (120 A) |
| **to>** | 0.40 - Standard Inverse |
| **Io>>** | Disabled |
| | |
| **CT** | 400/5 |
| **Relay** | MCAA13 (Earth Fault Indicator – Alarm only) |
| **Io>** | 0.4 A (32 A) |
| **to>** | Instantaneous |

## 3.3 EVENT INFORMATION

### 3.3.1 Fault Level Calculations

The calculated values of fault current from the Fault Level Assessment Tool (FLAT), Dinis and IPSA are as shown in Table 3-4.

**Table 3-4: Fault Current Values**

| | |
|---|---|
| **Schneider NMS FLAT Fault Current Values at fault location (T11 and T12 in parallel)** | |
| Three Phase Fault Level: | 6.652 kA |
| L-L Fault Level: | 5.761 kA |
| L-L-G Fault Level: | 5.923 kA |
| L-G Fault Level: | 783 A |
| | |
| **Dinis Fault Current Values at fault location (T11 and T12 in parallel)** | |
| Three Phase Fault Level: | Red = 6.164 kA /313°<br>Yellow = 6.164 kA /193°<br>Blue = 6.164 kA /73° |
| L-L Fault Level: | Red = 0 kA /0°<br>Yellow = 5.338 kA /223°<br>Blue = 5.338 kA /43° |
| L-L-G Fault Level: | Red = 0 kA /0°<br>Yellow = 5.595 kA /220°<br>Blue = 5.099 kA /47°<br>Residual = Not listed |
| L-G Fault Level: | 1.432 kA /348° |
| | |
| **IPSA Fault Current Values for fault at Irlam Primary Substation 6.6kV busbar (T11 and T12 in parallel)** | |
| Three Phase Fault Level: | Red = 12.422 kA /-79°<br>Yellow = 12.422 kA /160°<br>Blue = 12.422 kA /41° |
| L-L Fault Level: | Red = 0 kA<br>Yellow = 11.488 kA /-169°<br>Blue = 11.488 kA /11° |
| L-L-G Fault Level: | Red = 0 kA<br>Yellow = 11.931 kA /-170°<br>Blue = 11.038 kA /11° |
| L-G Fault Level: | 1.94 kA /-8° |

### 3.3.2 Recorded Fault Current

The 3-phase fault currents recorded by the relay, as shown in Table 3-5, show good correlation, with the FLAT and DINIS calculated fault currents for a 3-phase fault at the fault location.

The significant difference in and the FLAT and DINIS calculated fault currents for a 3-phase fault at the fault location and the IPSA calculated fault currents for a 3-phase fault at Irlam Primary indicate significant impedance between Irlam Primary and the fault location.

**Table 3-5: Comparison of calculated and recorded fault currents**

| Phase | Adaptive Protection Relay Disturbance Recorder Fault Current | Schneider NMS FLAT- Calculated 3-Phase Fault Level (at Fault Location) | Dinis Calculated 3-Phase Fault Level (at Fault Location) | IPSA Calculated 3-Phase Fault Level (at Irlam Primary) |
|---|---|---|---|---|
| Red | 5276.7 A | 6652 A | 6164 A | 12422 A |
| Yellow | 5531.3 A | 6652 A | 6164 A | 12422 A |
| Blue | 6301.7 A | 6652 A | 6164 A | 12422 A |
| Residual | 461 A | - | - | - |

# 4 EVENT TIME LINE

## 4.1 EVENT TIMES FROM CRMS

The events recorded at the CRMS are shown in Table 4-1.

**Table 4-1: Event Timings**

| Time | Event |
|---|---|
| 00:12:32.483 | Irlam 6.6 kV Feeder Earth Fault Alarm |
| 00:12:32.504 | Irlam 6.6 kV Neutral Current Alarm |
| 00:12:32.505 | Irlam Adaptive Protection (AP) Stage 1 Operated |
| 00:12:32.541 | Irlam 6.6 kV Bus Section A-B Circuit Breaker Opened |
| 00:12:32.813 | Irlam T11 & T12 6.6 kV Low Voltage Alarms |
| 00:12:32.969 | Irlam 6.6 kV Protection Operated Alarm |
| 00:12:32.988 | Irlam F3145 Tramway Rd CB Opened |
| 00:12:33.038 | Irlam 6.6 kV Protection Operated Alarm Reset |
| 00:12:33.213 | Irlam T11 6.6 kV VT Volts Normal |
| 00:12:33.371 | Irlam 6.6 kV Neutral Current Alarm Reset |
| 00:12:33.613 | Irlam T12 6.6 kV VT Volts Normal |
| 00:12:33.679 | Irlam 6.6 kV Neutral Current Alarm |
| 00:12:33.791 | Irlam 6.6 kV Neutral Current Alarm Reset |
| 00:12:34.019 | Irlam 6.6 kV Neutral Current Alarm |

## 4.2 DISTURBANCE RECORDS

The instantaneous and RMS disturbance records obtained from the Adaptive Protection relay are shown in Figure 4-1 and Figure 4-2 respectively.

In these figures, Output R3 is the trip signal from the Adaptive Protection Stage 1 to the 6.6 kV bus section circuit breaker, output R5 is the Adaptive Protection Stage 1 trip repeat signal to telecontrol and output R12 is the bus section circuit breaker “a” auxiliary contact repeat signal to telecontrol.

The trigger for the disturbance recorder is the operation of the Bus Section Adaptive Protection Stage 1. The total recording time of the MiCOM P40 Agile P145 Adaptive Protection relay is set for 1.5 secs, with a pre-trigger recording time of 0.5 secs and a post trigger recording time of 1.0 secs.

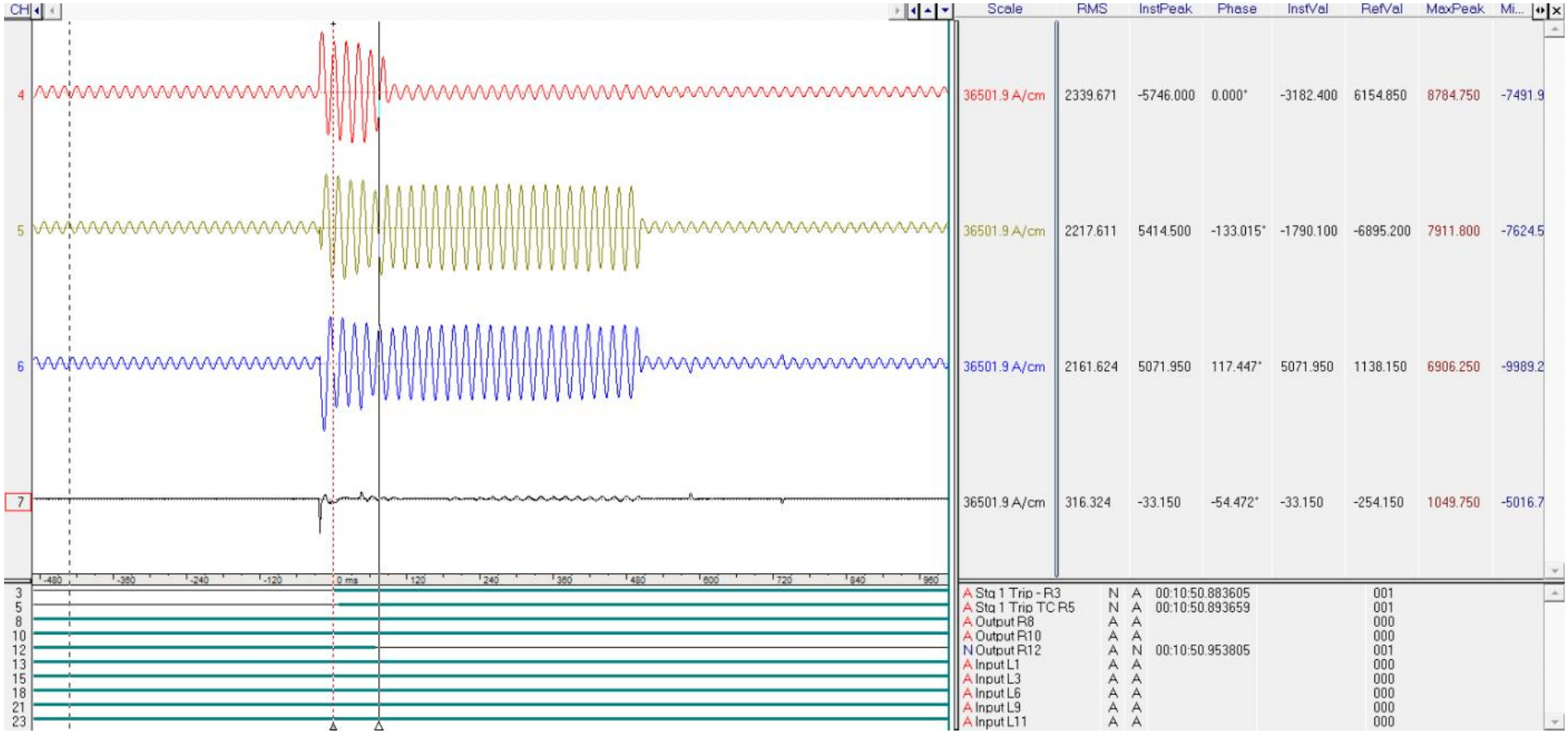


**Figure 4-1: Instantaneous Adaptive Protection Relay Recordings (IA=red, IB=yellow, IC=blue and IN(residual)=black)**

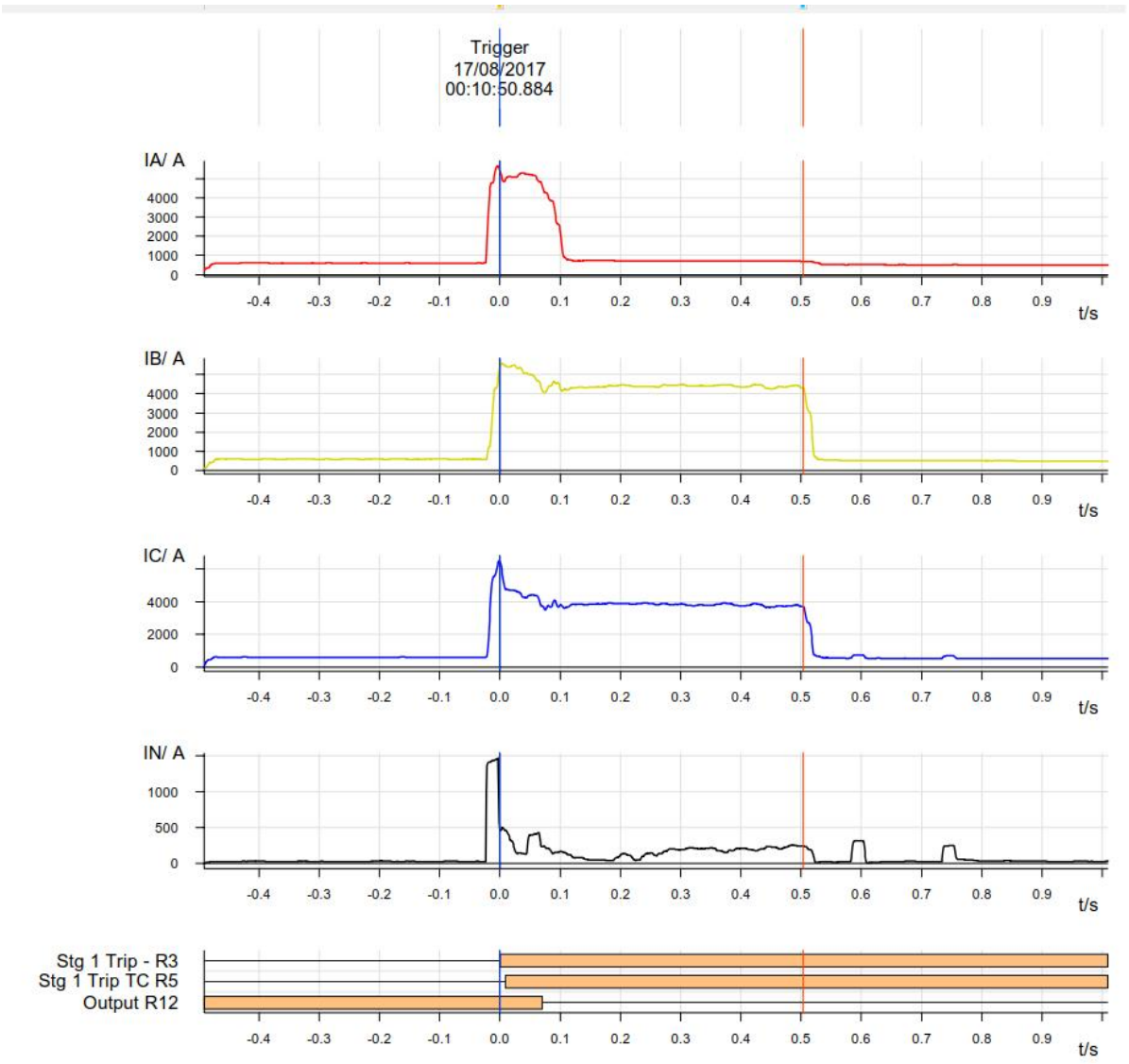


**Figure 4-2: RMS Adaptive Protection Relay Recordings**
**(IA=red, IB=yellow, IC=blue and IN(residual)=black)**

# 5 DISTURBANCE ANALYSIS

The disturbance records show that the Adaptive Protection responded to a three-phase to earth fault. The magnitude of the fault currents inclusive of load current at the instant that the Adaptive Protection operated, were 5656 A, 4363 A and 6083 A in the red, yellow and blue phases respectively. The residual fault current was 1459 A.

The three-phase to earth fault was present for 22.1 ms before the Adaptive Protection was triggered. In this case the fault current was only a multiple of 1.36 times the Adaptive Protection I>3 current setting. For fault currents greater than a multiple of 2 times the current settings, the detection time should be less.

The disturbance record shows that the 6.6 kV bus section circuit breaker tripped 69.8 ms after the trip signal from the Adaptive Protection relay was sent. This time is largely dependent on the circuit breaker operating time and would not change with fault current. Note: The event times from the CRMS suggest that the 6.6 kV bus section circuit breaker tripped 36 ms after the Adaptive Protection relay operated. Since a circuit breaker operating time is typically 70 ms, it is judged that the time between the Adaptive Protection alarm and CB opening as indicated by the CRMS is too short. The discrepancy between the disturbance recorder time and the CRMS time is probably due to the low time resolution of the CRMS recordings.

The time interval from fault initiation up to the tripping of the 6.6 kV bus section circuit breaker was 91.9 ms measured from the disturbance record.

After the 6.6 kV bus section circuit breaker tripped, the fault developed into a yellow to blue phase-to-phase fault with 725 A in the red phase, 4341 A in the yellow phase and 3848 A in the blue phase with a residual current of 81 A.

Based on the recorded maximum phase fault current of 4326 A and on the settings of the F3145 Tramway Rd 6.6 kV feeder overcurrent protection, the calculated operating time of the feeder overcurrent protection (excluding circuit breaker operating time) would be 0.287 secs.

Assuming a circuit breaker operating time of 70 ms, this would suggest an operating time of 358 ms (428 – 70) for F3145 Tramway Rd 6.6 kV feeder overcurrent protection.

The Adaptive Protection relay disturbance recorder, recorded a total fault duration of 0.525 secs i.e. the time from fault initiation to opening of the F3145 Tramway Rd 6.6 kV feeder circuit breaker to clear the fault.

The CRMS event-log indicates that the F3145 Tramway Rd 6.6 kV circuit breaker tripped approximately 0.428 secs after the 6.6 kV bus section circuit breaker was tripped by the Adaptive Protection Stage 1 operation. The total fault clearance time was 505 ms i.e. from the first 6.6 kV feeder earth fault alarm to the opening of the F3145 Tramway Rd 6.6 kV circuit breaker.

The total fault clearance times obtained from the disturbance record of the Adaptive Protection relay and from the CRMS event-log are not in line with the above calculated operating time of the F3145 Tramway Rd 6.6 kV feeder overcurrent protection. It is possible that settings recorded on the setting sheet may not be the as-installed settings. The actual settings should be confirmed on site.

The total recording time of the MiCOM P40 Agile P145 Adaptive Protection relay is set for 1.5 secs, with a pre-trigger recording time of 0.5 secs and a post trigger recording time of 1.0

secs. The opening of the F3145 Tramway Rd 6.6 kV feeder circuit breaker occurred within the set disturbance recorder window and was captured.

In order to capture the opening of feeder circuit breakers with longer protection operating times, it is recommended that the total recording time is increased to 2.0 secs with the same pre-trigger recording time of 0.5 secs. The recommended relay setting parameters are as follows:

Duration = 2.0 secs  Trigger Position = 25 (%)

Table 5-1 summarises the fault event times relative to fault inception. Table 5-2 summarises the currents obtained from the disturbance records. Pre-AP Operation and Post-AP Operation currents are relative to the fault current which triggered the Adaptive Protection (AP Fault Currents). Post Fault Current is the current after operation of the feeder protection.

**Table 5-1: Fault Event Timings Relevant to Fault Inception**

| Three Phase Fault Inception (from AP relay disturbance recorder) | Adaptive Protection Operated (from AP relay disturbance recorder) | 6.6 kV Bus Section Tripped (from AP relay disturbance recorder) | 6.6 kV Feeder Protection Operated (from AP relay disturbance record) |
|---|---|---|---|
| 0 ms | 22.7 ms | 91.9 ms | 524.8 ms |

**Table 5-2: Disturbance Recorder Current Summary**

| | Pre-AP Operation Current | AP Fault Current | Post-AP Operation Current | Post-Fault Current |
|---|---|---|---|---|
| **Red** | 601 A | 5517 A | 725 A | 523 A |
| **Yellow** | 599 A | 4287 A | 4341 A | 544 A |
| **Blue** | 613 A | 5714 A | 3848 A | 559 A |
| **Residual** | 26 A | 1449 A | 81 A | 24 A |

# 6 CONCLUSIONS

The fault as recorded on the disturbance recorder integral to the Adaptive Protection relay confirms the events observed from the CRMS. The initial operation of the Feeder Earth Fault and Neutral Current alarms was in response to the three-phase to earth fault seen in the disturbance records and which caused the Adaptive Protection to operate.

When the 6.6 kV bus section circuit breaker opened, the three-phase to earth fault evolved into a yellow phase to blue phase fault. The yellow phase fault current changed from 4287 A to 4341 A and the blue phase fault current from 5714 A to 3848 A.

The usual expected reduction in the fault current on opening the 6.6 kV bus section circuit breaker is not observed in this case. The magnitude of yellow phase fault current remain almost unchanged and the blue phase fault current is reduced to 67 % of it magnitude prior to opening the bus section circuit breaker.

As previously mentioned in section 3.3.2, the impedance between Irlam Primary and the fault location is significant. The expected reduction in fault current due to the increase in source impedance when the bus section circuit breaker is opened is dependent on the ratio of the source impedance to the impedance to the fault. The larger the impedance to the fault the less would the reduction in fault current. In this case the fault also evolved from a three-phase to a phase to phase fault by the time the bus section circuit breaker had opened, making a comparison of the two fault currents difficult.

The total fault clearance times obtained from the disturbance record of the Adaptive Protection relay and from the CRMS event-log are not in line with the calculated operating time of the F3145 Tramway Rd 6.6 kV feeder overcurrent protection. It is possible that settings recorded on the setting sheet may not be the as-installed settings. The actual settings should be confirmed on site.

Overall, the analysis has confirmed that the Adaptive Protection operated correctly, although in this case the opening the bus section circuit breaker did not reduce the fault current in each phase potentially due to the evolution of the fault.