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RESPOND POST FAULT ANALYSIS

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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	Littleborough Primary
Fault Mitigation Technique	Adaptive Protection
Voltage	6.6 kV
Date/Time	20 June 2017 / 20.58.41
Faulted Circuit	Whittle St 6.6kV circuit
Fault Location	Between Whittle St and Starring Way

3 SITE AND INSTALLATION INFORMATION

3.1 NETWORK DATA

The pre-fault Littleborough 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.

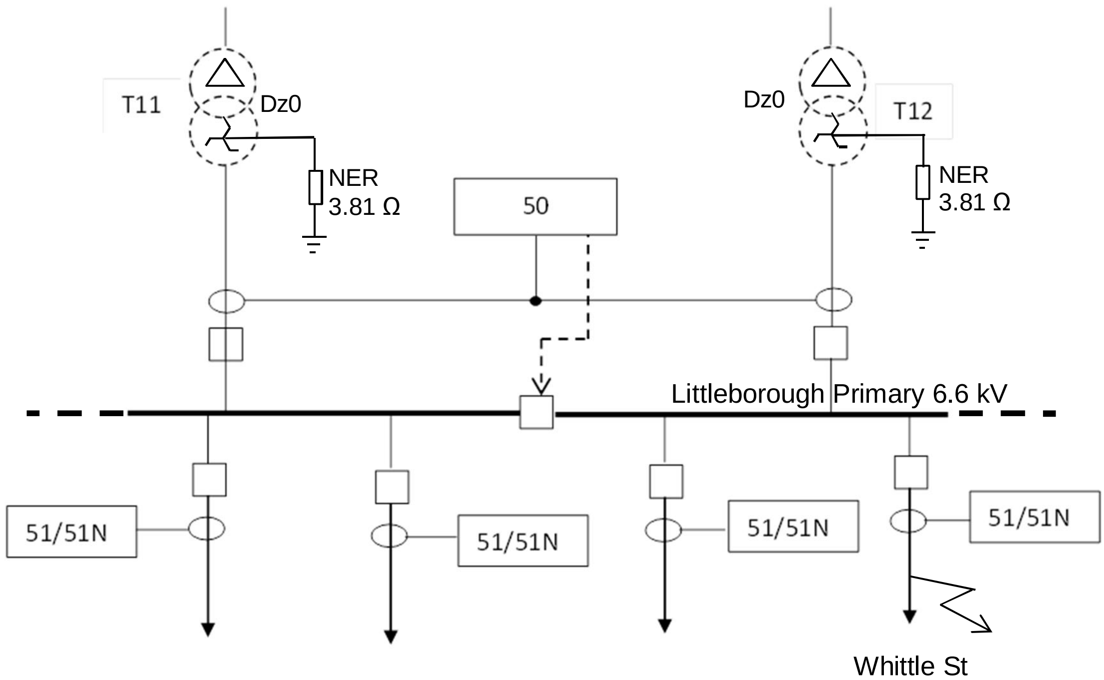

Figure 3-1: Littleborough Primary Substation Network

Table 3-1: Pre-fault Load Conditions

Pre-fault load data (1/2hour)	
Littleborough Primary	727 A
Whittle St Feeder	38 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.

Table 3-2: Littleborough 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 (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 Littleborough Primary 6.6 kV switchgear (21.9 kA), but this value is selected for these trials to ensure operation for 6.6 kV phase faults.

Table 3-3: Whittle St 6.6 kV Feeder Protection Settings

CT	400/5
Relay	CDG31 (2 Phase Overcurrent and Earth Fault)
I>	6.5 A (520 A)
t>	0.525 - Standard Inverse
Io>	1 A (80 A)
to>	0.35 - Standard Inverse

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:	10.609 kA
L-L Fault Level:	9.188 kA
L-L-G Fault Level:	9.188 kA
L-G Fault Level:	130 A
Dinis Fault Current Values at fault location (T11 and T12 in parallel)	
Three Phase Fault Level:	Red = 10.747 kA /276° Yellow = 10.747 kA /156° Blue = 10.747 kA /23°
L-L Fault Level:	Red = 0 kA /0° Yellow = 9.307 kA /186° Blue = 9.307 kA /6°
L-L-G Fault Level:	Red = 0 kA /0° Yellow = 9.767 kA /185° Blue = 8.851 kA /8° Residual = Not listed
L-G Fault Level:	Not listed

IPSA Fault Current Values for fault at Littleborough Primary Substation 6.6kV busbar (T11 and T12 in parallel)	
Three Phase Fault Level:	12.8 kA
L-L Fault Level:	11.69 kA
L-L-G Fault Level:	11.23 kA
L-G Fault Level:	1.957 kA
IPSA Fault Current Values for fault at Littleborough Primary Substation 6.6kV busbar (single Primary transformer (T12) in service)	
Three Phase Fault Level:	7.406 kA
L-L Fault Level:	Red = 0 kA Yellow = 6.930 kA /132° Blue = 6.930 kA /-48°
L-L-G Fault Level:	Red = 0 kA Yellow = 7.087 kA /132° Blue = 6.646 kA /-47° Residual = 456 A /117°
L-G Fault Level:	Red = 981 A

3.3.2 Recorded Fault Current

The 6.6 kV winding star point of each 33/6.6 kV Primary transformer is earthed through a 3.81 ohm liquid neutral earthing resistor (NER). The NERs should limit the earth fault contribution from each primary transformer to 1000 A. The maximum earth fault current should therefore be 2000 A with both primary transformers operating in parallel.

The initial fault current recorded by the relay in the red phase and the recorded residual current (4575 A and 4024 A respectively), as shown in Table 3-5, are almost double the expected magnitude for a single phase to earth fault based on two transformers with NERs operating in parallel.

Although the earth fault element of the Adaptive Protection relay is not enabled, the current in the faulted phase during the initial phase to earth fault was above the overcurrent pick-up setting and therefore the Adaptive Protection operated.

A post-fault site investigation identified that the NER associated with Primary transformer T11 had a low resistance value (2.80 ohms instead of 3.81 ohms). The conductivity of the electrolyte solution of this NER was adjusted to bring the resistance back up to 3.81 ohms.

A 2.80 ohm NER would limit the earth fault current contribution from Primary transformer T11 to 1361 A and therefore would not account for the doubling of the earth fault current recorded during the initial single phase to earth fault.

The Whittle St feeder is connected to the same section of the 6.6 kV busbar as Primary transformer T12. After the operation of the Adaptive Protection which tripped the 6.6 kV bus section circuit breaker, the initial fault evolved into a L-L-G fault supplied only by Primary transformer T12.

The recorded red and yellow phase fault currents shown in Table 5-2 as “Post-AP Operation Current”, shows good correlation with the IPSA calculated phase fault currents shown in Table 3-4 for a L-L-G fault supplied by T12 only. However, the IPSA calculated value of residual current for a L-L-G fault supplied by T12 only, is 456 A. The magnitude of the residual current (1048 A) recorded for the phase to phase to earth fault which was present after the Adaptive Protection tripped the 6.6 kV bus section circuit breaker, therefore suggests that there is a problem with the NER associated with Primary transformer T12 i.e. it is not of the expected resistance.

This NER has not yet been tested, but it is possible that the cable from the T12 6.6 kV winding star point to the NER terminal (or the NER terminal itself) may have an earth fault or some other form of connection earth, thus accounting for the very high earth fault current.

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

Phase	Adaptive Protection Relay Recorder Fault Current	Schneider NMS FLAT- Calculated L-G Fault Level (at Fault Location)	Dinis Calculated L-G Fault Level (at Fault Location)	IPSA Calculated L-G Fault Level (at Littleborough Primary)
Red	4575 A	130 A	-	1957 A
Yellow	769.1 A	-	-	-
Blue	913.7 A	-	-	-
Residual	4024 A (measured) 3986 A (derived)	130 A	-	1957 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
20:58:41.690	Littleborough 6.6 kV Neutral Current Alarm
20:58:41.757	Littleborough Adaptive Protection (AP) Stage 1 Operated
20:58:41.841	Littleborough 6.6 kV CB Auto Trip Alarm
20:58:41.870	Littleborough 6.6 kV Bus Section A-B Circuit Breaker Opened
20:58:42.44	Littleborough T12 Amps High Alarm
20:58:42.390	Littleborough T12 6.6 kV Low Voltage Alarm
20:58:42.444	Littleborough Whittle St Amps High Alarm
20:58:42.509	Littleborough Whittle St CB Auto Trip Alarm
20:58:42.539	Littleborough Whittle St CB Non-Reclose ARS Opened
20:58:42.713	Littleborough 6.6 kV Neutral Current Alarm Reset
20:58:43.190	Littleborough T12 6.6 kV Voltage Normal
20:58:43.244	Littleborough T12 Amps Normal
20:58:43.244	Littleborough Whittle St Amps Normal

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 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.

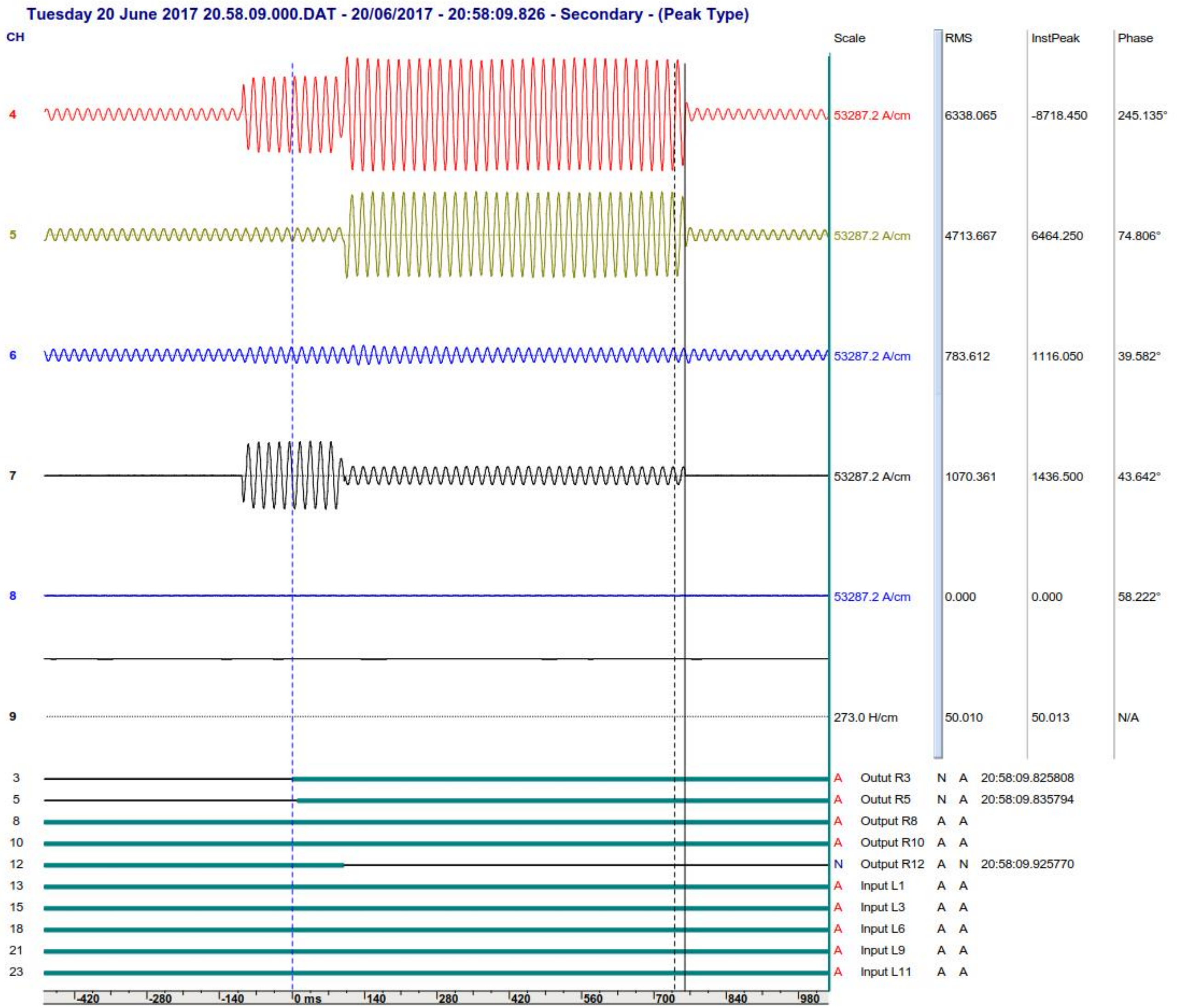

Figure 4-1: Instantaneous Adaptive Protection Relay Recordings (IA=red, IB=yellow, IC=blue and IN(residual)=black)

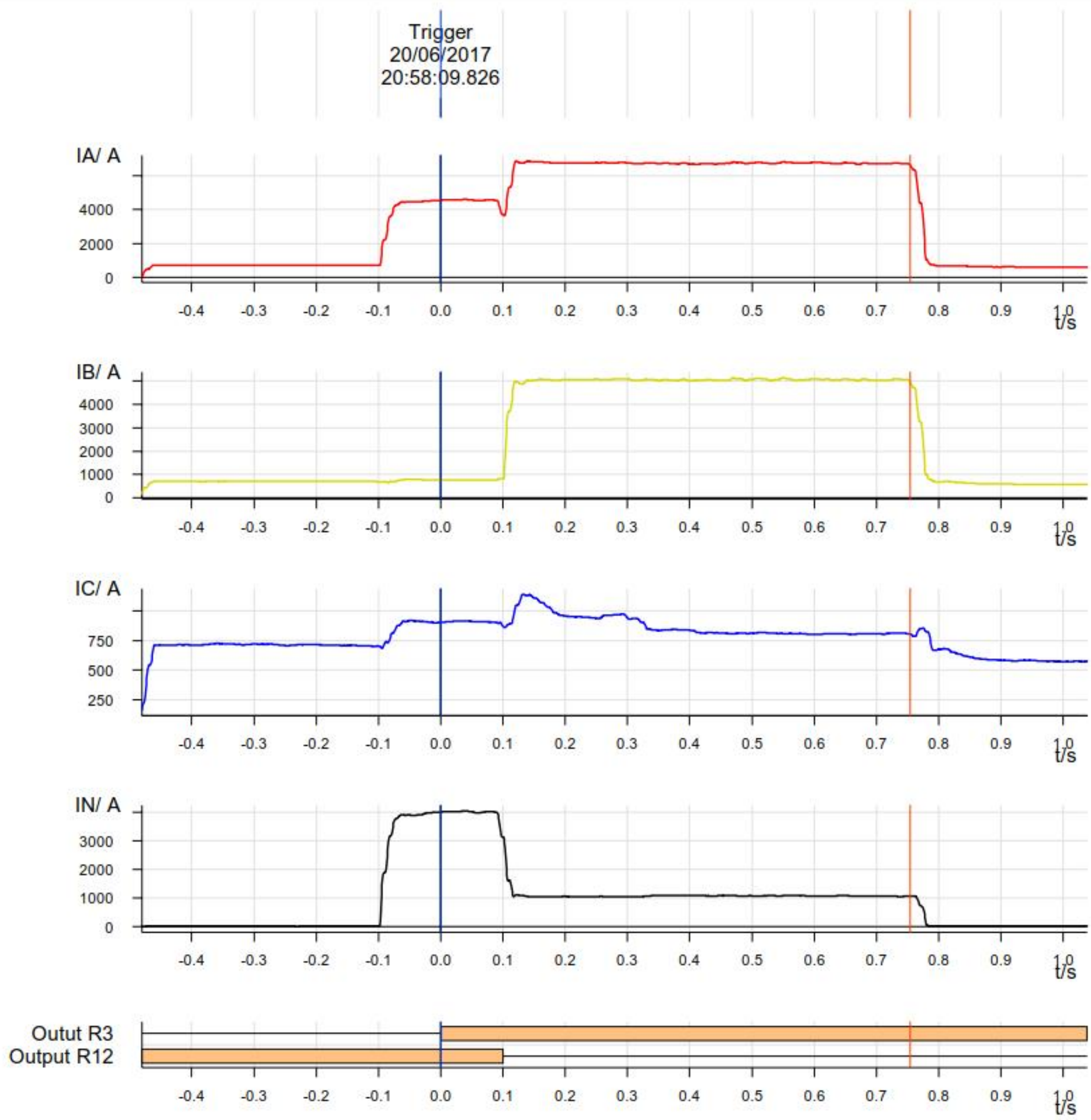

Figure 4-2: RMS Adaptive Protection Relay Recordings

5 DISTURBANCE ANALYSIS

The disturbance records show that the Adaptive Protection responded to a red phase to earth fault. The magnitude of the fault currents inclusive of load current were 4575 A, 769.1 A and 913.7 A in the red, yellow and blue phases respectively. The measured residual fault current was 4024 A.

The phase to earth fault was present for 100 ms before the Adaptive Protection was triggered. In this case the fault current was only a multiple of 1.01 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 6.6 kV bus section circuit breaker tripped 99.8 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.

From fault initiation up to the tripping of the 6.6 kV bus section circuit breaker was 199.8 ms.

After the 6.6 kV bus section circuit breaker tripped, the fault developed into a red phase to yellow phase to earth fault with 6734.7 A in the red phase, 5056.7 A in the yellow phase and 949 A in the blue phase with a residual current of 1048.1 A.

Based on the recorded maximum phase fault current of 6734.7 A and on the settings of the Whittle St 6.6 kV feeder overcurrent protection, the calculated operating time of the feeder overcurrent protection (excluding circuit breaker operating time) would be 1.40 secs.

For the recorded earth fault current of 1048.1 A and based on the settings of the Whittle St 6.6 kV feeder earth fault protection, the calculated operating time of the feeder earth fault protection (excluding circuit breaker operating time) would be 0.92 secs.

The Adaptive Protection relay event recorder, recorded a total fault duration of 0.85 secs i.e. the time from fault initiation to opening of the Whittle St 6.6 kV feeder circuit breaker to clear the fault.

The CRMS event-log, indicates that the Whittle St 6.6 kV circuit breaker tripped approximately 0.752 secs after the Adaptive Protection Stage 1 operation.

The total fault clearance times obtained from the event record of the Adaptive Protection relay and from the CRMS event-log are both in line with the above calculated operating time of the Whittle St 6.6 kV feeder earth fault protection.

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 Whittle St 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

Phase to Earth 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 event record)
0 ms	100 ms	199.8 ms	852.3 ms

Table 5-2: Disturbance Recorder Current Summary

	Pre-AP Operation Current	AP Fault Current	Post-AP Operation Current	Post-Fault Current
Red	704.1 A	4575 A	6734.7 A	602.4 A
Yellow	704.7 A	769.1 A	5056.7 A	591.4 A
Blue	711.2 A	913.7 A	949 A	582.3 A
Residual	21.51 A	4024 A	1048.1 A	22.54 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 Neutral Current alarm is in response to the red phase to earth fault seen in the disturbance records and which caused the Adaptive Protection to operate (*Note: the Adaptive Protection responded to the red phase fault current as the earth fault element is not enabled*)

The Adaptive Protection is set such that it would not operate for expected values of phase to earth fault currents. This incident however, demonstrates that the Adaptive Protection overcurrent element will respond to excessive phase to earth fault currents that may arise due to problems with the neutral earthing resistors on the infeeding Primary transformers.

In this case, when the 6.6 kV bus section circuit breaker opened there was no reduction in the fault current as expected, but rather an increase. This is due the initial single phase to earth fault evolving into a phase to phase to earth fault as soon as the bus section circuit breaker opened.

The magnitude of the phase fault currents during the phase to phase to earth fault are in line with the IPSA calculated fault currents for a L-L-G fault supplied by the T12 Primary transformer only.

The Adaptive Protection recorded residual currents both for the initial phase to earth fault and for the subsequent phase to phase to earth fault are considerably larger than expected.

The NER associated with T11 was inspected and although the measured resistance was slightly less than the specified 3.81 ohms, the value was not low enough to account for the large increase in the recorded residual current.

Even after the 6.6 kV bus section circuit breaker opened and the fault was supplied by T12 only, the recorded residual current was still considerably larger than expected. This suggests that there may be a problem with the NER associated with the T12 Primary transformer.

The T12 NER, has not yet been tested, but this will be done as soon as an outage can be scheduled.

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 as the initial phase to earth fault evolved into a phase to phase to earth fault.