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RESPOND POST FAULT ANALYSIS

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Electricity North West Ltd

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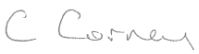
Signature				
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1 INTRODUCTION

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	18 February 2018 / 18.13.46
Faulted Circuit	Joseph Lister Drive/Dearnley C.of.E School 6.6 kV circuit
Fault Location	Between Joseph Lister Dr and Wardle Rd Flats

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 respective phase current input to the Adaptive Protection high-set instantaneous overcurrent relay (50) receives the sum of the current 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.

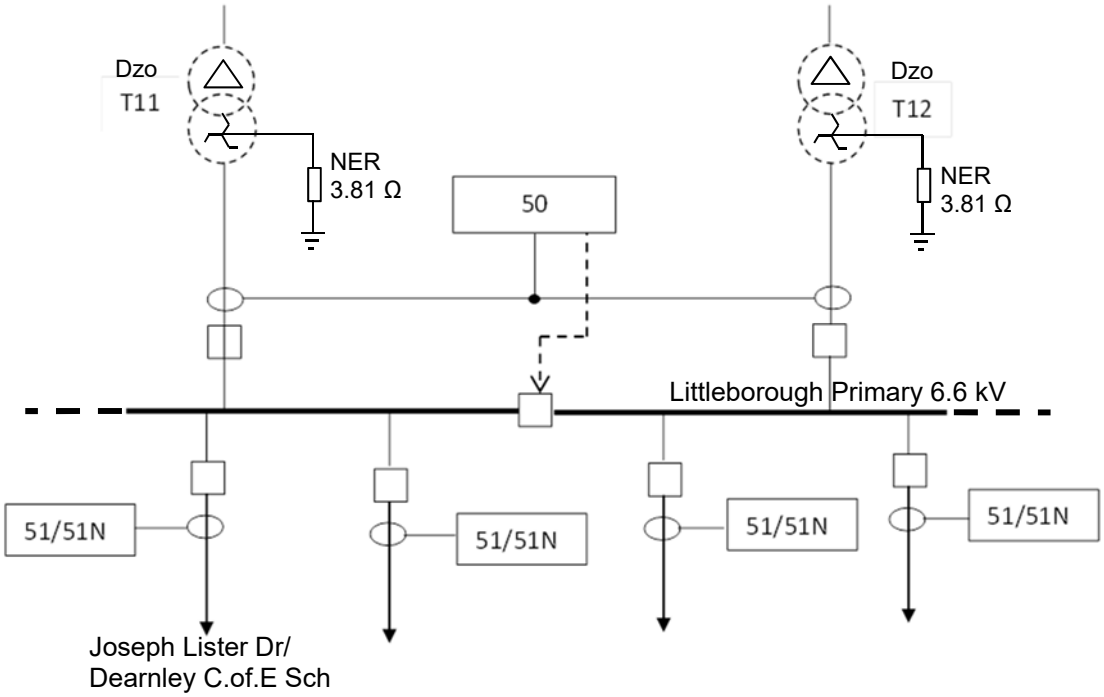

Figure 3-1: Littleborough Primary Substation Network

Table 3-1: Pre-fault Load Conditions

Pre-fault load data (1/2hour)	
Littleborough Primary	1138 A
Joseph Lister Drive/Dearnley C.of.E School 6.6kV Feeder	275 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	4520 A
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: Joseph Lister Drive/Dearnley C.of.E School 6.6 kV Feeder Protection Settings

CT	400/5
Relay	CDG31 (2 Phase Overcurrent and Earth Fault)
I>	6.25 A (500 A)
t>	0.525 - Standard Inverse
Io>	1 A (80 A)
to>	0.6 - 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	
Three Phase Fault Level:	No data available from NMS
L-L Fault Level:	No data available from NMS
L-L-G Fault Level:	No data available from NMS
L-G Fault Level:	No data available from NMS
Dinis Fault Current Values at Joseph Lister Dr	
Three Phase Fault Level:	Red = 7.532 kA /291° Yellow = 7.532 kA /171° Blue = 7.532 kA /51°
L-L Fault Level:	Red = 0 kA /0° Yellow = 6.523 kA /201° Blue = 6.533 kA /21°
L-L-G Fault Level:	Red = 0 kA /0° Yellow = 6.866 kA /198° Blue = 6.192 kA /23° Residual = Not listed
L-G Fault Level:	Red = 1.681 kA /336° Yellow = 0 kA /0° Blue = 0 kA /0° Residual = Not listed
IPSA Fault Current Values for fault at Littleborough Primary Substation 6.6kV busbar	
Three Phase Fault Level:	12.859 kA
L-L Fault Level:	11.734 kA
L-L-G Fault Level:	Phase Currents:12.196 kA & 11.27 kA (Residual Current not available)
L-G Fault Level:	1.969 kA

3.3.2 Recorded Fault Current

As shown in Table 3-5, during the initial red phase to earth fault, the residual current recorded (1772 A) by the Adaptive Protection relay is in general agreement with the Dinis (1618 A) calculated earth fault currents.

During the red phase to blue phase to earth fault prior to the tripping of the 6.6 kV bus section circuit breaker, the fault currents recorded by the AP relay in the red and blue phases (4882 A and 6275 A respectively), as presented in Table 3-5, show a greater variation in currents than the Dinis phase to phase to earth fault current results. Considering that the modelling of the upstream system in Dinis is based on an assumption and that the actual fault was an evolving fault, this larger variation in currents is not surprising.

IPSA fault current results are only available at Littleborough Primary substation rather than at the fault location and therefore an accurate match is not expected.

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

Phase	Adaptive Protection Relay Recorder Fault Current L-G	Schneider NMS FLAT- Calculated L-G Fault Level (at Fault Location)	Dinis Calculated L-G Fault Level (at Joseph Lister Dr)	IPSA Calculated L-G Fault Level (at Littleborough Primary)
Red	2645 A	N/A	1618 A (336°)	1969 A
Yellow	980 A	N/A	0	-
Blue	1040 A	N/A	0	-
Residual	1772 A	N/A	N/A	N/A
Phase	**Adaptive Protection Relay Recorder Fault Current L-L-G**	**Schneider NMS FLAT- Calculated L-L-G Fault Level (at Fault Location)**	**Dinis Calculated L-L-G Fault Level (at Joseph Lister Dr)**	**IPSA Calculated L-L-G Fault Level (at Littleborough Primary)**
Red	4882 A	N/A	6866 A (198°)*	12196 A
Yellow	1275 A	N/A	0 (0°)*	-
Blue	6275 A	N/A	6192 A (23°)*	11270 A
Residual	971 A	N/A	N/A	N/A

* DINIS and IPSA Phase fault currents are interposed to match the actual red – blue phase to earth fault.

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
17:53:31.375	Littleborough 6.6 kV Neutral Current Alarm
17:53:31.917	Littleborough Joseph Lister DR/Dearnley C.of.E School CB Non-Reclose ARS - Opened
18:13:43.000	Littleborough Joseph Lister DR/Dearnley C.of.E CB Non-Reclose ARS – Close by TC - Instructed
18:13:46.242	Littleborough Joseph Lister DR/Dearnley C.of.E CB Non-Reclose ARS - Closed
18:13:46.290	Littleborough 6.6 kV Neutral Current Alarm
18:13:46.975	Littleborough Bus Section Adaptive Protection (AP) Stage 1 Operated
18:13:47.049	Littleborough T11 6.6 kV - Low Voltage Alarm
18:13:47.058	Littleborough 6.6 kV CB Auto Trip Alarm
18:13:47.087	Littleborough 6.6 kV Bus Section A-B Circuit Breaker Opened
18:13:47.164	Littleborough 6.6 kV CB Auto Trip Reset
18:13:47.449	Littleborough T12 6.6 kV Low Voltage Alarm
18:13:47.874	Littleborough Joseph Lister DR/Dearnley C.of.E School CB Non-Reclose ARS - Opened
18:13:48.074	Littleborough 6.6 kV Neutral Current Reset
18:13:48.249	Littleborough T12 6.6 kV Low Voltage Normal
18:13:49.649	Littleborough T11 6.6 kV Low Voltage Normal
18:13:49.083	Littleborough Bus Section Adaptive Protection (AP) Stage 1 Operated Reset

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 4.0 secs, with a pre-trigger recording time of 1.33 secs and a post trigger recording time of 2.67 secs.

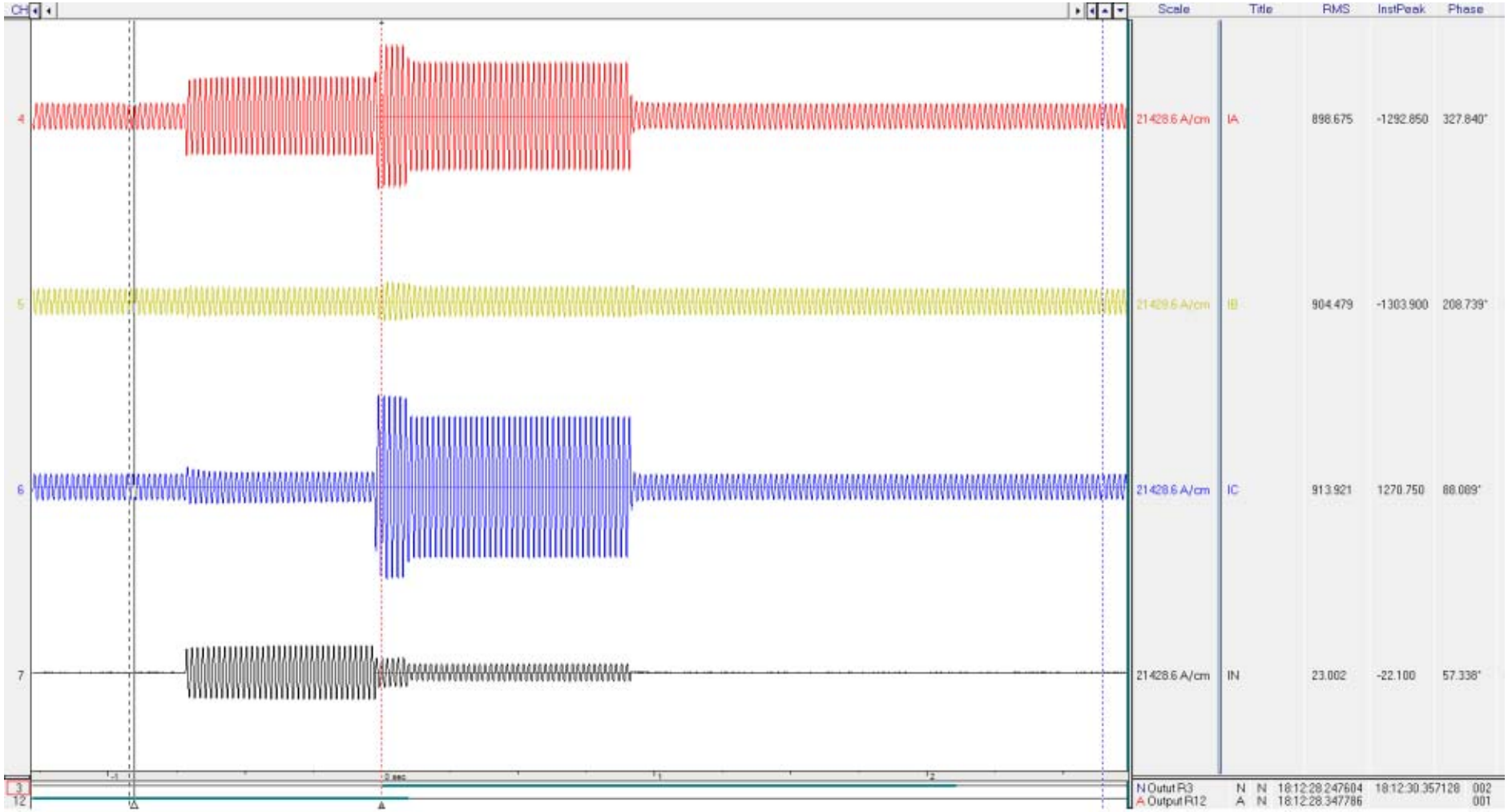

Figure 4-1: Instantaneous Adaptive Protection Relay Recordings (IA=red, IB=yellow, IC=blue and IN(residual)=black)

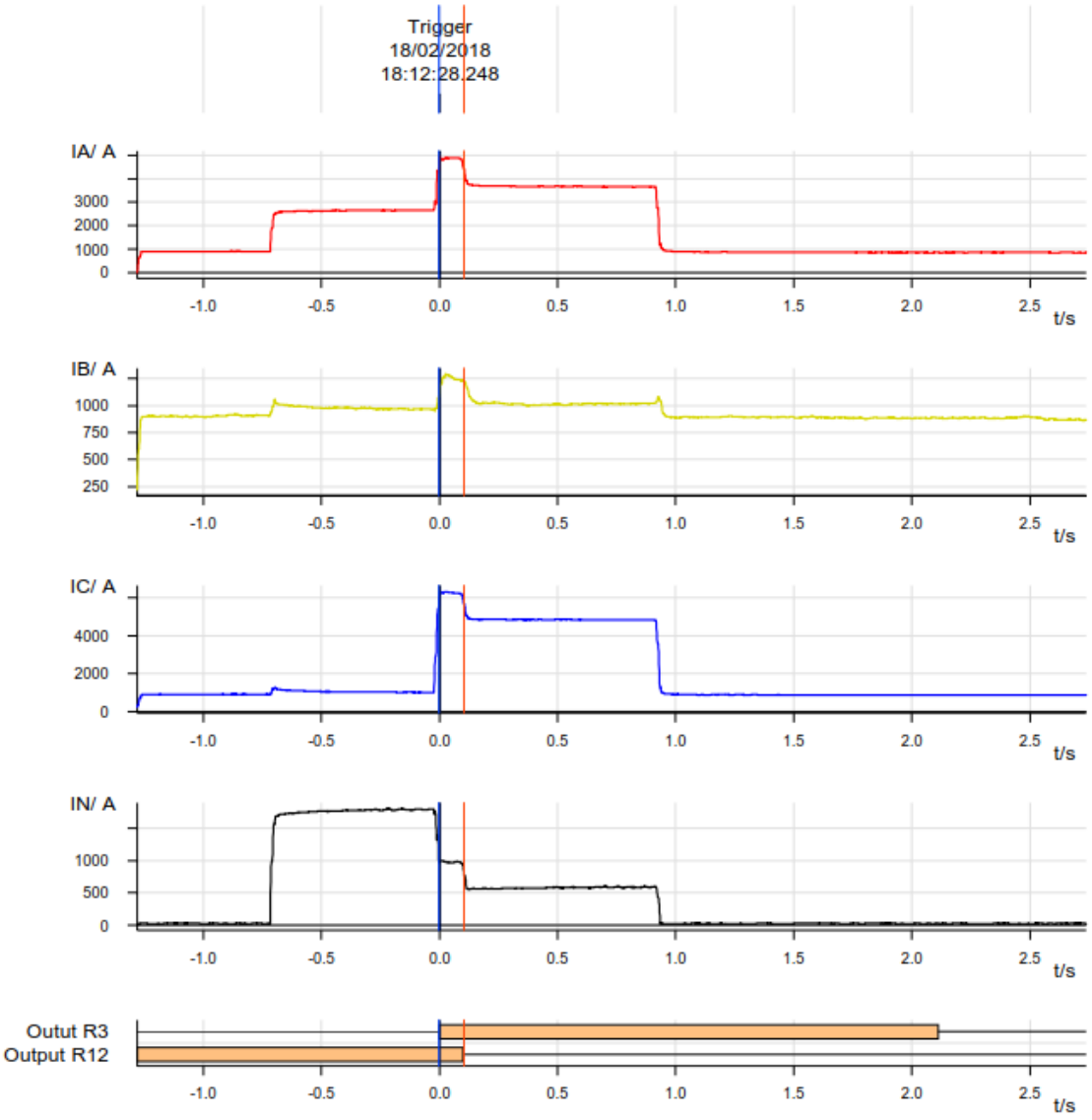

Figure 4-2: RMS Adaptive Protection Relay Recordings

5 DISTURBANCE ANALYSIS

The disturbance records show that the Littleborough Joseph Lister Drive/Dearnley C.of.E School CB closed onto a red phase to earth fault (this circuit had tripped 20 minutes earlier presumably due to this same fault). This earth fault persisted for 696 ms before evolving into red phase to blue phase to earth fault.

During the initial earth fault, the fault currents inclusive of load current were 2645 A in the red phase, 980 A in the yellow phase, 1040 A in the blue phase and a residual fault current 1772 A.

The Adaptive Protection responded to the red phase to blue phase to earth fault. The magnitudes of the fault currents inclusive of load current were 4882 A in the red phase, 1275 A in the yellow phase, 6272 A in the blue phase and a residual fault current 971 A.

This phase to phase to earth fault occurred 24.9 ms prior to being detected by the Adaptive Protection relay. The 6.6 kV bus section circuit breaker tripped 92.9 ms after the trip signal from the Adaptive Protection relay was sent. From initiation of the phase to phase to earth fault up to the tripping of the 6.6 kV bus section circuit breaker was 117.8 ms.

After the 6.6 kV bus section circuit breaker tripped, the fault currents reduced to 3667 A in the red phase, 999 A in the yellow phase, 4842 A in the blue phase with a residual fault current of 570 A.

The Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder eventually tripped 1.636 secs after being closed.

Based on the recorded maximum phase fault current of 6272 A and on the settings of the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder overcurrent protection, the expected operating time of the feeder overcurrent protection (excluding circuit breaker operating time) would be 1.42 secs. For the maximum recorded earth fault current of 1772 A and based on the settings of the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder earth fault protection, the minimum expected operating time of the feeder earth fault protection (excluding circuit breaker operating time) would be 1.36 secs.

Considering the recorded maximum phase fault current of 4842 A after the Littleborough bus section circuit breaker opened and the settings of the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder overcurrent protection, the expected operating time of the feeder overcurrent protection (excluding circuit breaker operating time) would be 1.58 secs. For the recorded earth fault current of 570 A after the Littleborough bus section circuit breaker opened and based on the settings of the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder earth fault protection, the expected operating time of the feeder earth fault protection (excluding circuit breaker operating time) would be 2.10 secs.

The Adaptive Protection relay event recorder recorded a total fault duration of 1.636 secs i.e. the time from fault initiation (i.e. closing the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder circuit breaker) to opening of the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV feeder circuit breaker to clear the fault.

The CRMS event-log, indicates that the Littleborough Joseph Lister DR/Dearnley C.of.E School 6.6 kV circuit breaker tripped approximately 1.632 secs after it was closed.

The total fault clearance times obtained from the Adaptive Protection relay disturbance recorder and from the CRMS event-log are both in line with the expected operating times of the Littleborough Joseph Lister DR/Dearnley C.of.E 6.6 kV feeder over current protection as estimated above, particularly giving consideration to the variation of the fault currents during the total fault clearance time.

Table 5-1 summarises the fault event times relative to the triggering of the AP relay

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

Phase to Earth Fault - Closure of Littleborough Joseph Lister DR/Dearnley C.of.E CB (from AP relay disturbance recorder)	Phase to 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)
-696 ms	0 ms	24.9 ms	117.8 ms	1636 ms

Table 5-2 summarises currents obtained from the disturbance records." Pre-AP Operation Current Post-Closure of Littleborough Joseph Lister DR/Dearnley C.of.E School CB" is the current after closure of the Littleborough Joseph Lister DR/Dearnley C.of.E School CB, but before operation of the Adaptive Protection relay. "AP Fault Current" is the current after operation of the Adaptive Protection, but before tripping of the 6.6 kV bus section CB. "Post AP Operation Current" is the current after the 6.6 kV bus section has opened, but before the Littleborough Joseph Lister DR/Dearnley C.of.E School CB trips. "Post Fault Load Current" is the current after the Littleborough Joseph Lister DR/Dearnley C.of.E School CB has tripped.

Table 5-2: Disturbance Recorder Current Summary

	Load Current Prior to-Closure of Littleborough Joseph Lister DR/Dearnley C.of.E School CB	Pre-AP Operation Current Post-Closure of Littleborough Joseph Lister DR/Dearnley C.of.E School CB	AP Fault Current	Post-AP Operation Current	Post-Fault Load Current
Red	897 A	2645 A	4882 A	3667 A	872 A
Yellow	895 A	980 A	1275 A	999 A	898 A
Blue	912 A	1040 A	6272 A	4842 A	878 A
Residual	18 A	1772 A	971 A	570 A	23 A

6 CONCLUSIONS

The fault as recorded on the disturbance recorder integral to the Adaptive Protection relay confirms the events observed from the CRMS including the closing of the Littleborough Joseph Lister Drive/Dearnley C.of.E School CB onto a red phase to earth fault, the opening of the bus section circuit breaker and subsequently the opening of the Littleborough Joseph Lister DR/Dearnley C.of.E School CB.

The operation of the Neutral Current alarm after the closure of the Littleborough Joseph Lister Drive/Dearnley C.of.E School CB is in response to the earth fault current seen in the disturbance records prior to the operation of the Adaptive Protection

20 Minutes prior to this event the Littleborough Joseph Lister Drive/Dearnley C.of.E School CB had tripped presumably due to this same fault.

The reduction in the fault currents due to the opening of the 6.6 kV bus section circuit breaker is clearly seen. The reduction in the phase fault currents in this case is as expected, it is difficult to be precise as the degree of the reduction will depend on the relative magnitudes for the source impedance, circuit and transformer impedances and fault resistance.

The residual current during the phase to phase to earth fault is seen to reduce from 971 A to 570 A (a reduction of approximately 40%). This reduction in residual current reflects the dominant effect of the earthing resistors at Littleborough Primary substation and the expected doubling of the earth resistance as the bus section is opened and the earthing resistors associated with the Primary transformers on each section of busbar are no longer in parallel.

The phase to phase to earth fault was present for 24.9 ms before the Adaptive Protection was triggered. In this case the fault current was only a multiple of 1.38 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 time between the Adaptive Protection issuing the trip signal and the 6.6 kV bus section circuit breaker tripping is largely dependent on the circuit breaker operating time and would not change with fault current.

Overall, the analysis has confirmed that the Adaptive Protection operated as expected and reduced the fault current to be interrupted by the feeder circuit breaker.