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RESPOND POST FAULT ANALYSIS

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Electricity North West Ltd

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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	8 May 2017 / 02.19.58
Faulted Circuit	Midge Holes/Dearnley 6.6kV circuit
Fault Location	Straight joint in joint pit at SD 93383 16785

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.

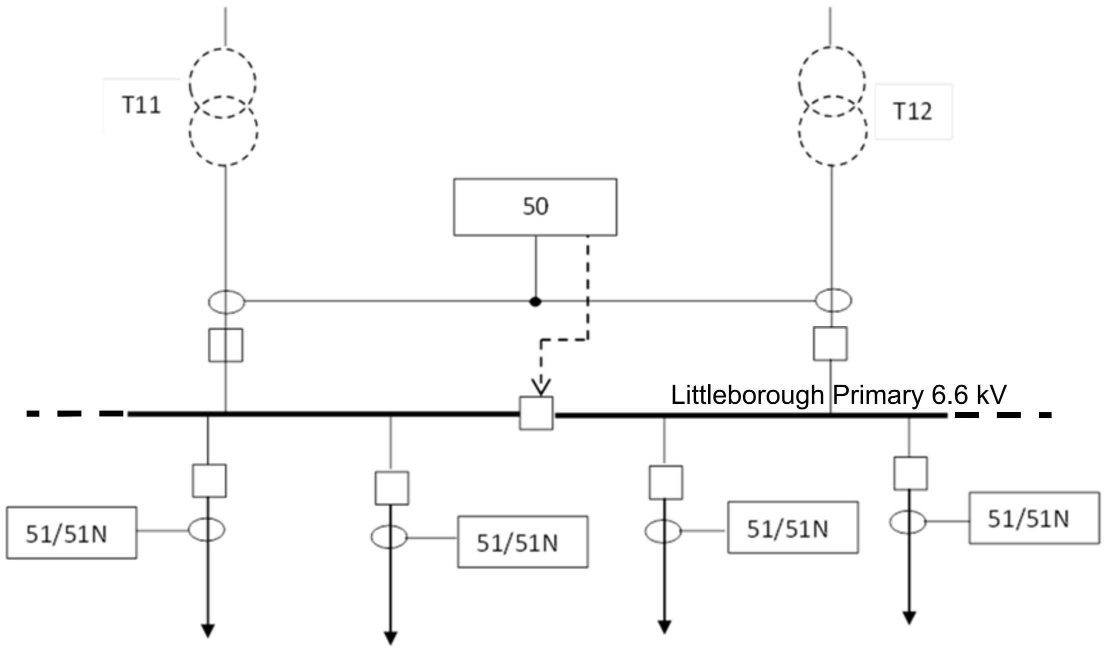

Figure 3-1: Littleborough Primary Substation Network

Table 3-1: Pre-fault Load Conditions

Pre-fault load data (1/2hour)	
Littleborough Primary	408 A
Midge Holes/Dearnley Feeder	21 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: Midge Holes/Dearnley 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:	13.59 kA
L-L Fault Level:	11.769 kA
L-L-G Fault Level:	11.769 kA
L-G Fault Level:	0.14 A
Dinis Fault Current Values at fault location	
Dinis fault calculation (Only for L-L-G faults):	Red = 0 kA /0° Yellow = 7.928 kA /192° Blue = 7.143 kA /16° Residual = Not listed
IPSA Fault Current Values for fault at Littleborough Primary Substation 6.6kV busbar	
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

3.3.2 Recorded Fault Current

The fault currents recorded by the relay in the red and blue phases (7964 A and 9822 A respectively), as shown in Table 3-5, although greater than the Dinis phase to phase to earth fault current results, do show some correlation, particularly considering that the modelling of the upstream system in Dinis is based on an assumption. However, it is noted that the FLAT phase to phase to earth fault current results are the same for the two phases, and the difference between the measured values is even larger than for the Dinis results, probably indicating an omission or error in the zero sequence parameters within the FLAT network representation. IPSA fault current results are only available at Littleborough Primary substation rather than 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	Schneider NMS FLAT- Calculated L-L-G Fault Level (at Fault Location)	Dinis Calculated L-L-G Fault Level (at Fault Location)	IPSA Calculated L-L-G Fault Level (at Littleborough Primary)
Red	7964 A	11769 A	7143 A (16°)*	11230 A
Yellow	719 A	-	0 (0°)*	-
Blue	9822 A	11769 A	7928 A (192°)*	11230 A
Residual	1479 A	-	-	-

* DINIS 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
02:19:58.732	Littleborough 6.6 kV Neutral Current Alarm
02:19:58.819	Littleborough Adaptive Protection (AP) Stage 1 Operated
02:19:58.931	Littleborough 6.6 kV Bus Section A-B Circuit Breaker Opened
02.19.59.033	Littleborough T11 and T12 6.6 kV Low Voltage Alarm
02:20:00.321	Littleborough Midge Holes/Dearnley 6.6 kV CB “ARS” Opened
02:20:00.462	Littleborough 6.6 kV Neutral Current Alarm Reset
02:20:01.033	Littleborough T11 6.6 kV Voltage Normal
02:20:23.270	Littleborough T12 6.6 kV Voltage Normal
02:24:14.542	Littleborough Midge Holes/Dearnley 6.6 kV CB “ARS” closed
02.24.14.587	Littleborough 6.6 kV Neutral Current Alarm
02.24.14.632	Littleborough T11 6.6 kV Low Voltage Alarm
02.24.14.930	Littleborough Midge Holes/Dearnley Amps High
02.24.14.930	Littleborough T11 Amps High
02.24.15.015	Littleborough 6.6 kV Neutral Current Alarm Reset
02.24.15.032	Littleborough T12 6.6 kV Low Voltage Alarm
02.24.15.568	Littleborough 6.6 kV Neutral Current Alarm
02.24.16.053	Littleborough Midge Holes/Dearnley 6.6 kV CB “ARS” Opened

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.

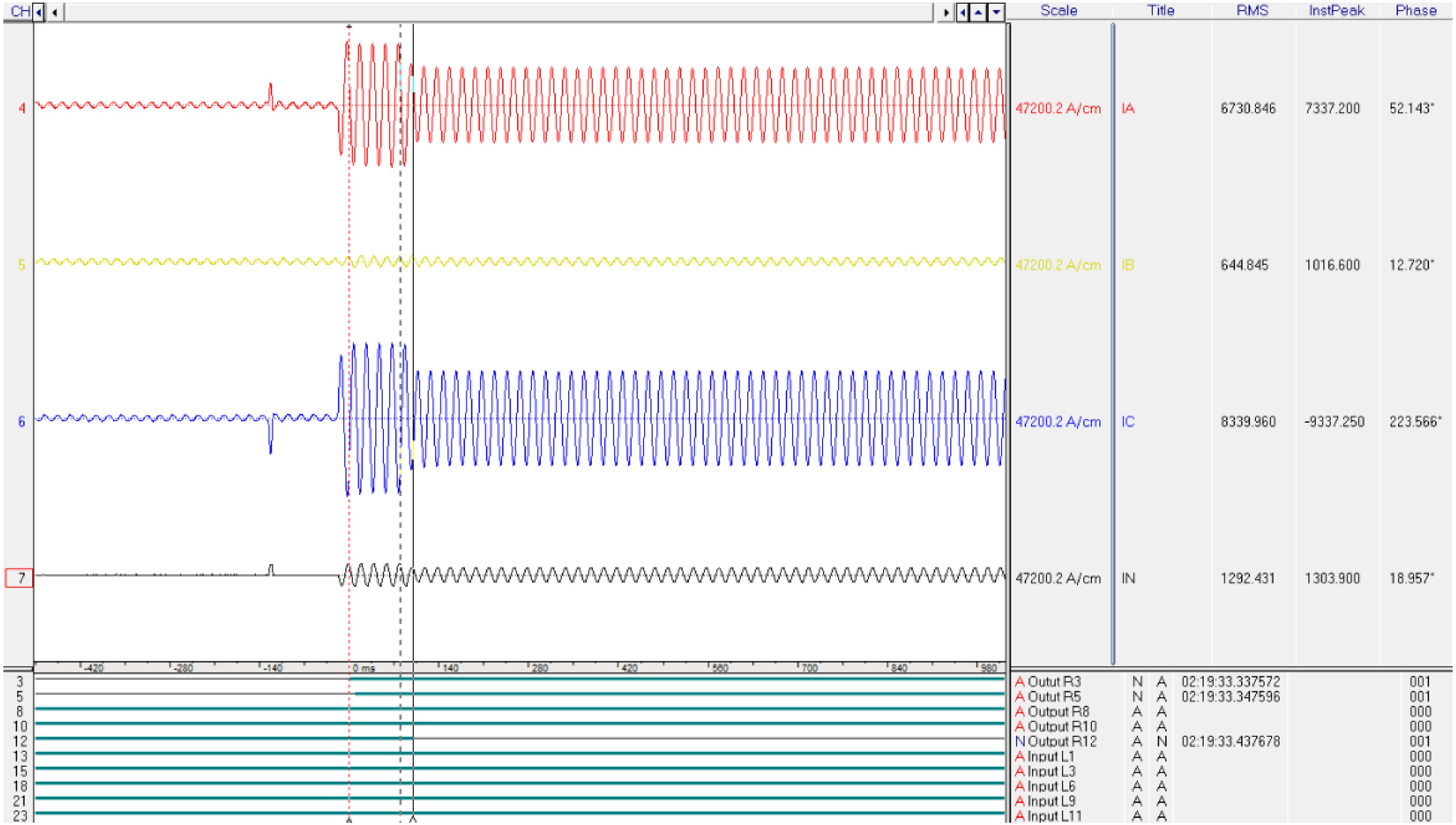

Figure 4-1: Instantaneous Adaptive Protection Relay Recordings (IA=red, IB=yellow, IC=blue and IN(residual)=black)

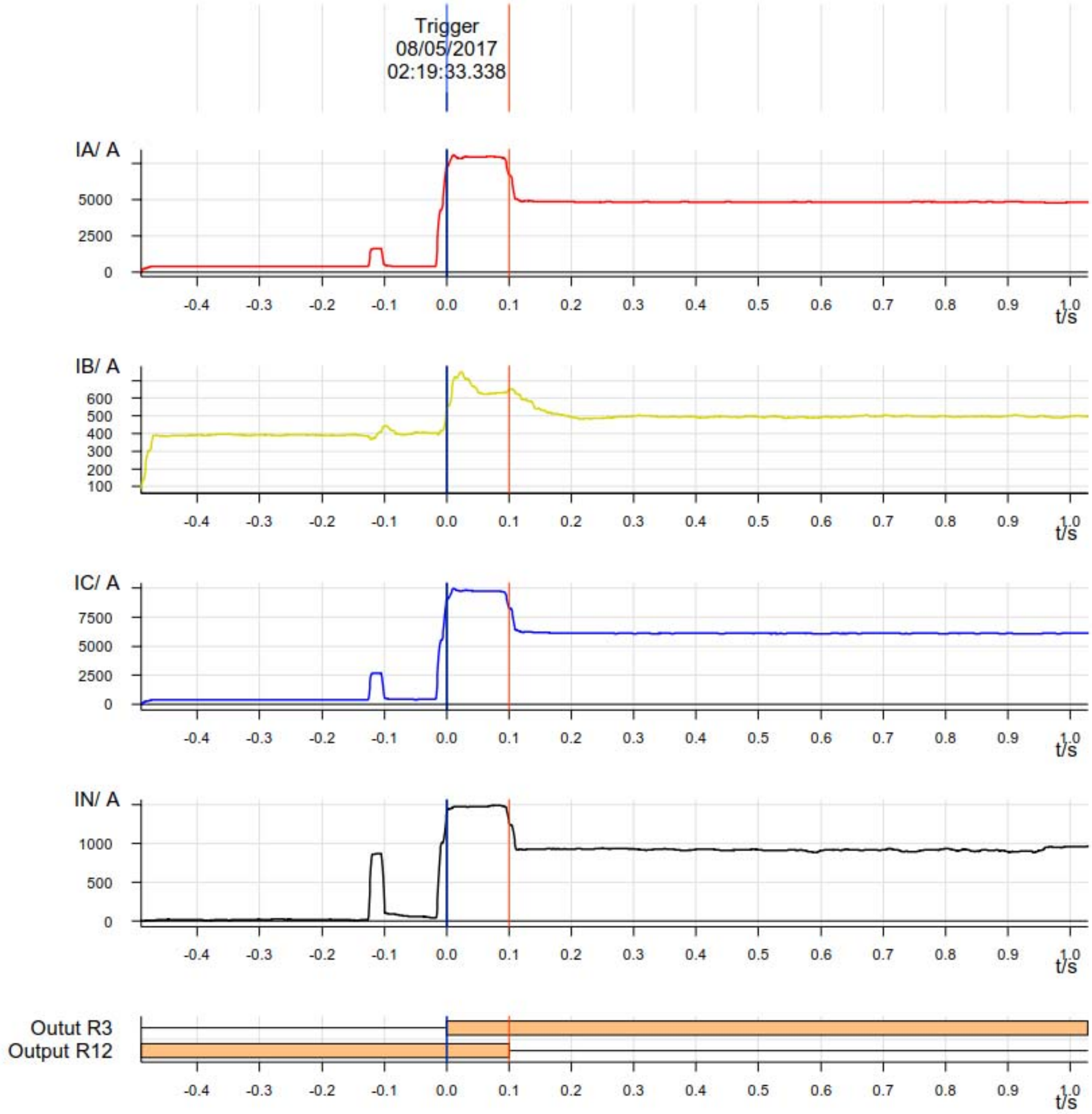

Figure 4-2: RMS Adaptive Protection Relay Recordings

5 DISTURBANCE ANALYSIS

The disturbance records show that the Adaptive Protection responded to a red phase to blue phase to earth fault. The magnitudes of the fault currents inclusive of load current were 7964 A in the red phase, 719 A in the yellow phase, 9822 A in the blue phase and a residual fault current 1479 A.

This phase to phase to earth fault occurred 18.5 ms prior to being detected by the Adaptive Protection relay. The 6.6 kV bus section circuit breaker tripped 99.7 ms after the trip signal from the Adaptive Protection relay was sent. From fault initiation up to the tripping of the 6.6 kV bus section circuit breaker was 116.1 ms.

After the 6.6 kV bus section circuit breaker tripped, the fault currents reduced to 4862 A in the red phase, 492 A in the yellow phase, 6126 A in the blue phase current with a residual fault current of 932 A.

Based on the initial recorded maximum phase fault current of 9822 A and on the settings of the Midge Holes/Dearnley 6.6 kV feeder overcurrent protection, the expected operating time of the feeder overcurrent protection (excluding circuit breaker operating time) would be 1.20 secs. For the initial recorded earth fault current of 1479 A and based on the settings of the Midge Holes/Dearnley 6.6 kV feeder earth fault protection, the expected operating time of the feeder earth fault protection (excluding circuit breaker operating time) would be 1.40 secs.

Considering the recorded maximum phase fault current of 6126 A after the Littleborough bus section circuit breaker opened and the settings of the Midge Holes/Dearnley 6.6 kV feeder overcurrent protection, the expected operating time of the feeder overcurrent protection (excluding circuit breaker operating time) would be 1.43 secs. For the recorded earth fault current of 932 A after the Littleborough bus section circuit breaker opened and based on the settings of the Midge Holes/Dearnley 6.6 kV feeder earth fault protection, the expected operating time of the feeder earth fault protection (excluding circuit breaker operating time) would be 1.67 secs.

The Adaptive Protection relay event recorder recorded a total fault duration of 1.679 secs i.e. the time from fault initiation to opening of the Midge Holes/Dearnley 6.6 kV feeder circuit breaker to clear the fault.

The CRMS event-log, indicates that the Midge Holes/Dearnley 6.6 kV circuit breaker tripped approximately 1.502 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 CRM event-log are both in line with the expected operating time of the Midge Holes/Dearnley 6.6 kV feeder over current protection as estimated above.

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 Midge Holes/Dearnley 6.6 kV feeder circuit breaker occurred just outside of the set disturbance recorder window and was not captured.

In order to capture the opening of the feeder circuit breaker, 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 required relay setting parameters are as follows:

Duration = 2.0 secs   Trigger Position = 25 (%)

Table 5-1 summarises the fault event times relative to inception. Table 5-2 summarises 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 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	18.5 ms	116.1 ms	1679 ms

Table 5-2: Disturbance Recorder Current Summary

	Pre-AP Operation Current	AP Fault Current	Post-AP Operation Current	Post-Fault Current
Red	395 A	7964 A	4862 A	Not Recorded
Yellow	389 A	719 A	492 A	Not Recorded
Blue	396 A	9822 A	6126 A	Not Recorded
Residual	25 A	1479 A	923 A	Not Recorded

6 CONCLUSIONS

The fault as recorded on the disturbance recorder integral to the Adaptive Protection relay confirms the events observed from the CRMS up to the opening of the bus section circuit breaker. The initial operation of the Neutral Current alarm is in response to the earth fault current seen in the disturbance records at the time of operation of the Adaptive Protection

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 is seen to reduce from 1479 A to 923 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 18.5 ms before the Adaptive Protection was triggered. In this case the fault current was only a multiple of 2.17 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.