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RESPOND POST FAULT ANALYSIS

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WSP | Parsons Brinckerhoff
Manchester Technology Centre
Oxford Road, Manchester M1 7ED

Tel: +0 (0) 161 200 5000
Fax: +0 (0) 161 200 5001
www.wsp-pb.com

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PRODUCTION TEAM

CLIENT

Innovation Engineer	Kieran Bailey	Kieran Bailey 
Innovation Delivery Manager	Paul Turner	

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Project Manager	Gillian Williamson
Technical Specialist	Peter Watson

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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	Bamber Bridge Primary
Fault Mitigation Technique	I_s Limiter (Type B)
Voltage	11 kV
Date/Time	18 August 2017 / 13:26.48 Hrs
Faulted Circuit	School Lane 11 kV feeder
Fault Location	11 kV T1 tails at Cottage Ln Hostel Substation. The fault was cleared by the local T1 11 kV CB at Cottage Ln Hostel Substation

3 SITE AND INSTALLATION INFORMATION

3.1 NETWORK DATA

The fault mitigation technique employed at Bamber Bridge Primary substation is an I_S-limiter.

An I_S-limiter is in principle a combination of an extremely fast acting switch, which can conduct a high current but has a low switching capacity, and a fuse with a high breaking capacity mounted in parallel. In order to achieve the desired short opening time, a small explosive charge is used as a stored energy mechanism to interrupt the switch (main conductor). When the main conductor has opened, the current still flows through the parallel fuse, where within 0.6 ms the current is limited and then finally interrupted at the next voltage zero.

The current flowing through the I_S-limiter is monitored by an electronic measuring and tripping device. A trip occurs as soon as an impermissibly high short-circuit current begins to flow. In order to determine whether tripping of the I_S-limiter is necessary, the instantaneous current and rate of rise of current across the I_S-limiter are constantly measured and evaluated.

The I_S-limiter is provided with an associated series circuit breaker which is connected between the I_S-limiter and the 11 kV CB at the end of section B busbar. In the event that any of the I_S-limiter's main conductors and fuses operate, within 100 ms the I_S-limiter series CB will trip disconnecting all three phases.

The pre-fault Bamber Bridge Primary network configuration is shown in Figure 3-1.

For the Respond trials, the I_S-limiter is connected in parallel with the bus-section 11 kV circuit breaker (CB) at Bamber Bridge. This parallel connection is achieved by utilising two existing previously unused 11 kV CBs, one at the end of each section of busbar (A and B).

When the I_S-limiter is in service, the bus-section 11 kV CB is open. With the bus-section open, any transformer fault current contribution from one section of busbar to the other section of busbar will pass through the I_S-limiter.

Should the I_S-limiter operate or be taken out of service, the bus section 11 kV CB can be closed to by-pass the I_S-limiter.

Following an I_S-limiter trip, the network can be reconfigured and the bus-section 11 kV CB closed by remote telecontrol in order to reduce the risk of loss of supply to customers. The tripped I_S-limiter insert(s) can then be replaced and the I_S-limiter restored to service position.

The I_S-limiter series CB is normally tripped by the I_S-limiter but it also has its own CTs and protection relay. This relay trips the I_S-limiter series CB if it sees a phase current of 3500 A or more (the earth fault element is not enabled). It performs this trip almost instantaneously (minimum time delay setting of 20 ms), which in reality means it will issue a trip command in about 40 ms.

If the I_S-limiter operates correctly it will interrupt the fault current in the faulted phase/s and trip the series circuit breaker before the I_S-limiter series CB protection relay can respond.

The I_S-limiter tripping value is set to 3500 A and is coupled with upper and lower instantaneous current measuring range settings and a rate of change of current setting. The value of 3500 A is

selected to prevent the I_S-limiter tripping for earth-faults whilst ensuring operation for phase to phase and three phase faults.

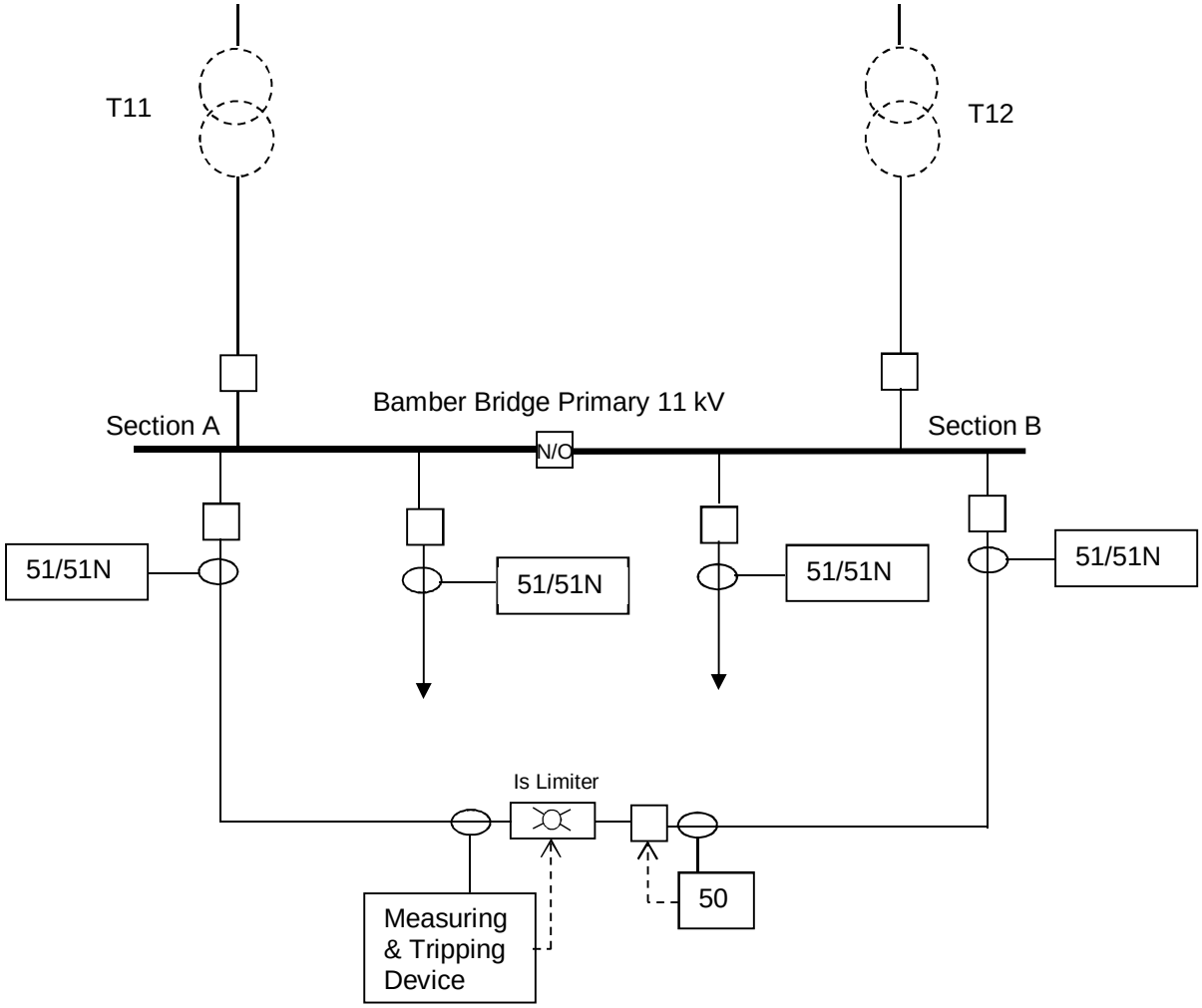

Figure 3-1: Bamber Bridge Substation Network

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

Table 3-1: Pre-fault Load Conditions

Pre-fault load data (1/2hour)	
Bamber Bridge	565 A
School Lane 11 kV Feeder	32 A

3.2 PROTECTION DATA

The I_S-limiter has the facility to be remotely switched in and out-of-service, in this case it was in-service.

The settings of the Bamber Bridge School Lane 11 kV feeder protection relay, the Bamber Bridge I_S-limiter, the protection relays in the associated Bamber Bridge I_S-limiter circuit and the local T1 11 kV CB at Cottage Ln Hostel substation are provided in Table 3-2 to Table 3-6.

Table 3-2: Bamber Bridge Primary I_S-limiter Settings

I_T (Tripping Value)	3500 A
i_1 (upper measuring range)	4000 A
i_2 (lower measuring range)	2500 A
di/dt (rate of rise of current)	1342 kA/ms
Comment	The tripping value of 3500 A is well below the short circuit capability of the Bamber Bridge Primary 11 kV switchgear (20.0 kA), but this value is selected for these trials to ensure operation for 11 kV phase faults.

Table 3-3: Bamber Bridge Primary I_S-limiter Series Circuit Breaker Protection Relay Settings

CT	1250/1
Relay	ABB REF615
I>	Disabled
I>>	2.8 x In (3500 A)
t>>	0.02 secs – Definite Time
Io>	Disabled
Io>>	Disabled
Comment	This relay did not operate nor register any fault current.

Table 3-4: Bamber Bridge Primary - 11 kV Circuit Breakers at the end of each section of busbar connected to the I_S-limiter

CT	1200/5
Relay	Argus 1 AG-142 DCD414B (3 Phase Overcurrent and Earth Fault)
I>	1.25 x In (1500 A)
t>	0.175 – Standard Inverse
Io>	0.1 x In (120 A)
to>	0.4 – Standard Inverse
Io>>	0.05 x In (60 A) – *Alarm only*
to>>	0 secs
Comment	These relays did not operate nor register any fault current.

Table 3-5: Bamber Bridge Primary – School Lane 11 kV Feeder Protection Settings

CT	600/5
Relay	Argus1 AG-142 DCD414B (3 Phase Overcurrent and Earth Fault)
I>	1 x In (600 A)
t>	0.35 - Standard Inverse
Io>	0.10 x In (60 A)
to>	0.35 - Standard Inverse
Io>>	0.1 x In (60 A) – *Alarm only*
to>>	0 secs
Comment	This relay did not operate nor register any fault current.

Table 3-6: Cottage Lane Hostel Local T1 11 kV Circuit Breaker (Lucy Sabre VRN2A - switchgear)

CT	100/5
TLF	7.5 A
Comment	The TLF and associated release coils operated tripping local T1 11 kV circuit breaker to clear the fault. There is no facility to record fault current at this location.

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 3-7.

Table 3-7: Fault Current Values

Schneider NMS FLAT Fault Current Values at fault location	
Three Phase Fault Level:	Not Available
Dinis Fault Current Values at Cottage Lane Hostel Substation	
Three Phase Fault Level (bus section closed):	6.745 kA
Three Phase Fault Level (bus section open):	Not Available
IPSA Fault Current Values for fault at Bamber Bridge Primary Substation 11 kV busbar	
Three Phase Fault Level (bus section closed):	8.08 kA
Three Phase Fault Level (Section A - with bus section circuit breaker and I_s Limiter open):	4.44 kA

IPSA fault current results are only available for Bamber Bridge Primary substation rather than at the fault location. The IPSA fault currents are therefore higher than the Dinis results for a fault at the fault location.

3.3.2 On-Site Inspection at Bamber Bridge Primary Substation

During the site inspection after the fault, it was found that yellow phase I_S-limiter fuse and the series CB had operated.

The Argus1 AG-142 relay on the School Lane 11 kV feeder issued an earth fault alarm, but did not operate.

Each of the Argus1 AG-142 relays on the 11 kV circuit breakers at the end of each section of busbar connected to the I_S-limiter, issued an earth fault alarm, but they did not operate.

The ABB REF615 relay on the I_S-limiter series CB also did not operate. This is as expected because the I_s-limiter switches off the current through the I_s-limiter and series CB before its conventional protection relay is able to identify the short-circuit current.

3.3.3 On-Site Inspection at Cottage Lane Hostel Substation

Cottage Lane Hostel Substation is the 3rd substation on the School Lane feeder approximately half a mile from Bamber Bridge Primary.

A 3 phase fault was found in a cable joint in the connection from the ring main unit to the local transformer. The Time Limit Fuse and associated release coils operated tripping the local T1 11 kV vacuum circuit breaker to clear the fault.

The cable joint was tested, and all 3 phases were found to be fused together. Unusually, there was no sign of damage to the joint. This may be attributable to the reduced fault current after the operation of the I_s-limiter and the fast operating time of the Time Limit Fuses.

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
13:26:48.195	I_S-limiter Feeder A Earth Fault Alarm
13:26:48.195	I_S-limiter Feeder B Earth Fault Alarm
13:26:48.198	School Lane Feeder Earth Fault Alarm
13:26:48.253	Bamber Bridge 11 kV Neutral Current Alarm
13:26:48.301	I_S-limiter Tripped
13:26:48.350	School Lane Feeder Earth Fault Alarm Reset
13:26:48.352	I_S-limiter Feeder B Earth Fault Alarm Reset
13:26:48.353	I_S-limiter Series CB opened
13:26:48.396	I_S-limiter Feeder A Earth Fault Alarm Reset
13:26:48.484	Bamber Bridge 11 kV Neutral Current Alarm Reset

4.2 DISTURBANCE RECORDS

The I_S-limiter does not record any fault current data.

Event and disturbance recorders are available in the following relays:

- The Argus1 AG-142 relay on the School Lane 11 kV feeder
- The Argus1 AG-142 relays on the 11 kV circuit breakers at the end of each section of busbar connected to the I_S-limiter
- The ABB REF615 relay on the I_S-limiter series circuit breaker

None of the above relays operated and no current was registered or recorded by either the event or disturbance recorders. Analogue waveforms of the fault currents are therefore not available.

5 DISTURBANCE ANALYSIS

Without any evidence to the contrary, it is assumed that the yellow phase I_S-limiter responded to the 3-phase fault at Cottage Lane Hostel Substation and operated to interrupt the fault current. The time interval between the I_s-limiter Feeder A and B Earth Fault Alarms and the tripping of the I_S-limiter is 106 ms.

The series circuit breaker opened 51 ms after the tripping of the I_S-limiter.

The time interval between the I_s-limiter Feeder A and B Earth Fault Alarms and the tripping of the I_s-limiter is longer than expected. However, this could due to the Earth Fault Alarms being initiated by earth fault currents below the threshold for I_s-limiter operation. As the fault developed and the fault current increased the I_s-limiter then operated.

The operation of only the yellow phase I_S-limiter for a three phase fault may be due to the fault current being very close to the tripping threshold (3500 A) and to slight differences in fault current in each phase. Following the operation of the yellow phase I_S-limiter, the fault current contribution through the I_S-limiter would be that of a phase-to-phase fault with a consequent reduction in the fault current magnitude. The opening of the yellow phase I_S-limiter could therefore have reduced the fault current through the I_S-limiter to below the trip threshold, thereby preventing the I_S-limiters in the other two phases from operating.

The CRMS event-log indicates that the time interval between the initiation of the I_s-limiter Feeder A and B alarms (start of the event) and the resetting of the Bamber Bridge 11 kV Neutral Current alarm (end of the event) was 289 ms.

The current limiting ability and speed of operation of the I_S-limiter means that the fault current prior to the operation of the I_S-limiter has little if any impact of the operating time of the TLF protection at Cottage Lane Hostel Substation.

Based on the a 3 phase fault current of 3372 A (half the fault current for a 3-phase fault at Cottage Lane Hostel Substation with the Is-limiter closed), the operating time of the 7.5 A Time Limit Fuse (100/5 CT) on Cottage Lane Hostel local T1 11 kV Circuit Breaker would be approximately 10 ms.

The total event time interval is longer than expected, but this could again be due to the fault current increasing as the fault evolves over time.

6 CONCLUSIONS

From the information available it appears that the I_S-limiter operated as designed and limited the prospective fault current. Without any captured analogue waveforms however, it is not possible to see the magnitude and duration of the initial fault current.

The disturbance recorders integral to the protection relays at Bamber Bridge substation did not capture the fault current prior to the operation of the I_S-limiter due to its extremely fast operating time.

6.1 RECOMMENDATIONS

Consideration should be given to the installation of temporary high speed transient fault recorders at sites where I_S-limiters are installed.