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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	Bamber Bridge Primary
Fault Mitigation Technique	Is Limiter (Type B)
Voltage	11 kV
Date/Time	22 May 2017 / 03:28 Hrs
Faulted Circuit	Bamber Bridge Local
Fault Location	Between Brampton Dr/Coniston Dr - Outside No.1 Duddle Lane

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 will pass from one section of busbar to the other section of busbar 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 inserts(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.

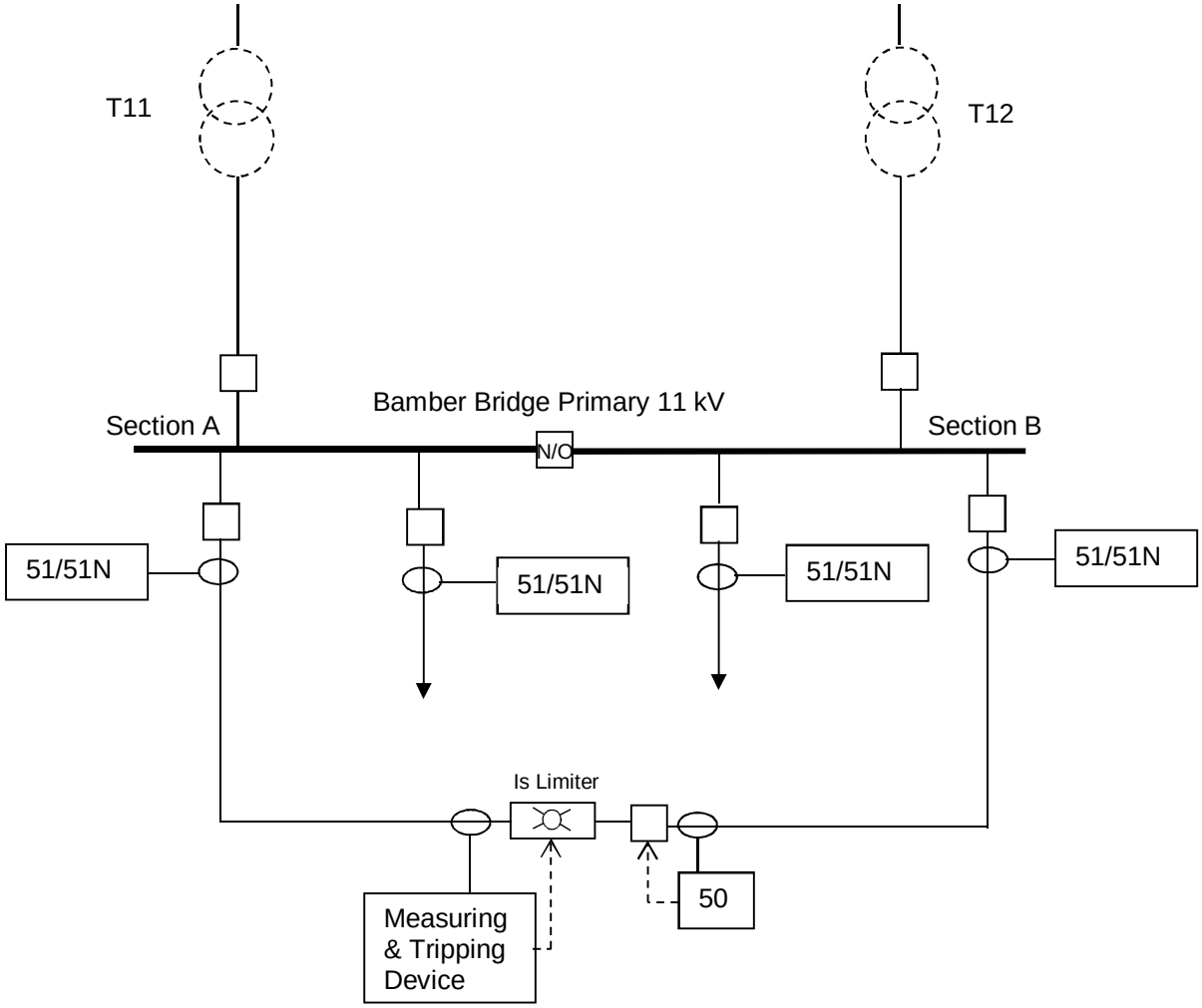

Figure 3-1: Bamber Bridge Substation Network

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	270 A
Bamber Bridge Local Feeder	24 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 Local 11 kV feeder protection relay, the I_S-limiter and the protection relays in the associated I_S-limiter circuit are provided in Table 3-2 to Table 3-5.

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 A/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 - Bamber Bridge Local 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>	0.15 x In (90 A)
to>	0.3 - Standard Inverse
Io>>	0.1 x In (60 A) – *Alarm only*
to>>	0 secs
Comment	The relay time is 52 mins behind BST (8 mins ahead of GMT). The relay time needs to be synchronised with the CRMS time. The integral disturbance recorder was not enabled at the time of this fault, however, subsequently it has been enabled.

Table 3-5: 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.

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 3-6.

Table 3-6: Fault Current Values

Schneider NMS FLAT Fault Current Values at fault location	
Three Phase Fault Level:	Not Available
Dinis Fault Current Values at Coniston Drive South	
Three Phase Fault Level (bus section closed):	6.177 kA
Three Phase Fault Level (bus section open):	3.785 kA
IPSA Fault Current Values for fault at Bamber Bridge Primary Substation 11 kV busbar	
Three Phase Fault Level (bus section closed):	8.133 kA
Three Phase Fault Level (bus section open):	4.46 kA

3.3.2 Recorded Fault Current

The event recorder in the Argus1 AG-142 relay on the Bamber Bridge Local 11 kV feeder recorded 3630 A in the red phase, 3664 A in the blue phase, 3647 A in the yellow phase and a residual current of 155.4 A as shown in Table 3-7.

The recorded values show a close correlation to the Dinis calculated 3-phase fault currents with the I_S-limiter open.

IPSA fault current results are only available for Bamber Bridge Primary substation rather than at the fault location. These fault currents will therefore be higher than for a fault at the fault location, nevertheless the IPSA calculated 3-phase fault currents with the I_S-limiter open does show a correlation with the recorded fault currents.

Table 3-7: Comparison of calculated and recorded fault currents

Phase	Bamber Bridge Local 11 kV Feeder Protection Event Recorder Fault Current	Schneider NMS FLAT-Calculated 3-Phase Fault Level (at Fault Location)	Dinis Calculated 3-Phase Fault Level (at Coniston Dr South)		IPSA Calculated 3-Phase Fault Level (at Bamber Bridge Primary)	
			I_S-limiter closed	I_S-limiter open	I_S-limiter closed	I_S-limiter open
Red	3630 A	Not Available	6177 A /277°	3785 A /271°	8133 A	4460 A
Yellow	3664 A	Not Available	6177 A /157°	3785 A /151°	8133 A	4460 A
Blue	3647 A	Not Available	6177 A /37°	3785 A /31°	8133 A	4460 A
Residual	155.4 A	Not Available	-		-	-

3.3.3 On-Site Inspection

During the site inspection after the fault, it was found that red phase I_S-limiter fuse and the series CB had operated. The I_S-limiter does not provide any fault current data.

The two 11 kV feeder CBs at the end of each section of busbar issued an earth fault alarm but they did not operate nor did they register any fault current.

The ABB REF 615 relay on the I_S-limiter series CB also did not operate nor did it register any fault current. This is as expected because the Is-limiter switches off the current through the Is-limiter and series CB before its conventional protection relay is able to identify the short-circuit current.

The fault currents were recorded on the Argus1 AG-142 relay on the Bamber Bridge Local 11 kV feeder, however, the disturbance recorder integral to this relay was not enabled and therefore analogue waveforms of the fault currents are not available.

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
03:28:06.316	Bamber Bridge Local Feeder Earth Fault Alarm
03:28:06.317	I_S-limiter Feeder B Earth Fault Alarm
03:28:06.318	I_S-limiter Feeder A Earth Fault Alarm
03:28:06.326	I_S-limiter Tripped
03:28:06.373	Bamber Bridge 11 kV Neutral Current Alarm
03:28:06.377	I_S-limiter Series CB Opened
03:28:06.423	I_S-limiter (Urgent) Protection Defective Alarm
03:28:06.468	I_S-limiter Feeder B Earth Fault Reset
03:28:06.503	Bamber Bridge Local Feeder Earth Fault Reset
03:28:06.519	I_S-limiter Feeder A Earth Fault Reset
03:28:06.642	Bamber Bridge 11 kV Neutral Current Reset
03:28:06.742	Bamber Bridge Local Amps High
03:28:06.742	T11 11 KV CB Amps High
03:28:06.742	T11 11KV VT Volts Low
03:28:07.142	T12 11 KV VT Volts Low
03:28:07.748	11kV Protection Operated
03:28:07.753	Bamber Bridge Local CB Opened

4.2 DISTURBANCE RECORDS

The disturbance recorder integral to protection relay on the Bamber Bridge Local 11 kV feeder was not enabled and therefore analogue waveforms of the fault currents are not available.

5 DISTURBANCE ANALYSIS

Without any evidence to the contrary, it is assumed that the red phase I_S-limiter responded to the fault and operated to interrupt the fault current. The time interval between the Bamber Bridge Local Feeder Earth Fault Alarm and the tripping of the I_S-limiter is 10 ms.

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

With consideration to the resolution of the CRMS recorded times, these time intervals are as expected.

The operation of only the red 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 and to the tolerances of each I_S-limiter. Following the operation of the red phase I_S-limiter the fault current contribution through the I_S-limiter would that of a phase-to-phase fault with a consequent reduction in the fault current magnitude. The opening of the red 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 Bamber Bridge Local 11 kV protection relay operated 1.371 secs after the I_S-limiter Series CB Opened.

Based on the highest (3664 A) of the three phase fault currents recorded by the Bamber Bridge Local 11 kV feeder protection relay event recorder and on its overcurrent settings, the calculated relay operating time is 1.33 secs. This is very close to the operating time derived from the CRMS event log.

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 feeder protection.

The fault current though the I_S-limiter prior to its operation, was not recorded and is therefore not known.

The Dinis calculated 3-phase fault current for a fault at the location with the I_S-limiter closed is 6177 A. The fault current through the I_S-limiter would therefore be half of this total fault current i.e. 3089 A. Considering that the modelling of the upstream system in Dinis is based on an assumption, it is likely that the actual fault current through the I_S-limiter was in the region of the I_S-limiter Tripping Value of 3500 A.

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.

Where disturbance recorders integral to the protection relays at Bamber Bridge substation are available they should be enabled. Due to the extremely fast operation time of the I_S-limiter it is possible that these fault recorders will not capture the fault current prior to the operation of the I_S-limiter, they will nevertheless they will provide additional detailed information to aid in post fault analysis.

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.

The relay time needs to be synchronised with the CRMS time.