Analysis of 115kV Local and Remote Substation Trips on 13kV Feeder Faults at National Grid

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Introduction

Two close-in single phase to ground faults occurred on 13.2kV feeders in December 2011 and February 2011, respectively. The feeder breakers got stuck that cascaded and resulted in unexpected operations of the local upstream 115kV transformer overcurrent protection. In the mean time, a false Direct Transfer Trip (DTT) signal was transmitted to the remote terminals and tripped the 115kV and 23kV breakers over there, resulting in unnecessary power outage at 115kV lines tapped off substation as well as remote substations. Correct and rapid fault clearance and power outage minimization are the most concern of utility companies. The protection schemes shall work properly to isolate faults quickly and minimize the impact on transmission system. This paper presents an analysis of the cascaded event utilizing fault records of digital relays to determine what happened and why the false DTT was sent. The fault records captured by fault monitoring equipment and Sequence of Events provided valuable information which gave an insight into the nature of this disturbance. The analog and digital data of fault records facilitate an efficient investigation and accurate analysis of these events.

System Overview and Incident Summary

EM substation is supplied by two 115kV transmission lines, line LE from WH substation and line LW from WM substation, separated by an in-line 115kV circuit breaker EM-CB. Two delta/wye-grounded 115kV/13.2kV step-down transformers are connected to each 115kV line via circuit switches EM-CS-1 and EM-CS-2 at EM substation. Both 115kV lines are protected via hi-speed permissive overreaching transfer trip (POTT) and directional carrier blocking (DCB) schemes. The local breaker EM-CB will be tripped and a DTT signal will be sent to the remote terminal of WH or WM to trip off the line if there is a fault inside the transformer No.1 or No.2 or fault current exceeds the interrupting capacity of the circuit switcher EM-CS-1 or EM-CS-2, respectively, or the circuit switcher is stuck.

On December 11, 2010, the National Grid Control Center reported that:

At 08:19:26, an A-Phase-to-Ground fault occurred on the 13.2kV L5 feeder at EM substation. The L5 feeder relay record shown that the feeder overcurrent relay responded to the fault correctly, but the feeder breaker L5 did not open after the relay trip commend was sent to the breaker for more than 10 cycles. Due to the breaker failure, the transformer neutral ground function (51N-T1) of the transformer No.1, feeder backup protection, tripped the circuit switcher EM-CB-1 as expected, but over tripped the 115kV in-line breaker EM-CB and initiated a direct transfer tripping (DTT) signal to the remote end substation of WH connecting the line LE.

On February 10, 2011, the National Grid Control Center reported that:

At 08:22:57, a close-in B-Phase-to-Ground fault occurred on the 13.2kV L2 feeder at EM substation. The L2 feeder relay record shown that the feeder overcurrent relay responded to the fault correctly, but the feeder breaker L2 did not open after the relay trip commend was sent to the breaker for more than 10 cycles. Due to the breaker failure, the 115kV transformer phase overcurrent function (51-T2) of the transformer No.2, feeder backup protection, tripped the circuit switcher EM-CB-1 as expected, but over tripped the 115kV in-line breaker EM-CB and initiated a direct transfer tripping (DTT) signal to the remote end substation of WM connecting the line LW.

The system one-line diagrams are shown in Figure1 and Figure 2. Relay targets reported at EM substation for the two events are as follows:

On December 11, 2010:	L5 Feeder Ground Overcurrent (51N-L5), SEL-351 relay
	No.1 Transformer Neutral Ground Overcurrent (51N-T1), SEL-351 relay
On February 10, 2011:	L2 Feeder Ground Overcurrent (51N-L2), SEL-351 relay
	No.2 Transformer 115kV Phase Overcurrent (51-T2), SEL-351 relay

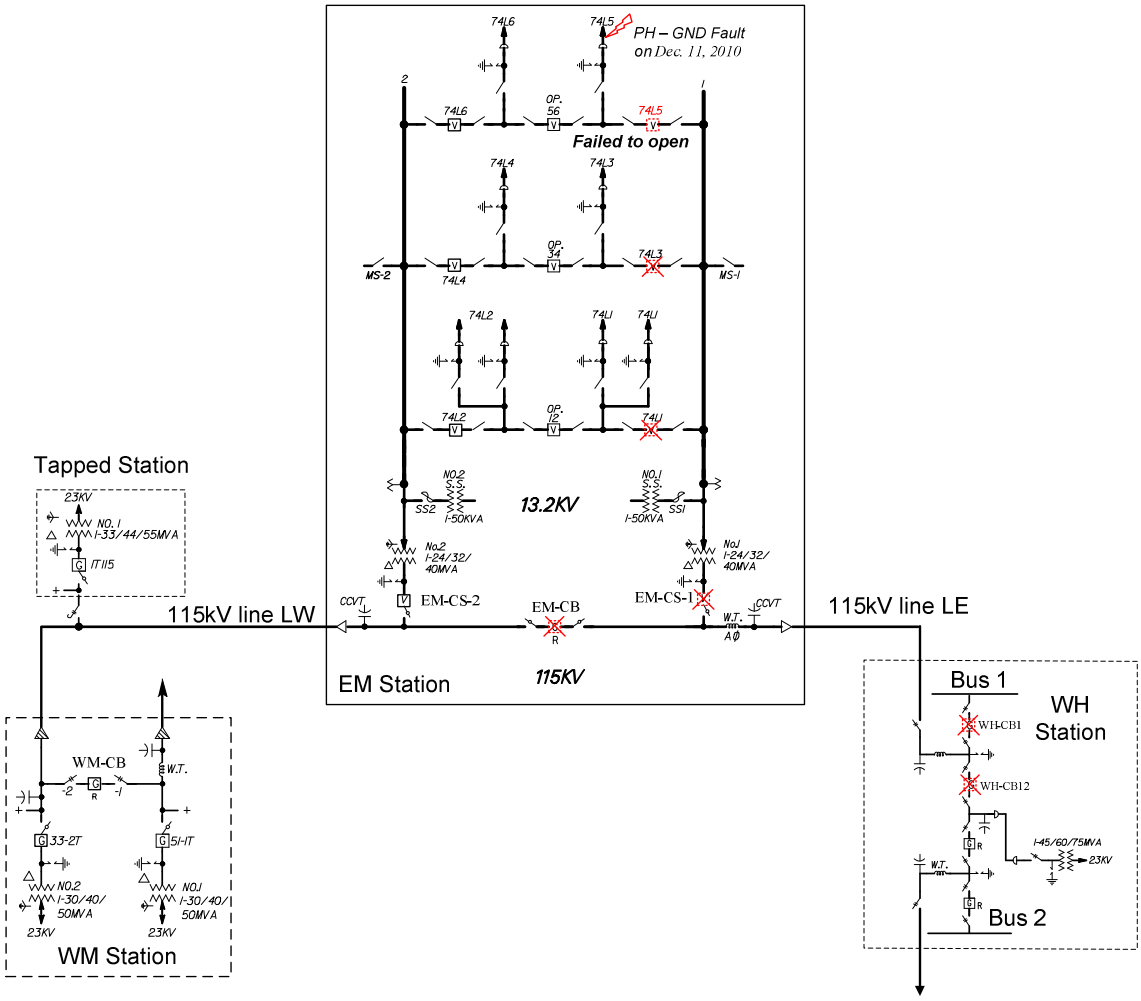

Figure 1. System One-Line Diagram with the L5 Feeder Fault

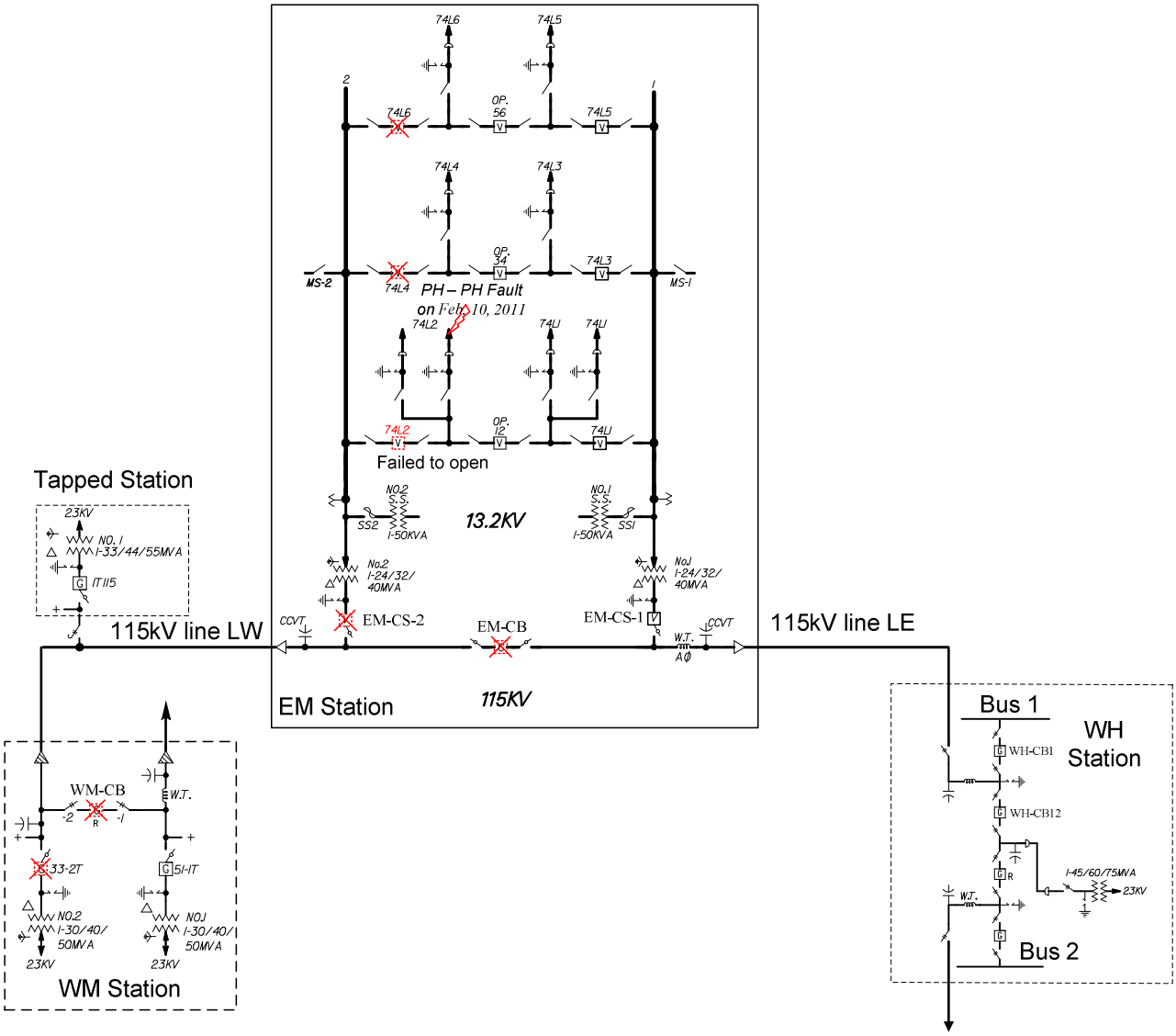

Figure 2. System One-Line Diagram with the L2 Feeder Fault

Investigation and Analysis

The first step of the investigation was to collect and review relay targets, sequence of event, and fault records from the digital fault recorders (DFRs) at the WH substation and the L5 and L2 feeder and transformer relays at the EM substation. Based on the reported relay targets and the fault records captured by the DFRs and relays, it was confirmed that:

1. An A-Phase-to-Ground fault occurred on the 13.2kV L5 feeder at EM substation on December 11, 2010. and the L5 feeder ground overcurrent relay (51N-L5) responded to the fault correctly, but the feeder breaker L5 did not open after the relay trip commend was sent to the breaker for more than 10 cycles (Figure 3). As a result of the breaker failure, the transformer neutral ground function (51N-T1) of the transformer No.1, feeder backup protection, operated correctly (Figure 4) and initiated the following operations as:

- Tripped the 115kV circuit switcher EM-CS-1 and the 13kV feeder breakers L1 and L3 as expected, which de-energized the transformer No.1 and the 13kV bus No.1 at EM substation.

- Tripped the 115kV in-line breaker EM-CB at EM substation and sent a direct transfer tripping (DTT) signal to the WH substation and tripped the 115kV circuit breakers WH-CB-1 and WH-CB-12 over there.

2. A B-Phase-to-Ground fault occurred on the 13.2kV L2 feeder at EM substation on February 10, 2011, and the L2 feeder ground overcurrent relay (51N-L2) responded to the fault correctly, but the feeder breaker L2 did not open after the relay trip commend was sent to the breaker for more than 10 cycles (Figure 5). As a result of the breaker failure, the transformer phase overcurrent function (51-T2) of the transformer No.2, feeder backup protection, operated correctly (Figure 6) and initiated the following operations as:

    - Tripped the 115kV circuit switcher EM-CS-2 and the 13kV feeder breakers L4 and L6 as expected, which de-energized the transformer No.2 and the 13kV bus No.2 at EM substation.

    - Tripped the 115kV in-line breaker EM-CB at EM substation and sent a direct transfer tripping (DTT) signal to the WM substation and tripped the 115kV in-line breaker WM-CB and the 23kV circuit breaker 2353 over there.

Based on the findings described above, the investigation focus then moved to identify why the L5 and L2 feeder breakers at EM substation failed to open, the transformer neutral ground or phase overcurrent relays tripped the 115kV in-line breaker EM-CB at EM and sent a direct transfer tripping (DTT) signal to WH or WM during the L5 or L2 feeder fault, respectively.

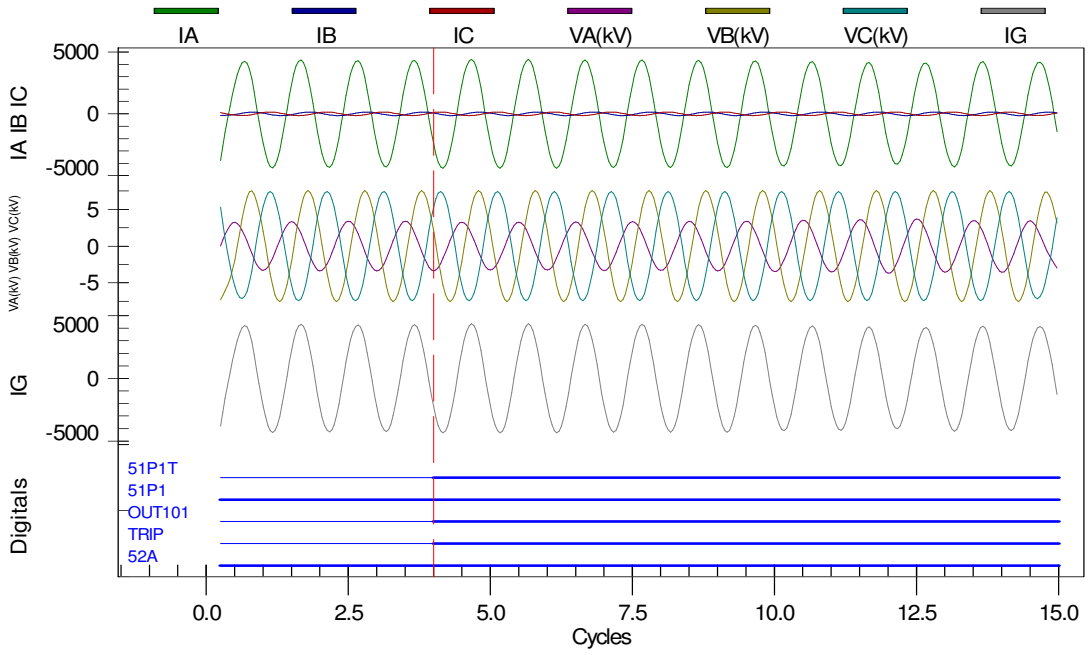

Figure 3. L5 Feeder Relay (SEL-351) Fault Records on 12/11/2010

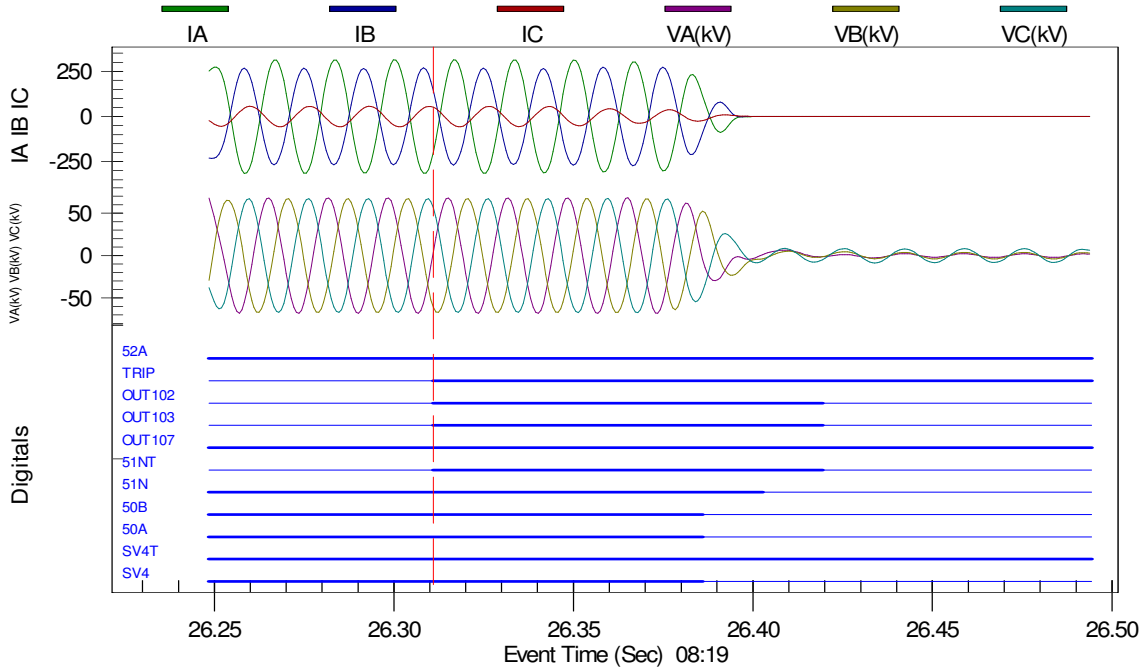

Figure 4. No.1 Transformer System 2 Relay (SEL-351) Fault Records on 12/11/2010

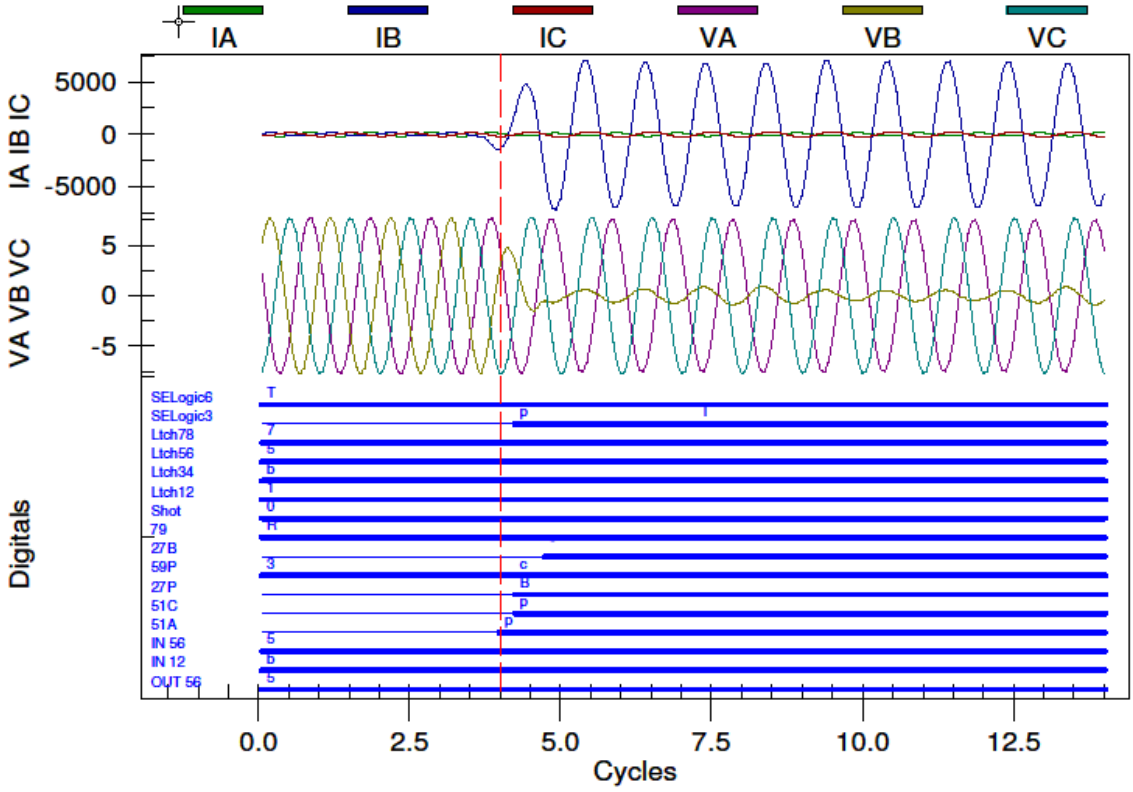

Figure 5. L2 Feeder Relay (SEL-351) Fault Records on 02/10/2011

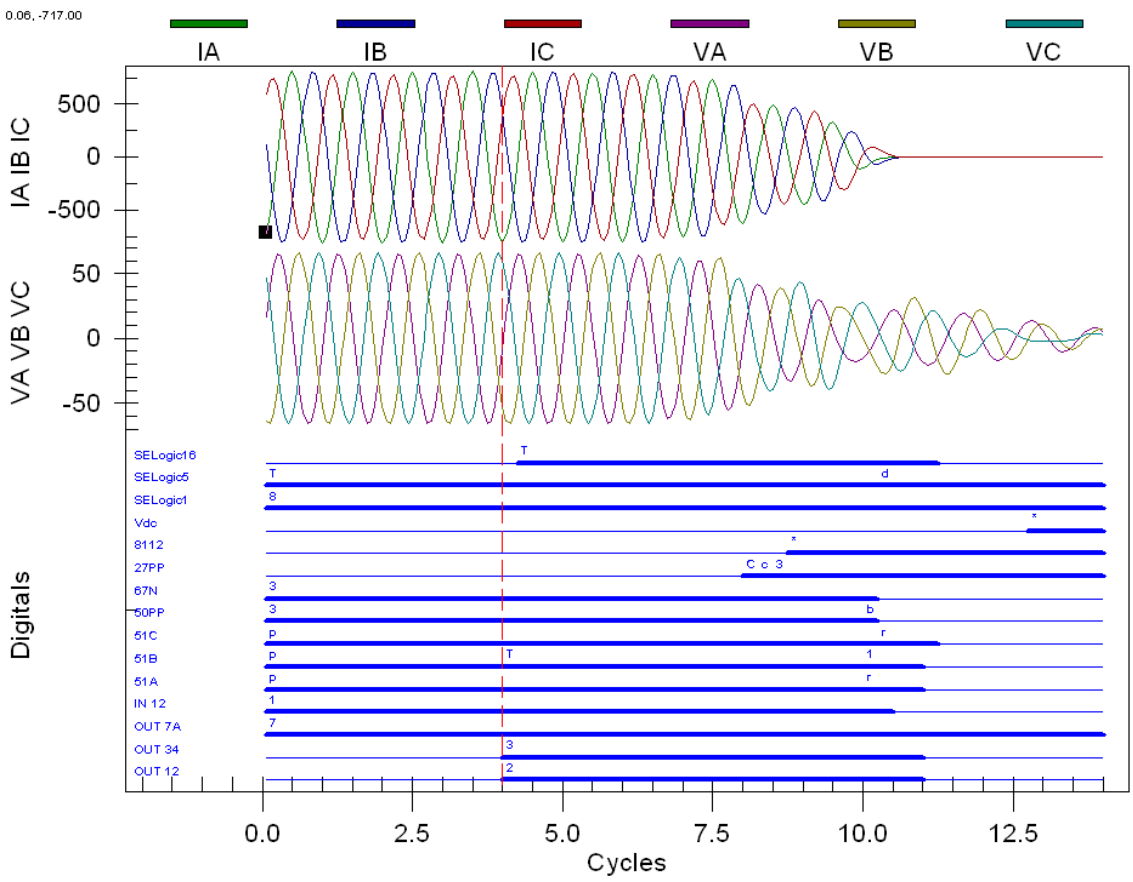

Figure 6. No.2 Transformer System 2 Relay (SEL-351) Fault Records on 02/10/2011

Why the L5 and L2 feeder breakers at EM substation did got stuck? Immediately after the L5 breaker failed to trip for the L5 feeder fault on December 11, 2010, it was noticed that several slow trips occurred with this type of circuit breakers at several substations in 2010. The manufacturer of the feeder breakers was contacted to investigate why the breaker did not trip. With technical support from the manufacturer, it was identified that the stuck of this type breaker was due to stuck bearing inside the breaker control. The department of Substation Services of National Grid then arranged to replace the failed bearing for this type of breakers across the National Grid system.

Should the No.1 transformer neutral ground relay (51N-T1) or the No.2 transformer inverse-time phase overcurrent relay (51-T2) have tripped the 115kV in-line breaker EM-CB and initiated a direct transfer trip (DTT) signal to WH or WM substation while operating on the L5 or L2 feeder fault, respectively?

According to the Relay Design and Operating Description at EM substation, transformer relaying includes primary and backup protection systems. Both transformer neutral ground and phase overcurrent functions are backup protection for the transformer No.1 orNo.2, which trips the 115kV circuit switcher EM-CS and 13kV bus circuit breakers L1, L3 and L5 or L2, L4 and L6, respectively, only. The backup protection trips for transformer faults, 13kV bus faults or close-in feeder faults with a 13kV feeder breaker failure. While, besides tripping the circuit switcher and feeder breakers, the primary protection of the transformers trips the 115kV in-line breaker EM-CB and picks up, after a short time delay, an auxiliary relay which sends a direct transfer trip (DTT) signal to the remote terminal WH or WM and trips the breakers over there.

Based on the fault records captured by the No.1 transformer relay (SEL-351) for the event on 12/11/2010, the transformer neutral overcurrent (51N-T1) protection picked up and isolated correctly for this close-in feeder fault with the13kV L5 circuit breaker failure. However, the 51N-T1 protection also tripped the 115kV in-line circuit breaker EM-CB and sent a Direct Transfer Trip (DTT) signal to WH and tripped out the 115kV breakers WH-CB-1 and WH-CB-1 at WH substation, which is as per how this SEL-351 relay has been set. By further review of the setting for this relay, it was noticed that not only the 51N-T1, but all backup functions of this transformer relay have been set to trip the 115kV breaker EM-CB at EM and initiate a DTT to trip the line LE at WH. Obviously, the relay setting is discrepant with what describes in the Relay Design and Operating Description. Given that it seems there are two improper settings for this SEL-351 relay, which are:

1. In the logic setting, the #1 transformer backup functions (51N-T1 and 51-T1) were incorrectly programmed to trip the in-line breaker EM-CB and send a DTT to WH.

2. In the pickup setting, the pickup level of a definite time current supervision element for the circuit switcher EM-CB-1 was set too low, which defeats the purpose of tripping the EM-CB and sending DTT in a short time-delay if and only if the circuit switcher fails to open. As a result, the EM-CB breaker was tripped and the DTT was sent (via OUT103) simultaneously as the circuit switcher EM-CB-1 tripped via the 51N-T1 function (via OUT102) since the current supervision had picked up prior to the fault. (via SV4T, see the SEL-351 relay fault records in Figure 4 in detail)

Similarly, for the L2 feeder fault on 02/10/2011, the No.2 transformer phase overcurrent (51-T2) protection picked up and isolated correctly for this close-in feeder fault with the13kV L2 circuit breaker failure. However, the 51-T2 protection also tripped the 115kV circuit breaker EM-CB and sent a Direct Transfer Trip (DTT) signal to WM and tripped out the 115kV and 23kV breakers WM-CB and 2353 at WM, which is as per how this SEL-351 relay, is set. By review of the setting for this relay, it was noticed that not only the 51-T2, but all backup functions of this relay have been set to trip the breaker EM-CB at EM and initiate a DTT to trip the line LW at WM. Obviously, the relay setting is discrepant with what describes in the Relay Design and Operating Description. Similar to the No.1 transformer relay, there are two setting errors for the No.1 transformer SEL-351 relay as:

1. In the logic setting, the #2 transformer Sys 2 backup functions (51N-T2 and 51-T2) were incorrectly programmed to trip the breaker EM-CB and send a DTT to WM.

2. In the pickup setting, the pickup level of a definite time current supervision element for the circuit switcher EM-CB-2 was set too low, which defeats the purpose of tripping the EM-CB and sending DTT in a short time-delay if and only if the circuit switcher fails to open. As a result, the EM-CB breaker was tripped and the DTT was sent (via OUT103) simultaneously as the circuit switcher EM-CB tripped via the 51-T2 function (via OUT102) since the current supervision had picked up prior to the fault. (via SV4T, see the SEL-351 relay fault records in Figure 6 and Table 1 - East Methuen L2 Stuck Breaker Operation 02/10/2011)

The trip logic for No.1 and No.2 transformer relays (SEL-351) were programmed as:

SV2 = 50P1 + 50G1
SV4 = 50P3
OUT101 = TRIP * (SVT2 + 51GT)
OUT102 = TRIP * (51AT + 51BT + 51CT + 51NT)
OUT103 = (OUT101 + OUT102) * SV4T

Where:50P1, 51G1 and 51GT -- Transformer primary protection.
51AT, 51BT, 51CT and 51NT -- Transformer backup protection
OUT101 -- Trip output for transformer primary protection
OUT102 -- Trip output for transformer backup protection
OUT103 -- Trip output to trip 115kV breaker EM-CB at EM and key DTT to remote terminal WH or WM

Table 1. EM L2 Stuck Breaker Operation 02/10/2011
#2 TR 50/51-T2, 50N/51N-T2, 51N-T2 SEL-351 SER REPORT

25	02/10/11	08:22:59.196	51N	Asserted
24	02/10/11	08:22:59.206	50P3	Asserted
23	02/10/11	08:22:59.206	SV4	Asserted
22	02/10/11	08:22:59.208	51B	Asserted
21	02/10/11	08:22:59.212	51C	Asserted
20	02/10/11	08:22:59.668	51A	Asserted
19	02/10/11	08:22:59.878	51N	Deasserted
18	02/10/11	08:22:59.988	51N	Asserted
17	02/10/11	08:22:59.998	51N	Deasserted
16	02/10/11	08:23:00.276	OUT102	Asserted
15	02/10/11	08:23:00.276	OUT103	Asserted
14	02/10/11	08:23:00.276	TRIP	Asserted
13	02/10/11	08:23:00.286	SV15	Asserted
12	02/10/11	08:23:00.376	51B	Deasserted
11	02/10/11	08:23:00.376	51A	Deasserted
10	02/10/11	08:23:00.386	50P3	Deasserted
9	02/10/11	08:23:00.386	51C	Deasserted
8	02/10/11	08:23:00.386	SV4	Deasserted
7	02/10/11	08:23:00.386	IN101	Deasserted
6	02/10/11	08:23:00.396	OUT102	Deasserted
5	02/10/11	08:23:00.396	OUT103	Deasserted
4	02/10/11	08:23:00.396	SV15	Deasserted
3	02/10/11	08:23:01.535	TRIP	Deasserted
2	02/10/11	08:23:05.872	SV1	Asserted
1	02/10/11	08:23:05.889	SV1	Deasserted

Conclusions and Follow-up Action

It was concluded that the root cause of the unexpected operations of the direct transfer trip (DTT) for the 13 kV feeder faults was due to improper logic and protection settings of the No.1 and No.2 transformer 115kV phase overcurrent and 13kV neutral ground functions (SEL-351 relays).

The trip logic for the No.1 and No.2 transformer relays (SEL-351) were re-programmed to initiate the DTT by primary protection only, which are listed as follows:

SV2 = 50P1 + 50G1
SV4 = OUT101
OUT101 = TRIP * (SVT2 + 51GT)
OUT102 = TRIP * (51AT + 51BT + 51CT + 51NT)
OUT103 = SV4T * (50P3 + 50G3)

Where: 50P1, 51G1 and 51GT -- Transformer primary protection.
51AT, 51BT, 51CT and 51NT -- Transformer backup protection
OUT101 -- Trip output for transformer primary protection
OUT102 -- Trip output for transformer backup protection
OUT103 -- Trip output to trip 115kV breaker EM-CB at EM and key DTT to remote terminal WH or WM

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Song Ji is a lead senior engineer in the Department of Protection Policy and Support of National Grid, where he analyzes system disturbances on transmission and supply networks, develops & reviews protection related standards. Song has more than 16 years experience in the power system studies, substation & power plant design, protection and control for utility and industrial systems ranging from 4.16 kV to 500 kV. Prior to joining National Grid, Song spent 4 years with Worley-Parsons Canada as a power system specialist and 9 years with Henan Electric Power of China State Grid as a power system engineer. He received BSEE in power system from Zhengzhou University in China and a MSEE in power system from Royal Institute of Technology in Sweden. He is a member of IEEE and a registered professional engineer in Alberta Canada.