Relay Functional Type Testing

I3 Working Group Report
Functional Protection Scheme Testing Report

Members: Bob Beresh, T. W. Cease, Tony Giuliante, Bryan Gwyn (Vice Chair), Juergen Holbach, Jerry Jodice (Chair), Amir Makki (Coordinator), Jeff Pond, Rick Turner, Steve Turner.

1. Scope of Work

The scope of work for the working group is to collect, and collate into a report, a series of functional tests that could show a particular problem related to system events. The members of the working group have identified and documented a number of functional test cases. These cases are listed in this report in separate informative annexes.

2. Introduction

The purpose of this report is to:

- Provide relay users with a sampling of test cases that have been performed in unique circumstances, and

- Serve as a reference for the development of test plans for evaluating system problems that other test procedures may not properly diagnose.

This material is applicable to a wide variety of system problems and it is not an instructional guide for specific testing.

Guidelines for generating functional tests are included for information about how these tests were performed and for information on future development of functional tests.

3. Identified Functional Test Case Studies

- ***Annex-1:*** Differential relay operation during transformer energization.

- ***Annex-2:*** Benefits of measuring input and output values while testing electromechanical relays and control circuits.

- ***Annex-3:*** Functional test to ensure that a Directional Comparison Blocking Scheme on a parallel line will not over trip for a current reversal due to sequential tripping.

- ***Annex-4:*** Differential relay in-service checks.
- ***Annex-5:*** Stable and unstable power swings during 2003 blackout.
- ***Annex-6:*** 3 Phase Fault with Overreaching Due to Apparent Impedance Effects from CCVT

4. Guidelines for Generating Functional Tests

The following are required to generate functional tests:

- Detailed test plan
- Simple power system equations
- Actual recorded and/or simulated COMTRADE records

Each detailed test plan should provide a complete explanation of the functional test as well as complete instructions how to perform the test using a step by step process. Each detailed test plan must also provide an explanation as to why the test is useful to perform such as preventing a common type of mis-operation from re-occurring; for example, transformer differential protection tripping during energization due to inrush current. Finally each detailed test plan must provide instructions how to determine test voltage and current signals based upon the relay settings for a particular application.

Use simple power system equations when possible to calculate test signals for the functional relay tests. Simple power system equations properly account for specific power system parameters such as impedance to calculate the test signals. The output from the power system equations should be voltage and current phasors to inject into the relay during each test step. The power system equations should only require the relay settings to calculate the test signals.

Some functional tests may require a COMTRADE record to inject test signals into the relay. If a COMTRADE record is provided the waveforms should be able to test the particular protection function for a wide variety of applications.

5. Generic Template for Writing a Functional Test Report

- ***Section-1:*** Title for the test case (for example: differential relay in-service checks).
- ***Section-2:*** Category (for example: transformer differential protection).
- ***Section-3:*** Details of the test case (for example: background, relevance, etc.).

- ***Section-4:*** Test Requirements (test equipment, wiring diagrams if possible, etc.).
- ***Section-5:*** Details of the testing procedure (Formulated values, transient files, sequence of applied signals, trip monitoring, logical conditions, etc.).
- ***Section-6:*** Test Results and Conclusion.

6. Conclusions

In response to the letter from the Northeast Power Coordinating Councilÿs Task Force on System Protection, which is included in this report as Attachment A, this Working Group identified six cases that can be used as functional tests that could show a particular problem related to system events. These cases have been taken from actual events or from practical laboratory testing of protection relays.

These functional tests can be reproduced and some have COMTRADE files that can be used to inject current and voltage to replay the recorded events.

It is recommended that these cases be reviewed at some point in the future and new cases added.

Informative Annex - 1

Title for the Test Case: Differential Relay Operation during Transformer Energization

Category: Functional Testing of Transformer Differential Protection Schemes (during energization).

Details of the Test Case: An example is the case of transformer differential protection operating during energization due to low second harmonic current content. Figure-1 shows a case where there was little restraint current and high magnitude differential current in B Phase during transformer energization. The trip occurred when the ratio of B Phase 2nd harmonic to fundamental current dropped low.

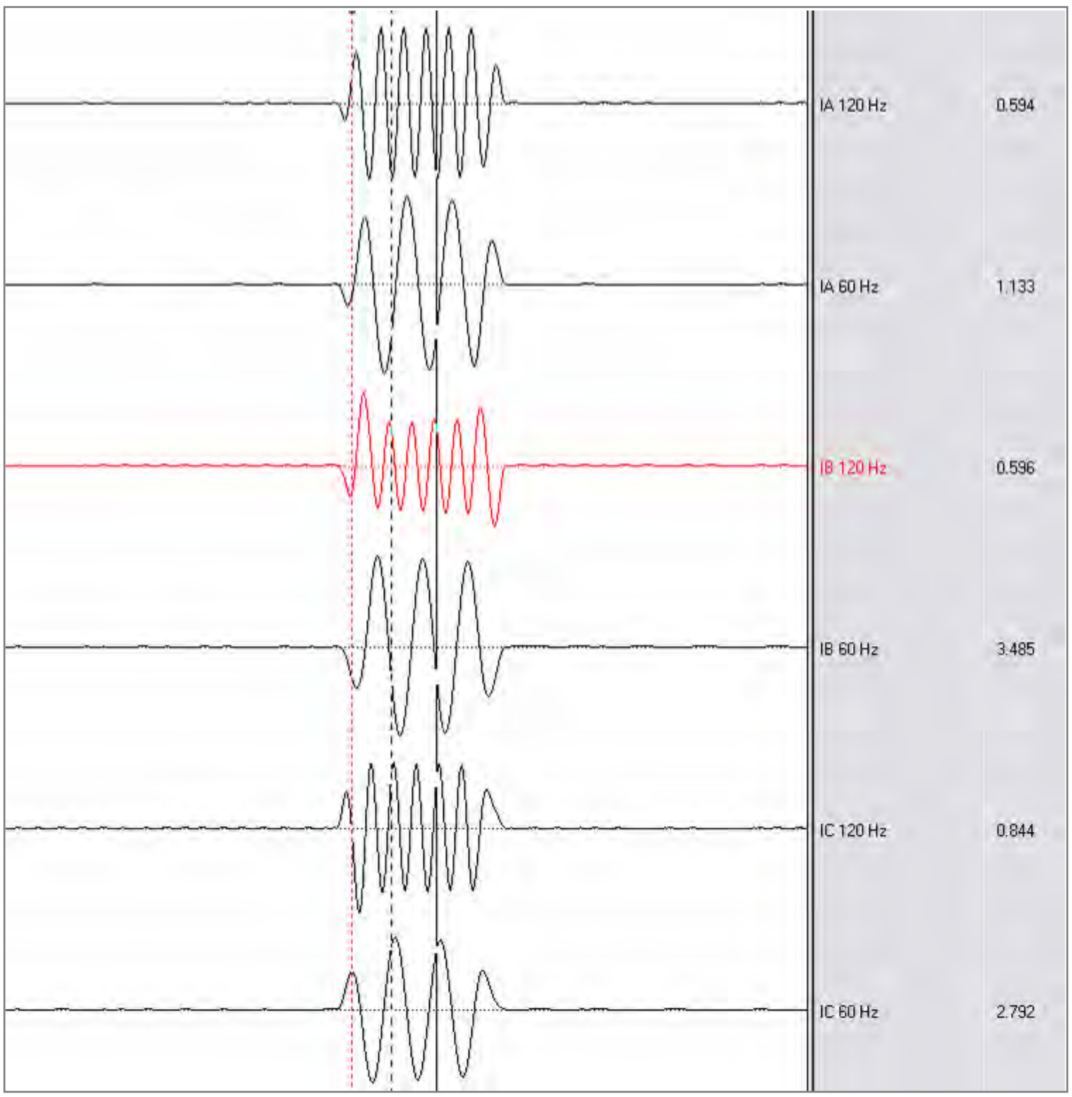

Figure-1; High Side CT Secondary Fundamental versus 2nd Harmonic Current

This event was recorded for a 400 MVA 230/115 kV auto-transformer that was energized from the high side while the low side was open. The CTs are wye connected on both sides. The 230 kV CTs are on the transformer bushings set full ratio 1200:5. The 115 kV CTs are on the 115 kV low side breaker set full ratio 3000:5. The tertiary winding feeds a small amount of station service load relative to the transformer size but does not have CTs connected to the bank differential. The auto-transformer is connected to a 230 kV straight bus through a motorized disconnect switch.

The relevant current phasors measured by the relay at the time of the trip along with the 2nd and 4th harmonic contents appear in Figure -2 below.

230 kV Secondary Currents

Fundamental (60 Hz)

$I_{A60} \equiv 1.13 \cdot e^{j \cdot 0 \cdot deg}$ Amps $\quad I_{B60} \equiv 3.41 \cdot e^{j \cdot 235.4 \cdot deg}$ Amps $\quad I_{C60} \equiv 2.77 \cdot e^{j \cdot 94.1 \cdot deg}$ Amps

2nd Harmonic (120 Hz)

$I_{A120} \equiv 0.59 \cdot e^{j \cdot 289.7 \cdot deg}$ Amps $\quad I_{B120} \equiv 0.6 \cdot e^{j \cdot 142.5 \cdot deg}$ Amps $\quad I_{C120} \equiv 0.84 \cdot e^{j \cdot 6 \cdot deg}$ Amps

4th Harmonic (240 Hz)

$I_{A240} \equiv 0.04 \cdot e^{j \cdot 310.4 \cdot deg}$ Amps $\quad I_{B240} \equiv 0.09 \cdot e^{j \cdot 206.2 \cdot deg}$ Amps $\quad I_{C240} \equiv 0.17 \cdot e^{j \cdot 65.3 \cdot deg}$ Amps

Figure-2; Current Phasors Measured at the Relay with 2nd & 4th Harmonic Current

This is an excellent case study to use the COMTRADE record format since you can test transformer differential protection to ensure it does not operate during inrush for many applications; that is most auto banks with five amp rated CT secondary values on the high side.

Test Requirements: Three-phase test set that can playback COMTRADE records. Three current signals are required.

Details of the Testing Procedure: Connect the three-phase test set to the relay as follows:

$I_A^{Test} \rightarrow I_{AW1}$
$I_B^{Test} \rightarrow I_{BW1}$
$I_C^{Test} \rightarrow I_{CW1}$

Playback the case to the relay with harmonic restraint disabled. If the relay trips then playback the case again with harmonic restraint enabled.

Test Results and Conclusion: The relay should trip when harmonic restraint is disabled. The relay should not trip when harmonic restraint is enabled.

Informative Annex - 2

Title for the Test Case: Benefits of measuring input and output values while testing Electro Mechanical (EM) relays and control circuits

Category: Testing Electro Mechanical Relays and Control Circuits.

Details of the Test Case: The benefits of using relay records from numerical relays have always been recognized as an advantage in evaluating relay performance. These records have been used for a number of cases such as:

1. Certifying relay testing
2. Confirming relay operation and targets during normal fault clearing conditions
3. Post mortem analysis of questionable relay operations

The lack of such records for EM relays has been considered as a disadvantage in using non-numerical devices. Many utilities and industrials in North American still have a significant number of EM relays in service today. Hence, the need for a cost effective system of non-intrusive sensors and recording system has been recognized.

Test Requirements: Non-intrusive sensor and recorder, as defined in the following:

1. A small AC/DC sensor that provides a non-intrusive, clamp-on solution for monitoring relay targets and control circuits is needed. The sensor uses a Hall Effect chip to sense current flow in target and control circuits. The sensor has a curved mu metal strip for shielding against external magnetic fields and for amplifying internal fields created by the current being monitored. Figure-1 shows a number of these sensors connected to EM relay circuits being tested.

2. A compact recorder is connected to a laptop computer and it receives information from the sensors via a multi-connection fan out plug. This is shown in Figure-2.

Figure-1; Non-Intrusive, clamp-on, Hall Effect Sensors

Figure-2; Hall Effect Sensors and Recorder with Multi-Channel Fan Out Plug

Details of the Testing Procedure: The clamp-on sensors are connected to the input and output circuits to be monitored for the test. The same laptop computer that is controlling the test sets can also be used to control the sensors and recording system. This will synchronize the timing of the test set files with the timing of the recorded files to verify the test results.

Test Results and Conclusion: Test results for three cases are presented.

1. Troubleshoot the reason for wrong EM target information during a Phase A to Phase B fault. Only the Phase A relay target dropped. This is shown in Figure-3. Expanding the Phase A relay trip signal and comparing it to the Lockout relay trip (LOR) coil signal, shows that the trip window to draw EM targets was less than 8 ms (this is shown in Figure-4). The time difference between the Phase A and Phase B EM relay operating times were checked and shown to be greater than 8 ms. When the Phase B relay eventually operated, the lockout relay trip coil was opened and there was no trip current to drop the Phase B relay target.

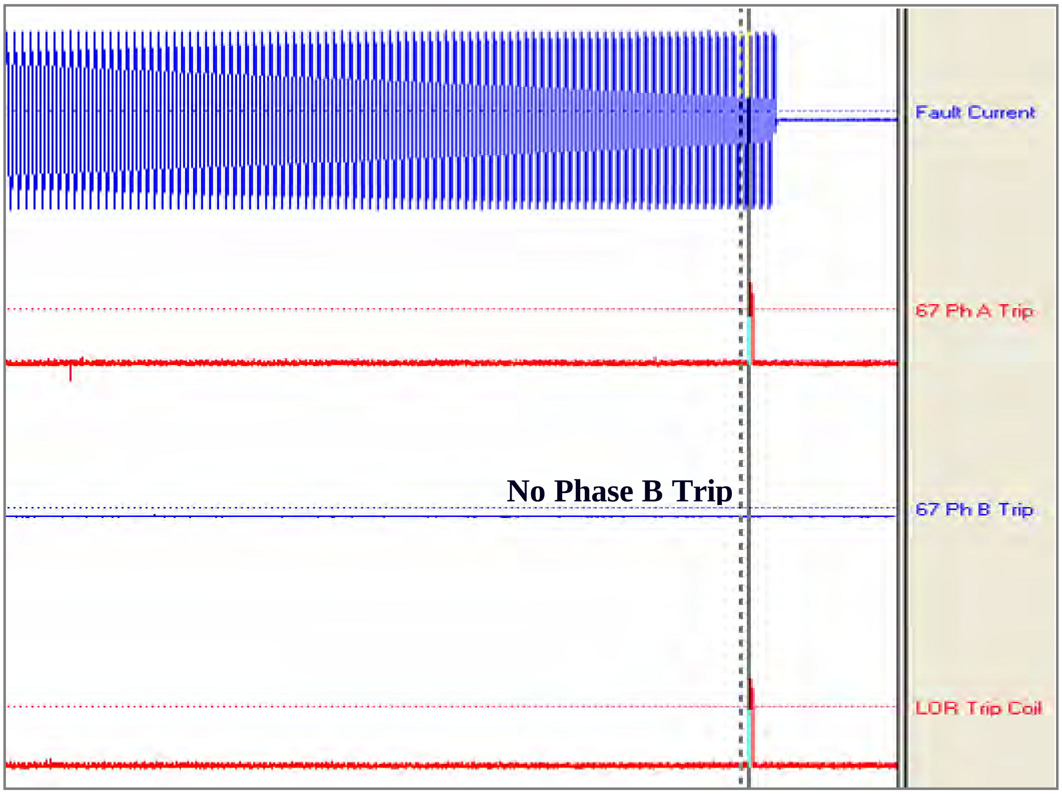

Figure-3; Phase AB Fault with No Phase B Relay Trip

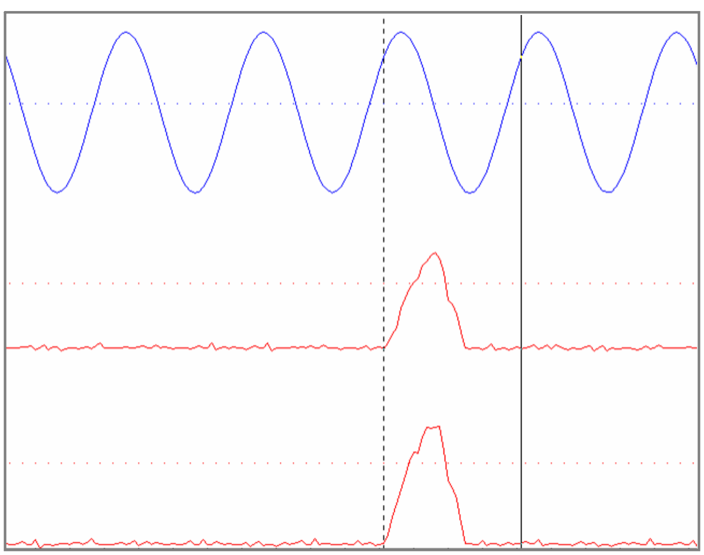

Figure-4; Phase A & LOR Coil Trip Window Less than 8 ms

2. Circuit breaker trip timing test on a 345 kV circuit breaker is shown in Figure-5. The lockout relay trip coil and circuit breaker trip coil waveforms were captured by the Hall Effect sensors. The trip sequence took 21 ms to completion.

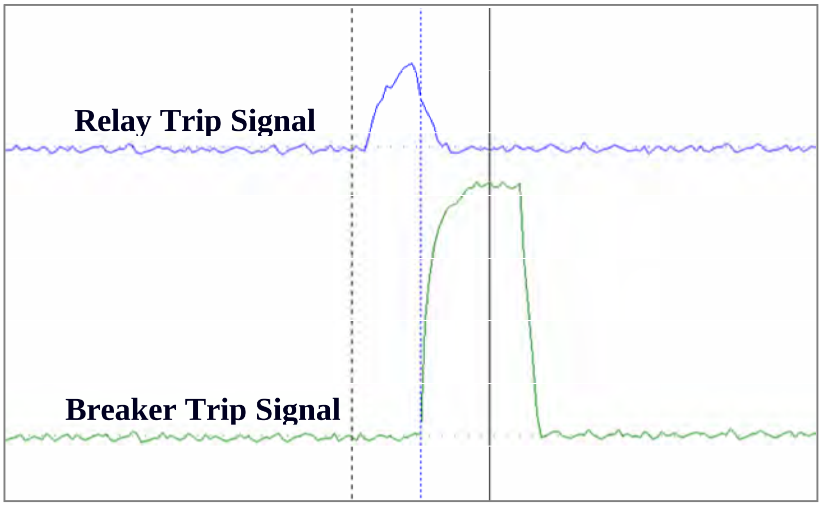

Figure-5; Trip Coil Waveforms of Relay and Circuit Breaker

3. Circuit breaker trip and close circuit tests are shown in Figure-6. Notice the discontinuity in the air compressor current after a few cycles. This was caused by an improperly installed air pressure switch. The switch was mounted such that the action of the shock absorber was crushed.

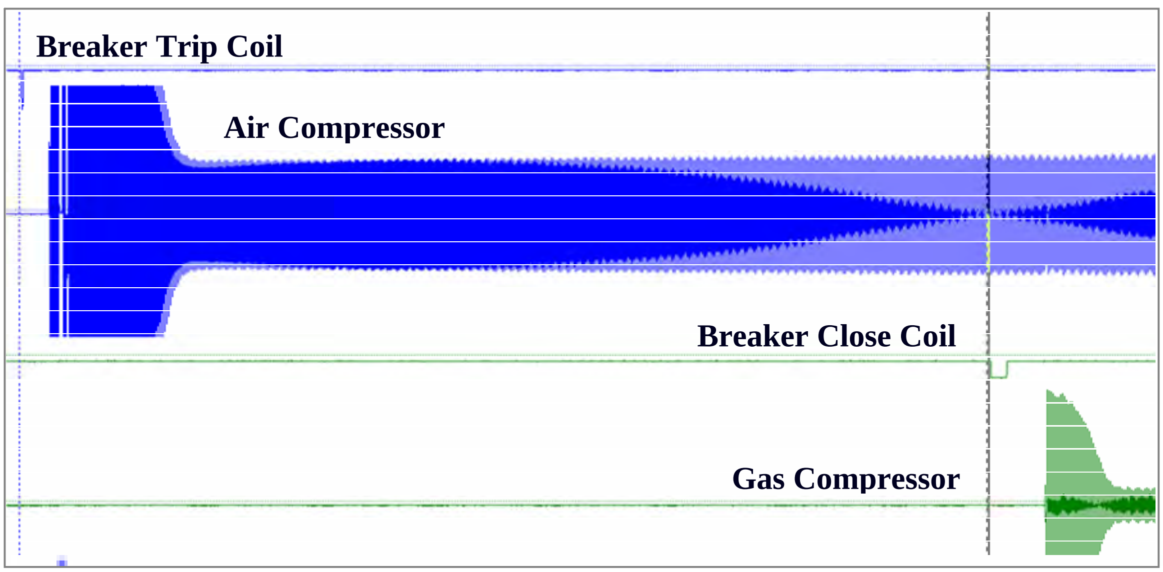

Figure-6; Circuit Breaker Trip and Close Circuit Tests

Informative Annex - 3

Title for the Test Case: Functional Test to ensure that a Directional Comparison Blocking (DCB) Scheme on a parallel line will not over trip for a current reversal due to sequential tripping

Category: Functional testing of a DCB Scheme for External and Internal Faults. Also, testing of scheme for current reversal condition on a parallel line when a sequential trip of the remote terminal occurs, causing current to reverse in the protection of the un-faulted line.

Details of the Test Case: A fault occurred on the 343 line resulting in an over trip of the 314 line which runs parallel to the 343 line. As determined from sequence-of-events and fault records captured the 343 and 314 operation is summarized as follows:

1. The 343 line at Sandy Pond tripped first for the 343 line fault (Figure 1).

2. Immediately after the 343 end at Sandy Pond tripped a current reversal occurred on the healthy parallel 314 line. At Sandy Pond, the 314 DCB scheme now detected the fault in the forward direction and stopped the carrier blocking signal (Figure 2).

3. As a result, the 314 carrier trip relay at Sandy Pond sensed high enough fault current (higher than the pickup value) in the trip direction, and did not receive the blocking signal from Millbury #3. As a result, the 314 line at Sandy Pond tripped on carrier trip relay instantaneously and sent a direct transfer tripping (DTT) to the 314 terminal at Millbury #3. The 314 line at Millbury #3 then tripped on DTT (Figure 3).

4. After which, the 343 line at Millbury #3 tripped, isolating the 343 fault.

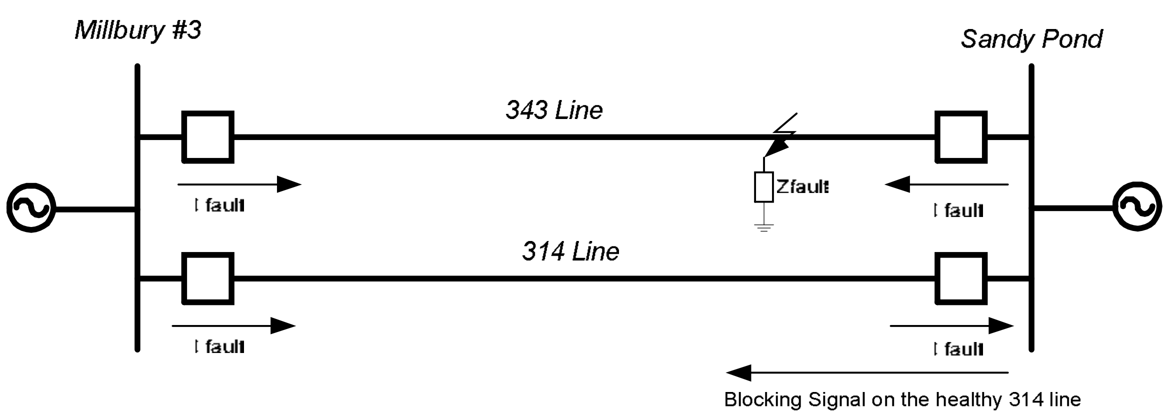

Figure 1 - 343 Fault Occurs

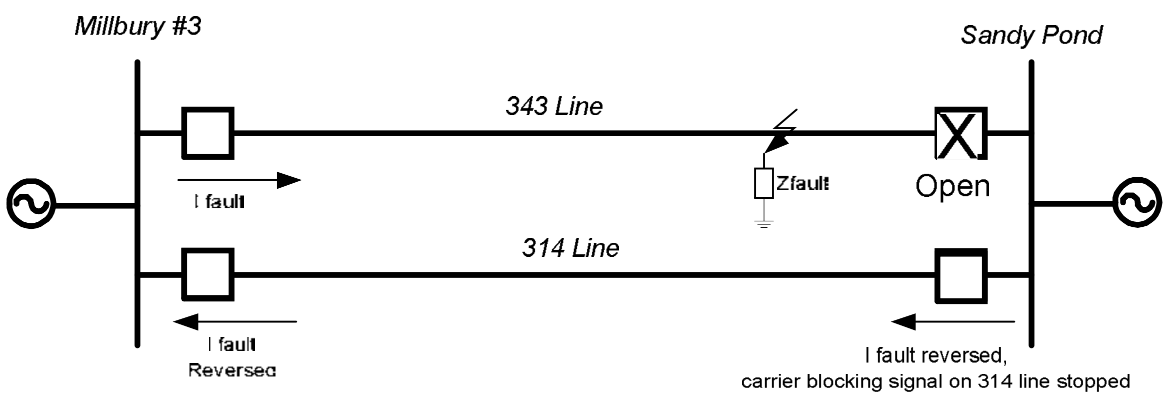

Figure 2 - Sandy Pond End of 343 Line Tripped

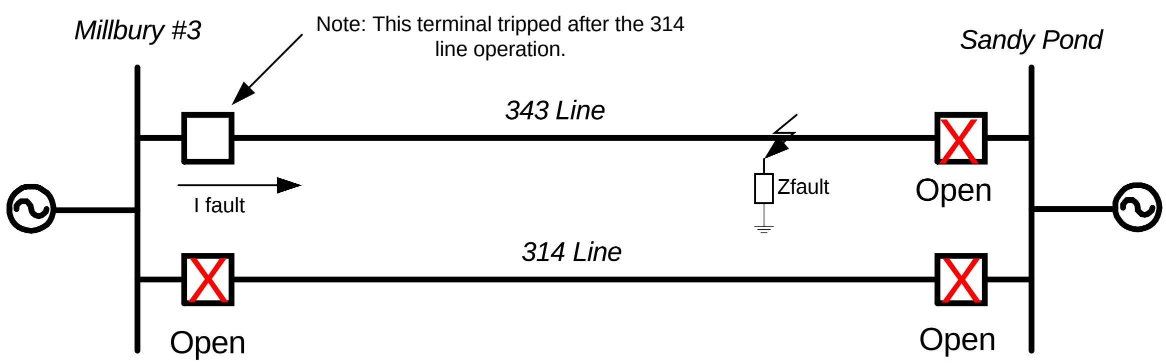

Figure 3 - 314 Line Tripped Due to Current Reversal and loss of block signal

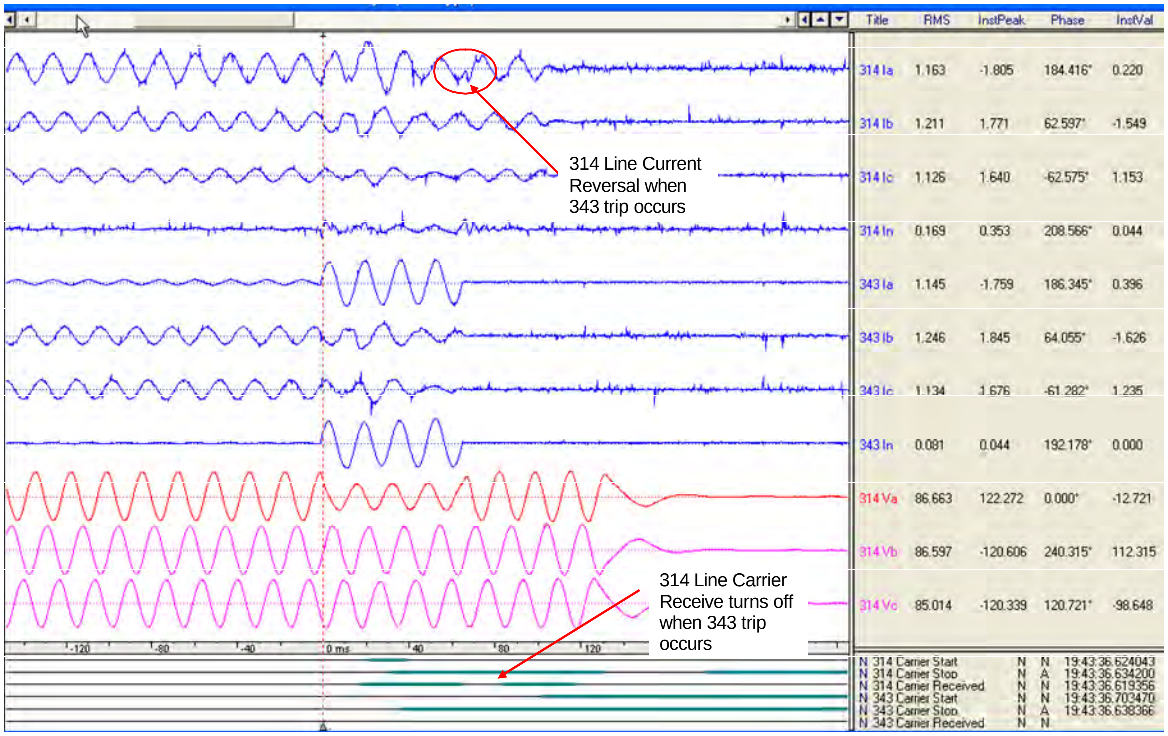

Figure 4 þ Millbury 3 Fault Record; showing current reversal and Carrier off

The conclusion was that the 314 misoperation was due to improper time coordination within the 314 line carrier blocking scheme. The particular timer setting for the 314 line was made per vendorÿs recommendation in 1989. The timer setting was increased to allow sufficient time to maintain the block for the current reversal condition.

Test Requirements:

The test plan:

1. Map (Sketch) scheme to be tested. Include CT and VT ratios, type of protection scheme.
2. Determine tests to be performed. In this case a simulated current reversal of the DCB scheme for a sequential breaker opening.
3. Determine desired results
4. Run a short circuit simulation for initial faults with all breakers closed. Record phasor quantities for all terminals of line.
5. Run a short circuit simulation simulating one breaker open on faulted line. Record phasor quantities for all terminals of the line.
6. Create spreadsheet of test parameters. Spreadsheet layout should be in format such that values can be imported or copied into the relay test software.

The test outlined above can be performed on a single relay or as and end-to-end test using a satellite synchronized relay test set.

Details of the Testing Procedure:

Step 1: Draw sketch of circuit to be tested and record CT and VT ratios.
Determine scheme to be tested.

Type of scheme to be tested: Directional Comparison Blocking Scheme.

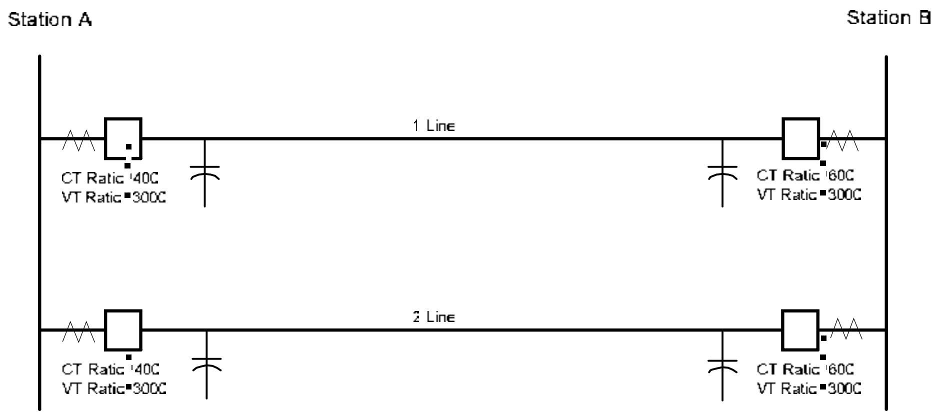

Figure 5 þ One Line Diagram of Circuit to be Tested

Step 2: Determine type of test

Type of Test: Current reversal on Un-faulted Line.

Step 3: Determine desired results

The protection scheme under test, which is the DCB scheme on the un-faulted line should maintain the block signal when current reverses due to sequential tripping of the circuit breaker on the faulted line.

Step 4: Run Short Circuit Simulation for initial fault with all CBs closed and record results in a spreadsheet or table (Table 1).

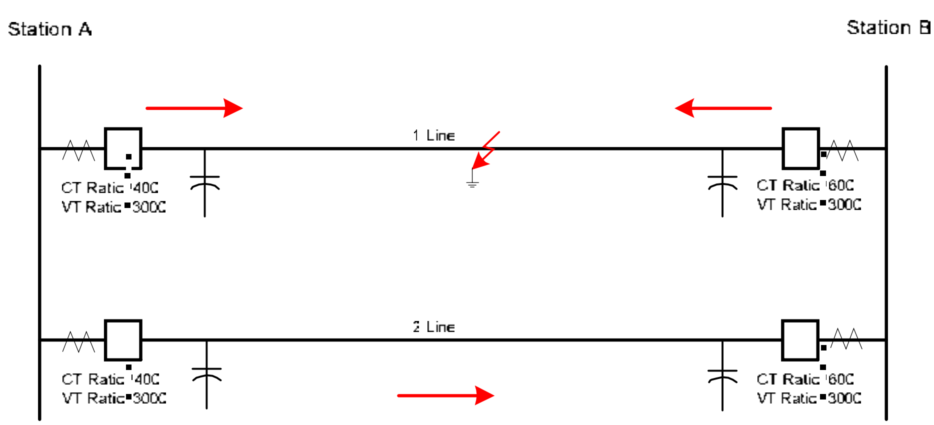

Figure 6 þ One Line Diagram þ Initial Fault

Table 1 þ Initial Fault

PH-G FAULT BOTH LINE 1 BOTH LINES IN SERVICE

	STATION A			STATION B	
	MAGNITUDE	ANGLE		MAGNITUDE	ANGLE
Va	65.91	-1	Va	53.2	-3.4
Vb	210.13	-126	Vb	213.85	-127
Vc	222.38	128.1	Vc	224.55	129.2
Ia	941	-71.2	Ia	941	108.8
Ib	164	91.7	Ib	165	-87.8
Ic	227	87.9	Ic	228	-92.6

Step 5: Run Short Circuit Simulation for fault with one CB open and record results in a spreadsheet or table (Table 2).

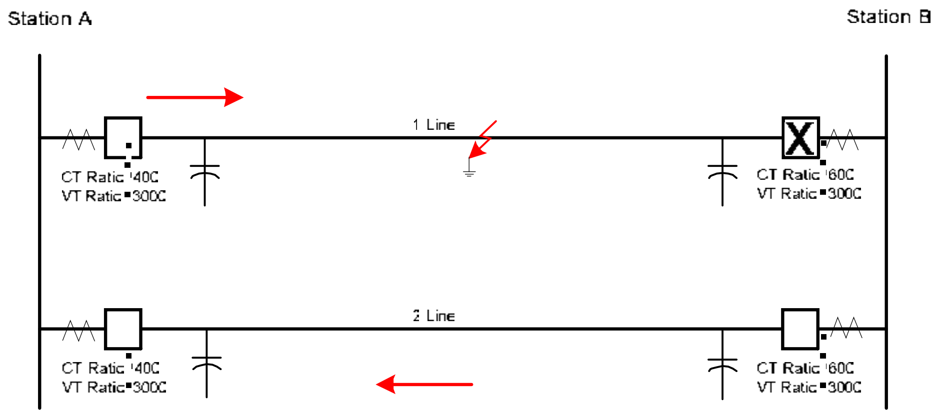

Figure 7 þ One Line Diagram þ Current Reversal on Un-faulted Line

Table 2 þ Trip at Station B on Faulted Line

PH-G FAULT BOTH FAULTED LINE CB OPEN AT STATION B

	STATION A			STATION B	
	MAGNITUDE	ANGLE		MAGNITUDE	ANGLE
Va	76.87	1.2	Va	112.04	1.4
Vb	209.73	-125.7	Vb	207.2	-124.2
Vc	221.47	127.9	Vc	216.44	126.7
Ia	4485	99.7	Ia	4485	-80.3
Ib	345	78	Ib	346	-101.7
Ic	458	77.6	Ic	460	-102.5

Step 6: Develop spreadsheet or table of test values for fault playback on un-faulted line. End-to-end test should include at least 60-cycles of prefault voltage and current when testing a microprocessor based relay to ensure the relay memory refreshed for proper functioning of the protection elements. When a test such as this is performed on the protection scheme it is recommended that post fault voltage and current values be used. Table 3 lists the test values for all tests to be performed.

When determining the test values care must be used when converting to secondary values. Use CT and PT ratios from one-line diagram. The secondary current magnitude must not exceed the output capabilities of the test set.

Once the test values have been created the engineer should determine if the values will achieve the desired result of the test. The relay settings should be reviewed to help make the determination.

Table 3 þ Test Values for Fault Playback

CURRET REVERSAL END TO END TESTS for UNFAULTED LINE

DURATION (CYCLES)								
PRE-FAULT				60				
FAULT 1				5				
FAULT 2				5				
RATIOS			CT =	400		CT =	600	
			VT=	3000		VT =	3000	
			STATION A			**STATION B**		
		PHASE	**MAGNITUDE**		**ANGLE**	**MAGNITUDE**		**ANGLE**
			PRIMARY	**SECONDARY**		**PRIMARY**	**SECONDARY**	
PRE-FAULT	CURRENT	A	100	0.3	0	100	0.2	180
		B	100	0.3	-120	100	0.2	60
		C	100	0.3	120	100	0.2	-60
	VOLTAGE	A	199,186	66.4	0	199,186	66.4	0
		B	199,186	66.4	-120	199,186	66.4	-120
		C	199,186	66.4	120	199,186	66.4	120
FAULT TYPE	**FAULT LINE 1 ALL CBs CLOSED**							
A PH - G	CURRENT	A	941	2.4	-71	941	1.6	109
		B	164	0.4	92	165	0.3	-88
		C	227	0.6	88	228	0.4	-92
	VOLTAGE	A	65,910	22.0	-1	53,200	17.7	-3
		B	210,130	70.0	-126	213,850	71.3	-127
		C	222,380	74.1	128	224,550	74.9	129
	FAULT LINE 1 CB OPEN AT STATION B							
A PH - G	CURRENT	A	4485	11.2	100	4485	7.5	-80
		B	345	0.9	78	346	0.6	-102
		C	458	1.1	78	460	0.8	-103
	VOLTAGE	A	76,870	25.6	1	112,040	37.3	1
		B	209,730	69.9	-126	207,200	69.1	-124
		C	221,470	73.8	128	216,440	72.1	127
POST FAULT	CURRENT	A	100	0.2	180	100	0.3	0
		B	100	0.2	60	100	0.3	-120
		C	100	0.2	-60	100	0.3	120
	VOLTAGE	A	199,186	66.4	0	199,186	66.4	0
		B	199,186	66.4	-120	199,186	66.4	-120
		C	199,186	66.4	120	199,186	66.4	120

Test Results and Conclusion: The test procedure detailed in this case study was not actually performed. However, the methods discussed have been used successfully in performing end-to-end tests of protection schemes to determine protection system performance. A short circuit simulation program will provide realistic values for fault conditions and will test the protective relay performance system conditions during a fault. The tests can be archived and used for other protection system tests, but it is recommended a short circuit simulation be performed to update the secondary test values.

Informative Annex - 4

Title for the Test Case: Differential Relay In-Service Checks

Category: Functional Testing of Differential Protection Schemes (In Service).

Details of the Test Case: The final step in commissioning a differential relay system within a substation is to perform in-service checks. This step is often neglected, but is a good double check that can find errors that were missed during the wiring checks. The types of errors that can be found include incorrect CT taps and reversed CT leads. Often, these types of errors will not result in an immediate trip because the load is minimal upon energization.

As an example, the oscillographic record below shows the high-side currents of an autotransformer for an external phase-to-phase fault. The differential relay was not expected to trip for the external fault, but did because one of the CTs was not set on the proper tap. The transformer had been in-service for more than a year.

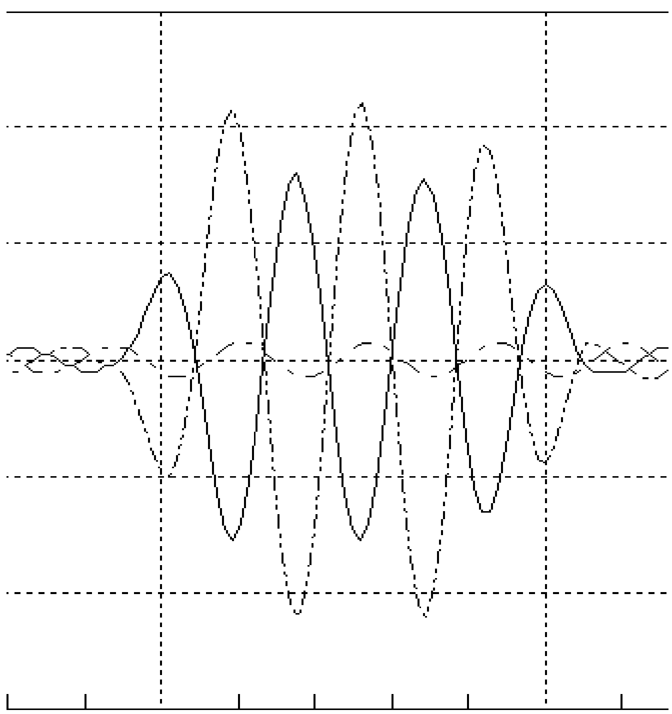

Figure-1; High-Side Currents for an External Phase-to-Phase Fault

Test Requirements and Procedures: In-service checks for differential relays will vary depending on the type of relay. Modern microprocessor relays are the easiest since they generally have a meter type command that provides the needed information to the user. For transformer differential and low-impedance bus differential relays, the quantities of interest are operate and restraint currents. Once the currents are obtained, the mismatch can be calculated by dividing the operate magnitude by the restraint magnitude. If the mismatch is greater than 0.1, the cause should be investigated. For a microprocessor based high-impedance bus differential relay, the quantity of interest is the voltage that exists across the high-impedance. In this case, if the reported voltage isnÿt very low, the cause should be investigated.

For electromechanical transformer differential relays, the currents entering the relay need to be measured for magnitude and phase angle. For two-winding transformer differentials with ideal CT ratios, the two measured currents should be 180 degrees out-of-phase and the per-unit magnitudes should be equal. The per-unit magnitude is determined by dividing the measured magnitude by its relay tap value. Since ideal CT ratios are often unavailable, subtract one per-unit value from the other and then divide by the smaller of the two per-unit values to determine the mismatch. The mismatch should be less than 0.05. For differential relays with greater than two inputs, the procedure is similar. However, the mismatch will need to be determined for each pair of inputs. If the mismatch is greater than expected, the cause should be investigated.

In-service checks for electromechanical bus differential relays will vary depending on the type of relay and the system design. Low-impedance bus differential relays can be checked in a manner similar to the electromechanical transformer differential relay. Rather than calculate a mismatch, the vector sum of the currents entering the relay will need to be calculated. If the vector sum isnÿt close to zero, the cause should be investigated.

Electromechanical high-impedance bus differential relays require a different approach to in-service checks. If the system design is such that the CTs have individual test switches, the currents can be measured and summed as with the low-impedance differential relays. If individual test switches are not available, a voltmeter can be used to measure the voltage developed across the input of the relay. Note that the input impedance of the voltmeter needs to be sufficiently larger than the impedance of the relay so that it doesnÿt adversely impact the measurement. A 20 Mohm input digital meter is usually sufficient. The voltmeter also needs to be capable of measuring the clamping voltage of the relay. The relay instruction manual should be consulted to determine the clamping voltage. Be aware that, if a problem does exist, the voltage at the relay terminals can be near, or at, the clamping voltage. Therefore, proper safety procedures should be followed when making this measurement. If the measured voltage isnÿt very low, the cause should be investigated.

In all cases, it is also advisable to compare the measured current magnitude values to another source, such as a panel meter or relay that is sourced by a different CT. Any discrepancy should be investigated.

Test Results and Conclusion: In-service checks are a good double check that can find errors that were missed during wiring checks.

Informative Annex - 5

Title for the Test Case: Stable and unstable power swings during 2003 blackout

Category: Functional Testing of power swing blocking/tripping function in distance relays

Details of the Test Case: On August 14th, 2003, stable and unstable power swings occurred on two 345 kV transmission lines and caused undesired operations of the distance protection function during the stable swings on both lines. If the power swing is stable, it is normally desired to block the distance function from operation. On the other hand, if the power swing becomes unstable, proper fast remedial actions have to be taken to restore system stability. Power swing detection relays at carefully selected locations determined by system studies would be preferred to separate the systems in order to prevent further line distance relay operations and further deteriorate system stability.

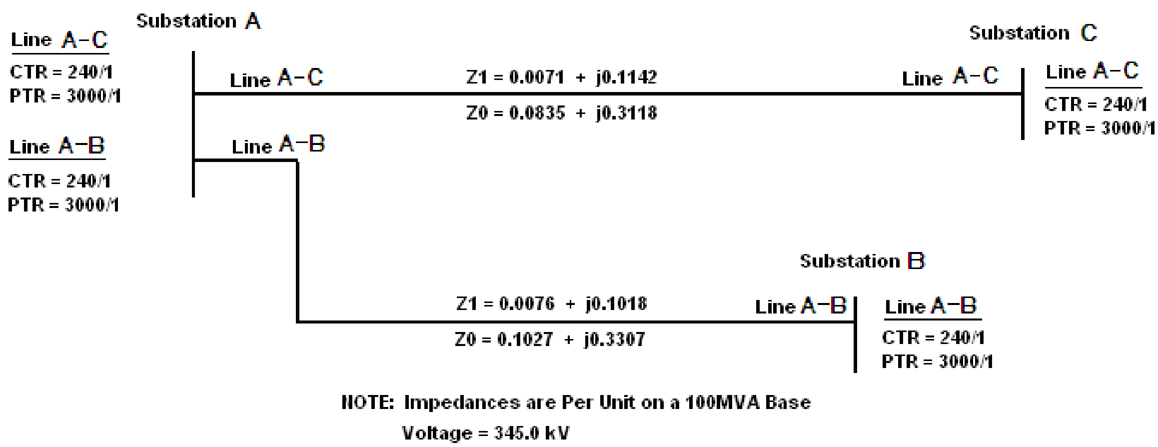

Figure-1; Topology and Parameters of the Transmission System

The COMTRADE files used are as follows:

Terminal A of the A-B Line: ýc1.cfg and c1.datü
Terminal B of the A-B Line: ýc2.cfg and c2.datü
Terminal A of the A-C Line: ýc3.cfg and c3.datü
Terminal C of the A-C Line: ýc4.cfg and c4.datü

The COMTRADE files are plotted in Figure 2 and Figure 3. Figure 2 shows the waveforms of voltages and currents measured at each terminal. In the figures, the magnitudes of the voltage and current oscillations during the power swings can be clearly seen. Moreover, by observation of the frequency of the oscillations, one can roughly determine where the power swing is stable and where it goes unstable (OOS). The power swing begin stable, and gradually evolve into an unstable swing.

A power swing can be more precisely described by its impedance trajectories. Figure 3 shows the impedance trajectories measured by the distance relay at each terminal. For clarity and illustration purposes, only the stable part of the power swing and the first cycle of the unstable part of the power swing are plotted in the R/X plane. Each impedance trajectory starts moving from the load zone at the beginning of the power swing. It approaches and occasionally enters the protection zones as can be seen in the plots. During the stable part of the power swing, the impedance moves but stays on its side. It never travels across the X axis on the R/X plane. Using this criterion, it can easily be seen in the plots at what point the power swing becomes unstable.

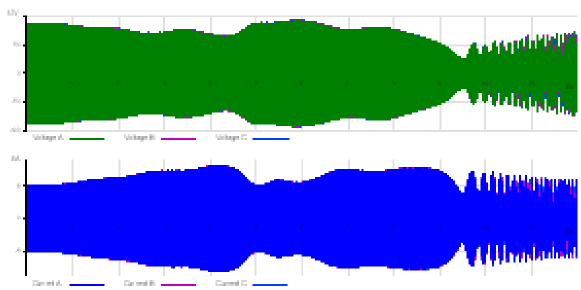

Figure-2a; Terminal A of A-B Line (Waveforms)

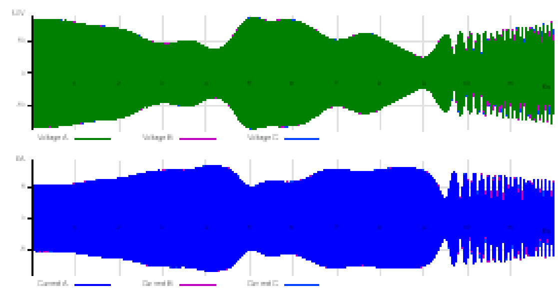

Figure-2b; Terminal B of A-B Line

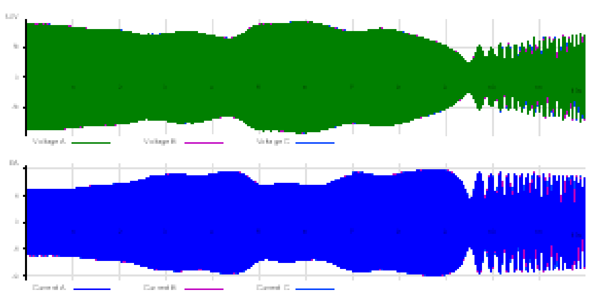

Figure-2c; Terminal A of A-C Line

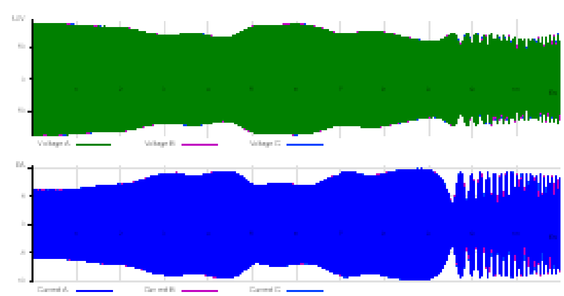

Figure-2d; Terminal C of A-C Line

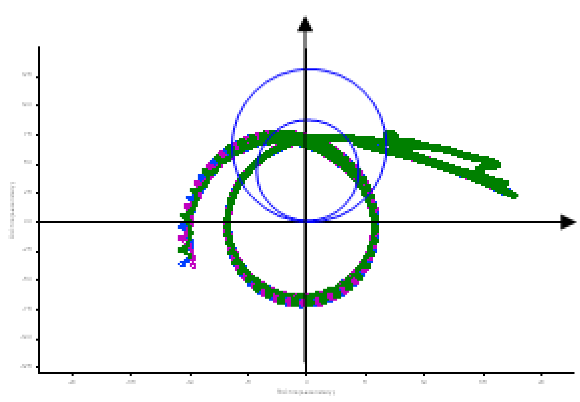

Figure-3a; Terminal A of A-B Line (Impedances)

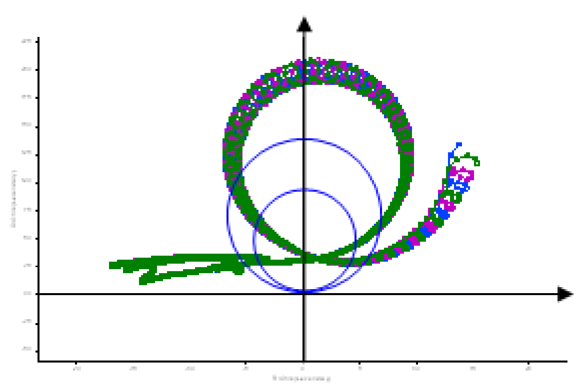

Figure-3b; Terminal B of A-B Line

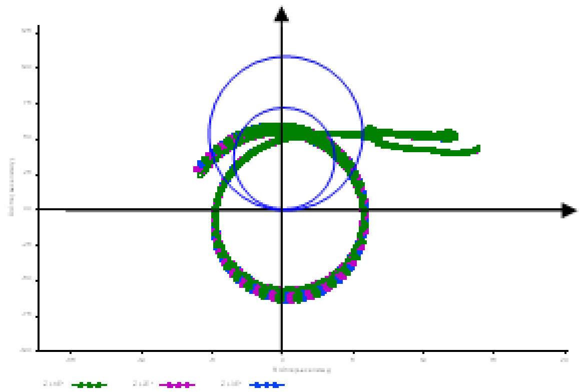

Figure-3c; Terminal A of A-C Line

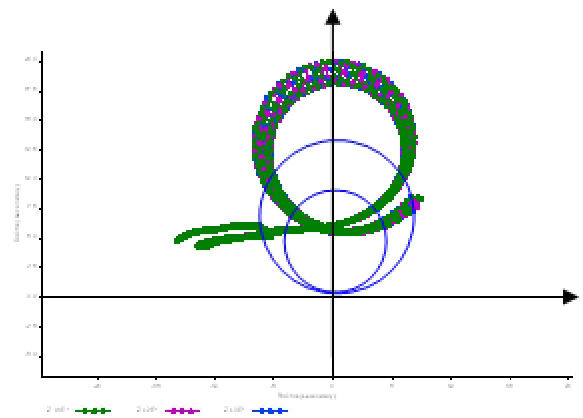

Figure-3d; Terminal C of A-C Line

The test cases can be used for two purposes:

1. **Verify that the power swing blocking function will block the distance relay if the stable swing impedance enters the distance characteristic as seen in case A and B.** In Case A the stable swing impedance (secondary) reached up to the impedance Z_{stable_min}= 5 + j7.5 Ohm before it increased again. Therefore the test case is only useful for long transmission lines where the reach of the zone under test will include this point.

2. **Verify that the relay is able to issue an out of step trip after the swing becomes unstable.** The out of step tripping is desired on certain locations in the network. If the relay under test has a out of step tripping function it can be tested whether the relay issues a trip in the correct moment. As long as the swing is stable (not crossing the Y-axis) the out of step function should not issue a trip. After the y-axis is crossed the out of step function may issue a trip on certain additional criterion and time delays!

Test Requirements: Three-phase test set that can playback COMTRADE records. Three current signals and three voltage signals are required.

Details of the Testing Procedure: Connect the three-phase test set to the relay:

1. **Test of Power swing blocking function**
   Playback the case to the relay with power swing blocking function disabled. If the distance function trips then playback the case again with power swing blocking function enabled. The relay is not supposed to trip again. The power swing impedance must stay long enough inside the distance protection zone under test to trip the relay if the power swing blocking function is disabled!

2. **Test of Out of Step tripping function.**
   Playback the case to the relay with power swing blocking function enabled and the out of step tripping function disabled. No trip should be observed during the

playback. Now enable the out of trip function and replay the case. A trip should become issued only after the swing became unstable (impedance trajectory crosses Y-axis). The precise moment depend on the additional criteria used in different implementations.

Test Results and Conclusion: During stable power swing the distance functions should be blocked by a power swing blocking function and no trip should occur if the impedance trajectory enters the distance characteristic and resides there for a while. If the swing becomes unstable (out-of-step) an out-of-step tripping function can if desired and programmed issue a trip command.

Informative Annex - 6

Title for the Case Study: 3 Phase Fault with Overreaching Due to Apparent Impedance Effects from CCVT

Category: Case Study of Apparent Impedance Effects from CCVT

Details of the Case Study: A three terminal 500 kV breaker and bus (KL572 and K Bus in the Figure below) in the central Ontario region was removed from service for maintenance purposes. The K bus was re-energized while grounds were still applied to the breaker and as a result of this switching error a three-phase fault occurred. The duration of the fault was 156 ms and the implications were that two 500 kV lines were tripped unexpectedly; 50 MW lost generation initially; 750 MW subsequent lost of generation and 2300 MW loss of load.

An overview of the station is illustrated in Figure 1. Prior to the event, the K bus was out of service to provide safety clearances for crews working in the station. Crews were performing tests on the KL572 breaker which was undergoing a major planned overhaul. Upon completion of the test, the K bus was to return to service while KL572 breaker was to remain out of service for further planned work.

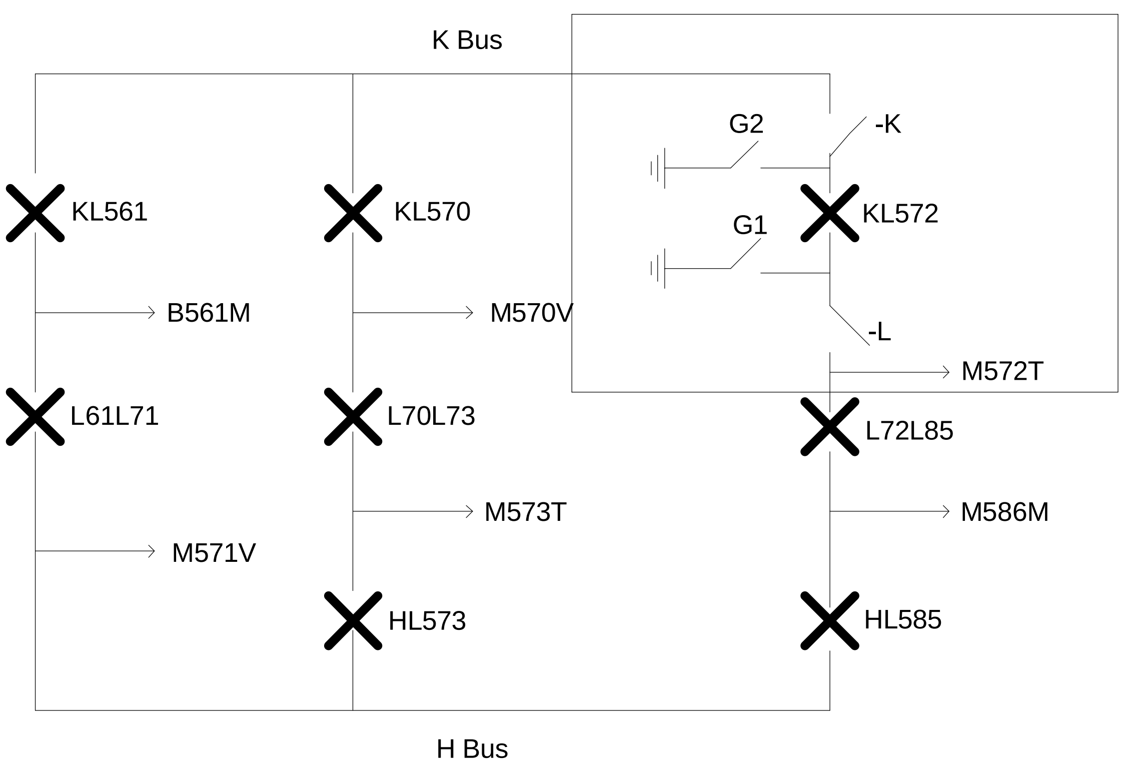

Figure-1; Illustration of System Diagram

Without confirming the position of the KL572 breaker and its disconnect KL572-K, the operator proceeded to close the KL561 breaker energizing the K bus and the KL572 breaker up to the KL572-L disconnect. A three phase to ground fault was produced through the KL572-G1 ground switch that is located between the KL572 breaker and the KL572-L disconnect. The M572T terminal correctly tripped from its own line protection in 55 ms. However, the fault was still being fed through the KL561 breaker[1]. The KL572 breaker failure protection ultimately tripped the KL561 and interrupted the fault in 156 ms (breaker KL572 was in TEST mode and unable to trip). Protection operations led to the tripping of circuits M572T, M573T and M570V. As well, there was an emergency shutdown of a small 50 MW co-generator.

M572T A & B 21Z1 protections operated at the remote terminal end. The protections appeared to have reacted to an unexpected "apparent" impedance but did not interfere with the correct operation of the circuit. No re-closing occurred. M573T ýBü protection at the remote terminal appeared to have reacted to an unexpected "apparent" impedance and detected the fault, tripping L70L73 and HL573 breakers as well as the remote terminal breakers. No re-closing occurred. M570V ýAü protection at its respective remote terminal also appeared to have reacted to an unexpected "apparent" impedance and detected the fault, tripping L70L73, as well as the remote terminal breakers. (Note: the KL570 breaker was out of service prior to the event.)

Results of the Case Study: It was determined through latter analysis that several relays operated incorrectly due to an apparent impedance issue. This was determined to be a result of CCVT transients. Corrective measures were taken. In one instance a firmware upgrade was necessary, and in a second instance an increase in a delay timer was necessary to resolve this issue of possible overreach due to apparent impedance issues that may arise under similar conditions. Also as a result of this event, further studies were conducted on CVCT models to better understand the transient behavior and develop more accurate CCVT models.

[1] The KL572 breaker was left in the test position and the 62a timer path disabled due to the pallet switch assembly being removed for breaker maintenance with the advanced breaker position auxiliary contact (aa) in the open position.

Attachment - A

January 4, 2006

Mr. Phillip Winston
Chair, IEEE Power System Relay Committee
Dear Mr. Winston:

A recent event within the NPCC Region has prompted the members to inquire about the requirements for type testing of the relays used to protect our transmission system. The event resulted in over-tripping several remote line terminals as a result of relay performance under the severe system conditions experienced during the fault. Not all remote trips resulted from
the same shortcomings of the remote relays.

During the investigation of the event, the owner determined that there exists a body of knowledge that could have been used as a resource to prevent some of the over-trips from ever having occurred. They also determined that one of the relays had a flaw known to the manufacturer, but for which no service bulletin had been issued. This caused to owner to ask if the industry had any standards that addressed type testing of the performance requirements of relays in their intended applications.

Our Regional Reliability Organization has asked for an internal response regarding how we should deal with this issue. In discussing it at our regional Task Force on System Protection, the general feeling of the group was that rather than developing regional type test requirements, IEEE standards/guides would be the appropriate vehicle for addressing the problem. Existing standards (C37.90.1, C39.90.2, C37.90.3, etc.) deal with "environmental" issues rather than functional testing, leaving the functional tests to the manufacturers and the users. C37.113 deals with application issues that the user community may need to consider, but stops short of identifying type test requirements to determine the relative sensitivity of relays to the conditions that may challenge a relays operating characteristics. The testing we have in mind would be tests that evaluate the ability of a relay to operate selectively and reliably for a variety of system events based on the type of application and extremes of system conditions that would realistically be encountered in implementation of these schemes.

Please consider initiating a PSRC task force to evaluate the feasibility of drafting a new standard to address these concerns. We look forward to hearing back from you regarding disposition of this request. Thank you.

Very truly yours,
James W. Ingleson
Chair, NPCC Task Force on System Protection