A Creative Line Differential Protection Scheme for the Hudson River Crossing Section of a 345kV Transmission Line

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Introduction: the RFK-305 Relay Upgrade Project

The line differential protection relay scheme protecting the Hudson River crossing portion of the 345kV RFK-305 transmission line was obsolete and parts replacement was becoming increasingly problematic. Additionally, along with standard CT's mounted in the cable crossing potheads, this particular design required the use of unique and expensive step-down and impedance matching current transformers used to supply the actual differential current signals monitored at both East (ETS) and West Transition Stations (WTS) to the relays which were located at the WTS only. One set of the monitored current signals must transverse the river from the ETS to the WTS, approximately 1.3 miles by use of small gauge copper wire installed with the main power conductors thus necessitating the need for impedance matching transformers to "boost" the strength of the current signals. These transformers were showing increased signs of degradation and replacements were not readily available and would require a custom build.

The upgraded line differential protection scheme proposed by ABB was a custom designed system for upgrading the line differential protection and communications system between both transition stations. Other relay manufacturers also submitted proposed designs, but all required the continued use of the specialized current transformers. The ABB design placed the IEDs at both transition stations thus eliminating the need for the specialized current transformers. The existing standard pothead CT's at both transition stations were to remain in the design to provide the main current sensing source for the ABB IEDs. The current signals would be transmitted between the relays by a communications path created out of the same wires that originally carried the actual line current signals. Prior to selecting ABB's design as the final to be implemented, several scheme type alternatives were also considered as follows:

- Installation of fiber optic cable under the river. This choice was found to be prohibitively expensive (approx. $3M) and also involved securing the rights to cross under two non-NYPA owned ROW's and personal property including private housing.
- Installation of microwave towers and transmitter / receivers at both stations. This choice was also prohibitively expensive (approx. $1M) and impractical as the only signals crossing

the river via the microwave channel would be eighteen (18) current signals, when the technology was capable of much more. Additional non-relaying type communication uses for this channel could not be identified.

- Replacement of the existing relays only. This option could not be implemented without retaining the problematic specialized current transformers. Two leading manufacturers, including ABB, were asked to review the design to determine if their relays could accommodate the existing current inputs without the special transformers and all indicated that their relays could not operate properly without the impedance matching transformers.
- Using leased fiber optic lines from the local telephone provider. The success of the differential protection scheme using a communications channel between the IEDs relies on the quality and consistency of the transmitted current signals which are time stamped for direct comparison by the IEDs. The time delay (latency) and signal quality could not be guaranteed by the local telco provider.

Ultimately, the protection equipment and communication system design proposed by ABB was considered the only viable alternative. Further, ABB was the only available supplier of this customized equipment and was the prime reason why its design was selected. Other advantages to this design over some others proposed included:

- Because of the ABB IED's current sensing configuration and custom logic, only three relays would be needed at each transition station with each relay being able to monitor (6) six conductors. Other designs would have required (6) six relays at each station, each monitoring only (3) three conductors. The ABB design satisfied the prime design criterion which was the ability to identify the fault location in a specific conductor of the (18) eighteen total conductors transiting the Hudson River.
- The existing lockout relay (LOR) design could be retained as the existing direct transfer trip (DTT) audiotone scheme was largely untouched by the design change.
- Since only (3) IEDs were required at each transition station, the ABB IEDs installed in the East Transition Station, an extremely small metal sided building, could fit into one, slightly shortened, standard relay panel. There was thus minimal impact to the floor layout of the East Transition Station.

Overview – Line Differential Protection

Line differential protection applies Kirchhoff's law and compares the currents entering and leaving the protected circuit. As the line-end IEDs are geographically separated, details of the measured currents must be exchanged between the IEDs to perform this comparison. This exchange is made utilizing IED to IED digital communications channel/s.

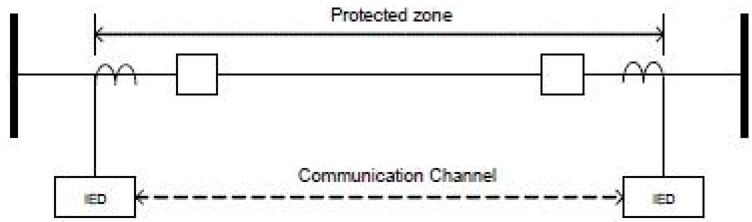


Figure 1: Example of two-terminal line differential application

In general, the principle of operation consists of the classical differential current vs restraint current evaluation, with operation for differential current above a characteristic formed by set minimum pickup plus single or dual slope. The differential current is the vector sum of all measured currents, separately for each phase. The restraint current can be calculated in a number of different ways, and is there to reflect how hard the CTs are working, i.e. the harder the CTs are working and the higher the error that may result, the higher the operate threshold needs to be, achieved by the sloped characteristic at higher calculated restraint current. The minimum pickup provides sensitivity at low currents, up to rated current or just above, where after the sloped characteristic provides added security as current levels increase.

A high set unrestrained differential current threshold can be used for fast tripping of internal faults with very high differential currents.

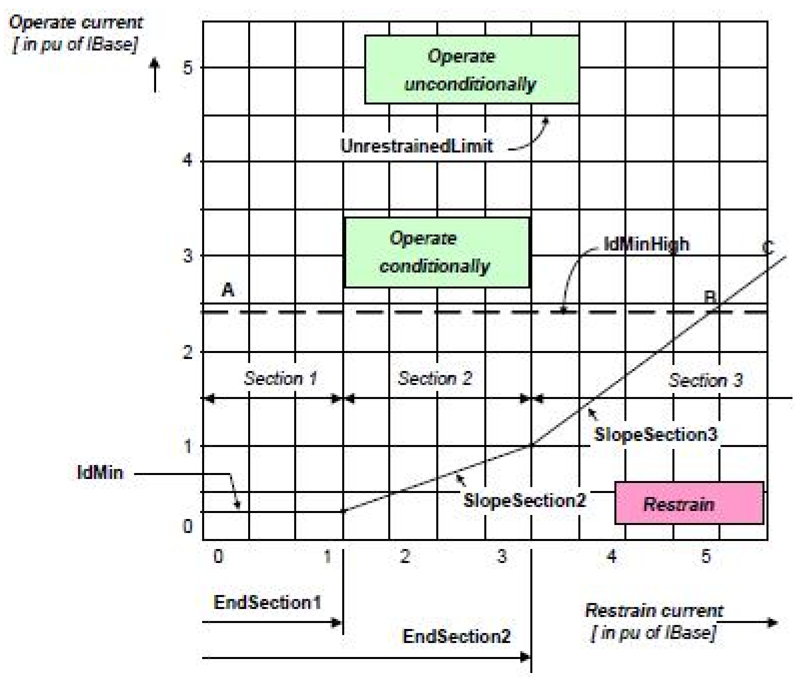


Figure 2: Example line differential operate characteristic showing minimum pickup, dual slope, and high set unrestrained threshold

Hudson River crossing application

The project was to replace the existing protection for fault location and faulted cable identification of six 3-phase HPOF cables for the 1.3 mile Hudson River underwater section of the 345kV RFK-305 transmission line.

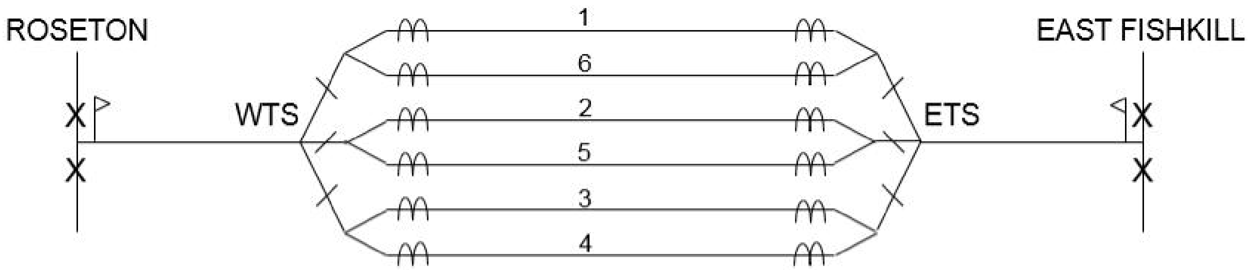


Figure 3: RFK-305 transmission line Roseton – East Fishkill showing under river section comprising six 3-phase HPOF cables

The existing protection consisted of 18 obsolete solid state differential relays all located at the West Transition Station (WTS) utilizing impedance matching transformers for the CT cable run to the East Transition Station (ETS). The challenge was to replace the existing 18 solid state cable protection relays with 6 microprocessor line differential IEDs without utilizing impedance matching CTs that are difficult to maintain, and without adding any additional communication interface for the protection, i.e. the IED to IED digital communication needed to use the existing copper CT cables as the communication interface.

The relaying solution opted for was to apply six line differential IEDs to provide the protection for the six cables. Therefore each pair of cables (1 and 6, 2 and 5, 3 and 4) formed a line differential zone, with one IED at the WTS end and one IED at the ETS end, in total three IEDs at WTS and three at ETS covering the three cable pairs.

Furthermore, it was decided that the actual 87L line differential protection was only required at WTS as the existing LORs to send a DTT (to Roseton to block autoreclosing for a fault in the under river cable portion of the line) were only at the WTS location.

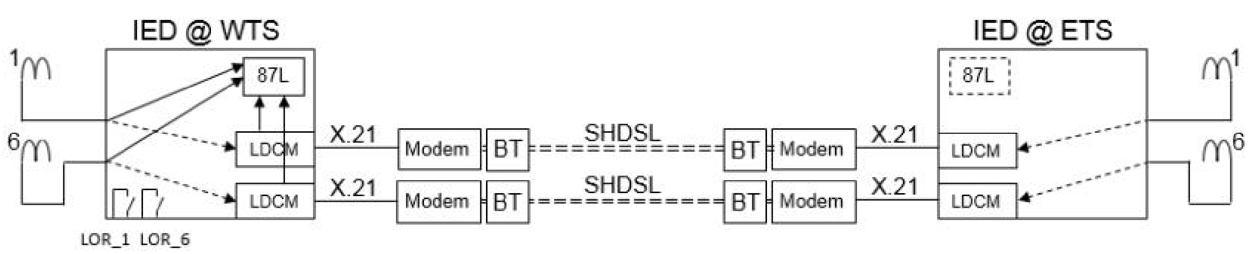


Figure 4: Actual application for one cable pair (1 and 6)

Figure 4 shows:

- 2x line differential IEDs for a cable pair, one located at WTS and one at ETS.
- 2x 3-phase currents connected to both the WTS and ETS IEDs.
- Line Data Communications Modules (LDCM), with X.21 output.
- DTM – SHDSL modem with X.21 plug-in module that permits interconnection of line differential IEDs using copper cables.
- BT – insulating barrier transformer.
- 87L protection measurement only in the WTS IED, as required by the application.

Communications interface

For each cable pair, two line differential IEDs, one at either end, communicated using the Line Data Communication Module (LDCM) in the IEDs. At each end, the design included one modem per cable to communicate with one LDCM in the line differential IED. To utilize the existing copper cables (the existing CT wires) as communication channels for the line differential protection; galvanic X.21/V.11 communication module was used in the IED and a modem with the corresponding interface was used to interconnect the IEDs with their modems at each end of the cable. To make use of the existing CT copper wires, modems with high capacity communication up to 32 channels per copper pair using SHDSL (Symmetrical High-speed Digital Subscriber Line) coding were used.

The communication modems (DTM) were setup in the following fashion. One modem was setup as a network termination (NT) unit and the other was setup as a line termination (LT) unit for each cable. By doing so it was possible to configure and monitor the LT unit through the corresponding NT unit sitting in the WTS. The LT unit generated the clock for synchronization between the IEDs.

During the initial site survey, the copper wires were inspected for purity and usability. For these tests, the pair of wires to measure the line attenuation and Signal to Noise Ratio (SNR) were looped between the two ends of the line. Since it was a loop back test, two pairs of wires were connected together at ETS and two modems at WTS were used to act as the end points. The handshaking signals between the two modems were used as the reference signals for the testing.

Line attenuation and SNR tests

As the line attenuation is dependent on the noise model used and the transmission rate across the channel, for testing purpose different transmission rates were used and the line attenuation measured across the loop. In addition to this, to measure the purity of the copper, the signal degradation across the line length was also measured. The modem software was used to visualize these measurements for all the tests.

Test No.	Transmission Rate (No. of Channels X Rate)	Line Attenuation (dB)	SNR Margin (dB)
1.	$3 \times 64 = 192\ kbps$	4	20
2.	$32 \times 64 = 2048\ kbps$	4	18

To give a general scale of reference for comparison of these values, in the copper cables, see the following for line attenuation.

Line Attenuation (dB)	Comments on performance
20 and below	Outstanding
20-30	Excellent
30-40	Very good
40-50	Good
50-60	Poor and may experience connectivity issues
60 and above	Bad

Similarly, see the following for SNR margin.

SNR Margin (dB)	Comments on performance
4 and below	Poor with no or intermittent synchronization issues
5-9	Fair but does not leave much room for variances in conditions
10-14	Good with no synchronization issues
15-19	Excellent
20 and above	Outstanding

From the test results and comparing with the reference shown above, it can be seen that the existing copper was good enough to utilize the maximum 32 channels in a single copper pair. Since the amount of data transmitted was minimal, just the 3 currents from each cable end and a few binary signals, it was decided to enable only 3 channels of 64kbps per modem pair in this design.

87Lfunction

The 87L characteristic was set as follows:

Minimum operate pickup	0.30 per unit
1st breakpoint	1.25 per unit
2nd breakpoint	3.00 per unit
1st slope	40.0%
2nd slope	80.0%

Per unit is based on the set I_{Base}. For this application, I_{Base} was set to the primary rating of the CTs.

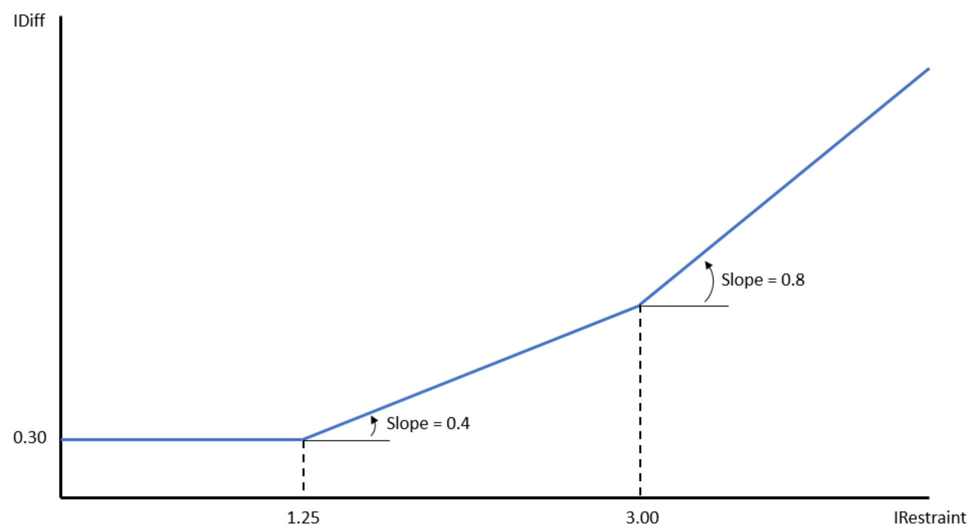


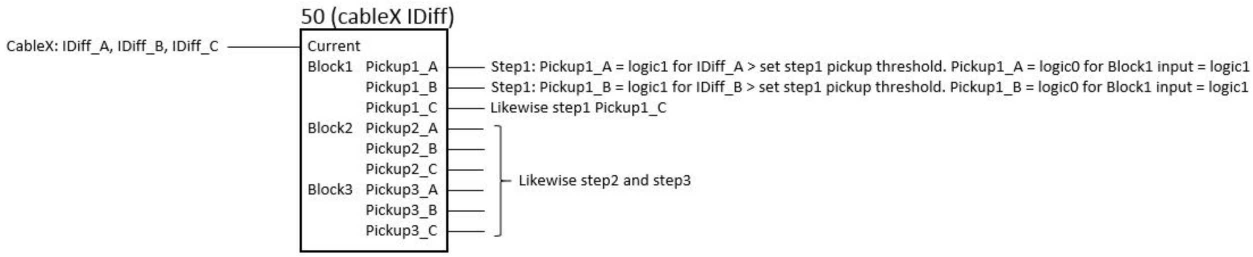
Figure 5: Set 87L characteristic

Each 87L zone comprises a pair of cables. Therefore, an 87L operation will indicate the cable pair on which the fault has occurred, and in which phase, as the 87L function has phase segregated operation, but it will not indicate in which cable of the cable pair the fault occurred.

One solution to this, of course, was to have just one cable per 87L zone, but this approach would require a doubling of the number of IEDs required. The solution to the problem had to be found without increasing the number of IEDs required.

Faulted cable identification

Each line differential system (2x IEDs, one at WTS and one at ETS) handles a pair of under river cables, so operation of the 87L protection will occur for a fault on either cable in the pair. The solution adopted to determine which cable in the pair is the faulted one for an 87L operation, is firstly to sum the local (WTS) and remote (ETS) currents per cable, per phase, thereby determining the differential currents, per cable, per phase. The three differential currents, per cable, are then applied to a 50 overcurrent function, separately for each of the two cables. Each of the IDiff 50 overcurrent functions has three pickup thresholds, step1, step2 and step3, with step1 having the lowest pickup threshold and step3 the highest. Any of the steps can be blocked by energizing its associated block input.



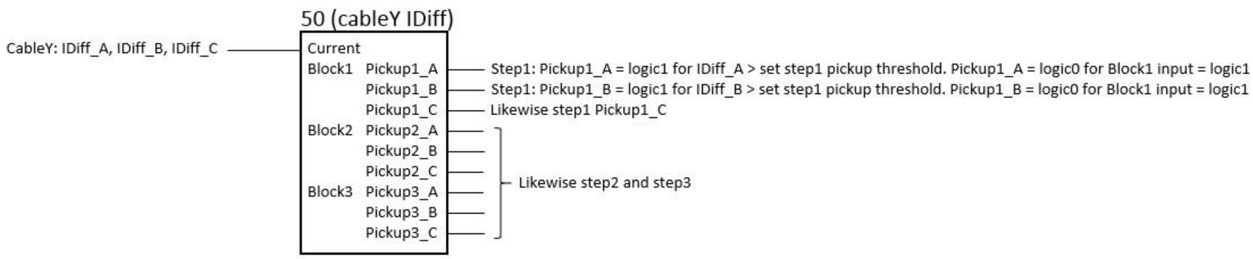


Figure 6: IDiff 50 overcurrent functions for cable pair X and Y

The restraint current, for each cable, is determined in the following way: all 3 phases of the local WTS currents are applied to two 50 overcurrent functions, with one having a higher pickup threshold than the other, say IRestraint> and IRestraint>>. Likewise, all 3 phases of the remote ETS currents for the same cable are applied to two additional 50 overcurrent functions, which have the same pickup thresholds as for the WTS currents, i.e. IRestraint> and IRestraint>>.

If any of the six currents (the three local WTS currents, and the three remote ETS currents) exceed the set IRestraint> threshold, the IRestraint> level for that cable has been exceeded. Likewise, if any of the six currents exceed the set IRestraint>> threshold, the IRestraint>> level for the same cable has been exceeded.

Figure 7 shows the IRestraint 50 overcurrent functions for cable X. The IRestraint 50 overcurrent functions for cable Y are identical.

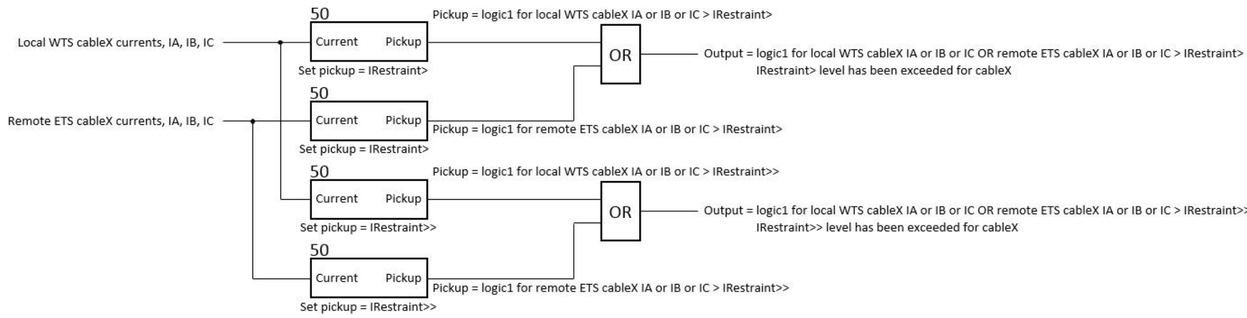


Figure 7: IRestraint 50 overcurrent functions for cable X

If no IRestraint level has been exceeded, no blocking of the IDiff 50 overcurrent function occurs. If the IRestraint> level has been exceeded, block step1 of the IDiff 50 overcurrent function. Similarly, if the IRestraint>> level has been exceeded, block step2 of the IDiff 50 overcurrent function. If the IRestraint>> level has been exceeded, IRestraint> level would also have been exceeded, so for IRestraint>> level exceeded, step1 and step2 would be blocked. In this way, the IDiff 50 overcurrent function's pickup threshold is effectively increased for increasing magnitude of restraint current.

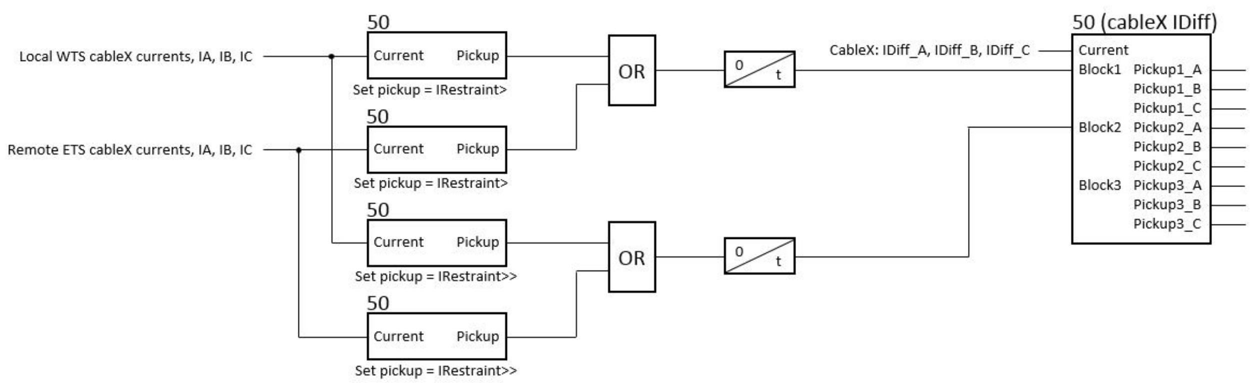


Figure 8: IDiff 50 overcurrent measurement, including IRestraint 50 overcurrent measurement, for cable X

Figure 8 shows the IDiff and IRestraint 50 overcurrent measurement for cable X. The IDiff and IRestraint 50 overcurrent measurement for cable Y is identical.

The 3-step IDiff 50 overcurrent function should always be more sensitive than the 87L characteristic. In other words, if the 87L function operates, identification of the actual faulted cable in the pair should always be possible.

The settings for the 87L characteristic were given earlier in the paper. Based on these, the pickup settings for the 3-step IDiff 50 overcurrent function can be determined for given IRestraint 50 overcurrent settings (both > and >>).

IRestraint>	select a value of 1.75 per unit
IRestraint>>	select a value of 3.50 per unit

The above two settings were chosen as a best fit to the 87L characteristic.

IDiff 50 overcurrent function settings

Pickup step 1	0.30 per unit = minimum operate pickup
Pickup step 2	0.50 per unit = 0.30 + (0.4 * (1.75 – 1.25))
Pickup step 3	1.40 per unit = 0.30 + (0.4 * (3.00 – 1.25)) + (0.8 * (3.50 – 3.00))

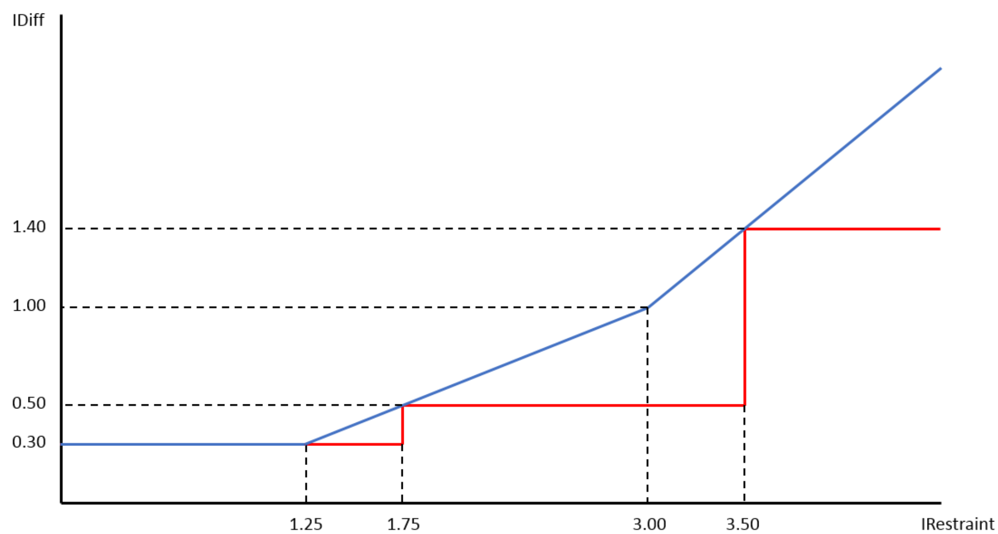


Figure 9: Set 87L characteristic plus the set faulted cable identification characteristic

<u>Example</u>

As an example, let's take the 87L zone for cable pair 1 and 6. Please note that in the actual engineering, the term 'pipe' was used rather than 'cable', as the three phases of each 'cable' were contained within a 'pipe'. From now on, the term 'pipe' will be used instead of 'cable'.

The four current sets (where one current set = all three phases of current) connected to the 87L zone are local WTS pipe 1, local WTS pipe 6, remote ETS pipe 1 and remote ETS pipe 6.

To identify the faulted pipe in the pipe pair, the current sets local WTS pipe 1 and remote ETS pipe 1 are summed. Similarly for pipe 6. As a security measure, the output of this summing is blocked until there is a pickup of the 87L function, indicating that an internal fault has occurred on the pipe pair. The releasing of this summing in this way is quite OK as without a fault occurring on the pipe pair, no subsequent identification of actual faulted pipe is required.

The output of the summing is applied to a 3-step 50 overcurrent function (IDiff overcurrent), one for pipe 1 and one for pipe 6. Step1 has the lowest (most sensitive setting), followed by step2 then step3. Step1 is blocked at a lower restraint current level (>) than step2 (>>). With no step blocked, the sensitivity of the 3-step IDiff 50 overcurrent function will be that of step1, the step with the lowest setting. With step1 blocked, but not step2, the sensitivity of the 3-step IDiff 50 overcurrent function will be that of step2, as step2 has a lower pickup setting than step3. With both step1 and step2 blocked, the pickup sensitivity of the 3-step IDiff 50 overcurrent function will be that of step3.

Exceeding an IRestraint level is based on, as a minimum, the current with maximum magnitude of the six (local WTS IA, IB, IC and remote ETS IA, IB, IC) going above the set IRestraint threshold (separately for pipe 1 and pipe 6). This method of determining the restraint level was adopted as it best matches how the 87L function calculates its restraint quantity, i.e. as the highest of all 87L zone boundary currents, and it then uses this as the common restraint current for all three phases of the IDiff vs IRestraint measurement.

A pipe 1 fault is indicated if the IDiff 50 overcurrent function gives a pickup in either step1, 2, or 3, but only after a few final security checks have been satisfied, i.e.

- that the 87L function did in fact issue a trip, and
- for steps 1 and 2 of the IDiff 50 overcurrent function, that there was in fact no restraint blocking.

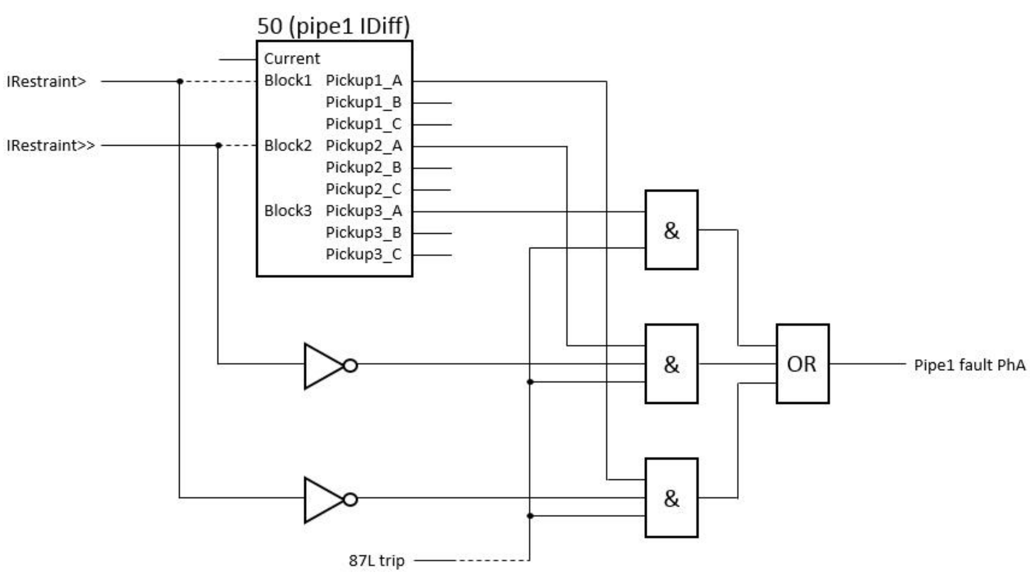


Figure 10: Final logic stage for pipe 1 fault phase A indication

Not shown in Figure 10, but identical, is the final stage logic for pipe 1 phases B and C, and pipe 6 phases A, B and C.

To wrap up, Figure 11 shows the complete simplified logic for faulted pipe identification

- pipe 1 – complete logic, but simplified to not show per phase.
- pipe 6 – only partial logic, but the pipe 6 logic is identical to the pipe 1 logic.

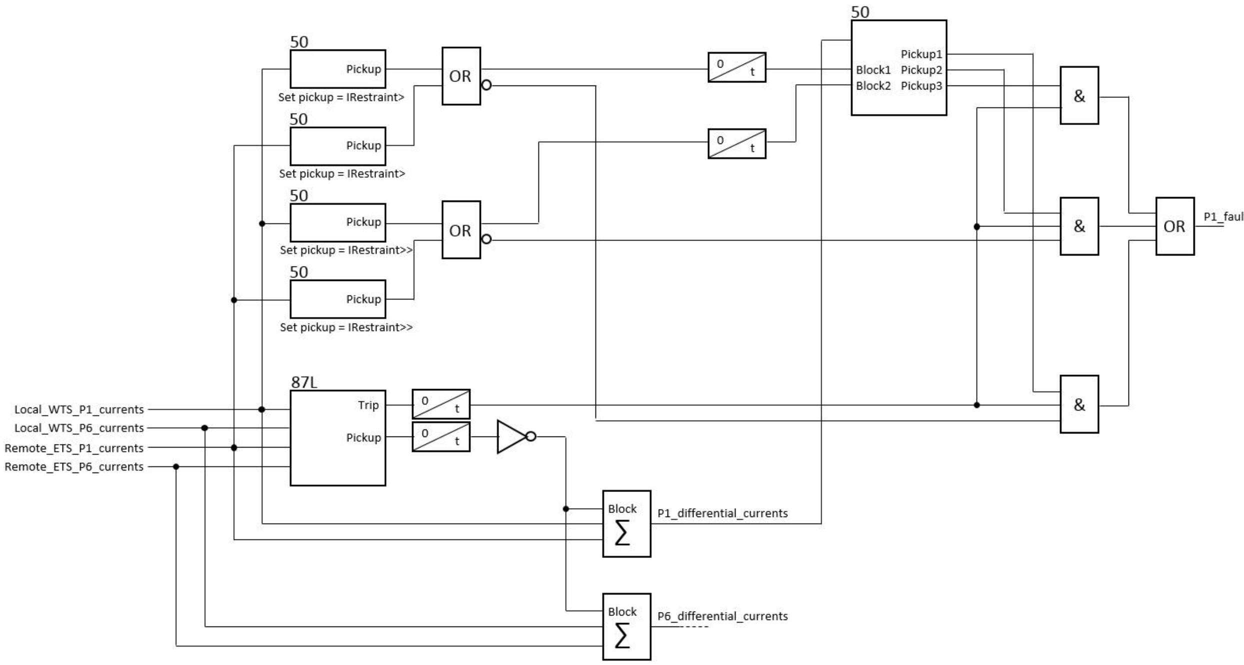


Figure 11: Complete simplified logic for faulted pipe identification

Lockout

It is imperative, for a fault occurring in the under river cable portion of the Roseton – East Fishkill line, that the LORs operate to trigger the DTT to block autoreclosing. Although the pipe identification detection was deliberately set to be more sensitive than the 87L, it was nevertheless decided that should the 87L operate, and an identification of faulted pipe was not made within a short interval of time (120ms), then the LORs for both pipes would be operated.

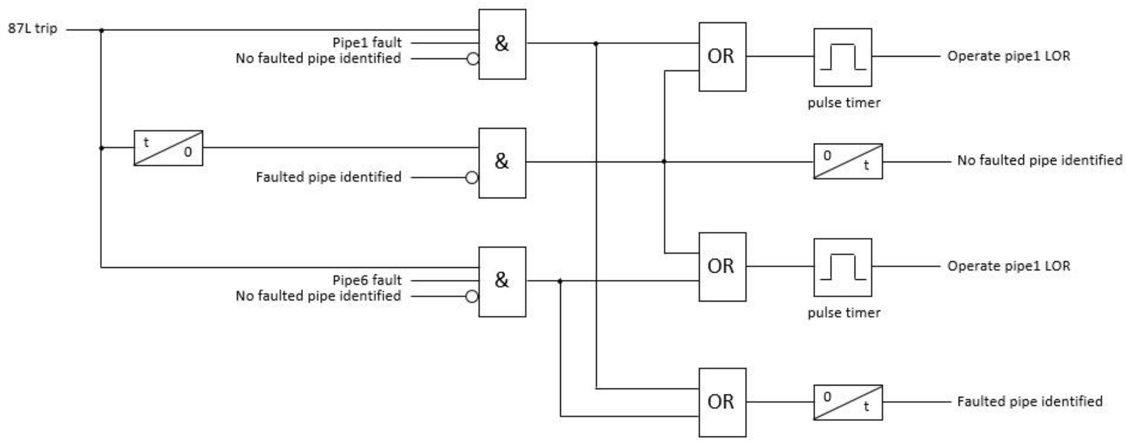


Figure 12: LOR operate logic for pipes 1 and 6

Indications

LHMI screens

At WTS

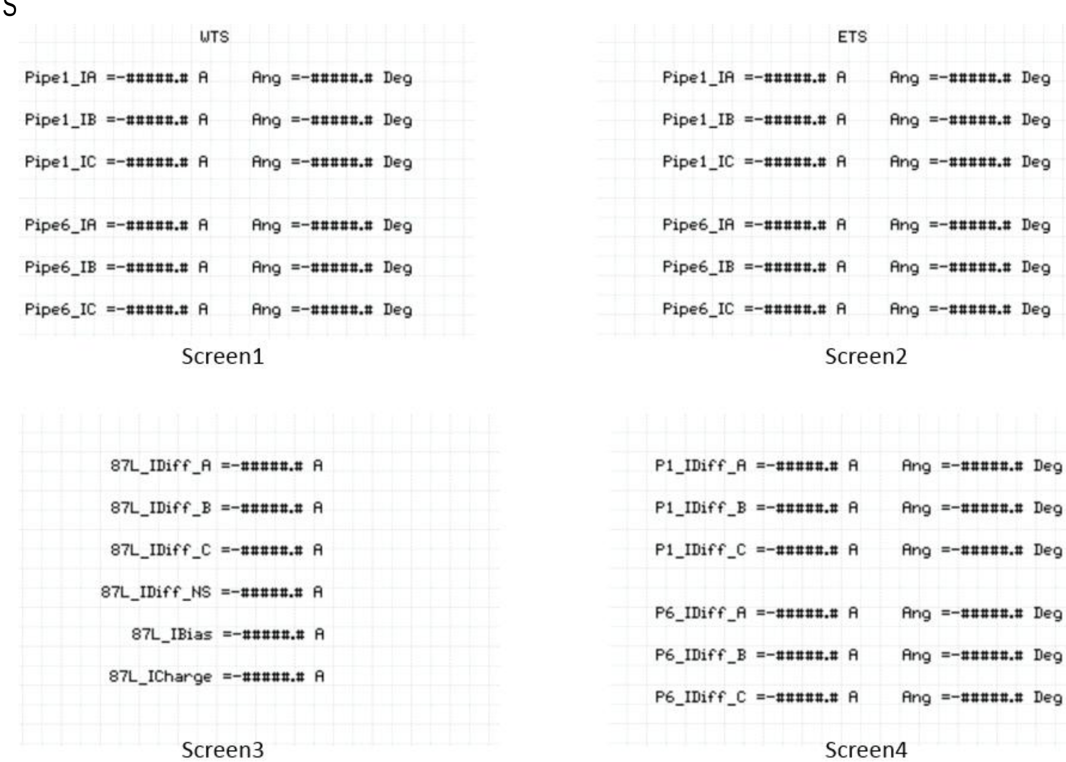


Figure 13: LHMI screen indications at WTS

At ETS
Only Screens 1 and 2.

Indication LEDs

At WTS

	Group 1	Group 2	Group 3
LED 1	87L pickup phA (yellow) 87L trip phA (red)	87L pickup phB (yellow) 87L trip phB (red)	87L pickup phC (yellow) 87L trip phC (red)
LED 2	Pipe 1 LOR operated (87L operated with pipe 1 identified as the faulted pipe) (red)	Pipe 6 LOR operated (87L operated with pipe 6 identified as the faulted pipe) (red)	Pipe 1&6 LOR operated (87L operated with no faulted pipe identified) (red)
LED 3	Pipe 1 fault phA (yellow)	Pipe 1 fault phB (yellow)	Pipe 1 fault phC (yellow)
LED 4	Pipe 6 fault phA (yellow)	Pipe 6 fault phB (yellow)	Pipe 6 fault phC (yellow)
LED 5	LDCM comm fail (yellow)	Open CT detected (yellow)	87L diff blocked (yellow)
LED 6	-	-	-
LED 7	-	-	-
LED 8	-	-	-
LED 9	-	-	-
LED 10	-	-	-
LED 11	-	-	-
LED 12	Pipe 1 I > IRestraint> (yellow)	Pipe 1 I > IRestraint>> (yellow)	-
LED 13	Pipe 1 step1 (yellow)	Pipe 1 step2 (yellow)	Pipe 1 step3 (yellow)
LED 14	Pipe 6 I > IRestraint> (yellow)	Pipe 6 I > IRestraint>> (yellow)	-
LED 15	Pipe 6 step1 (yellow)	Pipe 6 step2 (yellow)	Pipe 6 step3 (yellow)

At ETS
Only LED 5 Group 1 and 3.

Status LEDs

At WTS
Yellow LED: any pickup
Red LED: trip (pipe 1 or pipe 6 LOR operate)

At ETS
Red LED: trip (87L trip at WTS)
This red status LED at ETS will be reset with the reset LEDs action at WTS.

Factory acceptance testing (FAT)

Tests

Single side injection (in phase A), first on the WTS-side IED, then ETS-side IED:

The duration of the injected current was fixed at two cycles. This was the time duration assumed to be the absolute minimum time-on duration for an actual cable fault, i.e. from fault inception to clearance on opening of the circuit breakers. Correct operation at this minimum duration was important to determine, as the faulted pipe identification measurement is only released following pickup of the 87L function.

Inject @ WTS RED			
5.00	∠0°	2.0	~
6.25	∠0°	2.0	~

Inject @ ETS RED			
5.00	∠0°	2.0	~
6.25	∠0°	2.0	~

Figure 14: Sample of single side injection tests on WTS-side IED and ETS-side IED

Example 1

5.00A (= 1 pu) injection for 2 cycles on WTS-side IED

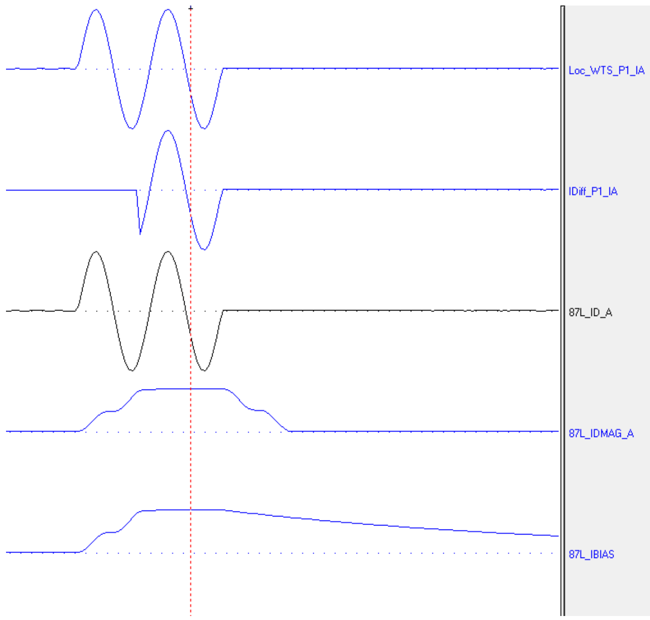


Figure 15: Relevant analog signals from the disturbance record

‘Loc_WTS_P1_IA’ is the injected current. ‘IDiff_P1_IA’ is the current connected to the IDiff 50 overcurrent function for pipe 1. ‘IDiff_P1_IA’ is the output from the summing of WTS IA plus ETS IA (in this example ETS IA = 0). The output from the summing is only released following pickup of the 87L function.

Steps 1, 2, 3 of the IDiff 50 overcurrent function are set, respectively, at 0.3, 0.5 and 1.4 pu. The first restraint level IRestraint> is set at 1.75 pu. Therefore no steps of the IDiff 50 overcurrent function should be blocked, and based on the injected current, steps 1 and 2 of the IDiff 50 overcurrent should operate.

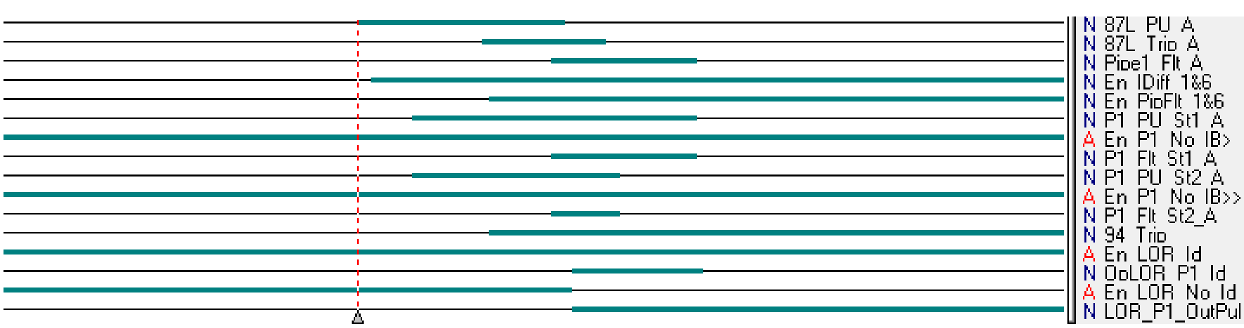


Figure 16: Relevant binary signals from the disturbance record

- Correct 87L pickup and trip in phase A – pickup of ‘87L PU A’ and ‘87L Trip A’ signals
- Correct identification of pipe 1 fault in phase A – pickup of ‘Pipe1 Flt A’ signal
- Correct no IRestraint> (IB>) or IRestraint>> (IB>>) level exceeded – no dropout in ‘En P1 No IB>’ and ‘En P1 No IB>>’ signals
- Correct pipe 1 IDiff 50 overcurrent pickup in phase A in steps 1 and 2 – pickup of ‘P1 PU St1 A’, ‘P1 Flt St1 A’, ‘P1 PU St2 A’ and ‘P1 Flt St2 A’ signals
- Correct output to operate pipe 1 LOR – pickup of ‘LOR P1 OutPul’ signal

Example 2

15.00A (= 3 pu) injection for 2 cycles on WTS-side IED

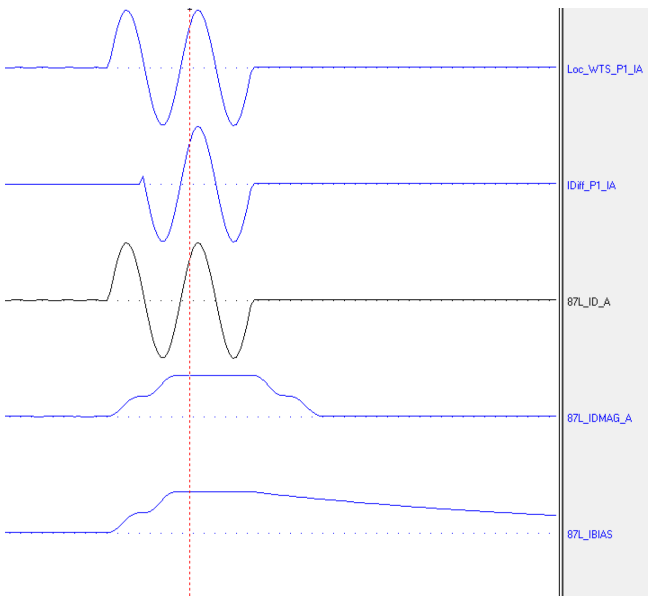


Figure 17: Relevant analog signals from the disturbance record

The second restraint level IRestraint>> is set at 3.50 pu. This level will not be exceeded, but the first level IRestraint> will be, blocking step 1 of the IDiff 50 overcurrent. Steps 2 and 3 of the IDiff 50 overcurrent function will not be blocked, and based on the injected current, steps 2 and 3 should both operate.

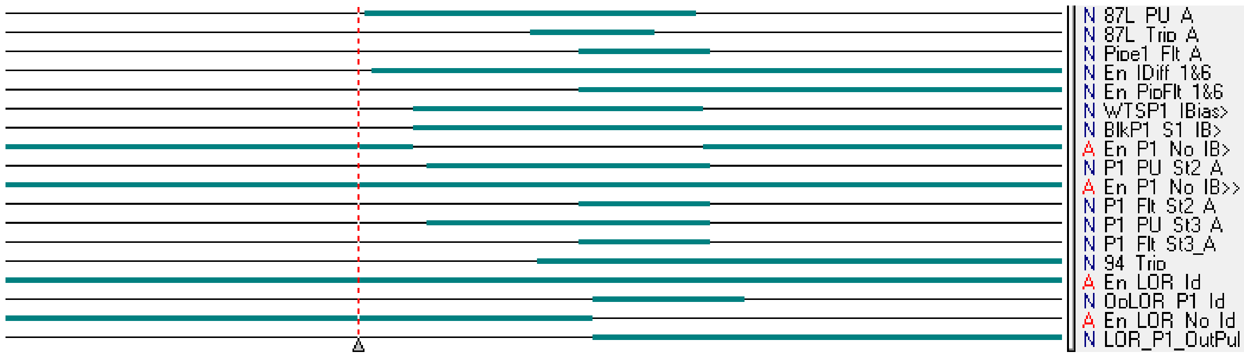


Figure 18: Relevant binary signals from the disturbance record

- Correct 87L pickup and trip in phase A – pickup of ‘87L PU A’ and ‘87L Trip A’ signals
- Correct identification of pipe 1 fault in phase A – pickup of ‘Pipe1 Flt A’ signal
- Correct IRestraint> (IB>) level exceeded (from WTS-side measured currents) – pickup of ‘WTSP1 IBias>’ and ‘BlkP1 S1 IB>’ signals, and corresponding dropout in ‘En P1 No IB>’ signal
- Correct no IRestraint>> (IB>>) level exceeded – no dropout in ‘En P1 No IB>>’ signal
- Correct pipe 1 IDiff 50 overcurrent pickup in phase A in steps 2 and 3 – pickup of ‘P1 PU St2 A’, ‘P1 Flt St2 A’, ‘P1 PU St3 A’ and ‘P1 Flt St3 A’ signals
- Correct output to operate pipe 1 LOR – pickup of ‘LOR P1 OutPul’ signal

Double side injection (in phase A):

This time the injection was 2-stage, the first stage being balanced through load condition, and the second stage the ‘fault’ condition. As before, the duration of the ‘fault’ condition was fixed at two cycles.

		Inject @ WTS RED				Inject @ ETS RED			
@ Ibias = 0.50	pu = 0.30	2.50	∠0°	300	~	2.50	∠180°	300	~
for test, pu = 0.40	2 A	2.50	∠0°	2.0	~	0.50	∠180°	2.0	~
@ Ibias = 1.00	pu = 0.30	5.00	∠0°	300	~	5.00	∠180°	300	~
for test, pu = 0.40	2 A	5.00	∠0°	2.0	~	3.00	∠180°	2.0	~
@ Ibias = 1.25	pu = 0.30	6.25	∠0°	300	~	6.25	∠180°	300	~
for test, pu = 0.40	2 A	6.25	∠0°	2.0	~	4.25	∠180°	2.0	~
@ Ibias = 1.65	pu = 0.46	8.25	∠0°	300	~	8.25	∠180°	300	~
for test, pu = 0.56	2.8 A	8.25	∠0°	2.0	~	5.45	∠180°	2.0	~
@ Ibias = 1.85	pu = 0.54	9.25	∠0°	300	~	9.25	∠180°	300	~
for test, pu = 0.64	3.2 A	9.25	∠0°	2.0	~	6.05	∠180°	2.0	~

Figure 19: Sample of double side injection tests on WTS-side IED and ETS-side IED

In Figure 19, the ‘fault’ condition was created by dropping the ETS-side current. Another identical set of tests was done, but this time by dropping the WTS-side current.

Of the five tests shown above, let’s take the first and last as examples.

<u>First</u>
Stage 1 injection = 2.50A = 0.50 pu. Therefore, for the 87L function, the X-axis point will be at 0.50 pu. At X-axis = 0.50, the Y-axis pickup value from the 87L characteristic is 0.30 pu. Adding a margin of 0.10 pu = 0.40 pu = 2.00A. For stage 2, by dropping the stage 1 current by this amount to 0.05A will give two things: 1) the X-axis point will remain unchanged at 0.05 pu and 2) the Y-axis point will jump from 0 to 0.40 pu, which is in the operate area of the characteristic. Pipe 1 must be identified as the faulted one. No IRestraint levels are exceeded, so no steps of the IDiff 50 overcurrent function will be blocked. However, as the differential current will only be 0.40 pu, only step 1 of the IDiff 50 overcurrent function should operate.

<u>Last</u>
Stage 1 injection = 9.25A = 1.85 pu. Therefore, for the 87L function, the X-axis point would be at 1.85 pu. At X-axis = 1.85, the Y-axis pickup value from the 87L characteristic is 0.54 pu. Adding a margin of 0.10 pu = 0.64 pu = 3.20A. For stage 2, by dropping the stage 1 current by this amount to 6.05A will give two things: 1) the X-axis point will remain unchanged at 1.85 pu and 2) the Y-axis point will jump from 0 to 0.64 pu, which is in the operate area of the characteristic. Pipe 1 must be identified as the faulted one. The IRestraint> level is exceeded, so step 1 of the IDiff 50 overcurrent function will be blocked. As the differential current will be 0.64 pu, step 2 of the IDiff 50 overcurrent function should operate, not step 3.

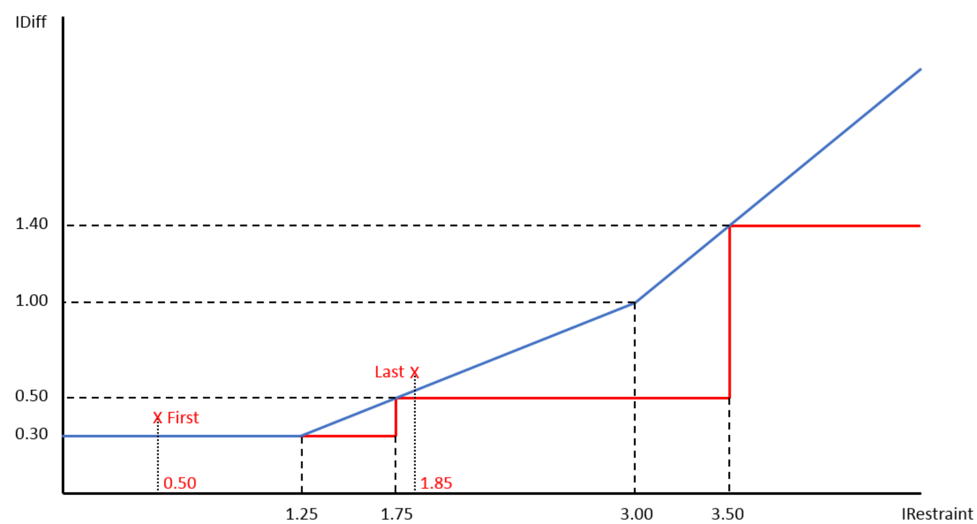


Figure 20: 87L and pipe identification characteristics with added ‘fault’ locations for First and Last examples

Operation for all test cases was as expected.

Conclusion

After two weeks of demolition and installation at the transition stations, the IEDs were commissioned into service on May 12, 2017. Since that date, the IEDs and associated communications and control equipment have performed properly. One of the most important aspects to the success of this project was the pre-installation and pre-commissioning work performed several months prior to the start of the actual installation. This was essentially a “dry run” for the overall project. This work involved the complete assembly of both IED panels, including the communications interconnections, at another NYPA facility. This allowed the NYPA and ABB engineers and NYPA technicians to fully inspect and test the equipment and work through any potential setting or wiring issues prior to the actual installation, which was performed within a typical line outage time frame. It also allowed the technician’s time to upgrade the test equipment and perform the complete set of commissioning tests to verify that the scheme worked as designed. The actual installation and commissioning went smoothly with only the physical work remaining as the unknown element during construction.

With the submerged oil cooled conductors approaching their 40 year in-service milestone, replacement with solid dielectric conductors is being considered. During the replacement, installation of fiber optic cables, with the new conductors, will be included in the scope of work. Due to the flexibility of the ABB relay design, all that will be required is a relay card change to allow the differential signals to travel back and forth over the fiber optic cables.

Authors

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Mike joined ABB Inc. in Raleigh, North Carolina as a Senior Applications / Product Specialist in November 2011. Prior to relocating to North America, Mike worked as a Senior Applications Specialist / Senior Regional Technical Manager for 12 years at the SA Product factory in Västerås, Sweden. Before joining ABB AB in Sweden in January 2000, Mike was Senior Consultant, Protection (Transmission) at Eskom (national power utility, South Africa). Mike joined Eskom as a training engineer in 1983, and rose to Protection Design Manager (Line Protection), before switching to Senior Consultant. Mike graduated from the University of Cape Town with BSc (electrical engineering) degree (with honors) in 1980.

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