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

Mike Kockott
ABB Inc.

TEXAS A&M, 72ND ANNUAL CONFERENCE FOR PROTECTION RELAY ENGINEERS
COLLEGE STATION, TX
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Co-author acknowledgement

Alex Echeverria, NYPA

Eric Anderson, NYPA

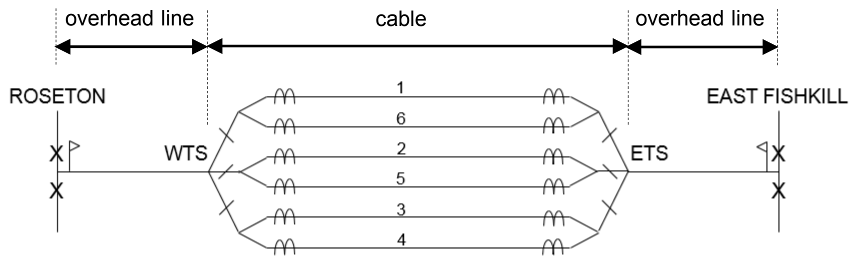
Bharat Vasudevan, ABB Inc.

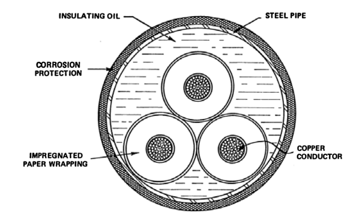
Application overview

Roseton – East Fishkill 345kV line

– Under river (Hudson River) section WTS – ETS (1.3 mile)

- Six 3-phase HPOF cables (pipes)





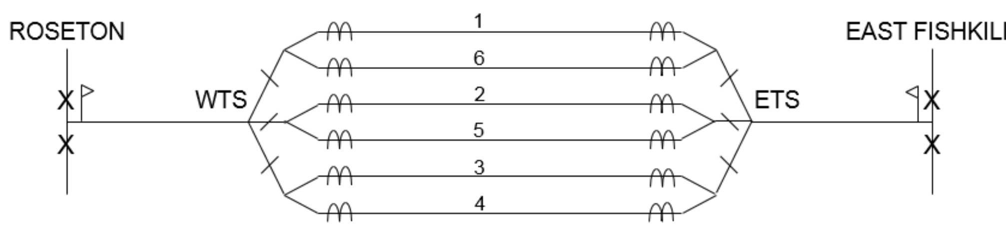
– Cable differential protection, required to…

- detect cable fault
- identify actual faulted cable (pipe)
- at WTS-side, operate LORs to send DTT to Roseton to LO autoreclosing for a fault on the cable portion

Application overview

Situation prior to upgrade

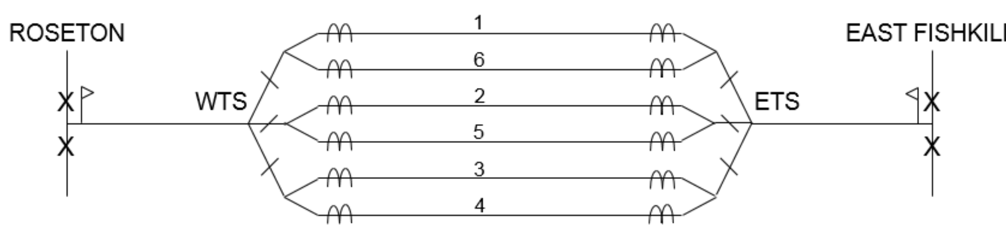
– 18 obsolete solid state differential relays, all located at WTS
  - parts becoming an increasing problem
– To get ETS currents to WTS, used small gauge copper wires installed with the main conductors
– impedance matching transformers were required at ETS to ‘boost’ the strength of the transmitted current signals from ETS to WTS (impedance matching transformers: increased signs of degradation, replacements not readily available, would require a custom build)



Application overview

Requirements for upgrade

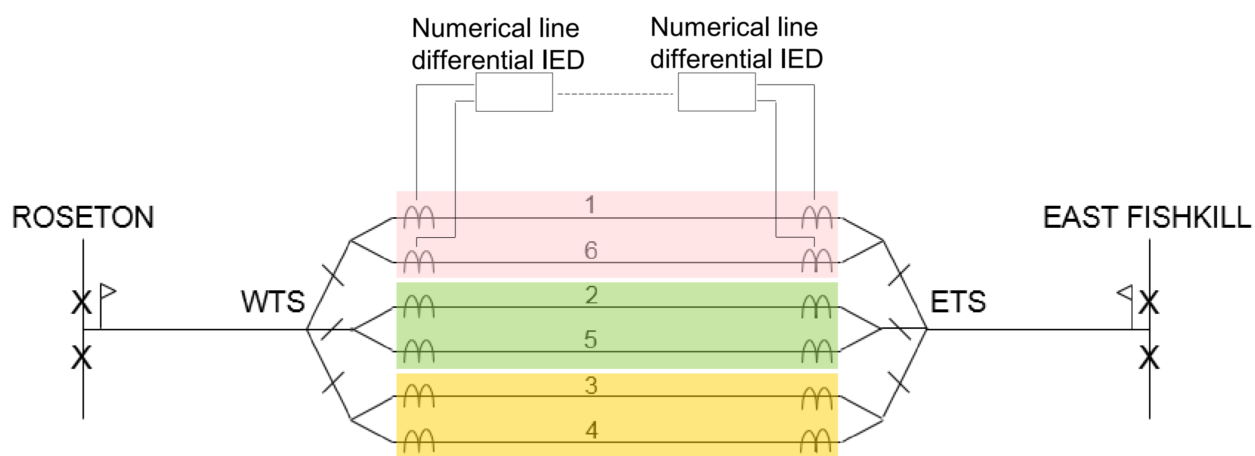
- Utilize the existing infrastructure, i.e. no fiber to be installed, so need to use the existing CT circuit copper wires as WTS – ETS inter-IED communications interface
- Do away with the impedance matching transformers - must not be required
- Utilize WTS LORs (lockout relays) and existing DTT (direct transfer trip) equipment and infrastructure
- Identify the faulted phase/s, as well as the actual faulted cable (pipe)



Application overview

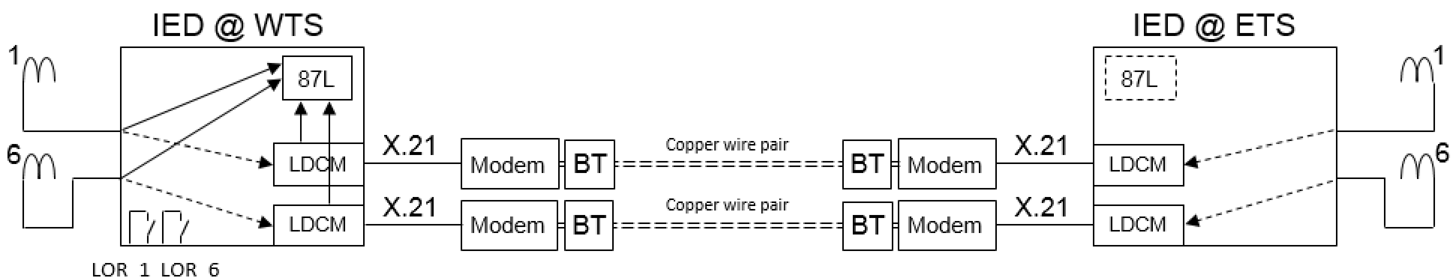
New solution

- Install modern numerical line differential IEDs at WTS and ETS
- Optimum solution – 6 IEDs, 2 IEDs per pipe pair



Application overview

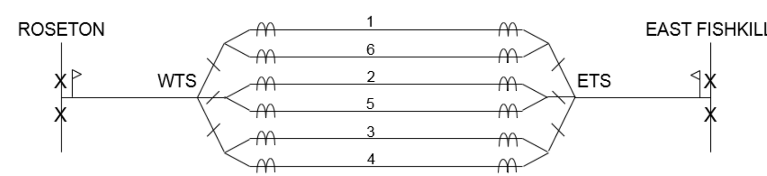
87L for pipes 1 and 6



– LDCM (Line Data Communications Module), with X.21 output

– Modem (with X.21 plug-in module) to interconnect the line differential IEDs using the copper wires

– BT insulating barrier transformer



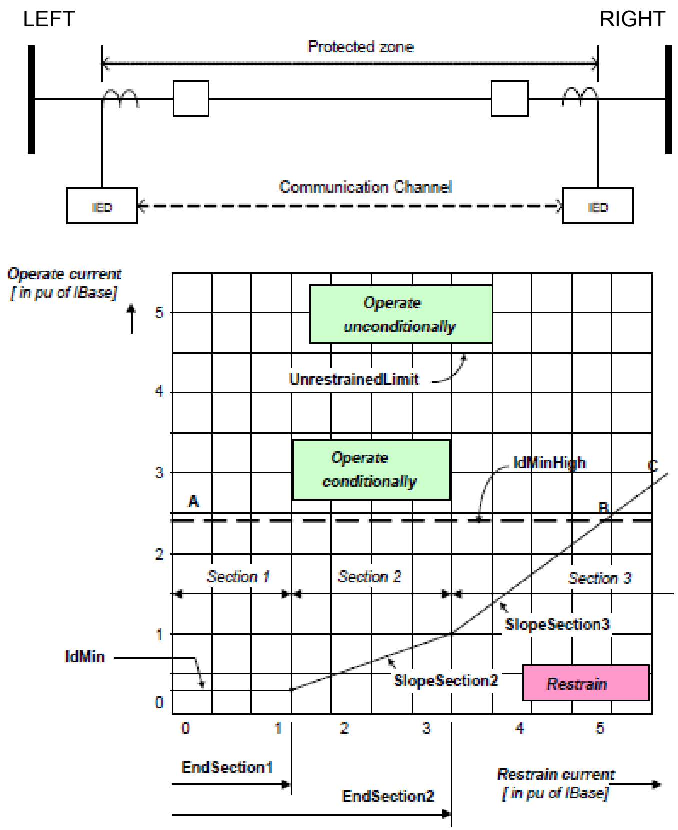
Verification of copper wire usability as communications interface

Measurements made for line attenuation and signal-to-noise (checking purity of the copper)

Result:

Existing copper wires OK to use as communications interface

87L – overview

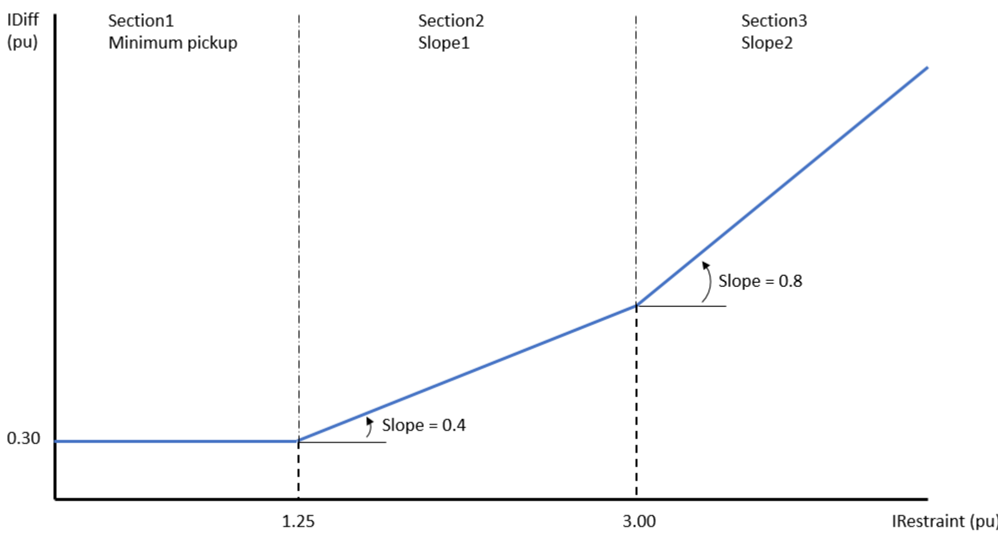


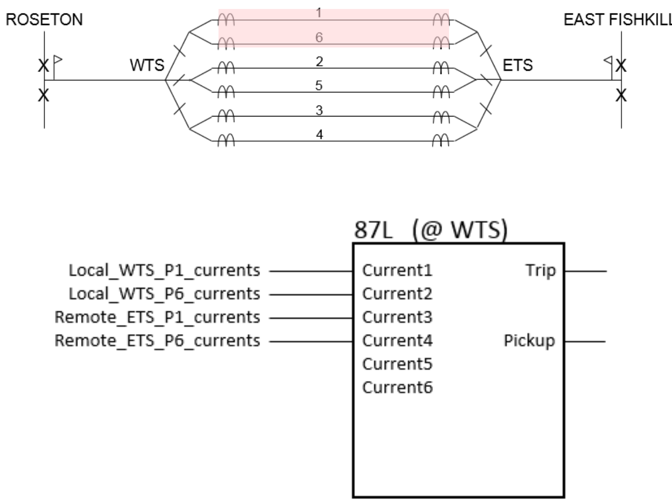
- Operate/Restraint characteristic
  - Minimum pickup (IdMin) + one or more slopes
  - Operate area above the characteristic
  - Operate current (Y-axis value)
    - $I_{Op\_A} = I_{Diff\_A} = I_{L\_A} + I_{R\_A}$
    - Similarly for phases B and C
  - Restrain current (X-axis value)
    - Different methods
    - This application

      $I_{Res} = MAX(|I_{L\_A}|, |I_{L\_B}|, |I_{L\_C}|, |I_{R\_A}|, |I_{R\_B}|, |I_{R\_C}|)$, common for all 3 phases

87L – this application

87L characteristic





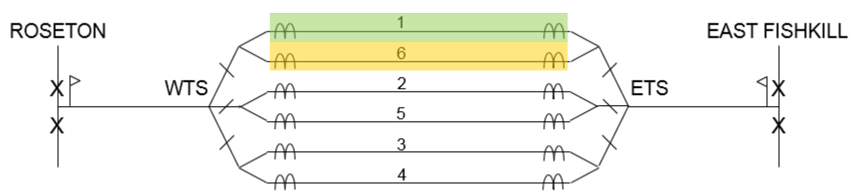
Faulted pipe identification

The 87L function will…

– operate for an internal fault in the pipe pair (1&6, 2&5, 3&4)

– indicate the faulted phase/s

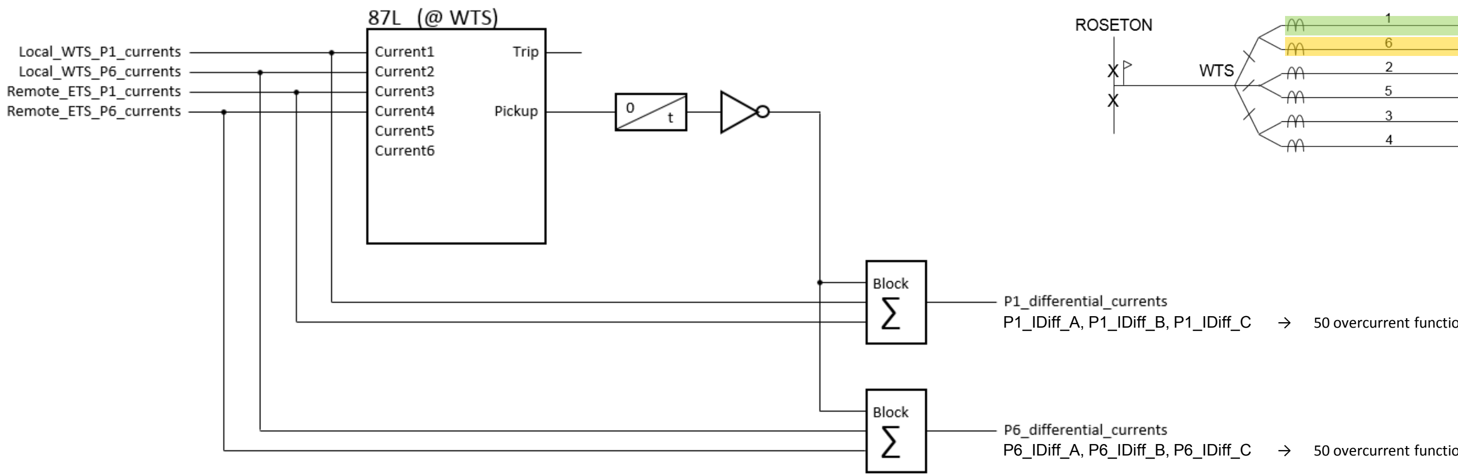
To determine the actual faulted pipe, need to establish two additional differential zones, one per pipe

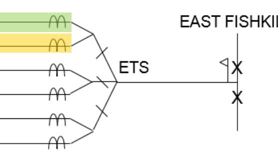


Faulted pipe identification

Pipe differential zone

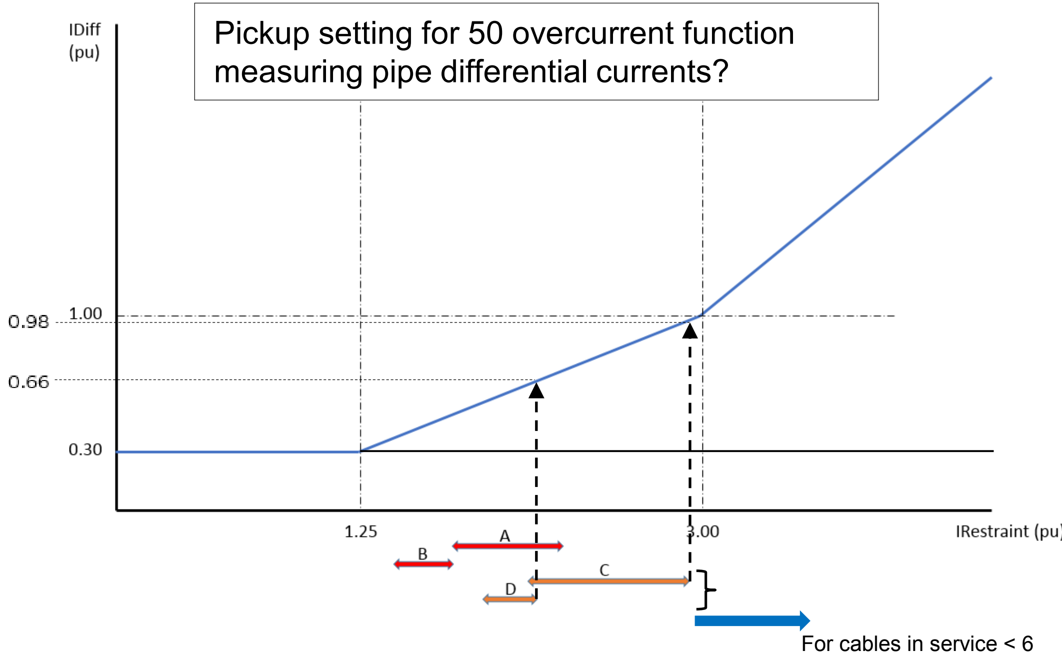
– Sum WTS + ETS currents, per phase, per pipe

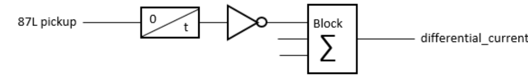


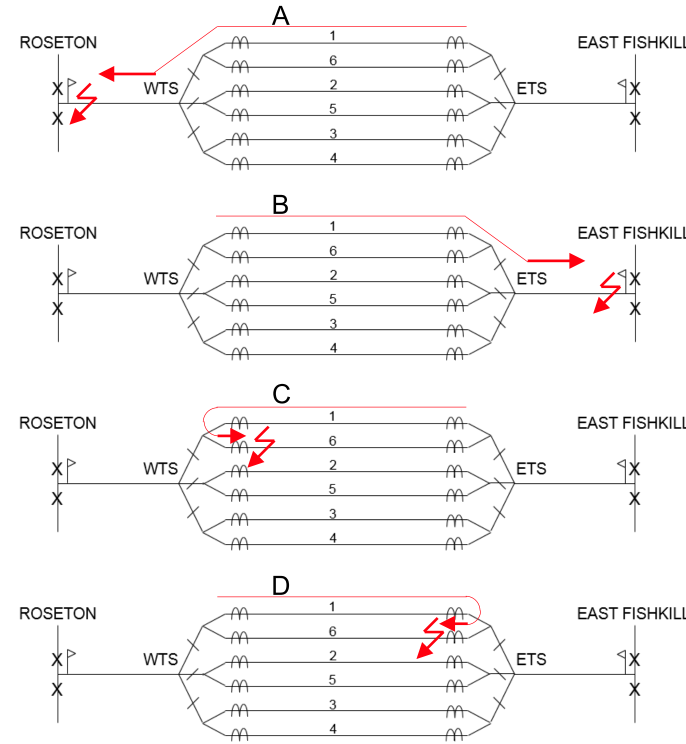


Faulted pipe identification

Fault levels

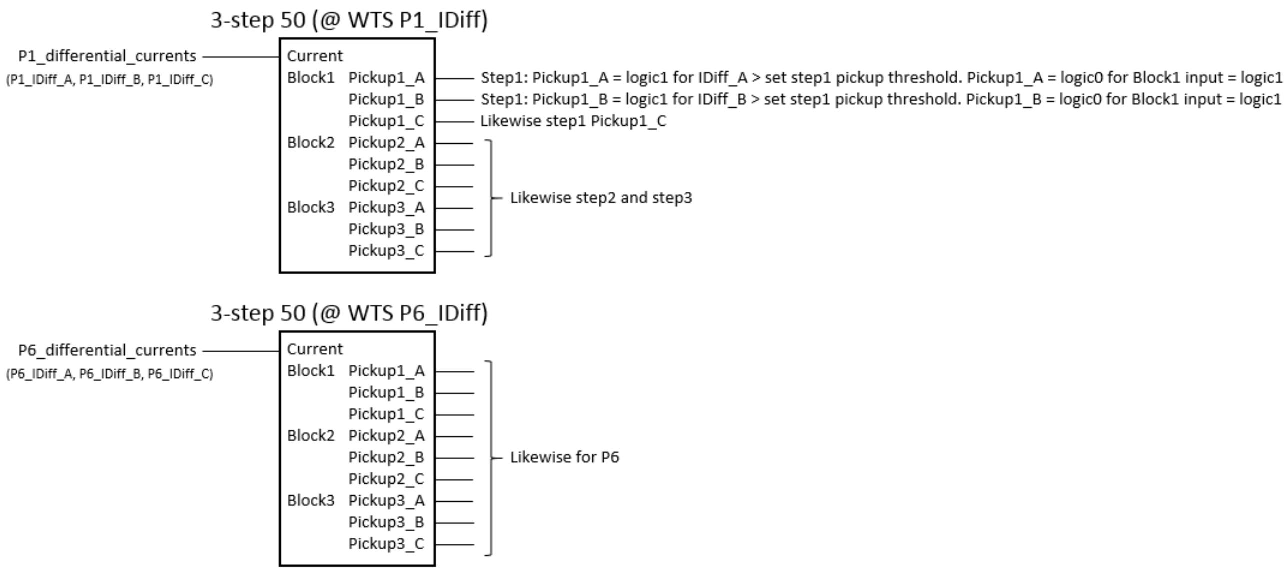






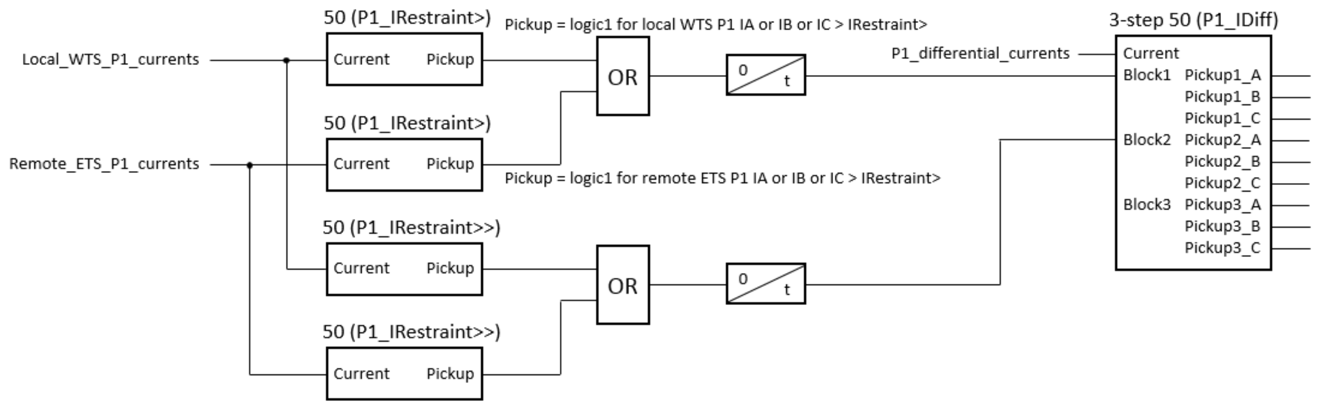
Faulted pipe identification

3-step IDiff 50 overcurrent function, per pipe



Faulted pipe identification

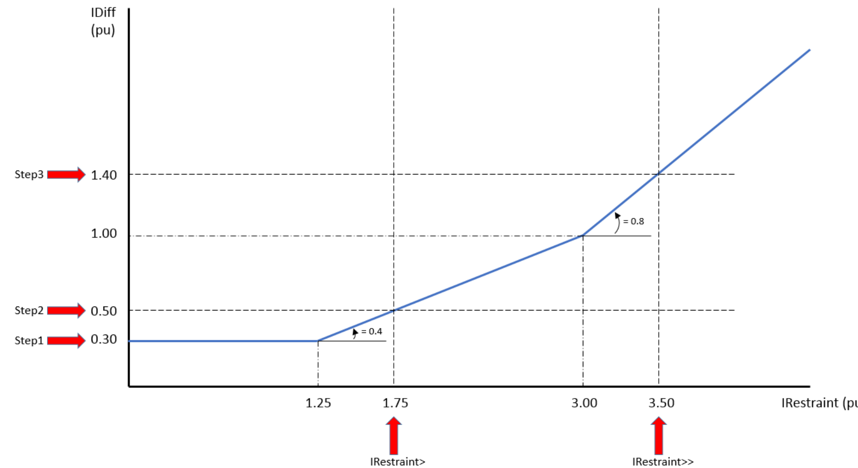
IRestraint 50 overcurrent functions, per pipe (shown for P1)



Faulted pipe identification

Faulted pipe identification "characteristic"

- More sensitive than 87L characteristic
- Task 1: select values for IRestrait> and IRestraint>>
  - IRestraint>: set = 1.75 pu
  - IRestraint>>: set = 3.50 pu
- Task 2: select values for 3-step IDiff 50 function
  - Step1: set = 87L minimum pickup = 0.30 pu
  - Step2: set = 87L pickup at IRestraint = 1.75 pu
  - Step3: set = 87L pickup at IRestraint = 3.50 pu



Step2: set = 0.30 + (0.40*(1.75 - 1.25))

= 0.50 pu

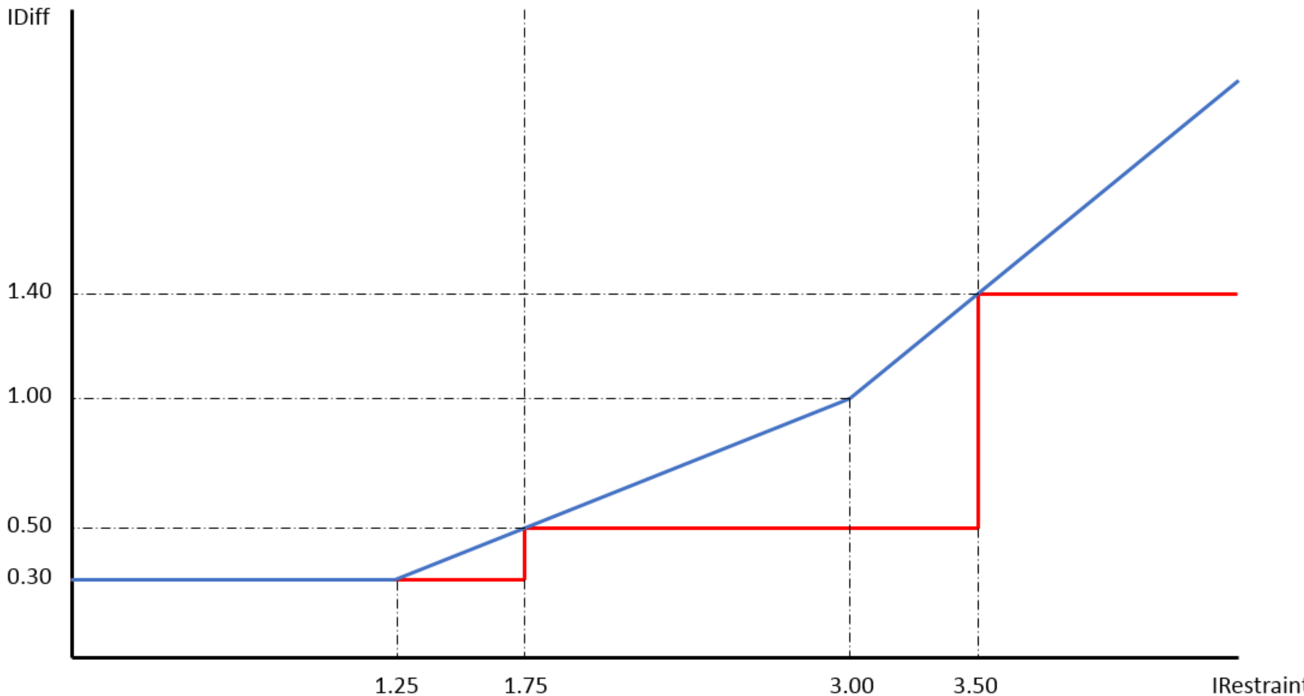
Step3: set = 0.30 + (0.40*(3.00 - 1.25))

+ (0.80*(3.50 - 3.00))

= 1.40 pu

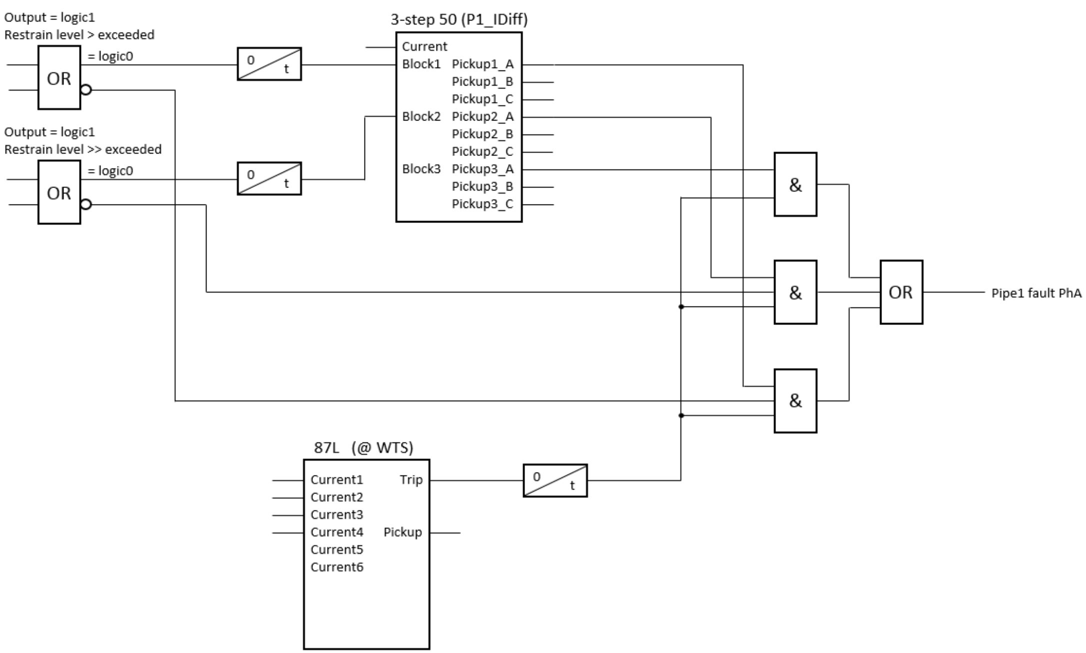
Faulted pipe identification

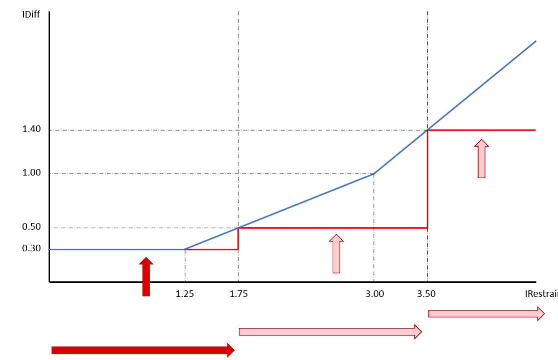
Faulted pipe identification “characteristic” + 87L characteristic



Faulted pipe identification

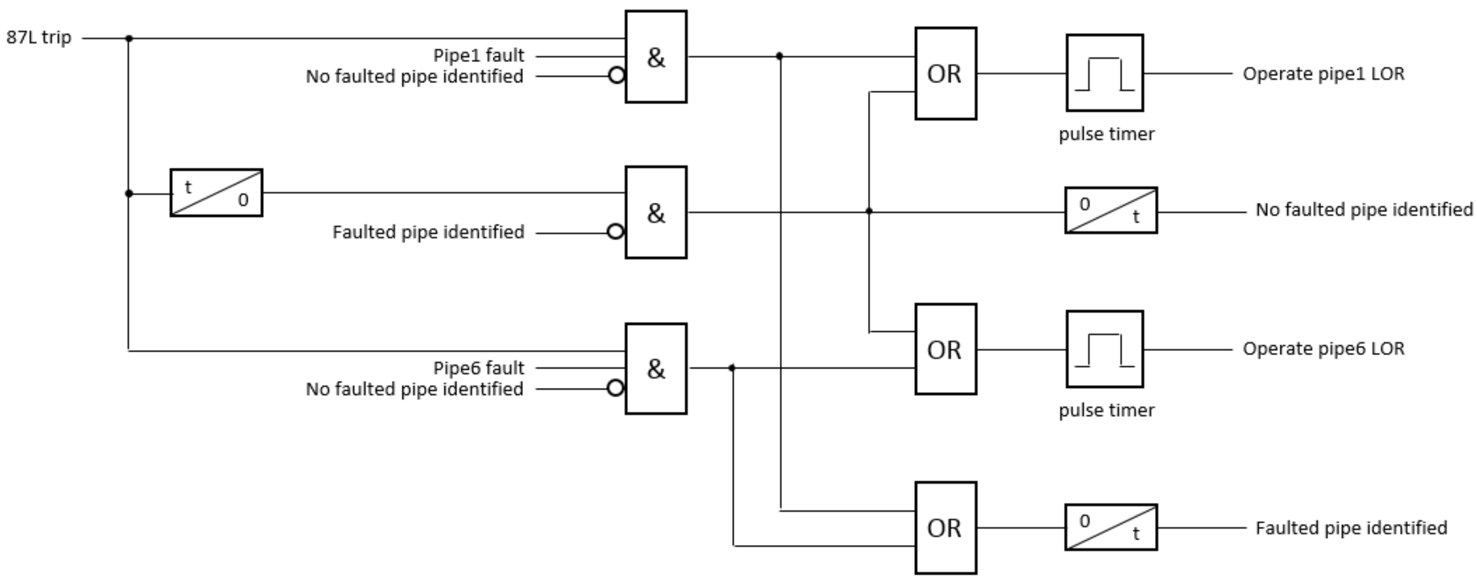
Faulted pipe identification, per phase





Faulted pipe identification

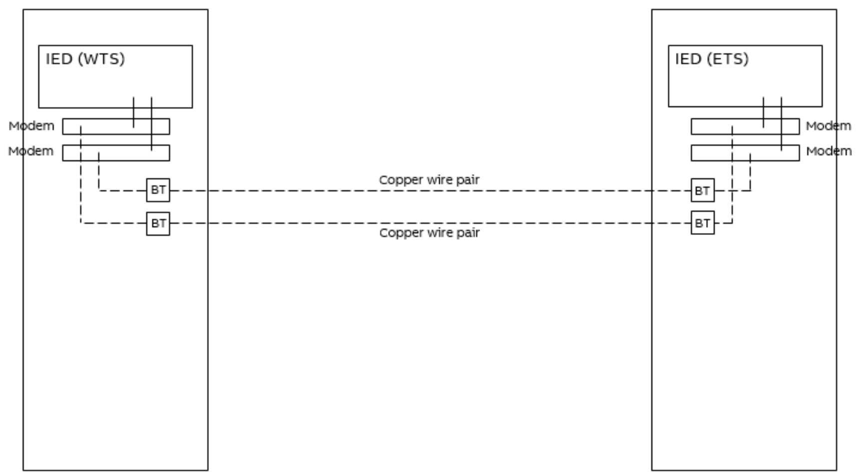
LOR relay operation



Evaluation Testing (FAT)

Complete assembly of both IED panels, including the communications interconnections

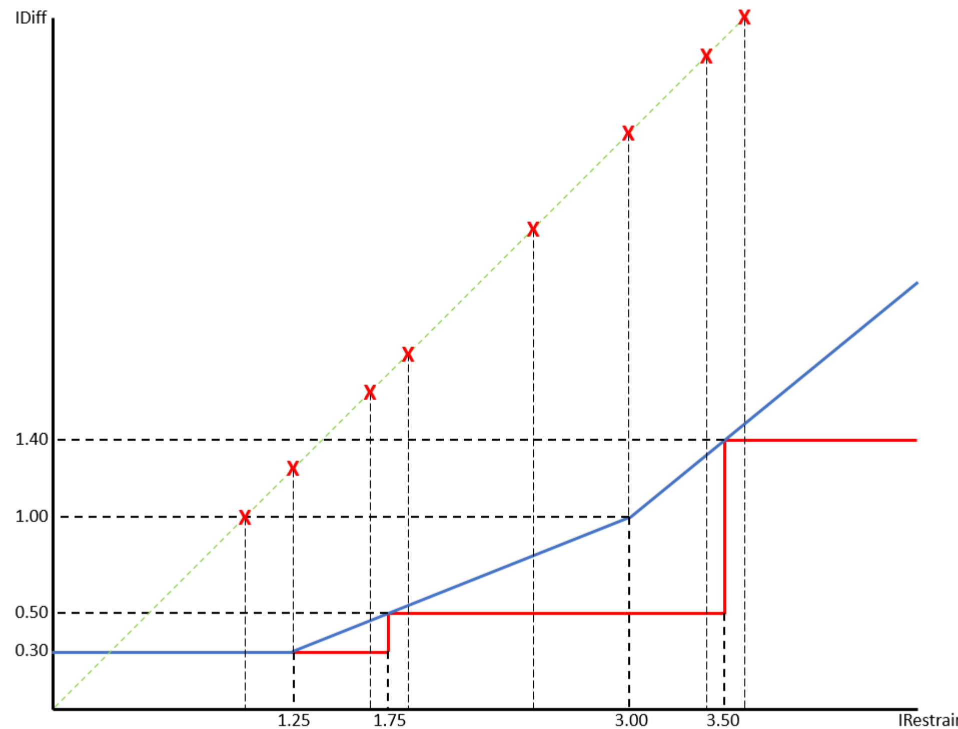
– Also served as a ‘dry-run’ for the on-site commissioning



Evaluation Testing (FAT)

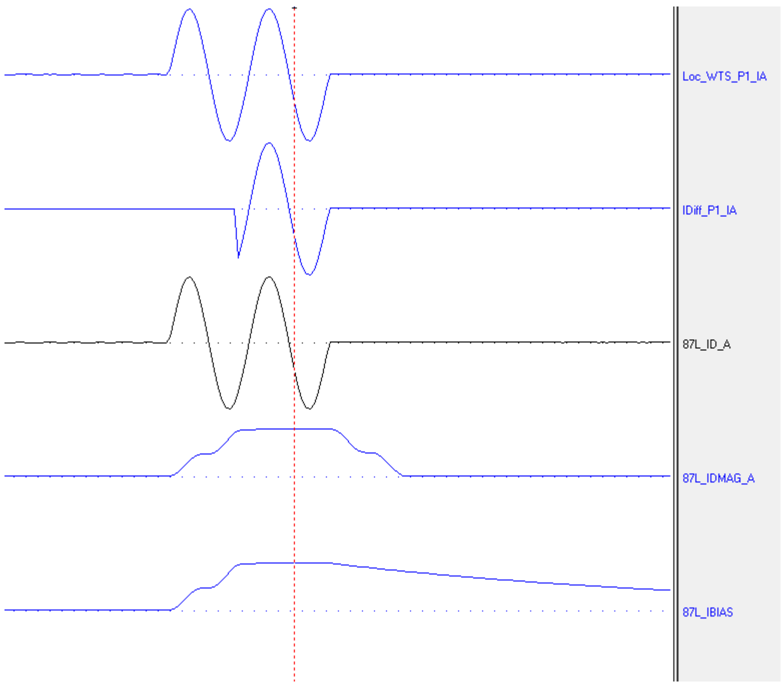
Single ended

Inject @ WTS IED			Inject @ ETS IED		
5.00	2.0	~			
6.25	2.0	~			
8.25	2.0	~			
9.25	2.0	~			
12.50	2.0	~			
15.00	2.0	~			
17.00	2.0	~			
18.00	2.0	~			
			5.00	2.0	~
			6.25	2.0	~
			8.25	2.0	~
			9.25	2.0	~
			12.50	2.0	~
			15.00	2.0	~
			17.00	2.0	~
			18.00	2.0	~



Evaluation Testing (FAT)

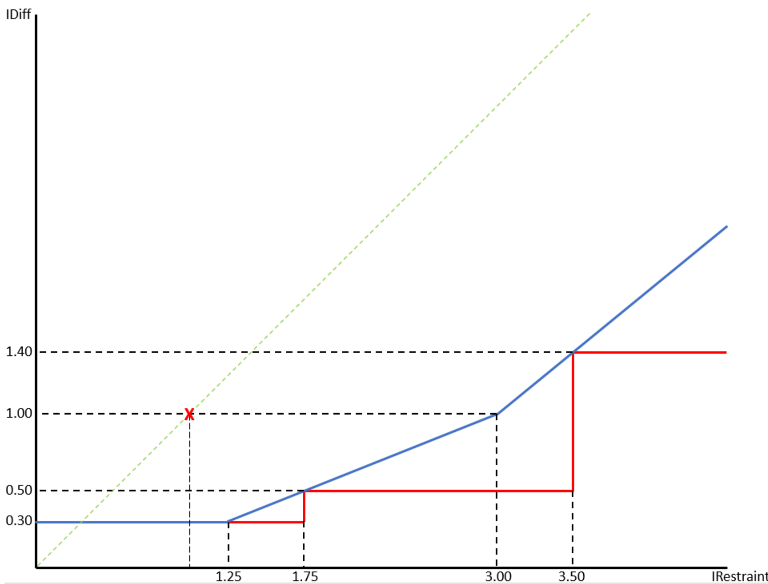
Single ended, cont.



- 5.00A (= 1 pu) phase A injection at WTS IED
  - *Loc_WTS_P1_IA* = injected current
  - *IDiff_P1_IA* = *Loc_WTS_P1_IA* + *Rem_ETS_P1_IA*
  - Output from ∑
    - released on 87L pickup
    - connected to the P1 pipe identification 3-step IDiff 50 overcurrent function

Evaluation Testing (FAT)

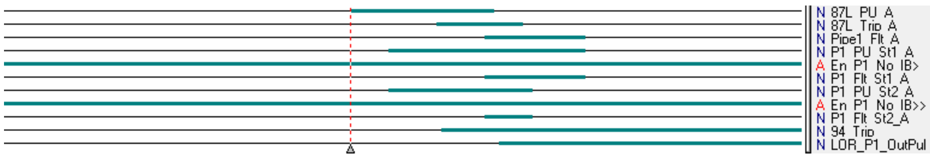
Single ended, cont.



- 5.00A (= 1 pu) phase A injection at WTS IED
  - No Restraint level exceeded
    - No steps of the 3-step IDiff 50 overcurrent function are blocked
  - IDiff 50 overcurrent function
    - P1 differential current > step1 and step2, but < step3

Evaluation Testing (FAT)

Single ended, cont.

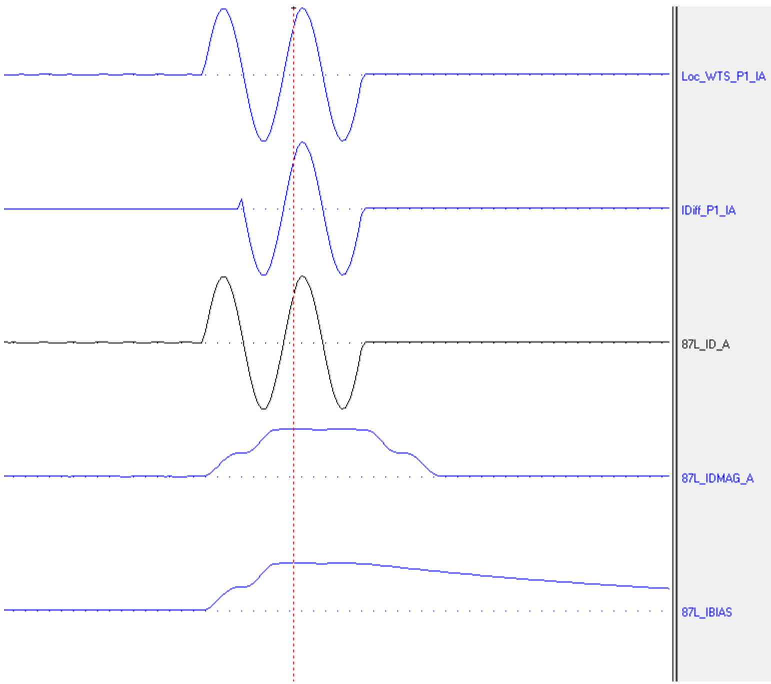


- 5.00A (= 1 pu) phase A injection at WTS IED

- 87L pickup and trip, phase A
- P1 fault identified, phase A
- Restrain level > (IB>) not exceeded
- IDiff 50 function pickup step1 phase A
- Restrain level >> (IB>>) not exceeded
- IDiff 50 function pickup step2 phase A
- Operate P1 LOR

Evaluation Testing (FAT)

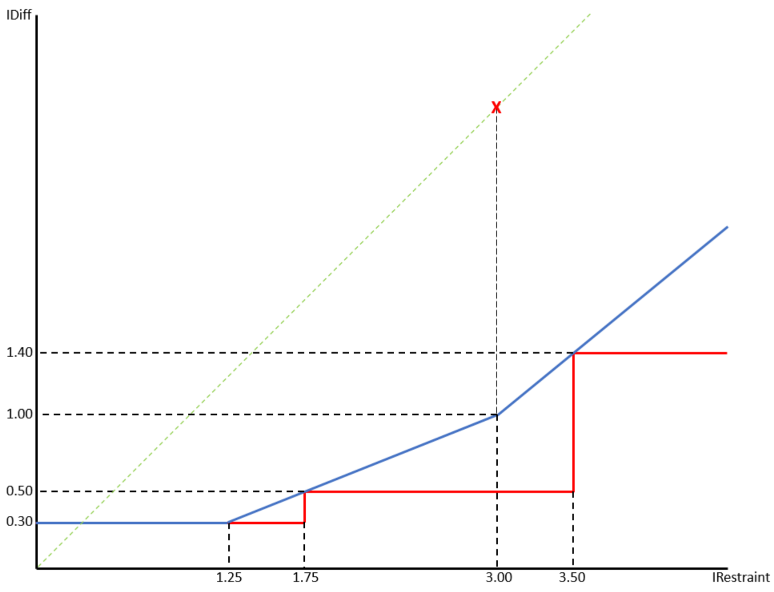
Single ended, cont.



- 15.00A (= 3 pu) phase A injection at WTS IED
  - *Loc_WTS_P1_IA* = injected current
  - *IDiff_P1_IA* = *Loc_WTS_P1_IA* + *Rem_ETS_P1_IA*
    - Output from ∑
      - released on 87L pickup
      - connected to the P1 pipe identification 3-step IDiff 50 overcurrent function

Evaluation Testing (FAT)

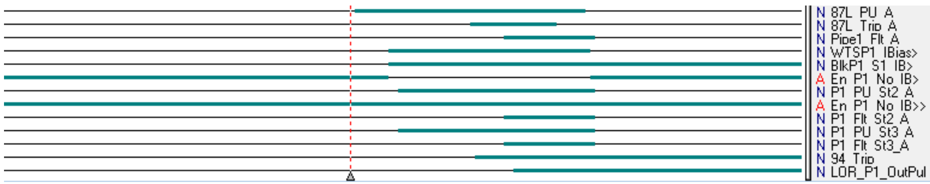
Single ended, cont.



- 15.00A (= 3 pu) phase A injection at WTS IED
  - Restraint level IRestraint> is exceeded, but not IRestraint>>
    - Step1 of the 3-step IDiff 50 overcurrent function will be blocked
  - IDiff 50 overcurrent function
    - P1 differential current > all steps, but step1 is blocked

Evaluation Testing (FAT)

Single ended, cont.



– 15.00A (= 3 pu) phase A injection at WTS IED

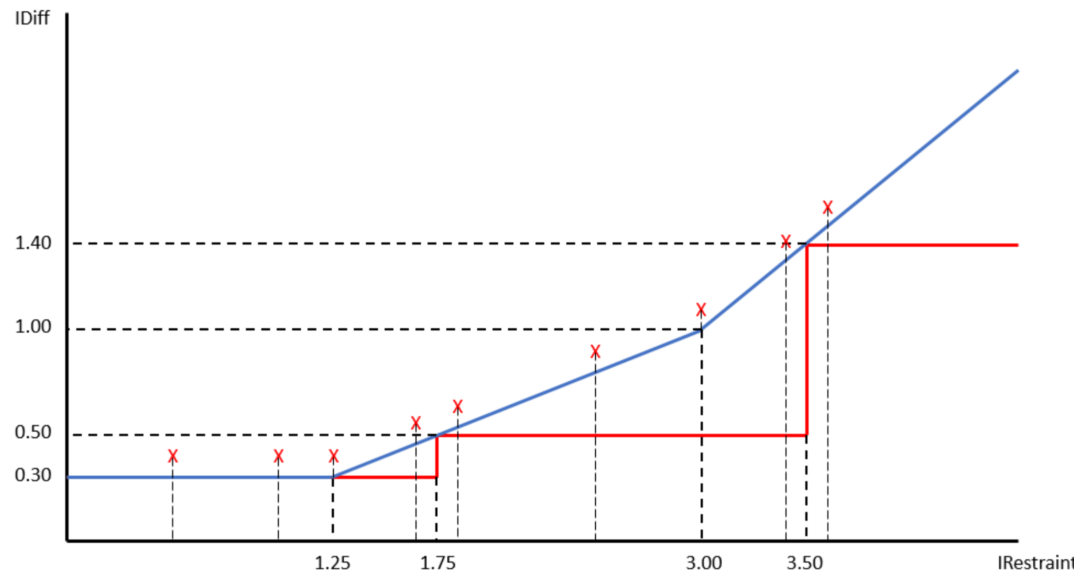
– 87L pickup and trip, phase A
– P1 fault identified, phase A
– Restrain level > (IB>) exceeded
– Restrain level >> (IB>>) not exceeded
– IDiff 50 function pickup step2 phase A
– IDiff 50 function pickup step3 phase A
– Operate P1 LOR

Evaluation Testing (FAT)

Inject @ WTS IED				Inject @ ETS IED			
2.50	∠0°	300	~	2.50	∠180°	300	~
2.50	∠0°	2.0	~	0.50	∠180°	2.0	~
5.00	∠0°	300	~	5.00	∠180°	300	~
5.00	∠0°	2.0	~	3.00	∠180°	2.0	~
6.25	∠0°	300	~	6.25	∠180°	300	~
6.25	∠0°	2.0	~	4.25	∠180°	2.0	~
8.25	∠0°	300	~	8.25	∠180°	300	~
8.25	∠0°	2.0	~	5.45	∠180°	2.0	~
9.25	∠0°	300	~	9.25	∠180°	300	~
9.25	∠0°	2.0	~	6.05	∠180°	2.0	~
12.50	∠0°	300	~	12.50	∠180°	300	~
12.50	∠0°	2.0	~	8.00	∠180°	2.0	~
15.00	∠0°	300	~	15.00	∠180°	300	~
15.00	∠0°	2.0	~	9.50	∠180°	2.0	~
17.00	∠0°	300	~	17.00	∠180°	300	~
17.00	∠0°	2.0	~	9.90	∠180°	2.0	~
18.00	∠0°	300	~	18.00	∠180°	300	~
18.00	∠0°	2.0	~	10.10	∠180°	2.0	~

Double ended, 2 stage injection

- stage1, balanced through current
- stage2, reduce one side by a pre-determined amount



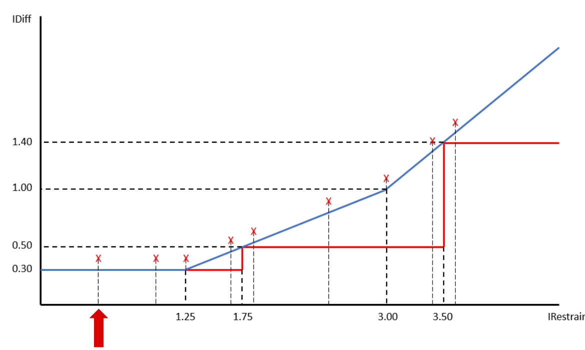
Evaluation Testing (FAT)

Double ended, 2 stage injection

–At IRestraint (X-axis) = 2.50A = 0.50 pu, IDiff (Y-axis) value for pickup = 0.30 pu

–Add margin of 0.10 pu → 0.40 pu = 2.00A

Inject @ WTS IED					Inject @ ETS IED			
2.50	∠0°	300	~		2.50	∠180°	300	~
2.50	∠0°	2.0	~		0.50	∠180°	2.0	~
5.00	∠0°	300	~		5.00	∠180°	300	~
5.00	∠0°	2.0	~		3.00	∠180°	2.0	~
6.25	∠0°	300	~		6.25	∠180°	300	~
6.25	∠0°	2.0	~		4.25	∠180°	2.0	~
8.25	∠0°	300	~		8.25	∠180°	300	~
8.25	∠0°	2.0	~		5.45	∠180°	2.0	~
9.25	∠0°	300	~		9.25	∠180°	300	~
9.25	∠0°	2.0	~		6.05	∠180°	2.0	~
12.50	∠0°	300	~		12.50	∠180°	300	~
12.50	∠0°	2.0	~		8.00	∠180°	2.0	~
15.00	∠0°	300	~		15.00	∠180°	300	~
15.00	∠0°	2.0	~		9.50	∠180°	2.0	~
17.00	∠0°	300	~		17.00	∠180°	300	~
17.00	∠0°	2.0	~		9.90	∠180°	2.0	~
18.00	∠0°	300	~		18.00	∠180°	300	~
18.00	∠0°	2.0	~		10.10	∠180°	2.0	~



– Stage2, keep one current (WTS) unchanged (= 2.50A), and drop the other (ETS) by 2.00A to 0.50A
– X-axis point remains unchanged, and Y-axis point jumps to 0.40 pu

– Expected result: P1 fault identified, phase A
– No restraint level exceeded, no IDiff 50 overcurrent function steps blocked, only step1 pickup phase A

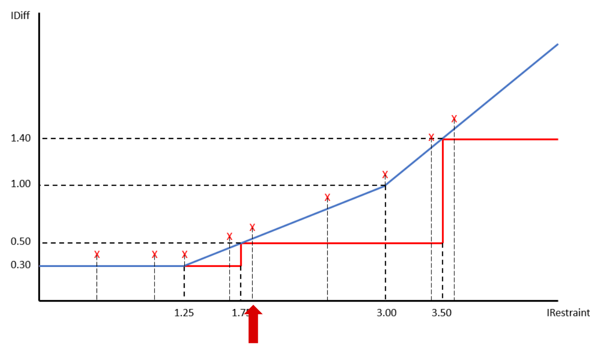
Evaluation Testing (FAT)

Double ended, 2 stage injection

–At IRestraint (X-axis) = 9.25A = 1.85 pu, IDiff (Y-axis) value for pickup = 0.54 pu

–Add margin of 0.10 pu → 0.64 pu = 3.20A

Inject @ WTS IED				Inject @ ETS IED			
2.50	∠0°	300	~	2.50	∠180°	300	~
2.50	∠0°	2.0	~	0.50	∠180°	2.0	~
5.00	∠0°	300	~	5.00	∠180°	300	~
5.00	∠0°	2.0	~	3.00	∠180°	2.0	~
6.25	∠0°	300	~	6.25	∠180°	300	~
6.25	∠0°	2.0	~	4.25	∠180°	2.0	~
8.25	∠0°	300	~	8.25	∠180°	300	~
8.25	∠0°	2.0	~	5.45	∠180°	2.0	~
9.25	∠0°	300	~	9.25	∠180°	300	~
9.25	∠0°	2.0	~	6.05	∠180°	2.0	~
12.50	∠0°	300	~	12.50	∠180°	300	~
12.50	∠0°	2.0	~	8.00	∠180°	2.0	~
15.00	∠0°	300	~	15.00	∠180°	300	~
15.00	∠0°	2.0	~	9.50	∠180°	2.0	~
17.00	∠0°	300	~	17.00	∠180°	300	~
17.00	∠0°	2.0	~	9.90	∠180°	2.0	~
18.00	∠0°	300	~	18.00	∠180°	300	~
18.00	∠0°	2.0	~	10.10	∠180°	2.0	~



– Stage2, keep one current (WTS) unchanged (= 9.25A), and drop the other (ETS) by 3.20A to 6.05A

– X-axis point remains unchanged, and Y-axis point jumps to 0.64 pu

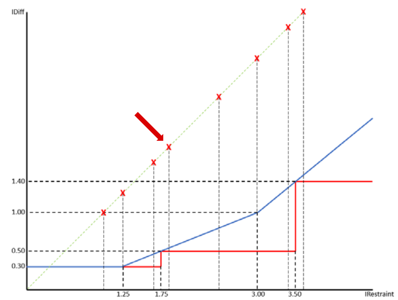
– Expected result: P1 fault identified, phase A

– Restraint level (>) exceeded, step1 of IDiff 50 overcurrent function blocked, only step2 pickup phase A

Conclusion

FAT

– Successful – ‘expected’ operation for all test cases



– E.G. for test indicated
- IDiff = 1.85 pu >> pickup setting = 0.30 pu (step1)
- IRestraint = 1.85 pu just > pickup setting = 1.75 pu (IRestraint>)
- IDiff step1 operated faster than IRestraint>, picking up momentarily before being blocked by IRestraint> pickup
- OK for increased margin between IRestraint and pickup setting
- ‘Gray’ area around the transition point

Commissioning

– Put into service 12 May 2017

– All equipment, including the communications, has to date performed as expected