Dual Differential Protection of a 240kV Autotransformer

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High Impedance Differential

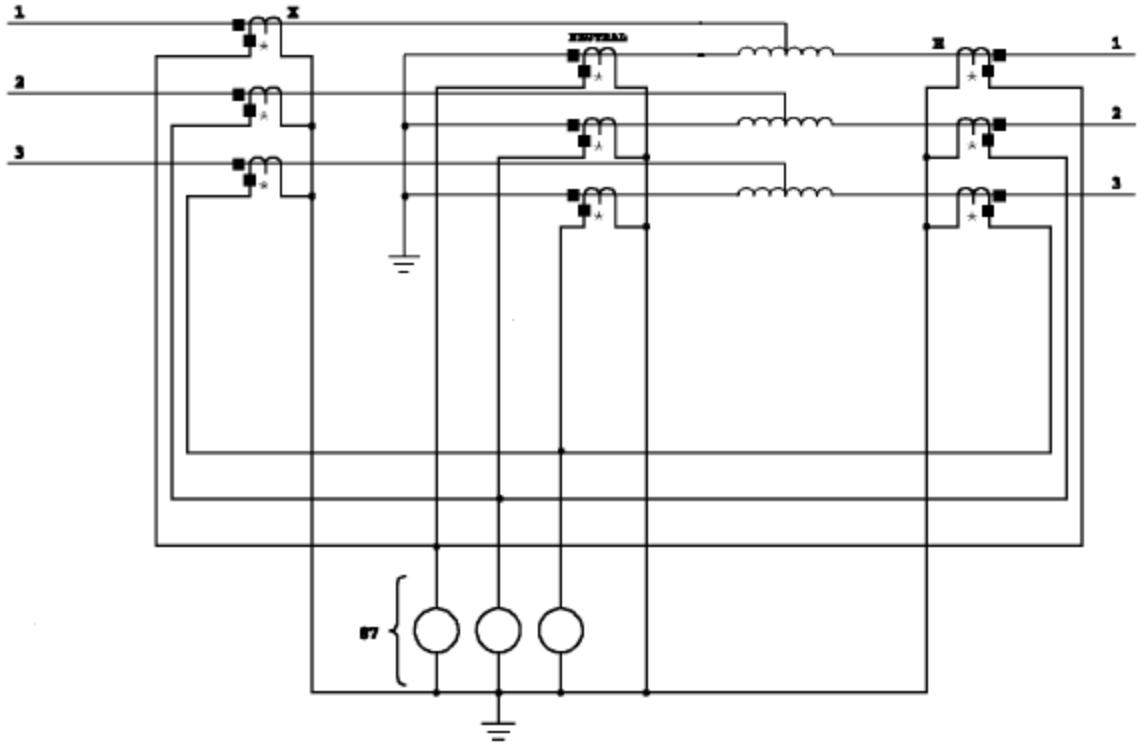
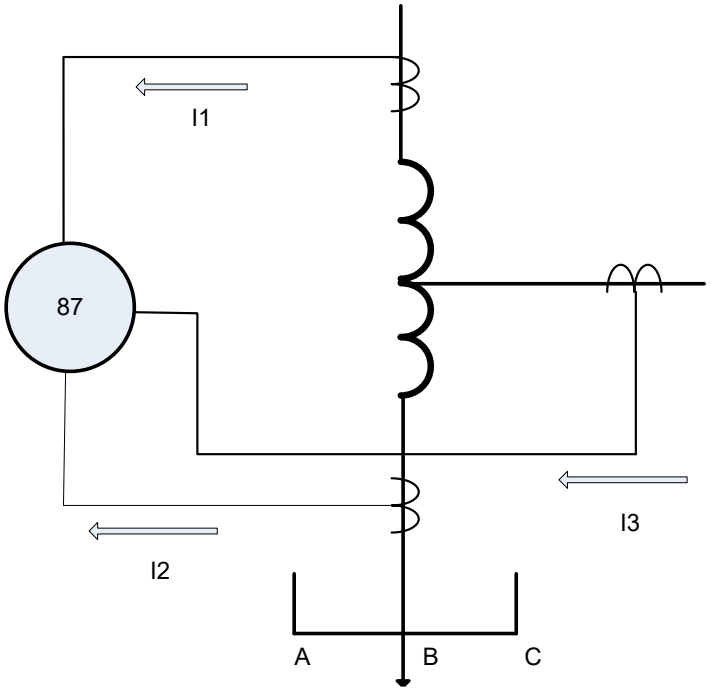


Figure 6 from IEEE C37.91 Guide on Transformer Protection

Phase Segregated Low Impedance Differential



I1 + I2 + I3 = 0,
(converted back to CT primary),
when there is no internal fault

Advantages of the Phase segregated differential

- Immune to the magnetizing inrush current. Inrush current is not a source of differential current. It flows through.
- No imbalance current due to on-load tap changer.
- Accurate faulted phase indication

Advantages of the Phase segregated differential - continued

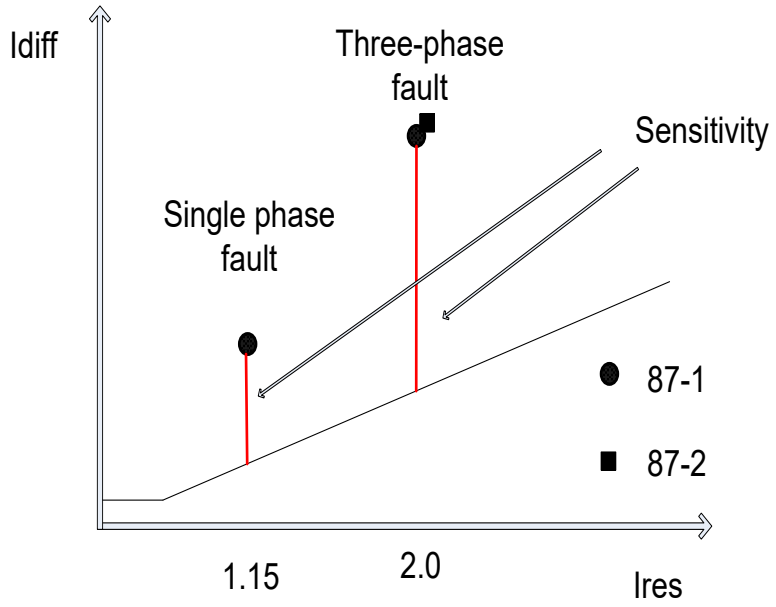
Conventional Differential:
ground fault sensitivity is lower due to
zero sequence component filtering from the winding current

For A-G fault, Ib = Ic =0,

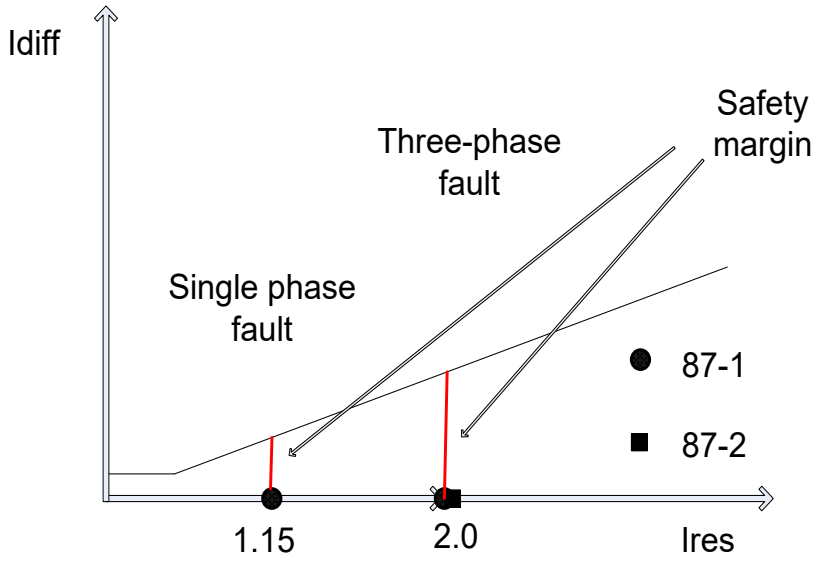
$$Ires = \frac{1}{\sqrt{3}} \cdot \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{vmatrix} Ia \\ Ib \\ Ic \end{vmatrix} = \left(\frac{1}{\sqrt{3}} \cdot Ia,\ 0,\ \frac{1}{\sqrt{3}} \cdot Ia\right)$$

Advantages of the Phase segregated differential - continued

- More Sensitive to Ground Fault



Internal Fault



External Fault

Limitation of the Phase segregated differential

- No protection to turn-to-turn fault
- No protection to fault in the tertiary winding

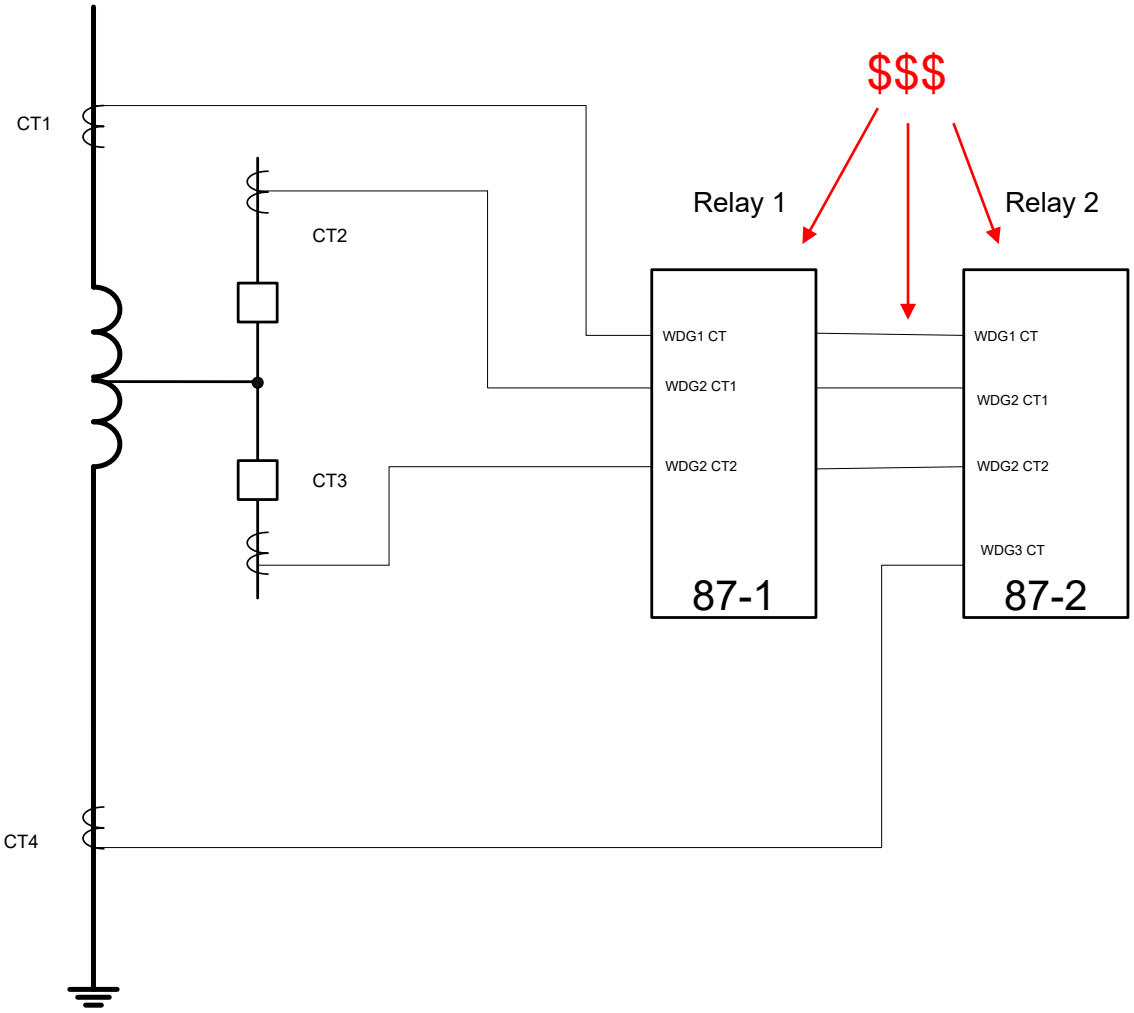
Dual Differential

- A dual differential scheme, consisting of a phase segregated and a conventional transformer differential protection, will have better sensitivity and reliability

Dual Differential – the Best Solution

Conditions	Conventional Differential	Phase segregated Differential	Dual Differential (Conventional + phase segregated)
Magnetizing inrush current	Need harmonic restraint. Could miss operate due to inrush current with low harmonic component	Immune to inrush current.	Immune to inrush current
OLTC	OLTC can cause imbalance current; Needs higher restraint slope setting	Immune to OLTC	Immune to OLTC
Ground fault	Lower sensitivity and security of ground fault than those of phase-to-phase faults	Ground fault has the sensitivity and security with phase-to-phase fault	Ground fault has the sensitivity and security with phase-to-phase fault
Tertiary winding Fault	Protect the fault in tertiary winding	No protection	Protect the fault in tertiary winding
Winding turn to turn fault	Protect turn to turn fault	No protection	Protect turn to turn fault
Fault phase indication	No accurate	Accurate fault phase indication	Accurate fault phase indication

Dual Diff in the Traditional Way

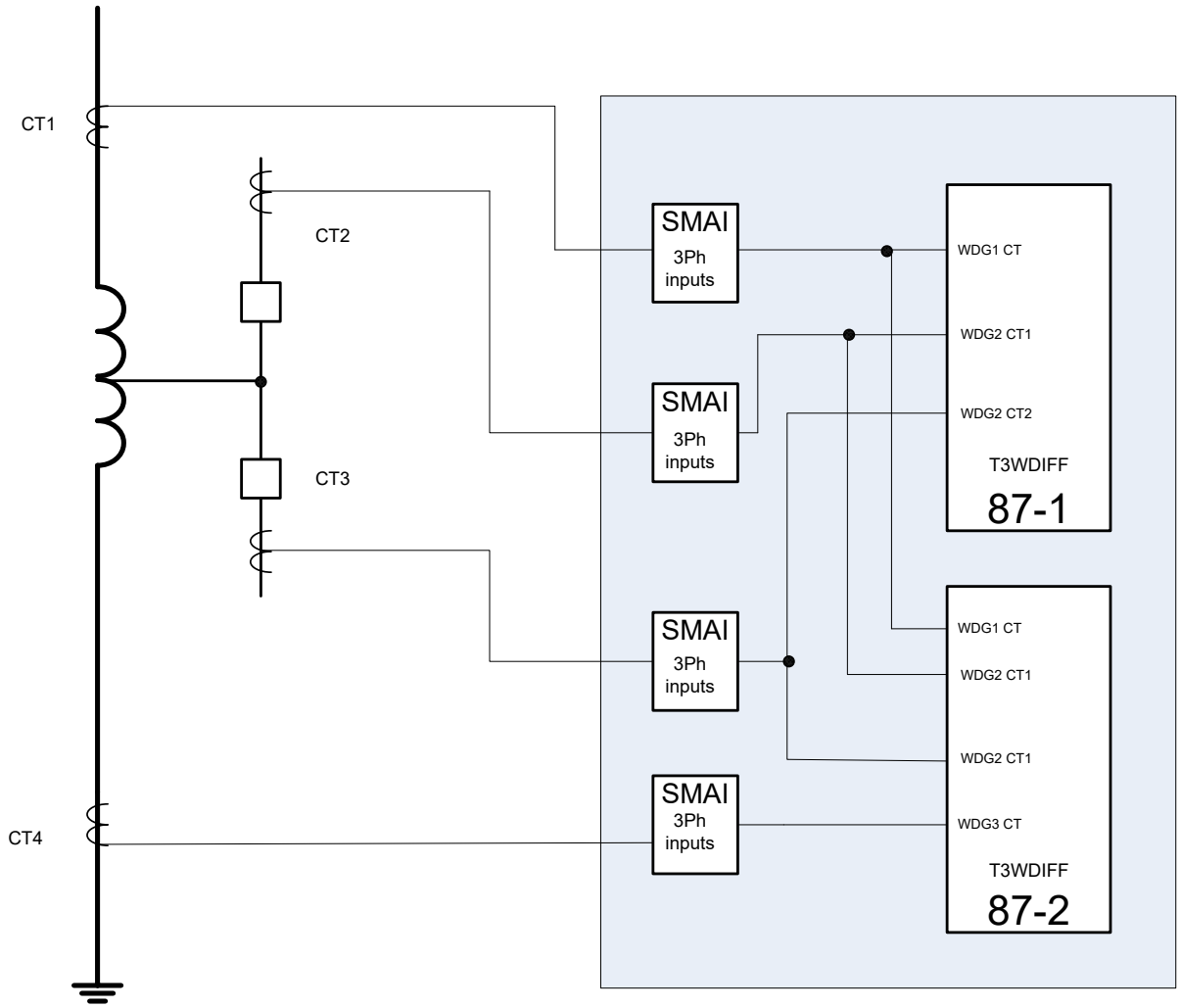


Differential Protection for a 240kV Autotransformer

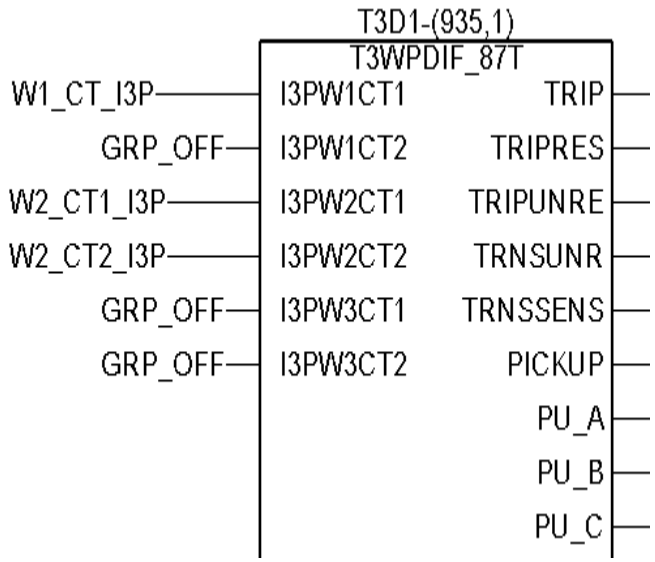
Transformer Data

- 240/72/13.8kV 270/360/450MVA autotransformer
- Tertiary is not loaded
- OLTC with 33 positions, voltage range from 204kV to 262 kV
- Neutral side phase CTs are available

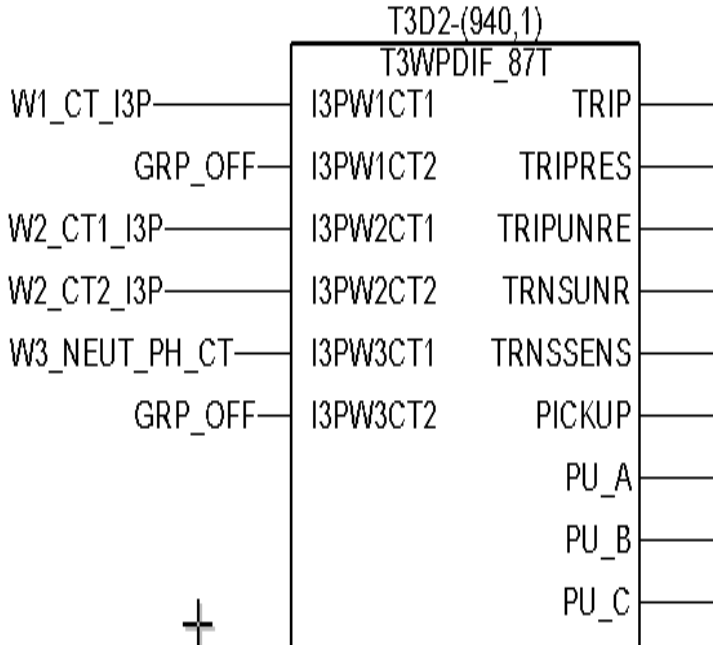
Dual Differential in One Relay



Dual Differential Configuration



Conventional Diff. 87-1



Phase Segregated Diff. 87-2

Setting Phase Segregated Diff.

- The T3WDiff function block needs to be set properly to perform the phase segregated differential calculations.

Settings	Phase segregated differential 87-2
Transformer MVA	450
Transformer WDG1 Rated Voltage (kV)	72
Transformer WDG2 Rated Voltage (kV)	72
Transformer WDG3 Rated Voltage (kV)	72
WDG1 CT ‘T’ Connection(2 CTs)	No
WDG2 CT ‘T’ Connection(2 CTs)	Yes
WDG3 CT ‘T’ Connection(2 CTs)	No
WDG1 3Io Removal	No
WDG2 3Io Removal	No
WDG3 3Io Removal	No

Setting Optimization

- 2nd Harmonic settings:
- Phase segregated differential does not need harmonic restraint setting
- Conventional differential 2nd harmonic restraint setting can be safely lowered to reduce the possibility of false tripping during inrush

Setting Optimization

Restraint Characteristic Settings

- Phase segregated differential slope can be set 5-10% lower than the convential 87, for transformers with OLTC
- Minimal pickup setting can be set as low as 0.1 p.u.

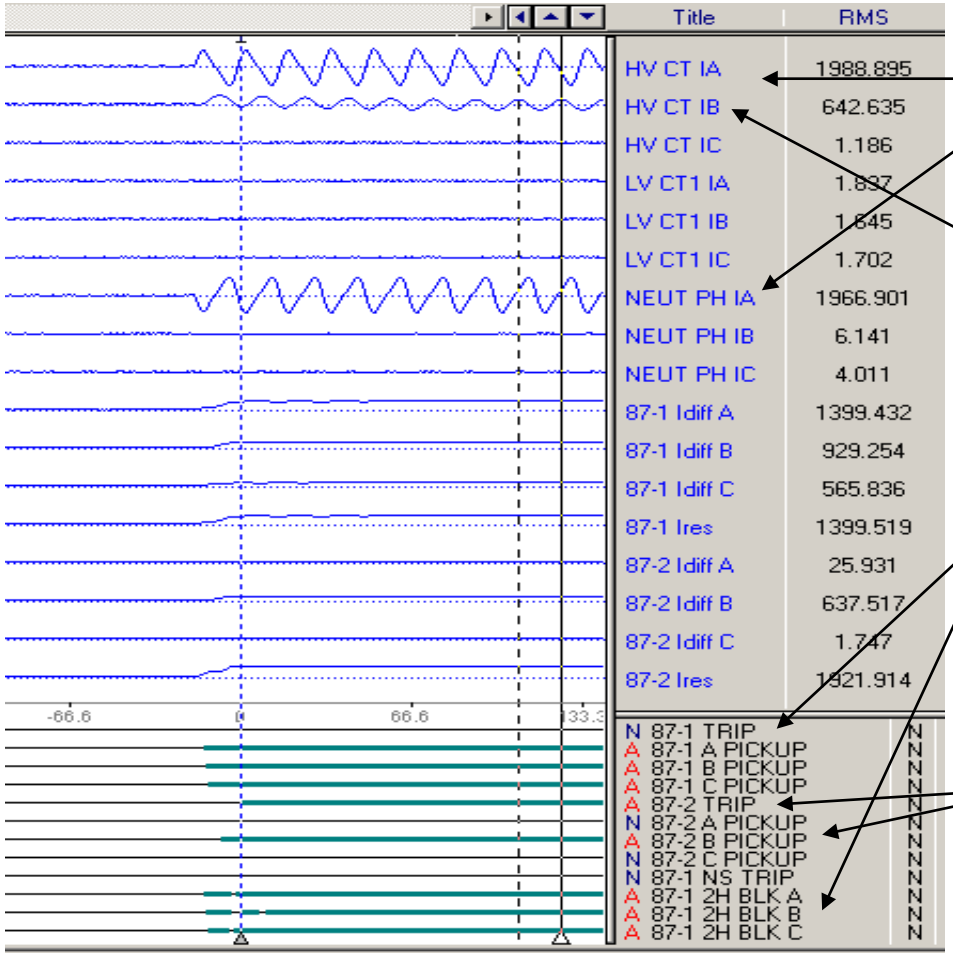
Setting Optimization

- Turn-to-turn fault is protected by the sensitive negative sequence current element.

Setting Optimization

Settings	87-1	87-2
Minimal Pickup	0.25	0.15
Slope 1 starting value	0.8	0.6
Slope 1 percentage	30	25
Slope 2 starting value	3.0	3.0
Slope 2 percentage	85	85
Unrestrained Differential pickup	15	15
2nd harmonic percentage	10	100 (max)
Harmonic cross blocking mode	Yes	No
Sensitive Negative Sequence Element Enable	Yes	No
Negative sequence pickup level	0.04	N/A

Transform Switch onto Fault Test



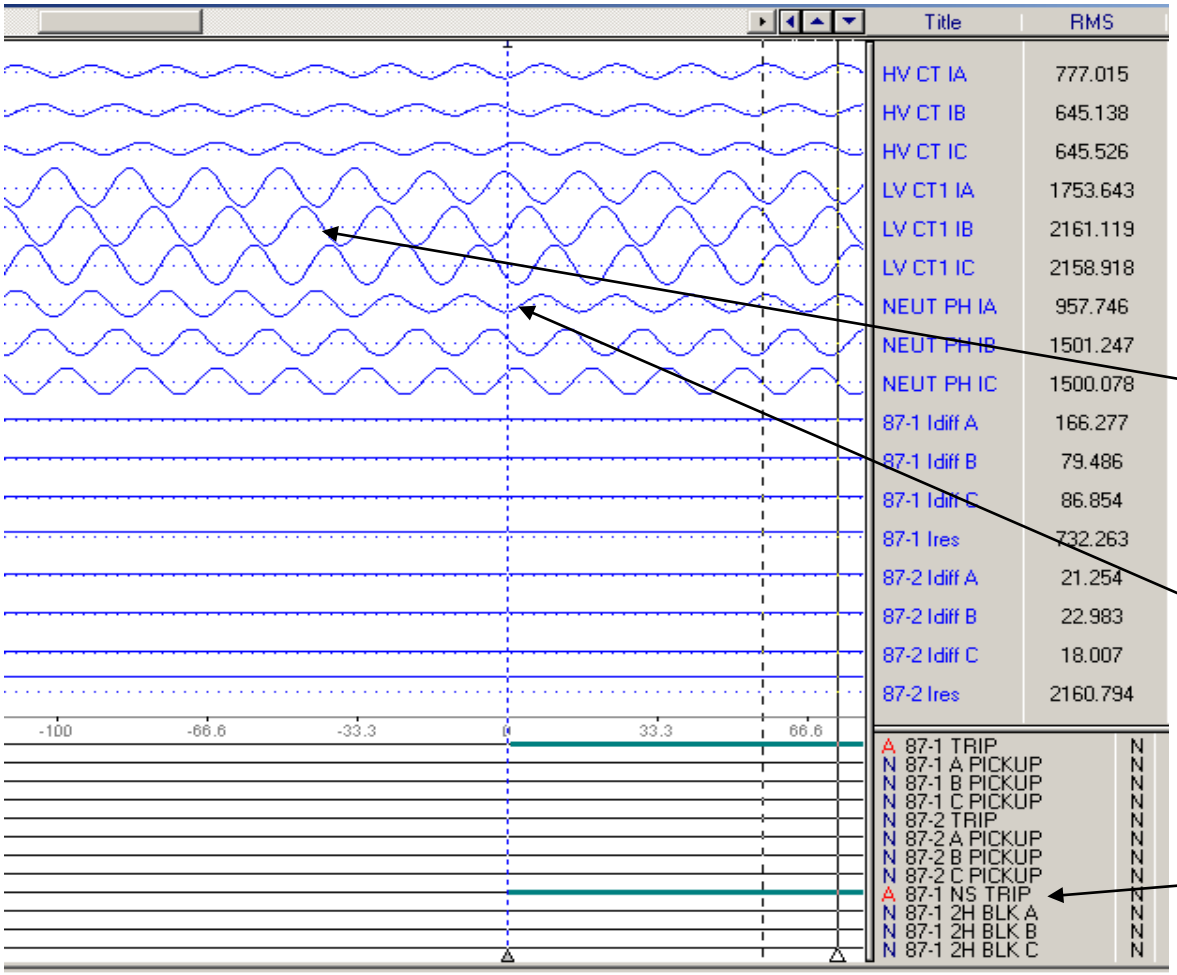
Simulated inrush current

Simulated fault current

87-1 was inhibited by 2nd harmonic

87-2 phs B operated

Transformer Turn-to-turn Fault Test



Simulated turn-to-turn fault in phase A

Pre-fault normal load

Fault inception

87-1 Negative Sequence element tripped