



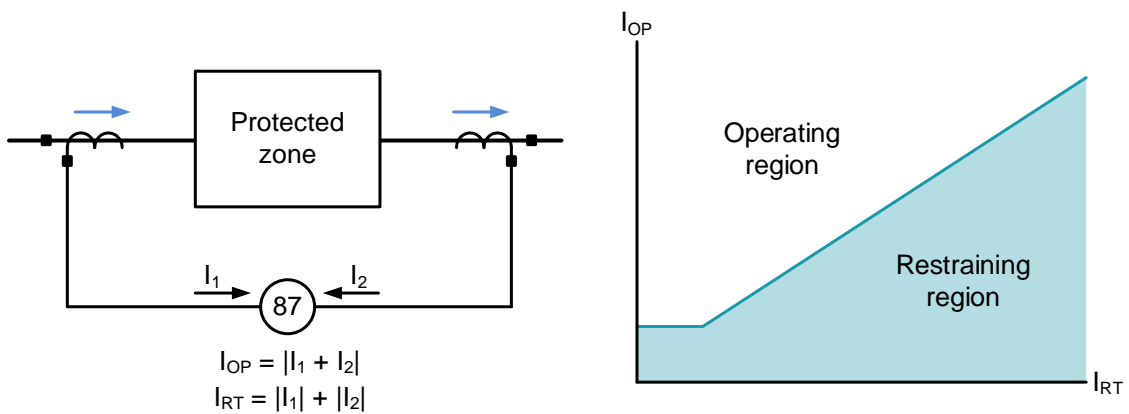
Stop the Epidemic! Transformer Protection Misoperations

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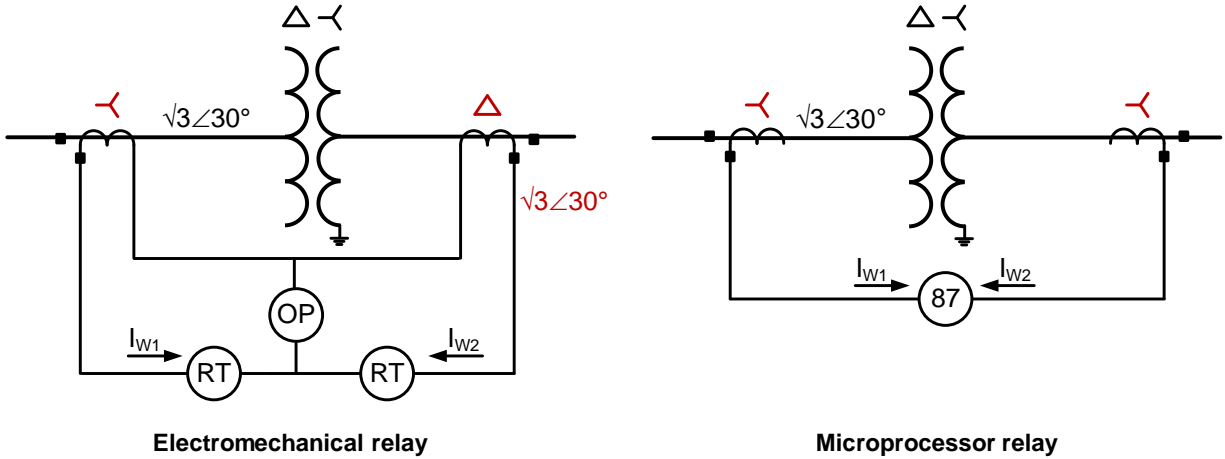
1

Percent-restrained differential



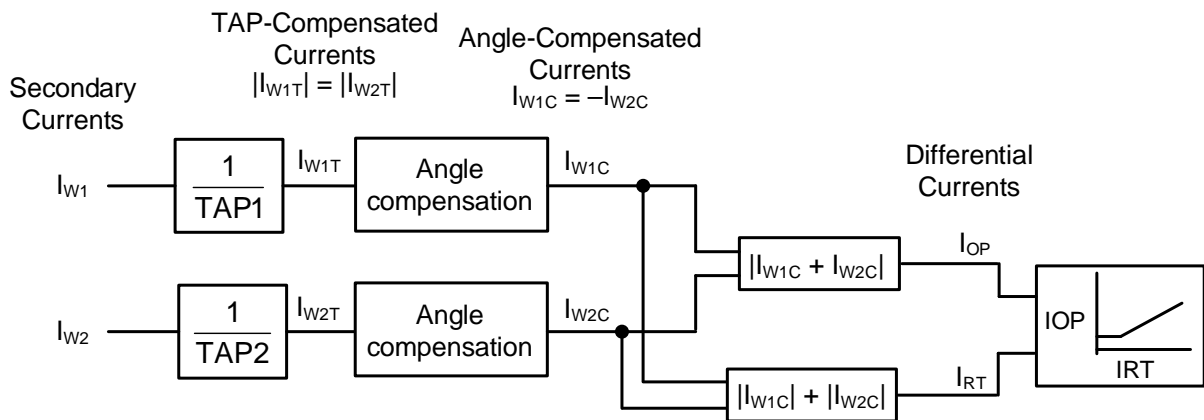
2

Protecting a transformer



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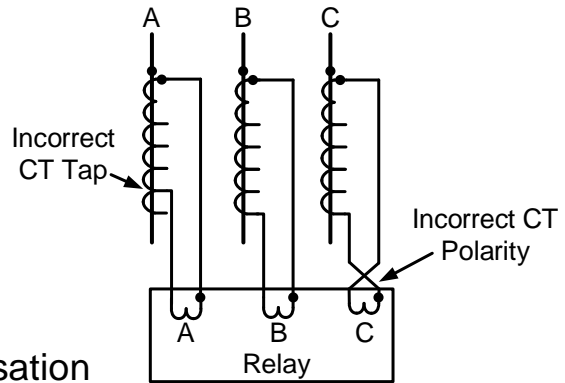
Inside an 87R relay



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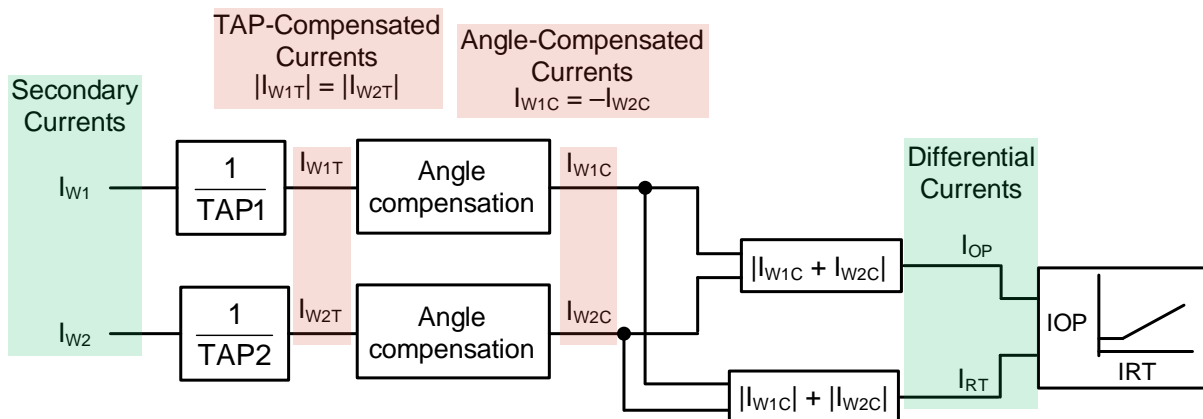
What could possibly go wrong?

- CT wiring errors
 - Swapped phases
 - Incorrect polarity
 - Incorrect tap position
- Settings errors
 - Incorrect TAP compensation
 - Incorrect phase angle compensation



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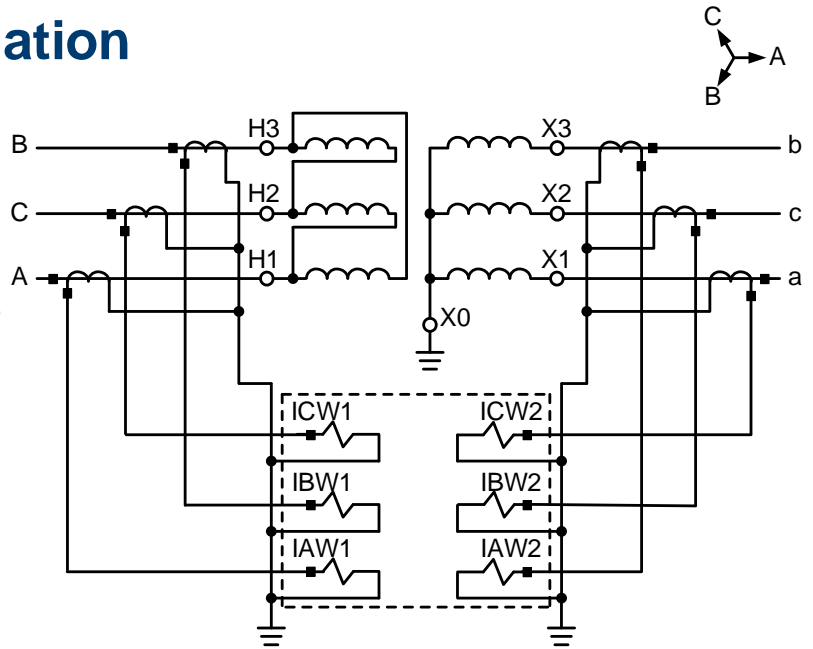
Data for troubleshooting



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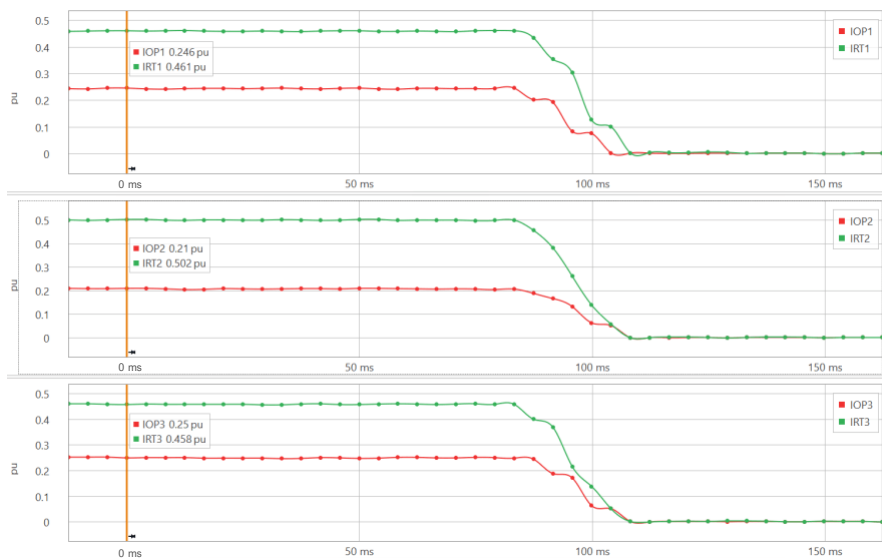
Example installation

- DABY (Dyn1) distribution transformer
- 30 MVA, 69 kV / 12.47 kV
- Standard CT connections
- ABC system phase sequence
- Non-standard phase-to-bushing connections
- Data from event reports



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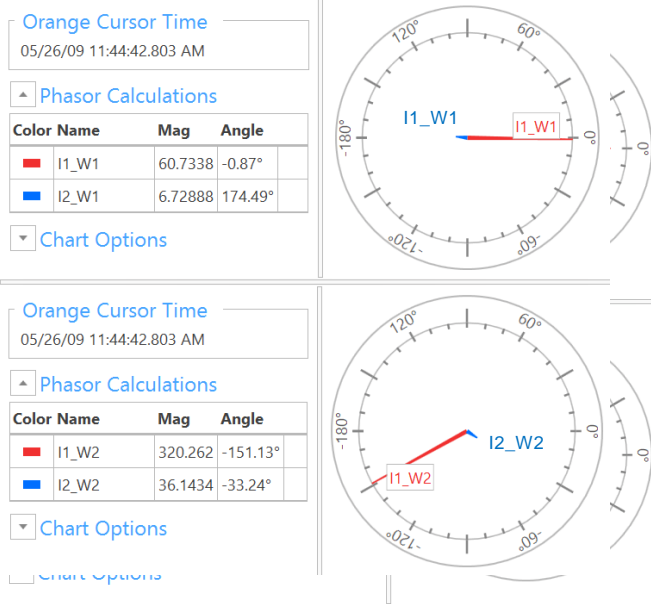
Check OP current



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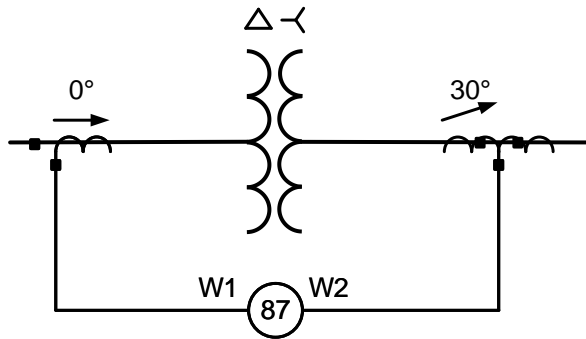
Swapped phases

- Examine phase sequence for each winding
- $I1 > I2$ for each winding

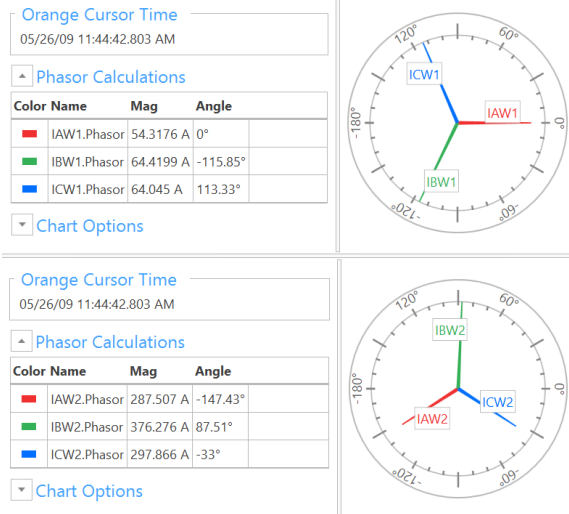
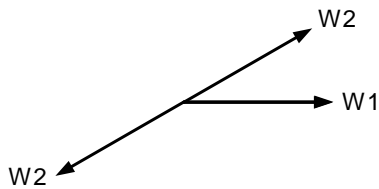


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Incorrect CT polarity



Phasors at relay



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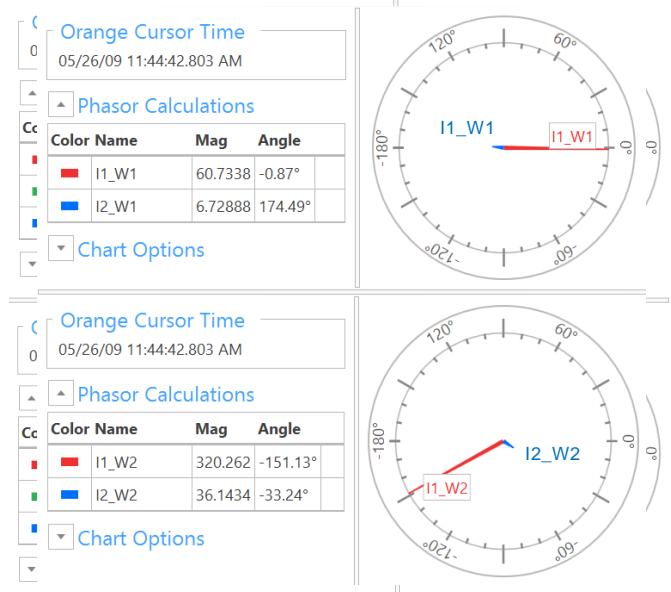
Incorrect CT Tap position (one CT)

- Check for matching phase current magnitudes on each winding
- Evaluate

$$\frac{I1_W1}{I2_W1} \approx \frac{I1_W2}{I2_W2}$$

$$\frac{60.73}{6.73} \approx \frac{320.26}{36.14}$$

$$9.02 \approx 8.86$$



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Three-phase magnitude problems

- TAP settings entered in wrong order
- One TAP setting calculated using different MVA
- CT ratio in settings \neq CT ratio in field
 - Compare load data to another device
 - Check if currents after TAP compensation are equal
 - Calculate expected currents based on transformer ratio

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Calculate expected currents based on transformer ratio

$$IAW2 \approx IAW1 \cdot \frac{V_{W1}}{V_{W2}}$$

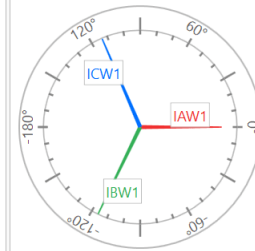
$$IAW2 \approx 54.32 \cdot \frac{69}{12.47} = 300.57 \text{ A}$$

Orange Cursor Time
05/26/09 11:44:42.803 AM

Phasor Calculations

Color Name	Mag	Angle
IAW1.Phasor	54.3176 A	0°
IBW1.Phasor	64.4199 A	-115.85°
ICW1.Phasor	64.045 A	113.33°

Chart Options

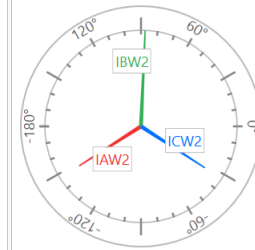


Orange Cursor Time
05/26/09 11:44:42.803 AM

Phasor Calculations

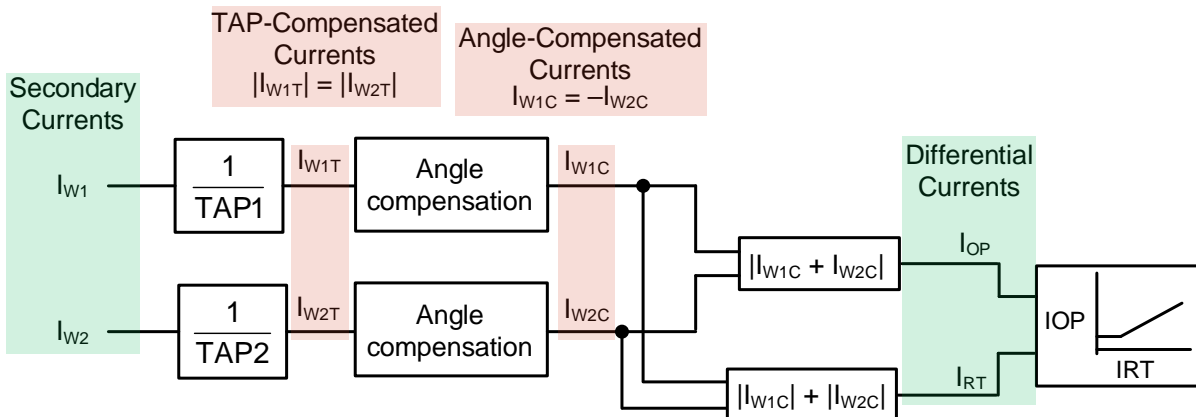
Color Name	Mag	Angle
IAW2.Phasor	287.507 A	-147.43°
IBW2.Phasor	376.276 A	87.51°
ICW2.Phasor	297.866 A	-33°

Chart Options



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Incorrect phase angle compensation



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Obtaining compensated currents

- Manually
- Spreadsheets
- Event software calculations

$$\begin{bmatrix} IAW1C \\ IBW1C \\ ICW1C \end{bmatrix} = \frac{1}{CTR1 \cdot TAP1} \cdot [\text{Matrix } 0] \cdot \begin{bmatrix} IAW1 \\ IBW1 \\ ICW1 \end{bmatrix}$$

Magnitude, Angle, and Phase Rotation Check (MET SEC<Enter> Command)									
Winding 1	IAW1		IBW1		ICW1		3I2W1		Command
I (A, Sec)	Read	Expected	Read	Expected	Read	Expected	Read	Expected	
Angle (deg)	0	0	-119	-120	120	120	0.04	0.00	

Calculations

#----- User Settings -----

CTR1 = CTR1.set #define CT ratio for winding 1

CTR2 = CTR2.set #define CT ratio for winding 2

W1CTC = 0 #define compensation matrix setting for winding 1

W2CTC = 1 #define compensation matrix setting for winding 2

TAP1 = TAP1.Set #define TAP setting for winding 1

TAP2 = TAP2.Set #define TAP setting for winding 2

W1CT = 0 #set to 0 for wye and 1 for delta

W2CT = 0 #set to 0 for wye and 1 for delta

$$\begin{bmatrix} IAW2C \\ IBW2C \\ ICW2C \end{bmatrix} = \begin{bmatrix} 0.25 \angle -116 \\ 0.24 \angle 113 \\ 0.21 \angle 0 \end{bmatrix}$$

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Are compensated currents equal and 180° out of phase?

Calculations

#----- User Settings -----

CTR1 = CTR1.set #define CT ratio for winding 1

CTR2 = CTR2.set #define CT ratio for winding 2

W1CTC = 0 #define compensation matrix setting for winding 1

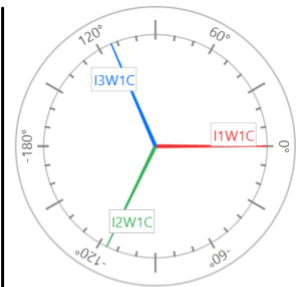
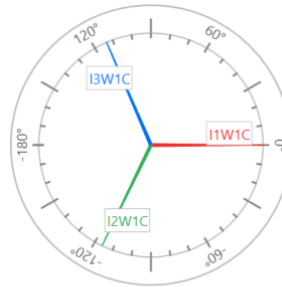
W2CTC = 1 #define compensation matrix setting for winding 2

TAP1 = TAP1.Set #define TAP setting for winding 1

TAP2 = TAP2.Set #define TAP setting for winding 2

W1CT = 0 #set to 0 for wye and 1 for delta

W2CT = 0 #set to 0 for wye and 1 for delta



Existing compensation

Corrected compensation

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Comprehensive differential metering report gives you eyes on it all

Operate Currents (per unit)			Restraint Currents (per unit)		
IOPA	IOPB	IOPC	IRTA	IRTB	IRTC
0.00	0.03	0.02	0.41	0.49	0.49

Tap and Matrix Compensation:				Reference Terminal = S		
Phase A	Terminal Currents			Tap Comp. (per unit)	Matrix Comp.	
	(A,pri)	(A,sec)	(DEG)		(per unit)	(DEG)
IAS	51.52	0.64	0.00	0.21	0.21	0.00
IAT	285.53	0.71	-149.74	0.21	0.21	179.95
Phase B						
IBS	63.37	0.79	-120.01	0.25	0.25	-120.01
IBT	363.07	0.91	90.78	0.26	0.23	64.51
Phase C						
ICS	63.55	0.79	120.72	0.25	0.25	120.72
ICT	294.44	0.74	-29.34	0.21	0.24	-62.72

Compensation Settings:

CTCONS: Y	TAPS: 3.14	TSCTC: 0
CTCONT: Y	TAPT: 3.47	TTCTC: 11

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Help us stop the epidemic!

- Finding errors in transformer differential installations can be complicated
- Procedure in paper can be used to identify all types of installation errors (wiring and settings)
- Comprehensive differential metering reports are one-stop-shop for data



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Questions?