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Application of Standard Three Phase Power Transformer Protection Relays to Special Railway Transformers

Mike Kockott, Zoran Gajić, Bharadwaj Vasudevan, Alexandre Piatniczka

Hitachi Energy

Overview

- Introduction
- 87T protection for
  - Three-phase, two-winding power transformer
  - Three-phase, three-winding power transformer
  - Single-phase railway transformer
  - Split single-phase railway transformer
  - Railway autotransformer
  - Scott transformer
- Other protections
- Conclusions

Introduction

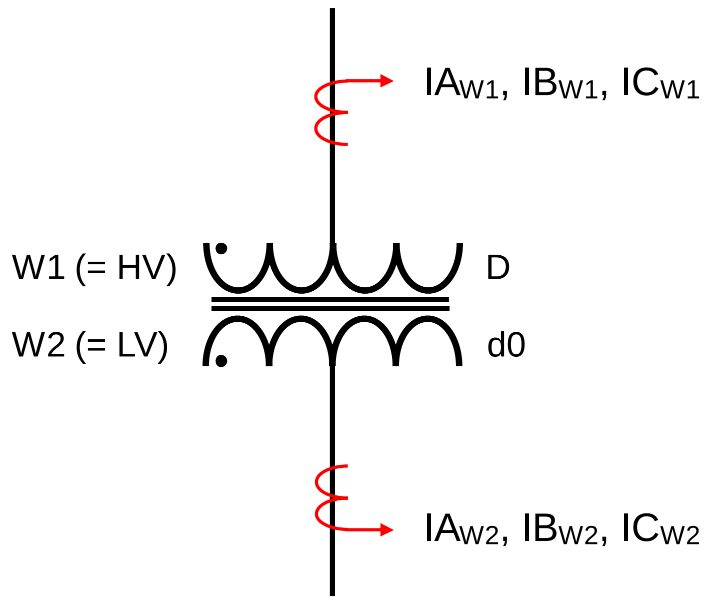
- Triggered by a US project
- Objective: to show how to use standard three-phase transformer protection relays to protect 50/60Hz railway transformers
  - 50/60Hz railway systems are found in many countries around the world, including the US
- To bear in mind:
  - three-phase transformer protection relays treat the analog quantities in a three-phase manner
  - for non three-phase railway transformer applications the analog quantities will be treated in the same way

Three-phase, two-winding power transformer

- Balanced through-load

$$|I_{W1}| = \frac{V_{W2}}{V_{W1}} * |I_{W2}|$$

$$= \frac{V_{LV}}{V_{HV}} * |I_{W2}|$$



- Per phase differential currents for Dd0 transformer

$$\overline{ID\_A} = \overline{IA_{HV}} + \frac{V_{LV}}{V_{HV}} * \overline{IA_{LV}}$$

$$\overline{ID\_B} = \overline{IB_{HV}} + \frac{V_{LV}}{V_{HV}} * \overline{IB_{LV}}$$

$$\overline{ID\_C} = \overline{IC_{HV}} + \frac{V_{LV}}{V_{HV}} * \overline{IC_{LV}}$$

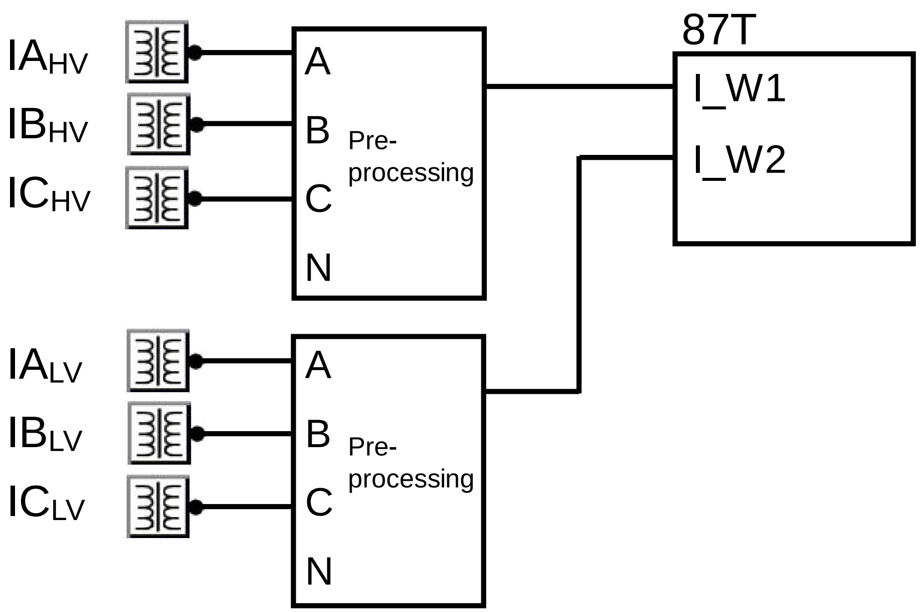
Three-phase, two-winding power transformer

- Differential current matrix equation for Dd0 transformer

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overbrace{\begin{bmatrix} \overline{IA_{HV}} \\ \overline{IB_{HV}} \\ \overline{IC_{HV}} \end{bmatrix}}^{I\_W1} + \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overbrace{\begin{bmatrix} \overline{IA_{LV}} \\ \overline{IB_{LV}} \\ \overline{IC_{LV}} \end{bmatrix}}^{I\_W2}$$

Three-phase, two-winding power transformer

- Connection of currents to the 87T function



Three-phase, two-winding power transformer

- Rated values

W1	$S_{R1} = S$	$V_{R1} = V_{HV}$	$I_{R1} = \frac{S}{\sqrt{3} * V_{HV}}$
W2	$S_{R2} = S$	$V_{R2} = V_{LV}$	$I_{R2} = \frac{S}{\sqrt{3} * V_{LV}}$

- Typical settings

Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Clock Number W2	0 (0 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off

Three-phase, two-winding power transformer

- Example

Dd0 transformer S = 120MVA V_{R1} = 230kV V_{R2} = 66kV

For balanced through-load, for LV-side currents = 524.9A = 50%I_{R2}, HV-side currents will be = 150.6A

$IA_{HV} = 150.6\angle 0°$ $IA_{LV} = 524.9\angle 180°$

$IB_{HV} = 150.6\angle -120°$ $IB_{LV} = 524.9\angle 60°$

$IC_{HV} = 150.6\angle 120°$ $IC_{LV} = 524.9\angle -60°$

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 150.6\angle 0° \\ 150.6\angle -120° \\ 150.6\angle 120° \end{bmatrix} + \frac{66}{230} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 524.9\angle 180° \\ 524.9\angle 60° \\ 524.9\angle -60° \end{bmatrix}$$

$$= \begin{bmatrix} 150.6\angle 0° \\ 150.6\angle -120° \\ 150.6\angle 120° \end{bmatrix} + \begin{bmatrix} 150.6\angle 180° \\ 150.6\angle 60° \\ 150.6\angle -60° \end{bmatrix}$$

Three-phase, three-winding power transformer

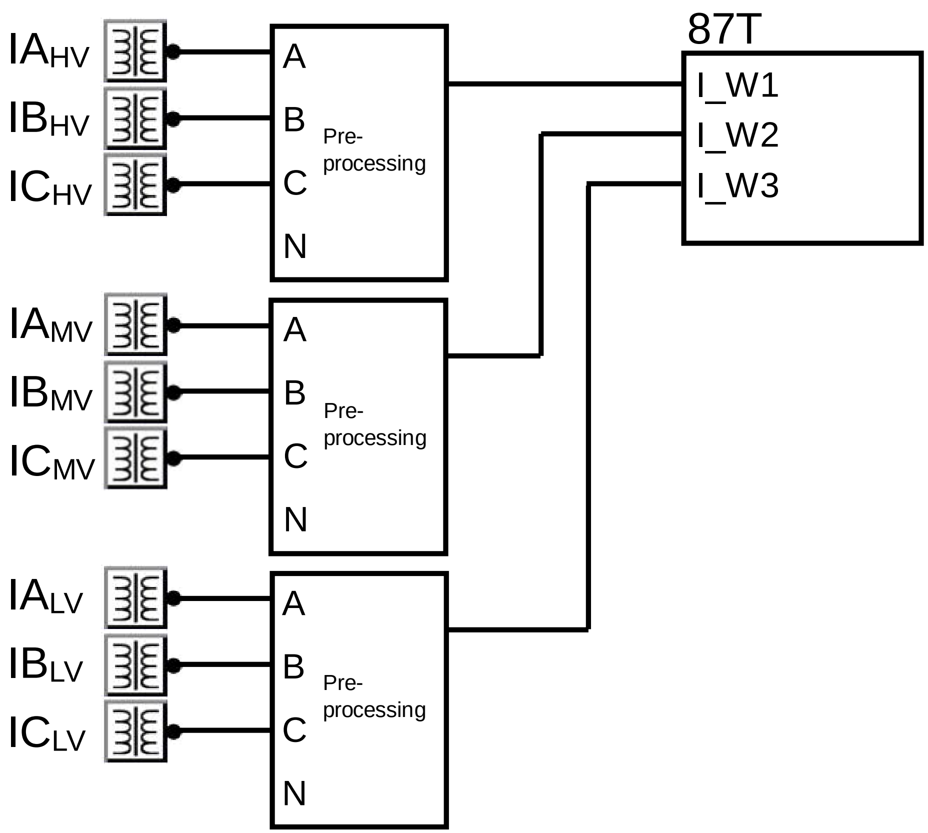
- Differential current matrix equation for Dd0d0 transformer

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \underbrace{\begin{bmatrix} \overline{IA_{HV}} \\ \overline{IB_{HV}} \\ \overline{IC_{HV}} \end{bmatrix}}_{I\_W1} + \frac{V_{MV}}{V_{HV}} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \underbrace{\begin{bmatrix} \overline{IA_{MV}} \\ \overline{IB_{MV}} \\ \overline{IC_{MV}} \end{bmatrix}}_{I\_W2}$$

$$+ \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \underbrace{\begin{bmatrix} \overline{IA_{LV}} \\ \overline{IB_{LV}} \\ \overline{IC_{LV}} \end{bmatrix}}_{I\_W3}$$

Three-phase, three-winding power transformer

- Connection of currents to the 87T function



- Typical settings

Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Voltage W3	V_{R3}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Rated Current W3	I_{R3}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Connect Type W3	Delta (D)
Clock Number W2	0 (0 deg)
Clock Number W3	0 (0 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off
ZS Current Subtraction W3	Off

Single-phase railway transformer

- Balanced through-load

$$|IA| = \frac{V_{LV}}{V_{HV}} * |IM|$$

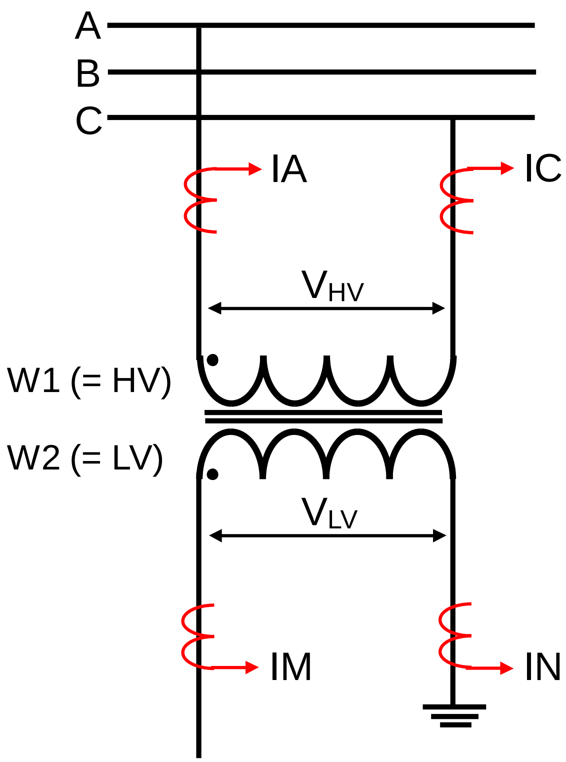
$$|IC| = \frac{V_{LV}}{V_{HV}} * |IN|$$

- Per phase differential currents

$$\overline{ID\_A} = \overline{IA} + \frac{V_{LV}}{V_{HV}} * \overline{IM}$$

$$\overline{ID\_B} = 0$$

$$\overline{ID\_C} = \overline{IC} + \frac{V_{LV}}{V_{HV}} * \overline{IN}$$



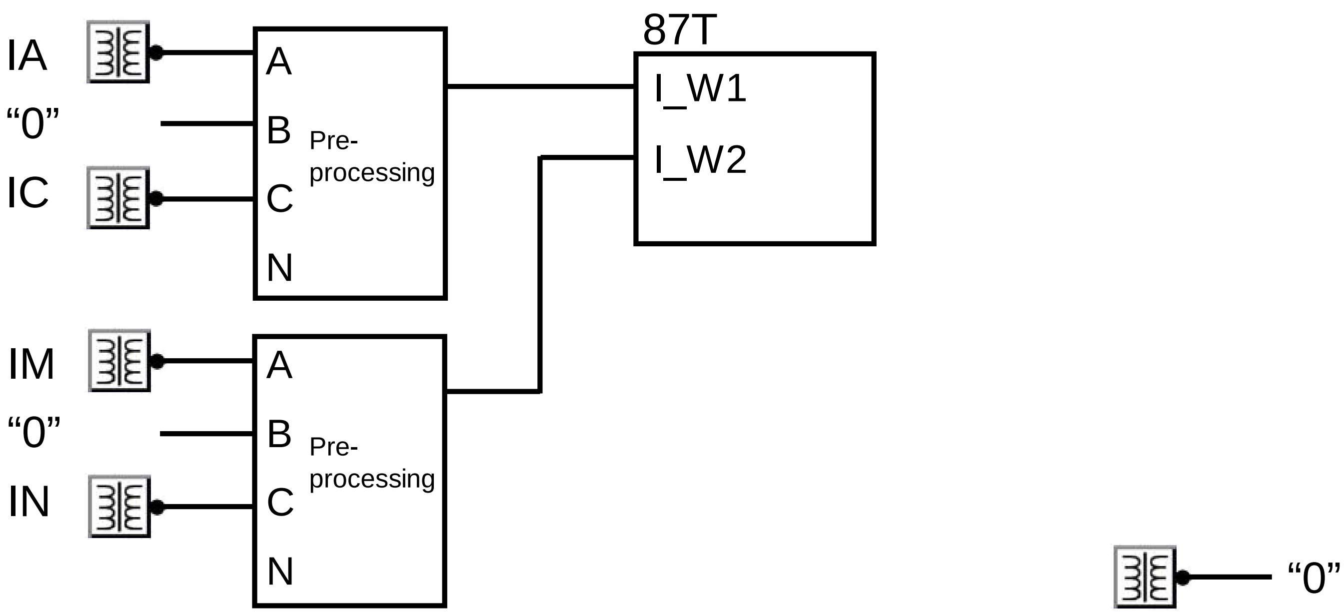
Single-phase railway transformer

- Differential current matrix equation for single-phase railway transformer

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overset{I\_W1}{\begin{bmatrix} \overline{IA} \\ 0 \\ \overline{IC} \end{bmatrix}} + \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overset{I\_W2}{\begin{bmatrix} \overline{IM} \\ 0 \\ \overline{IN} \end{bmatrix}}$$

Single-phase railway transformer

- Connection of currents to the 87T function



Single-phase railway transformer

- Rated values

W1	$S_{R1} = S$	$V_{R1} = V_{HV}$	$I_{R1} = \frac{S}{V_{HV}}$
W2	$S_{R2} = S$	$V_{R2} = V_{LV}$	$I_{R2} = \frac{S}{V_{HV}}$

- Typical settings

Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Clock Number W2	0 (0 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off

Single-phase railway transformer

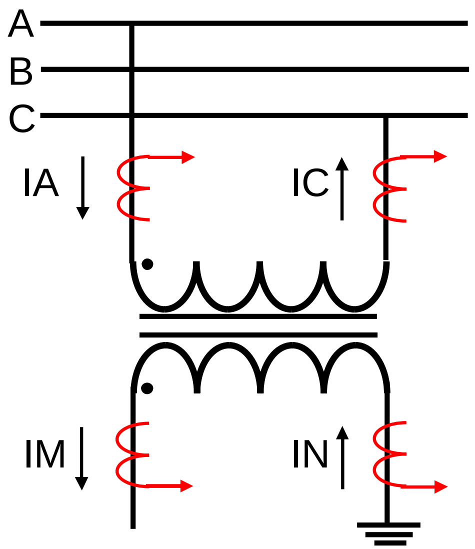
- Example

  Single-phase railway transformer S = 30MVA V_{R1} = 115kV V_{R2} = 27.5kV

  For balanced through-load, for LV-side currents = 545.4A = 50%I_{R2}, HV-side currents will be = 130.4A

  IA = 130.4∠0° IM = 545.4∠180°

  IC = 130.4∠180° IN = 545.4∠0°



Single-phase railway transformer

- Example

Single-phase railway transformer S = 30MVA V_{R1} = 115kV V_{R2} = 27.5kV

For balanced through-load, for LV-side currents = 545.4A = 50%I_{R2}, HV-side currents will be = 130.4A

IA = 130.4∠0° IM = 545.4∠180°

IC = 130.4∠180° IN = 545.4∠0°

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 130.4\angle 0^\circ \\ 0 \\ 130.4\angle 180^\circ \end{bmatrix} + \frac{27.5}{115} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 545.4\angle 180^\circ \\ 0 \\ 545.4\angle 0^\circ \end{bmatrix}$$

$$= \begin{bmatrix} 130.4\angle 0^\circ \\ 0 \\ 130.4\angle 180^\circ \end{bmatrix} + \begin{bmatrix} 130.4\angle 180^\circ \\ 0 \\ 130.4\angle 0^\circ \end{bmatrix}$$

Split single-phase railway transformer

- Balanced load

$$|IA| = \frac{V_{LV}}{V_{HV}} * |IM| + \frac{V_{LV}}{V_{HV}} * |IS|$$

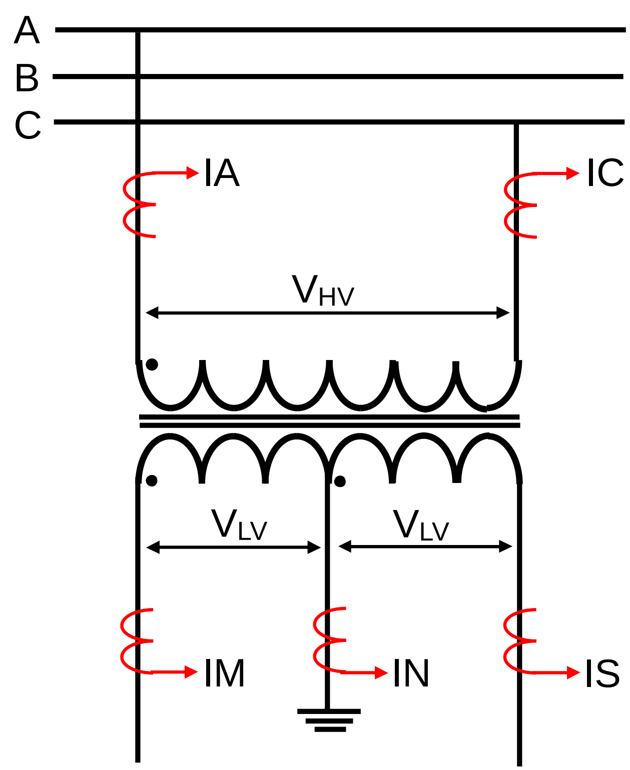
$$|IC| = \frac{V_{LV}}{V_{HV}} * |IS| + \frac{V_{LV}}{V_{HV}} * |IM|$$

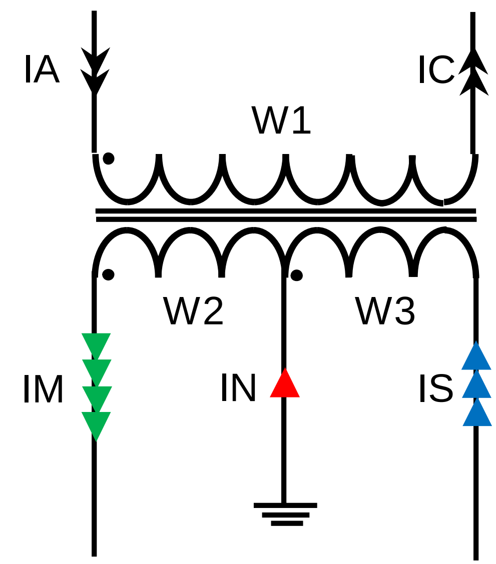
- Per phase differential currents

$$\overline{ID\_A} = \overline{IA} + \frac{V_{LV}}{V_{HV}} * \overline{IM} + \frac{V_{LV}}{V_{HV}} * (-\overline{IS})$$

$$\overline{ID\_B} = 0$$

$$\overline{ID\_C} = \overline{IC} + \frac{V_{LV}}{V_{HV}} * \overline{IS} + \frac{V_{LV}}{V_{HV}} * (-\overline{IM})$$





$V_{W1} = V_{HV}$
$V_{W2} = V_{W3} = V_{LV}$

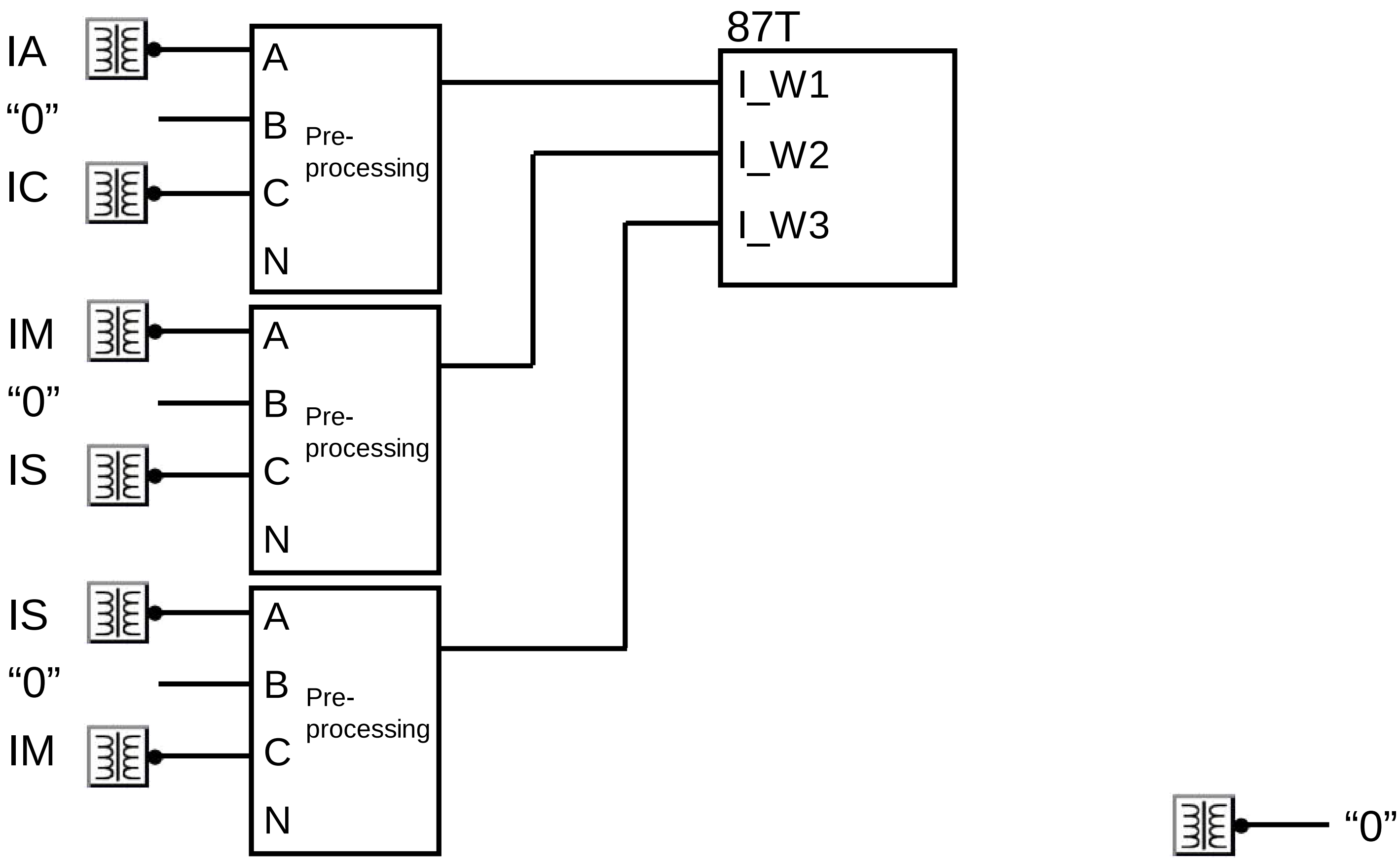
Split single-phase railway transformer

- Differential current matrix equation for split single-phase railway transformer

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overset{I\_W1}{\begin{bmatrix} \overline{IA} \\ 0 \\ \overline{IC} \end{bmatrix}} + \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overset{I\_W2}{\begin{bmatrix} \overline{IM} \\ 0 \\ \overline{IS} \end{bmatrix}} + \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} * \overset{I\_W3}{\begin{bmatrix} \overline{IS} \\ 0 \\ \overline{IM} \end{bmatrix}}$$

Split single-phase railway transformer

- Connection of currents to the 87T function



Split single-phase railway transformer

- Rated values

W1	$S_{R1} = S$	$V_{R1} = V_{HV}$	$I_{R1} = \frac{S}{V_{HV}}$
W2	$S_{R2} = \frac{S}{2}$	$V_{R2} = V_{LV}$	$I_{R2} = \frac{S}{2*V_{HV}}$
W3	$S_{R3} = \frac{S}{2}$	$V_{R3} = V_{LV}$	$I_{R3} = \frac{S}{2*V_{HV}}$

- Typical settings

Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Voltage W3	V_{R3}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Rated Current W3	I_{R3}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Connect Type W3	Delta (D)
Clock Number W2	0 (0 deg)
Clock Number W3	6 (180 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off
ZS Current Subtraction W3	Off

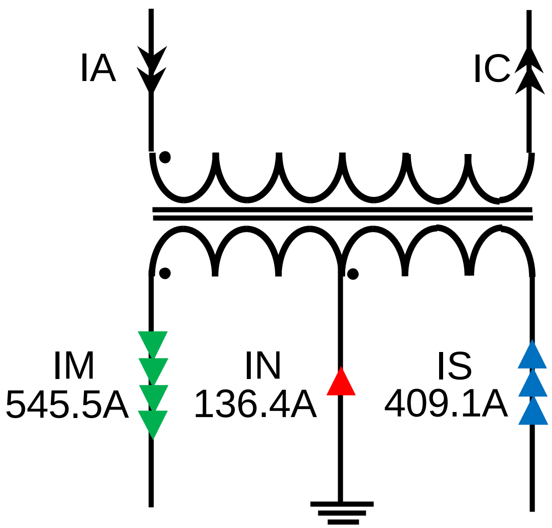
Split single-phase railway transformer

- Example

Split single-phase railway transformer S_{R1} = 60MVA S_{R2} = S_{R3} = 30MVA

V_{R1} = 115kV V_{R2} = V_{R3} = 27.5kV

Typical LV-side load profile



HV-side currents for balanced load flow

$IA = 228.3\angle 0°$

$IC = 228.3\angle 180°$

$IM = 545.5\angle 180° = 50\% I_{R2}$

$IS = 409.1\angle 0°$

Split single-phase railway transformer

- Example

  Split single-phase railway transformer

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 228.3\angle 0° \\ 0 \\ 228.3\angle 180° \end{bmatrix} + \frac{27.5}{115} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 545.4\angle 180° \\ 0 \\ 409.1\angle 0° \end{bmatrix}$$

$$+ \frac{27.5}{115} * \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} * \begin{bmatrix} 409.1\angle 0° \\ 0 \\ 545.4\angle 180° \end{bmatrix}$$

$$= \begin{bmatrix} 228.3\angle 0° \\ 0 \\ 228.3\angle 180° \end{bmatrix} + \begin{bmatrix} 130.4\angle 180° \\ 0 \\ 97.8\angle 0° \end{bmatrix} + \begin{bmatrix} 97.8\angle 180° \\ 0 \\ 130.4\angle 0° \end{bmatrix}$$

Railway autotransformer

- Balanced load

$$|IF| = \frac{V_{LV}}{V_{HV}} * |IC|$$

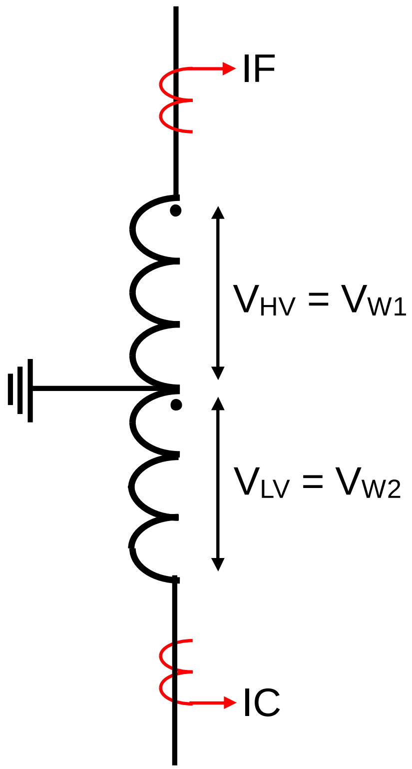
$$\frac{V_{LV}}{V_{HV}} = 1$$

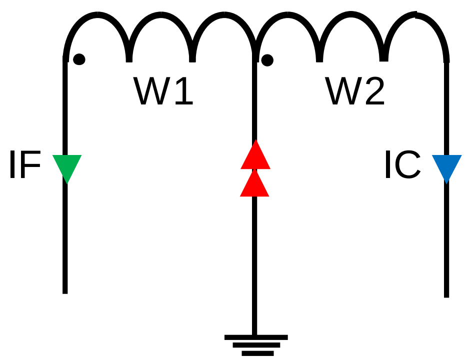
- Per phase differential currents

$$\overline{ID\_A} = 0$$

$$\overline{ID\_B} = 0$$

$$\overline{ID\_C} = \overline{IF} + \frac{V_{LV}}{V_{HV}} * (-\overline{IC}) = \overline{IF} + (-\overline{IC})$$





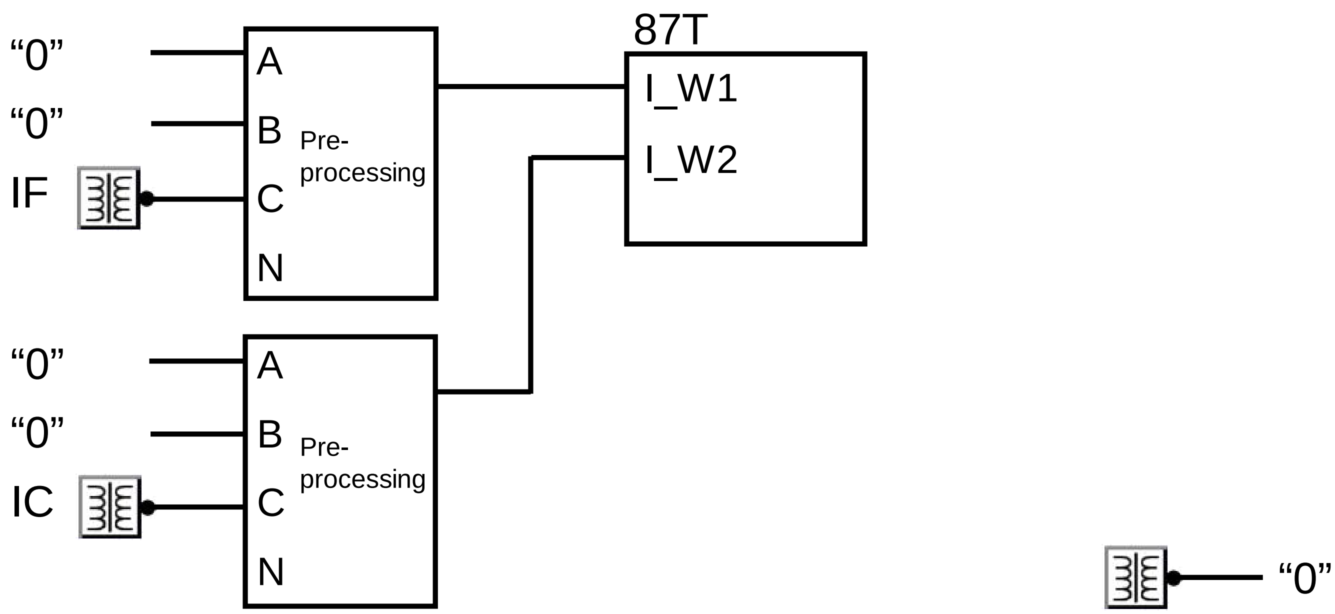
Railway autotransformer

- Differential current matrix equation for railway autotransformer

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \overset{I\_W1}{\begin{bmatrix} 0 \\ 0 \\ \overline{IF} \end{bmatrix}} + \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} * \overset{I\_W2}{\begin{bmatrix} 0 \\ 0 \\ \overline{IC} \end{bmatrix}}$$

Railway autotransformer

- Connection of currents to the 87T function



Railway autotransformer

- Rated values

W1	$S_{R1} = S$	$V_{R1} = V_{HV} = V_{LV}$	$I_{R1} = \frac{S}{V_{HV}}$
W2	$S_{R2} = S$	$V_{R2} = V_{LV} = V_{HV}$	$I_{R2} = \frac{S}{V_{HV}}$

- Typical settings

Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Clock Number W2	6 (180 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off

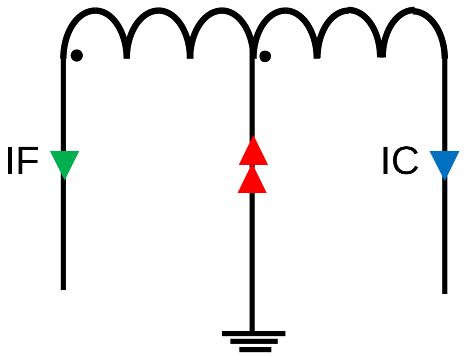
Railway autotransformer

- Example

  Railway autotransformer S = 5MVA V_{R1} = 27.5kV V_{R2} = 27.5kV

  For balanced load, for LV-side current IC = 136.4A, HV-side IF current will be = 136.4A

  IF = 136.4∠180° IC = 136.4∠180°



Railway autotransformer

- Example

  Railway autotransformer S = 5MVA V_{R1} = 27.5kV V_{R2} = 27.5kV

  For balanced load, for LV-side current IC = 136.4A, HV-side IF current will be = 136.4A

IF = 136.4∠180° IC = 136.4∠180°

$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 136.4\angle 180^\circ \end{bmatrix} + \frac{27.5}{27.5} * \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 136.4\angle 180^\circ \end{bmatrix}$$

$$= \begin{bmatrix} 0 \\ 0 \\ 136.4\angle 180^\circ \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 136.4\angle 0^\circ \end{bmatrix}$$

Railway autotransformer

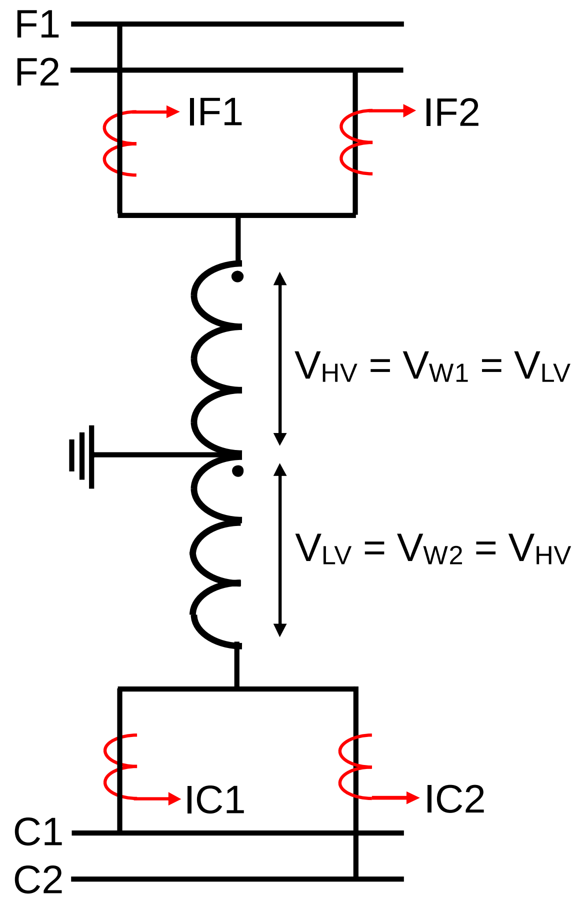
- Autotransformer shared between two track sections
- Per phase differential currents

$$\overline{ID\_A} = 0$$

$$\overline{ID\_B} = 0$$

$$\overline{ID\_C} = \overline{IF1} + \overline{IF2} + \frac{V_{LV}}{V_{HV}} * (-\overline{IC1}) + \frac{V_{LV}}{V_{HV}} * (-\overline{IC2})$$

$$= \overline{IF1} + \overline{IF2} + (-\overline{IC1} + -\overline{IC2})$$



Railway autotransformer

- Differential current matrix equation for railway autotransformer shared between two track sections

I_W1_1 (CT1) I_W1_2 (CT2)

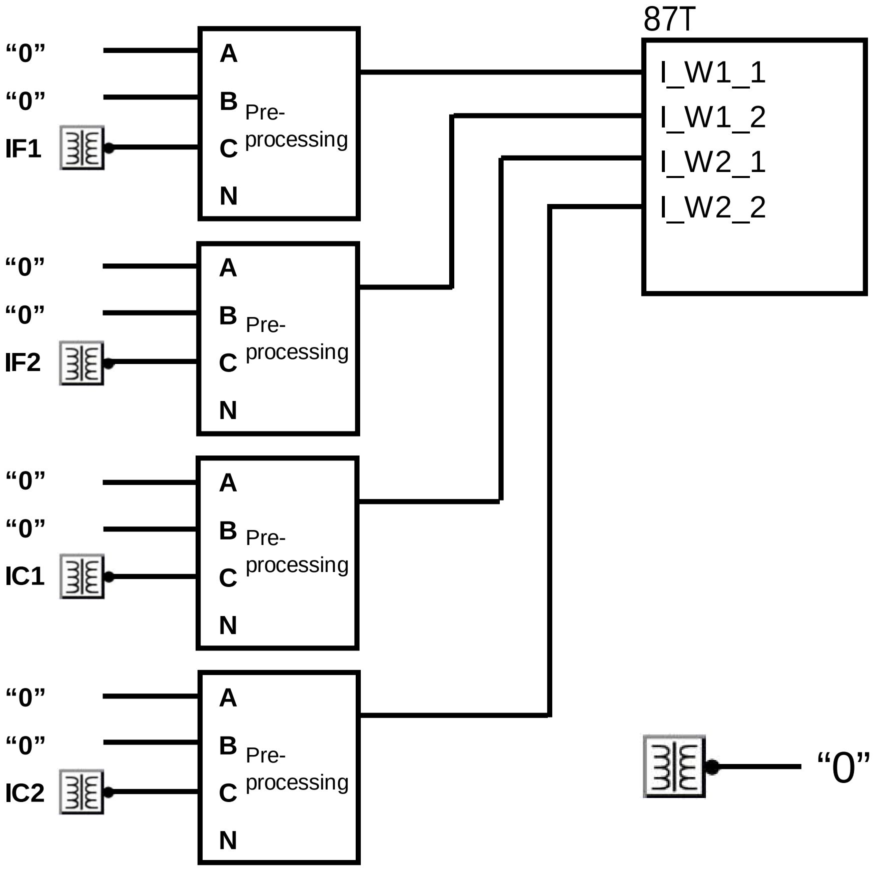
$$\begin{bmatrix} \overline{ID\_A} \\ \overline{ID\_B} \\ \overline{ID\_C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ \overline{IF1} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ \overline{IF2} \end{bmatrix}$$

I_W2_1 (CT1) I_W2_2 (CT2)

$$+ \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ \overline{IC1} \end{bmatrix} + \frac{V_{LV}}{V_{HV}} * \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ \overline{IC2} \end{bmatrix}$$

Railway autotransformer

- Connection of currents to the 87T function (autotransformer shared between two track sections)



- Typical settings

Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Clock Number W2	6 (180 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off

Scott transformer

- Balanced load

$$|IM| = \frac{\frac{1}{2} * V_{HV}}{V_{LV}} * |IB - IC|$$

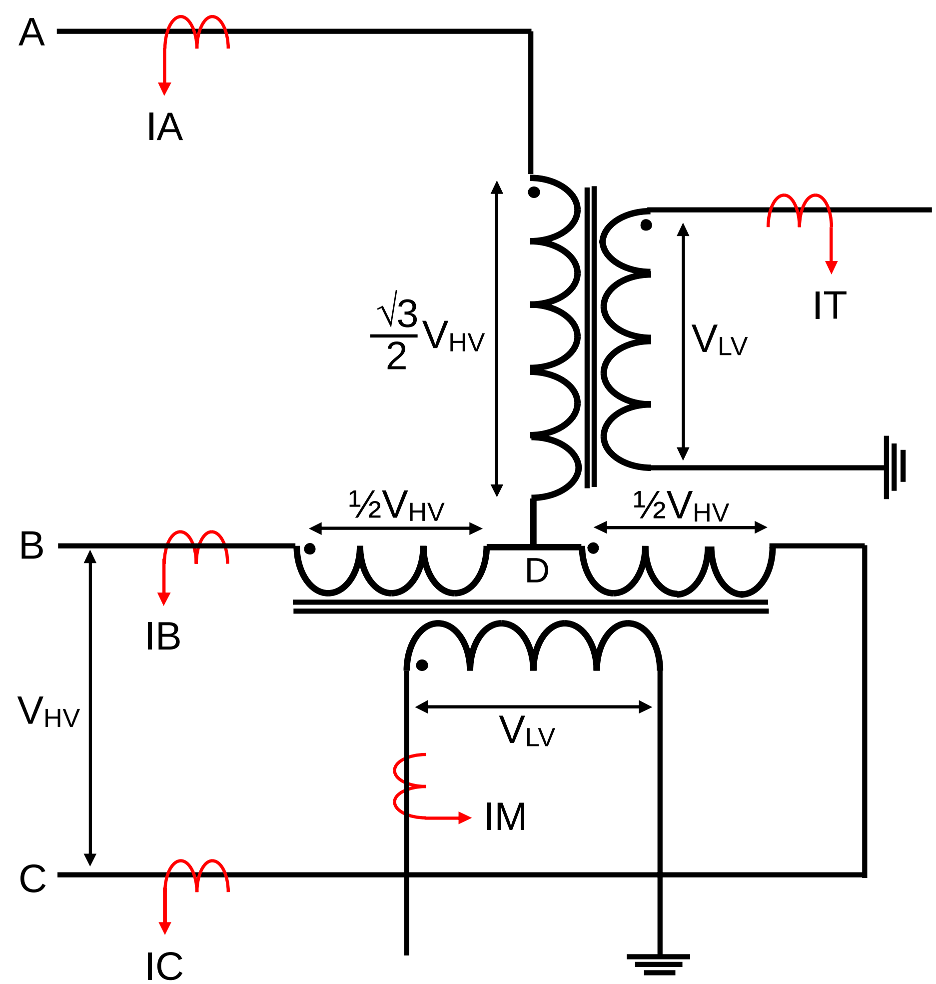
$$|IT| = \frac{\frac{\sqrt{3}}{2} * V_{HV}}{V_{LV}} * |IA|$$

- Per phase differential currents

$$\overline{ID\_A} = \overline{IT} + \frac{\frac{\sqrt{3}}{2} * V_{HV}}{V_{LV}} * \overline{IA}$$

$$\overline{ID\_B} = 0$$

$$\overline{ID\_C} = \overline{IM} + \frac{\frac{1}{2} * V_{HV}}{V_{LV}} * (\overline{IB} - \overline{IC})$$



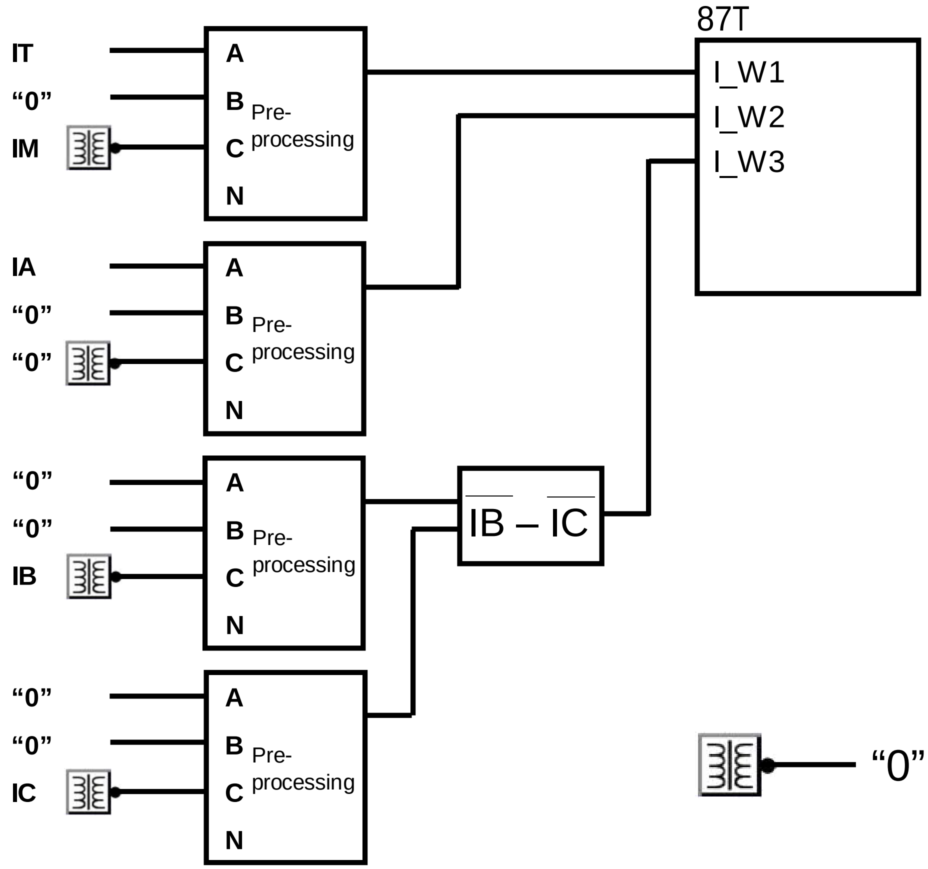
Scott transformer

- Differential current matrix equation for split single-phase railway transformer

$$\begin{bmatrix}\overline{ID\_A}\\ \overline{ID\_B}\\ \overline{ID\_C}\end{bmatrix} = \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} * \overset{I\_W1}{\begin{bmatrix}\overline{IT}\\ 0\\ \overline{IM}\end{bmatrix}} + \frac{\frac{\sqrt{3}}{2} * V_{HV}}{V_{LV}} * \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} * \overset{I\_W2}{\begin{bmatrix}\overline{IA}\\ 0\\ 0\end{bmatrix}} + \frac{\frac{1}{2} * V_{HV}}{V_{LV}} * \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} * \overset{I\_W3}{\begin{bmatrix}0\\ 0\\ \overline{IB} - \overline{IC}\end{bmatrix}}$$

Scott transformer

- Connection of currents to the 87T function (autotransformer shared between two track sections)



Scott transformer

- Rated values

W1	$S_{R1} = \frac{S}{2}$	$V_{R1} = V_{LV}$	$I_{R1} = \frac{S}{2*V_{LV}}$
W2	$S_{R2} = \frac{S}{2}$	$V_{R2} = \frac{\sqrt{3}}{2}*V_{HV}$	$I_{R2} = \frac{S}{\sqrt{3}*V_{HV}}$
W3	$S_{R3} = \frac{S}{2}$	$V_{R3} = ½*V_{LV}$	$I_{R3} = \frac{S}{V_{HV}}$

- Typical settings

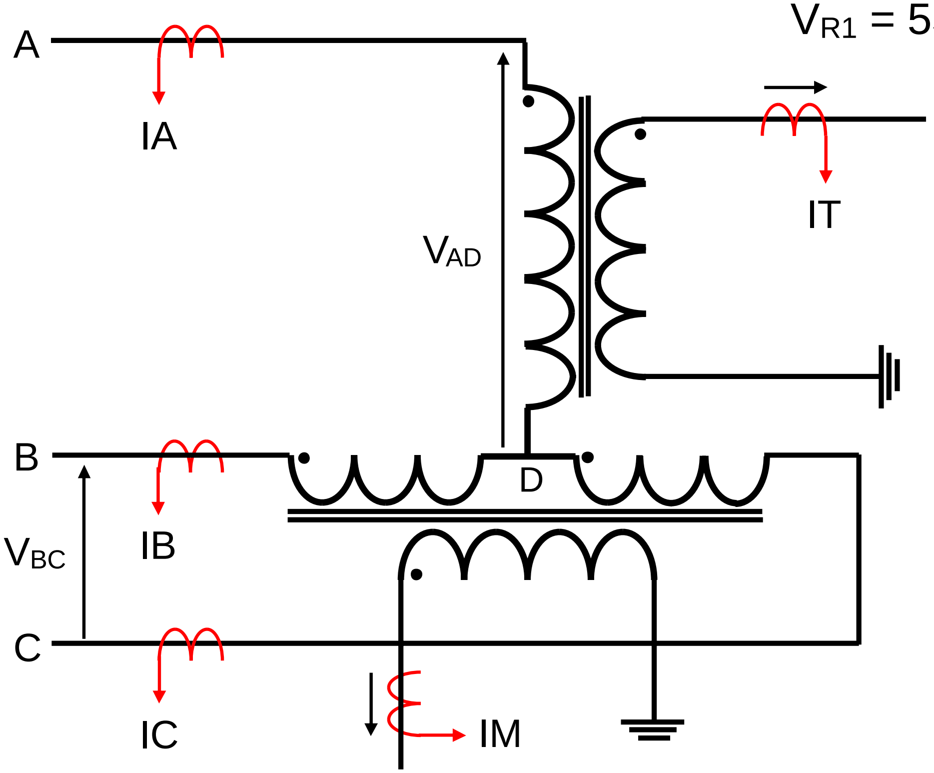
Rated Voltage W1	V_{R1}
Rated Voltage W2	V_{R2}
Rated Voltage W3	V_{R3}
Rated Current W1	I_{R1}
Rated Current W2	I_{R2}
Rated Current W3	I_{R3}
Connect Type W1	Delta (D)
Connect Type W2	Delta (D)
Connect Type W3	Delta (D)
Clock Number W2	0 (0 deg)
Clock Number W3	0 (0 deg)
ZS Current Subtraction W1	Off
ZS Current Subtraction W2	Off
ZS Current Subtraction W3	Off

Scott transformer

- Example

Scott transformer $S = 90MVA$ $S_{R1} = S_{R2} = S_{R3} = 45MVA$

$V_{R1} = 55kV$ $V_{R2} = 133.4kV$ $V_{R3} = 77kV$



$|V_{BC}| = |V_{HV}|$, $V_{BC} = |V_{HV}|\angle 0°$

$|V_{AD}| = \frac{\sqrt{3}}{2}|V_{HV}|$, $V_{AD} = \frac{\sqrt{3}}{2}|V_{HV}|\angle 90°$

For $|IM| = |IT| = 50\% I_{R1}$, $IM = 409.1\angle 180°$

$IT = 409.1\angle -90°$

the HV-side currents are:

$IA = 168.7\angle 90°$

$IB = 168.7\angle -30°$

$IC = 168.7\angle -150°$

$IB - IC = 292.2\angle 0°$

Scott transformer

- Example

  Scott transformer

$$\begin{bmatrix}\overline{ID\_A}\\ \overline{ID\_B}\\ \overline{ID\_C}\end{bmatrix} = \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}409.1\angle -90^\circ\\ 0\\ 409.1\angle 180^\circ\end{bmatrix} + \frac{133.4}{55} * \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}168.7\angle 90^\circ\\ 0\\ 0\end{bmatrix}$$

$$+ \frac{77}{55} * \begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}0\\ 0\\ 292.2\angle 0^\circ\end{bmatrix}$$

$$= \begin{bmatrix}409.1\angle -90^\circ\\ 0\\ 409.1\angle 180^\circ\end{bmatrix} + \begin{bmatrix}409.1\angle 90^\circ\\ 0\\ 0\end{bmatrix} + \begin{bmatrix}0\\ 0\\ 409.1\angle 0^\circ\end{bmatrix}$$

Other protections discussed in paper

- Restricted earthfault (87N) – split single-phase railway transformer
- 50/51
- 51G
- 49

- As for the 87T protection, the paper shows how to connect the analog quantities for the above protections for the different types of railway transformers

Conclusions

- It has been shown how to use standard three-phase transformer protection relays to protect the most common types of 50/60Hz railway transformers
- Even though standard three-phase transformer protection relays treat the analog quantities in a three-phase manner, and this will remain so, they can be adapted and successfully applied to different types of railway transformers on 50Hz or 60Hz railway supply systems