Transformer protection

- Failure of transformer can have long time consequences
  - long replacement time

- Minimize impact of transformer faults
  - reduce likelihood
    - track external events that impact life of insulation
- heating of insulation has big impact on life
- also transient overvoltages

Causes for heating:

TANH
- oil-filled
- dielectric oil
- also a coolant
15 MVA/20 MVA/25 MVA
↑ passively cooled
circulating oil with pumps
fans
- Harmonic current load
  due to external loads

- Harmonic loading increases heat

- $k$ factor rated transformers

5, 7, 11, 13 ...
- overexcitation
  - steady state overvoltage
  - partial saturation
  - detect based on harmonics
  - odd harmonics $\rightarrow$ 5th

$\Rightarrow$ hysteresis losses

- Through faults (transformer is carrying current to a fault)
  - similar with frequent large motor starting or even after energization,
Track sources of heating to predict life span loss

C 37.91
Protection for internal faults

- a fault that evolves to
  point where there is a
  fire can log repair time

firewalls
First line: differential protection

1. CT ratios may not cancel the Power Transformer ratio → taps on Relay
2. Power Transformer Taps

Complicating factors:
3. Magnetizing Current

- Transformer always draws small current in steady-state.
- 2-3% of rated current.

- Magnetizing Inrush Current
Transformer Phase Shift

\[ \Delta Y, (Y \Delta) \Rightarrow \text{ANSI/IEEE Standard} \]

\[ \Rightarrow V_{LN} \text{ on HV side leads} \]
\[ V_{LN} \text{ on LV side by 30°} \]

\[ \Rightarrow \Delta Y/ \Rightarrow \text{impact turns ratios} \]

\[ \Rightarrow \Delta Y/ \Rightarrow \text{will have } I_0 \]
\[ \text{will not have } I_0 \]
E-m relays

Option 1:

\[ \Delta \]

Connect \( \Delta \) properly to cancel shift.

Option 2:

`needs zero sequence trap`
And remove To

microprocessor relay

relay perform matrix multiplication

Shift compensate 50
Compensation matrices for transformer differential protection

- Apply one for each winding of the transformer
- Typical usage is:

\[
\begin{pmatrix}
I_{A,\text{sec\_cor}} \\
I_{B,\text{sec\_cor}} \\
I_{C,\text{sec\_cor}}
\end{pmatrix} = \text{MAT}_{\text{correction}} \cdot \frac{1}{\text{Tap}_{\text{HV}} \cdot \text{CTR}_{\text{HV}}} \begin{pmatrix}
I_{A,\text{Primary}} \\
I_{B,\text{Primary}} \\
I_{C,\text{Primary}}
\end{pmatrix}
\]

- Matrices for commonly used transformer connections in the North America
  - Standard Y Connected winding ($Y_0$ using IEC clock position notation):
    \[
    \text{MAT}_0 := \begin{pmatrix}
    1 & 0 & 0 \\
    0 & 1 & 0 \\
    0 & 0 & 1
    \end{pmatrix}
    \]
  
  - $\Delta$ connected winding, $D_{AB}$ ($D_1$ using IEC clock position notation):
    \[
    \text{MAT}_1 := \frac{1}{\sqrt{3}} \begin{pmatrix}
    1 & -1 & 0 \\
    0 & 1 & -1 \\
    -1 & 0 & 1
    \end{pmatrix}
    \]
  
  - $\Delta$ connected winding, $D_{AC}$ ($D_{11}$ using IEC clock position notation):
    \[
    \text{MAT}_{11} := \frac{1}{\sqrt{3}} \begin{pmatrix}
    1 & 0 & -1 \\
    -1 & 1 & 0 \\
    0 & -1 & 1
    \end{pmatrix}
    \]
  
  - Zero sequence removal matrix:
    \[
    \text{MAT}_{12} := \frac{1}{3} \begin{pmatrix}
    2 & -1 & -1 \\
    -1 & 2 & -1 \\
    -1 & -1 & 2
    \end{pmatrix}
    \]