Transformer Models

- External Faults
  - Two winding transformers
    - $X_0 \quad X_i = X_e$
    - $V$ depends on core structure
      - 5 leg core
        - or 3 single cores
      - $X_0 = X_i = X_e$
- Mismatched single phase transformers

- Firewall

- Spare

A  B  C
A slightly different spare

Series imbalance techniques for modeling

\[ Z_{TM} A = Z_{TM} B \neq Z_{TC} \]
Example - Generation Step Up Transformer

3 Winding Transformers

\[ I_1 = I_2 \times 3 \]

\[ 3 \times \frac{1}{3} \]

\[ \frac{1}{6} \]

\[ \text{station services} \]
Intermediate Transmission Section
Static VAR compensators
of LCC HVDC (Line commutated converter)

Low order harmonics
5, 7, 11, 13, ...

Sequence behavior of harmonics
0 1 2 3 4 5 ...
+ - - + - +

500kV

University of Idaho
Similarly (Ideal Transformer)

\[ N_1 I_1 + N_m I_m + N_y I_L = 0 \]

- Ideal transformers have leakage & magnetization
  \[ X_m, R_c \]

Z winding low frequency equivalent

\[ R_h + jX_h + \frac{X}{2} + jX - R_x \]

\[ V_t + R_c \]

\[ I \]
TO per unit

RH JX
midpoint
JX
RX

T-equivalent model
Winding transformers (see page 127)

3 winding transformers

Each winding has a voltage ratio and MVA capacity.
2 wire: - Zero sequence behavior.

\[ I_{0} + I_{A1} + I_{B2} \]

\[ I_{A0} + I_{A1} + I_{A2} \]

\[ I_{B0} + I_{B1} + I_{B2} \]
Per unit (T-equivalent) of 3 winding

\[ \frac{R_{th} + \frac{jX_{th}}{2}}{M_{th}} \text{ kN mm} \]

\[ \varphi \]

- even if neglect core loss and magnetic branch
- Pertaining to midpoint (T-point)

Still need
Need to know $\tilde{Z}_H, \tilde{Z}_x, \tilde{Z}_y$

$\rightarrow$ Short circuit test data

3 tests

1) Voltage on $H$, short $M$, open $L$

$$Z_{Hm} \ (\tilde{Z}_{Hx})$$

$$= \tilde{Z}_H + \tilde{Z}_m$$

2) $Z_{Hl} = Z_{hl} + Z_L \ (\tilde{Z}_H + \tilde{Z}_L)$

3) $Z_{ml} = Z_m + Z_L \ (\tilde{Z}_x + \tilde{Z}_y)$
I'm not sure about the first part of the equation. It seems to be "Foot on System Sense". The rest of the equation is:

\[
\begin{align*}
z \text{ hat} & = \xi + \xi y \text{ on 10MV} \\
\text{or} & \ z \text{ x on 10MV} \\
\text{mixing} & \\
\text{Need to put test results on common} \\
x/2 & = 50 - 25 \\
\text{Big transformers have high x/2 ratios}
\end{align*}
\]
Standard equations

\[ Z_H = \frac{1}{2} \left( \bar{Z}_{HX} + \bar{Z}_{HY} - \bar{Z}_{XY} \right) \]

\[ Z_X = \frac{1}{2} \left( \bar{Z}_{HX} - \bar{Z}_{HY} + \bar{Z}_{XY} \right) \]

\[ Z_Y = \frac{1}{2} \left( -\bar{Z}_{HX} + \bar{Z}_{HY} + \bar{Z}_{XY} \right) \]

- Often find one of these has a small, negative reactance
Winding Impedance calculations for three winding autotransformer

\[ \text{MVA} := 1000\text{kW} \quad \text{pu} := 1 \]

Useful Constants \hspace{1cm} \text{V1 is l-l since will be in Delta}

\[ V_h := \frac{525\cdot\text{kV}}{\sqrt{3}} \quad V_m := \frac{241.5\cdot\text{kV}}{\sqrt{3}} \quad V_1 := 34.5\cdot\text{kV} \quad S_b := 100\cdot\text{MVA} \]

Test Impedances, found at bases listed next to numbers (in percent). Note Zhm and Zhl are reversed from the other cases

\[ X_{hm} := 7.94\% \quad 448\text{ MVA} \]
\[ X_{hl} := 3.46\% \quad 25\text{ MVA} \]
\[ X_{ml} := 2.98\% \quad 25\text{ MVA} \]

Convert test impedances to 100 MVA Base (answers still in percent), based on the data from data sheets regarding H/L and H/M

\[ X_{h\text{new}} := \frac{100}{25} \cdot X_{hl} \quad X_{hl\text{new}} = 0.138\cdot\text{pu} \]
\[ X_{hm\text{new}} := \frac{100}{448} \cdot X_{hm} \quad X_{hm\text{new}} = 0.018\cdot\text{pu} \]
\[ X_{ml\text{new}} := \frac{100}{25} \cdot X_{ml} \quad X_{ml\text{new}} = 0.119\cdot\text{pu} \]

Find \( X_h, X_m, \) and \( X_l \)

\[ X_h := (0.5) \cdot (X_{h\text{new}} + X_{hm\text{new}} - X_{ml\text{new}}) \quad X_h = 1.846\cdot\% \]
\[ X_m := (0.5) \cdot (X_{hm\text{new}} + X_{ml\text{new}} - X_{hl\text{new}}) \quad X_m = -0.074\cdot\% \]
\[ X_l := (0.5) \cdot (X_{ml\text{new}} + X_{hl\text{new}} - X_{hm\text{new}}) \quad X_l = 11.994\cdot\% \]
Sequence equivalent circuits

Positive

Negative
Zero sequence

\[ x_t \]

\[ x_{l+} \]

\[ x_{y} \]

\[ x_{t+} \]

\[ x_{y} \]
- Represent transfer leakage
  impedances of Autotransformer

\[ X_s, X_c, X_t \]