Winding Impedance calculations for three winding autotransformer

$MVA := 1000kW$ $\qquad pu := 1$

Useful Constants $\qquad V_l$ is l-l since will be in Delta

$V_h := \frac{525 \cdot kV}{\sqrt{3}} \qquad V_m := \frac{241.5 \cdot kV}{\sqrt{3}} \qquad V_l := 34.5 \cdot kV \qquad S_b := 100 \cdot MVA$

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

$X_{hm} := 7.94\%$ $\qquad$ 448 MVA

$X_{hl} := 3.46\%$ $\qquad$ 25 MVA

$X_{ml} := 2.98\%$ $\qquad$ 25 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

$X_{hlnew} := \frac{100}{25} \cdot X_{hl} \qquad X_{hlnew} = 0.138 \cdot pu$

$X_{hmnew} := \frac{100}{448} \cdot X_{hm} \qquad X_{hmnew} = 0.018 \cdot pu$

$X_{mlnew} := \frac{100}{25} \cdot X_{ml} \qquad X_{mlnew} = 0.119 \cdot pu$

Find Xh, Xm, and Xl

$X_h := (0.5) \cdot \left(X_{hlnew} + X_{hmnew} - X_{mlnew}\right) \qquad X_h = 1.846 \cdot \%$

$X_m := (0.5) \cdot \left(X_{hmnew} + X_{mlnew} - X_{hlnew}\right) \qquad X_m = -0.074 \cdot \%$

$X_l := (0.5) \cdot \left(X_{mlnew} + X_{hlnew} - X_{hmnew}\right) \qquad X_l = 11.994 \cdot \%$

- Autotransformer specific extension:

Define a constant: $r := \frac{(V_h - V_m)}{V_h}$ $r = 0.54$

- Given Xh, Xm and Xl, find the physical transformer winding reactances

$$X_s := \left(\frac{1}{r}\right)^2 \cdot X_h + \frac{(1-r)}{r^2} \cdot X_m \qquad X_s = 6.215 \cdot \%$$

$$X_c := \left(\frac{1}{r}\right) \cdot X_m \qquad X_c = -0.137 \cdot \%$$

$$X_t := X_l - \frac{1-r}{r} \cdot X_m \qquad X_t = 12.057 \cdot \%$$

- Alternate conversion:

$$X_{s\_c} := X_{hmnew} \cdot \left(\frac{V_h}{V_h - V_m}\right)^2 \qquad X_{s\_c} = 6.078 \cdot \%$$

$$X_{c\_t} := X_{mlnew} \qquad X_{c\_t} = 11.92 \cdot \%$$

$$X_{s\_t} := X_{hmnew} \cdot \left[\frac{V_h \cdot V_m}{(V_h - V_m)^2}\right] + X_{hlnew} \cdot \left(\frac{V_h}{V_h - V_m}\right) - X_{mlnew} \cdot \left(\frac{V_m}{V_h - V_m}\right)$$

$$X_{s\_t} = 18.271 \cdot \%$$

$$X_s := 0.5 \cdot (X_{s\_c} + X_{s\_t} - X_{c\_t}) \qquad X_s = 6.215 \cdot \%$$

$$X_c := 0.5 \cdot (X_{s\_c} + X_{c\_t} - X_{s\_t}) \qquad X_c = -0.137 \cdot \%$$

$$X_t := 0.5 \cdot (X_{c\_t} + X_{s\_t} - X_{s\_c}) \qquad X_t = 12.057 \cdot \%$$

- If instead you are given the physical transformer reactances, you can do the following to find Xh, Xm and Xl.

$n := \left(\frac{V_h}{V_m}\right)$

- Note that this is the voltage ratio of the autotransformer

$X_{m\_auto} := \left(\frac{n-1}{n}\right)\cdot X_c \qquad X_{m\_auto} = -0.074\cdot\%$

above we had: $X_m = -0.074\cdot\%$

$X_{l\_auto} := X_t + \frac{X_c}{n} \qquad X_{l\_auto} = 11.994\cdot\%$

above we had $X_l = 11.994\cdot\%$

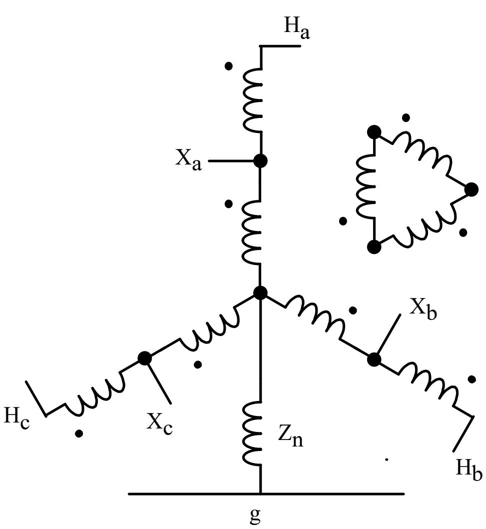
$X_{h\_auto} := \left(\frac{n-1}{n}\right)^2\cdot X_s - \left(\frac{n-1}{n^2}\right)\cdot X_c \qquad X_{h\_auto} = 1.846\cdot\%$

above we had $X_h = 1.846\cdot\%$

- Suppose this 3 winding transformer is grounded through an impedance of 0.1pu (on the MVA base used for Xhl, calculate the new zero sequence equivalent circuit

$X_{n\_new} := 0.1\text{pu}\cdot\frac{100}{25} \qquad X_{n\_new} = 40\cdot\%$

as above: $n := \left(\frac{V_h}{V_m}\right)$



$$X_{hmn0}(Z_n) := \frac{1}{2}\cdot\begin{bmatrix} 1 & 1 & -1 & \frac{-(n-1)}{n^2} \\ 1 & -1 & 1 & \frac{(n-1)}{n} \\ -1 & 1 & 1 & \frac{1}{n} \end{bmatrix}\cdot\begin{pmatrix} X_{hmnew} \\ X_{hlnew} \\ X_{mlnew} \\ 6\cdot Z_n \end{pmatrix}$$

$$X_{hmn0}\left(X_{n\_new}\right) = \begin{pmatrix} -27.962 \\ 64.726 \\ 67.194 \end{pmatrix} \cdot \%$$

Note that if Xn = 0, this gives the identical results to part (a)

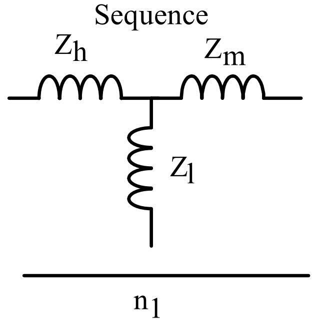
$$X_{hmn0}(0) = \begin{pmatrix} 1.846 \\ -0.074 \\ 11.994 \end{pmatrix} \cdot \%$$

And if Xn is infinity (ungrounded)

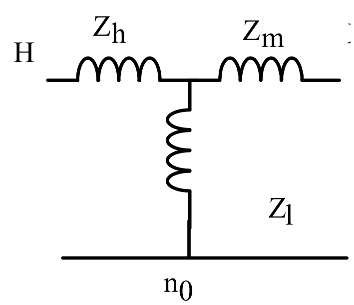
$$X_{hmn0}\left(10^{10}\right) = \begin{pmatrix} -7.452 \times 10^{9} \\ 1.62 \times 10^{10} \\ 1.38 \times 10^{10} \end{pmatrix}$$

- Symmetrical Components Equivalent Circuits for Xn = 0

Positive and Negative Sequence



Zero Sequence



Zero sequence circuit wth Xn non-zero