Leakage reactance: $X_1 = X_2$

(Positive sequence = negative sequence)

- Zero sequence depends on core type

A) 3 single phase cores

$X_1 = X_2 = X_0 \Rightarrow$ no change in flux path
(3) 5 leg core

\[ x_0 = x_2 = x_1 \]
- Three legs core

- Toroids as a shadow & connected testing

\[ x_1 = x_2 > x_0 \] — manufacturer data or testing
One more single phase core issue...

→ replacement transformer installed

\[ Z_{T1} = Z_{T2} \neq Z_{T3} \]

1 2 3

not identical to other 2

spara
- Series Imbalance
- Use the series fault techniques.
3 winding transformers

Possible applications

Power converters
- HVDC
- Static VAR compensators
- Large rectifier load

Harmonics start ly from balanced source: 0, 1, 2, 3, 4, 5, 6, 7...
Generator Step-up Transformer

\[ G \]

\[ V \]

Load

Schematic Drawing

125 9/18
\[ \phi = 0 = \phi_0 = \phi \]

\[ V = \frac{1}{2} x \]

\[ \frac{\partial}{\partial y^+} \]

\[ \frac{\partial}{\partial y^-} \]

\[ V \]

Similarly, if \( N \) ions have leakage + magnetization, then:

\[ V = \frac{1}{2} x \]

\[ V = \frac{1}{2} x \]
2 winding equivalent

\[ \text{Ideal} \]

\[ \text{per unit --} \]

\[ \text{T equivalent} \]

\[ \text{neglect usually for SS and quasi steady state} \]
3 winding transformer - 3 phase (simplified diagram)

\[ N_x \times e_x + V_x \]

\[ N_y \times e_y + V_y \]

\[ V_H \]
Per Unit Equivalent (T-equivalent)

Even if neglect $R_c + jX_m$
can't remove to
"T-point"
Short circuit tests to determine

\[ Z_{x}, \quad Z_{x}, \quad Z_{y} \]

- 3 tests

3 tests → 

1. Volt on \( H \), short \( X \), y open

\[ Z_{H} = Z_{H} + Z_{x} \]

2. Volt on \( H \), short \( H \), z open

\[ Z_{H} = Z_{x} + Z_{y} \]

3. Volt on \( H \), short \( y \), x open

\[ Z_{x} = Z_{x} + Z_{y} \]
Common short equation

\[ Z_h = \frac{1}{(2 + H_x + 2 + H_y) / 2} \]

\[ Z_x = \frac{1}{(2 + H_x - Z_{xy} + Z_{xy})} \]

\[ Z_y = \frac{1}{2 - \frac{1}{2} (2 + H_x + Z_{xy} + Z_{xy})} \]

After all and all do one do a small negative reactance...
Winding Impedance calculations for three winding autotransformer

MVA := 1000kW  
pu := 1

Useful Constants  
V₁ is 1-1 since will be in Delta

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

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

\[ X_{hm} := 7.94\% \]
\[ X_{hl} := 3.46\% \]
\[ X_{ml} := 2.98\% \]

448 MVA
25 MVA
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

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

Find Xₕ, Xₘ, and X₁

\[ X_{h} := (0.5) \cdot (X_{hlnew} + X_{hmmnew} - X_{mlnew}) \quad X_{h} = 1.846 \cdot \text{\%} \]
\[ X_{m} := (0.5) \cdot (X_{hmmnew} + X_{mlnew} - X_{hlnew}) \quad X_{m} = -0.074 \cdot \text{\%} \]
\[ X_{l} := (0.5) \cdot (X_{mlnew} + X_{hlnew} - X_{hmmnew}) \quad X_{l} = 11.994 \cdot \text{\%} \]

\( \text{at 100 MVA} \)

\( \text{pos, negative \& zero - if 3 \text{phase}} \)
\( \text{single phase coils} \)
Positive + Negative

System

JXH

M

JXm

--- system

Phase shift of load

JXl

M

dependence

load

2 unloaded