

3W Transformer Test Report Impedance Calculator Equations

Positive Sequence

P_{Loss} = Test Report Load Losses (Not Total Losses)

S_{Base} = Test Report MVA

$\%Z$ = Test Report Primary – Secondary %Impedance

$V_{High_{Test}}$ = Test Report Primary Voltage

$V_{Low_{Test}}$ = Test Report Secondary Voltage

V_{High} = Nominal System Primary Voltage

V_{Low} = Nominal System Secondary Voltage

$$R_{pu} = \frac{P_{Loss}}{S_{Base}}$$

$$X_{pu} = \sqrt{\left(\frac{\%Z}{100}\right)^2 - R_{pu}^2}$$

Change to 100MVA Base:

$$R_{pu@100} = R_{pu} \frac{100}{S_{Base}}$$

$$X_{pu@100} = X_{pu} \frac{100}{S_{Base}}$$

if Test Voltage \neq Nominal System Voltage:

Voltage Base Change is Required

if $V_{Low_{Test}} \neq V_{Low}$:

$$R_{pu} = R_{pu} \left(\frac{V_{Low_{Test}}}{V_{Low}} \right)^2$$

$$X_{pu} = X_{pu} \left(\frac{V_{Low_{Test}}}{V_{Low}} \right)^2$$

if $V_{High_{Test}} \neq V_{High}$ AND $V_{Low_{Test}} = V_{Low}$:

$$R_{pu} = R_{pu} \left(\frac{V_{High_{Test}}}{V_{High}} \right)^2$$

$$X_{pu} = X_{pu} \left(\frac{V_{High_{Test}}}{V_{High}} \right)^2$$

Use these Equations for:

Primary – Secondary

Primary – Tertiary

Secondary - Tertiary

IEEE 57.12.90 Three Winding Transformer Zero Sequence Impedance Testing Procedure and Equations

IEEE 57.12.90 requires three (3) separate test procedures.

First test is used to determine a quantity known as Z_{1no} .

Same phase Voltage source is applied between the three Primary and Neutral terminals.

Secondaries are left open.

Phase Voltage is increased until current reaches some arbitrary amount that prevents overloading the Tertiary

The applied Voltage, resulting total current and phase power are recorded.

Second test is used to determine a quantity known as Z_{1ns} .

Same phase Voltage source is applied between the three Primary and Neutral terminals.

Secondaries are shorted to Neutral.

Phase Voltage is increased until current reaches some arbitrary amount that prevents overloading the Secondary

The applied Voltage, resulting total current and phase power are recorded.

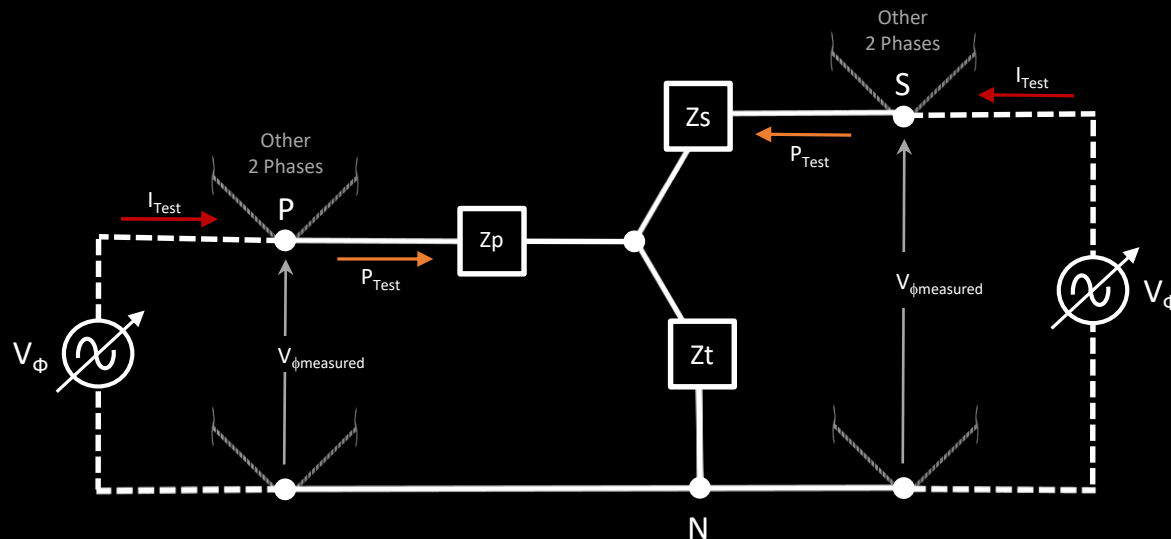
Third test is used to determine a quantity known as Z_{2no} .

Same phase Voltage source is applied between the three Secondary and Neutral terminals.

Primaries are left open.

Phase Voltage is increased until current reaches some arbitrary amount that prevents overloading the Tertiary

The applied Voltage, resulting total current and phase power are recorded.



The measured data is then mathematically corrected to determine the Z, R, and X for each test.

First... Consider the Impedance magnitudes $|Z|$ for each test...

Recall or realize that the per-unit Impedance magnitude is the ratio of the test voltage required to produce rated phase current divided by the rated test voltage.

However, the test voltage applied was not enough to produce the required current...

Therefore, a correction is needed.

Z1no test:

$$I_{Pri (rated)} = \frac{S_{Base (test)}}{\sqrt{3}V_{LL Pri (rated)}}$$

$$V_{\phi Pri (rated)} = \frac{V_{LL Pri (rated)}}{\sqrt{3}}$$

$$V_{\phi (corrected)} = V_{\phi (test)} \frac{I_{Pri (rated)}}{\frac{I_{test}}{3}}$$

$$|Z_{pu}| = \frac{V_{\phi (corrected)}}{V_{\phi Pri (rated)}}$$

$$|Z_{pu}| = 3\sqrt{3} \frac{V_{\phi (test)}}{V_{LL Pri (rated)}} \frac{I_{Pri (rated)}}{I_{test}}$$

Z1ns test:

$$I_{Pri (rated)} = \frac{S_{Base (test)}}{\sqrt{3}V_{LL Pri (rated)}}$$

$$V_{\phi Pri (rated)} = \frac{V_{LL Pri (rated)}}{\sqrt{3}}$$

$$V_{\phi (corrected)} = V_{\phi (test)} \frac{I_{Pri (rated)}}{\frac{I_{test}}{3}}$$

$$|Z_{pu}| = \frac{V_{\phi (corrected)}}{V_{\phi Pri (rated)}}$$

$$|Z_{pu}| = 3\sqrt{3} \frac{V_{\phi (test)}}{V_{LL Pri (rated)}} \frac{I_{Pri (rated)}}{I_{test}}$$

Z2no test:

$$I_{Sec (rated)} = \frac{S_{Base (test)}}{\sqrt{3}V_{LL Sec (rated)}}$$

$$V_{\phi Sec (rated)} = \frac{V_{LL Sec (rated)}}{\sqrt{3}}$$

$$V_{\phi (corrected)} = V_{\phi (test)} \frac{I_{Sec (rated)}}{\frac{I_{test}}{3}}$$

$$|Z_{pu}| = \frac{V_{\phi (corrected)}}{V_{\phi Sec (rated)}}$$

$$|Z_{pu}| = 3\sqrt{3} \frac{V_{\phi (test)}}{V_{LL Sec (rated)}} \frac{I_{Sec (rated)}}{I_{test}}$$

Note:

Z1no, **Z1ns**, **Z2no** are different measurements and calculations.

Next... Consider the real power measurements.

Real power delivered (losses) is used to determine Resistance.

However, losses under full load are needed to determine the Resistance.

So the Ploss measurements are scaled up to reflect full load conditions...

Z1no test:

$$P_{loss} = P_{test} \left(\frac{I_{Pri (rated)}}{\frac{I_{test}}{3}} \right)^2$$
$$P_{loss} = 9P_{test} \left(\frac{I_{Pri (rated)}}{I_{test}} \right)^2$$

Z1ns test:

$$P_{loss} = P_{test} \left(\frac{I_{Pri (rated)}}{\frac{I_{test}}{3}} \right)^2$$
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Z2no test:

$$P_{loss} = P_{test} \left(\frac{I_{Sec (rated)}}{\frac{I_{test}}{3}} \right)^2$$
$$P_{loss} = 9P_{test} \left(\frac{I_{Sec (rated)}}{I_{test}} \right)^2$$

Calculate Resistance:

$$R_{pu} = \frac{P_{loss}}{S_{Base (test)}}$$

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Calculate Reactance:

$$X_{pu} = \sqrt{|Z_{pu}|^2 - R_{pu}^2}$$

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Reactance does not change with Temperature.

Done with this part...

$$Z1no = R_{pu} + jX_{pu}$$

$$Z1ns = R_{pu} + jX_{pu}$$

$$Z1no = R_{pu} + jX_{pu}$$

But... Wait a second, if you are really particular...

I²R losses are Temperature dependent.

Resistance of the copper windings increase with Temperature.

IEEE 57.12.90 requires that the test temperature of the transformer oil be recorded... T_{test} used for this example.

Losses under full load and maximum operating temperature are needed to rate the Transformer Resistances.

Maximum transformer operating temperature is typically 65°C above accepted lab temperature of 20°C or 85°C.

So, the losses are again mathematically corrected for maximum operating temperature....

Use: 225.0 for aluminum windings

Z1no test:

$$P'_{loss} = P_{loss} \frac{T_{max} + 234.5}{T_{test} + 234.5}$$

$$R'_{pu} = \frac{P'_{loss}}{S_{Base (test)}}$$

$$Z'_{pu} = R'_{pu} + jX_{pu}$$

Z1ns test:

$$P'_{loss} = P_{loss} \frac{T_{max} + 234.5}{T_{test} + 234.5}$$

$$R'_{pu} = \frac{P'_{loss}}{S_{Base (test)}}$$

$$Z'_{pu} = R'_{pu} + jX_{pu}$$

Z2no test:

$$P'_{loss} = P_{loss} \frac{T_{max} + 234.5}{T_{test} + 234.5}$$

$$R'_{pu} = \frac{P'_{loss}}{S_{Base (test)}}$$

$$Z'_{pu} = R'_{pu} + jX_{pu}$$

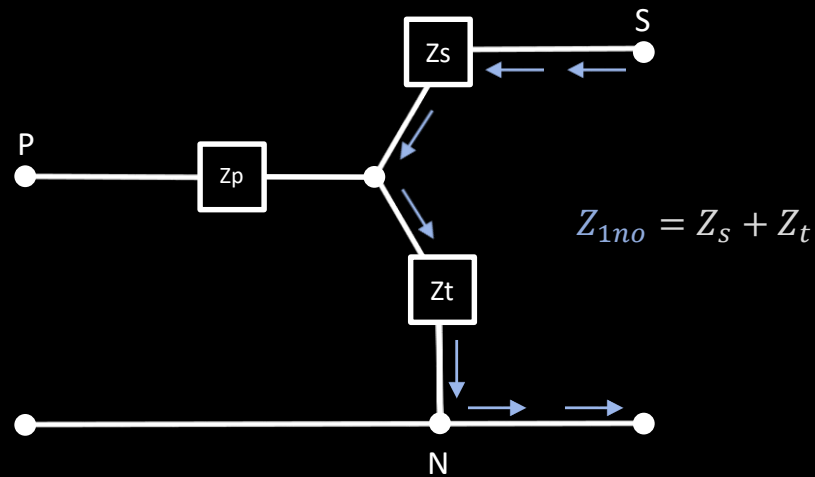
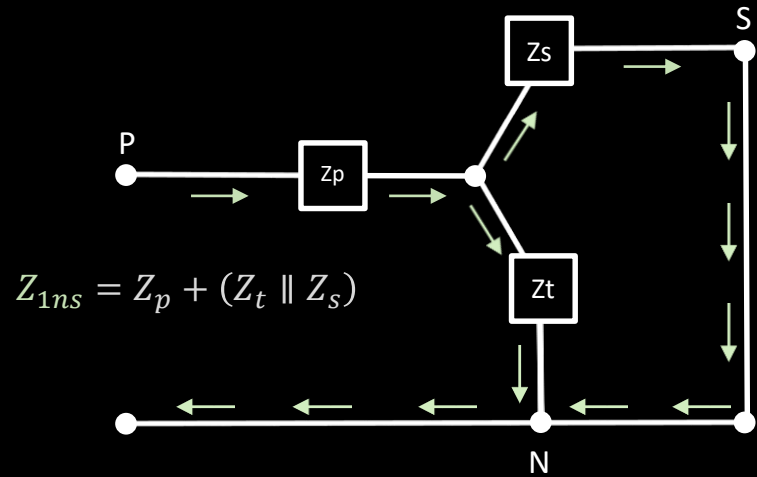
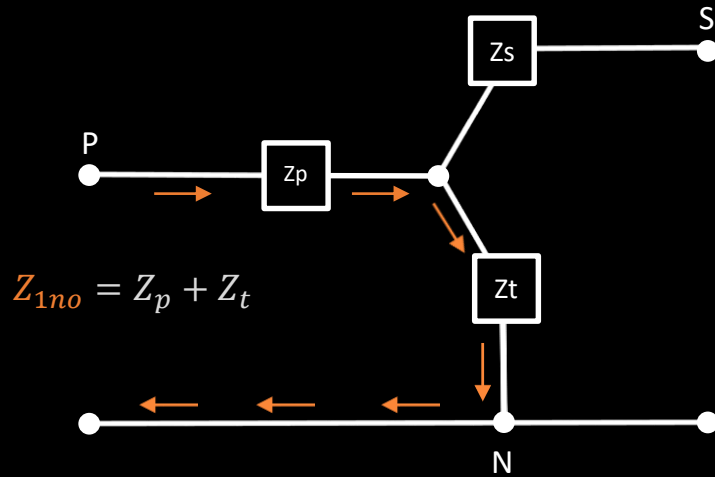
Done with this part...

$$Z1no = R'_{pu} + jX_{pu}$$

$$Z1ns = R'_{pu} + jX_{pu}$$

$$Z1no = R'_{pu} + jX_{pu}$$

What does Z_{1no} , Z_{1ns} , Z_{2no} represent?



Now... Solve for Z_p , Z_s , and Z_t .

Keep in mind that these are complex numbers.

$$Z_{1no} = Z_p + Z_t$$

$$Z_{2no} = Z_s + Z_t$$

$$Z_{1ns} = Z_p + \frac{Z_t Z_s}{Z_t + Z_s}$$

solving 3 equations and 3 unknowns:

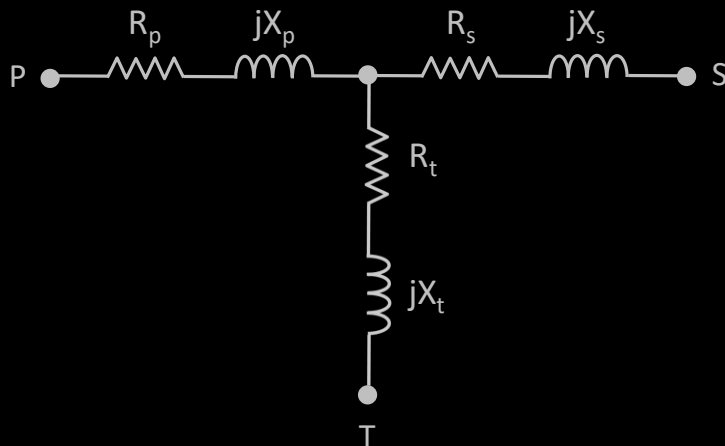
$$Z_t = \pm \sqrt{Z_{2no}(Z_{1no} - Z_{1ns})}$$

$$Z_t = + \sqrt{Z_{2no}(Z_{1no} - Z_{1ns})} \quad \text{assumed}$$

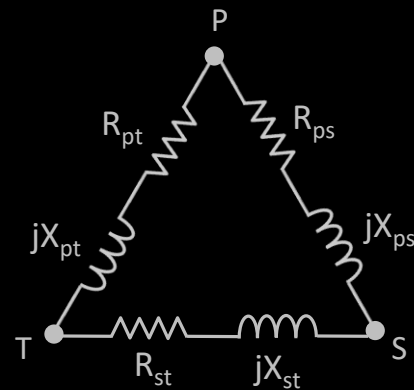
$$Z_p = Z_{1no} - Z_t$$

$$Z_s = Z_{2no} - Z_t$$

You now have the Transformer T - Model



The Δ - Model can be calculated:



$$\begin{aligned} Z_{ps} &= Z_p + Z_s \\ Z_{pt} &= Z_p + Z_t \\ Z_{st} &= Z_s + Z_t \end{aligned}$$



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Questions or Comments ...

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