Comparing Primary and Secondary Ohms and Converting to Per Unit on Secondary When CTR and VTR Don't Cancel

- First look at a regular transformer

We know the following:

$$\frac{V_1}{N_1} = \frac{V_2}{N_2} \qquad \text{which can be rearranged as:} \qquad \frac{V_1}{V_2} = \frac{N_1}{N_2} = \text{VTR}$$

Similarly (using power transformer polarity)

$$I_1 \cdot N_1 - I_2 \cdot N_2 = 0 \qquad \text{which can be rearranged as:} \qquad \frac{I_1}{I_2} = \frac{N_2}{N_1} = \text{CTR}$$

- Now if we wanted to relate an impedance across the transfomer

$$Z_2 = \frac{V_2}{I_2} = \frac{V_1 \cdot \left(\frac{N_2}{N_1}\right)}{I_1 \cdot \left(\frac{N_1}{N_2}\right)} = \frac{V_1}{I_1} \cdot \left(\frac{N_2}{N_1}\right)^2 = Z_1 \cdot \left(\frac{N_2}{N1}\right)^2$$

This is how we usually view this...

Alternate simplification

$$Z_2 = \frac{V_2}{I_2} = \left[\frac{V_1 \cdot \left(\frac{N_2}{N_1}\right)}{I_1 \cdot \left(\frac{N_1}{N_2}\right)}\right] = \frac{V_1 \cdot \text{CTR}}{I_1 \cdot \text{VTR}} = Z_1 \cdot \frac{\text{CTR}}{\text{VTR}}$$

- In the case of the measurements seen at the protective relay, the voltages are stepped down through a set of voltage transformers with little current (which is not measured)
- And the currents are stepped down through a separate set of current transformers with the voltage not measured
- The measured voltage and current go into different inputs to the relay

- The relay "sees" and effective secondary impedance based on the voltages and currents stepped down by these separate VTs and CTs

- This will be more important when we look at distance relays, but it also matters for fault location calculations

Example

$$Z_{line\_primary} := (5 + j \cdot 50)\text{ohm}$$

$$VTR := \frac{345\text{kV}}{120\text{V}}$$

$$CTR := \frac{800\text{A}}{5\text{A}}$$

- Now find the effective secondary line impedance.

$$Z_1 := Z_{line\_primary}$$

$$Z_2 := Z_1 \cdot \frac{CTR}{VTR} \qquad Z_2 = (0.28 + 2.78i)\,\Omega \qquad Z_{line\_secondary} := Z_2$$

If we had a three phase fault at the far end of the transmission line, then taking V/I

What does this do to per unit analysis?

- Note that our conventional idea of per unit analysis is no longer accurate

$$Z_{BLV} := \frac{120\text{V}}{\sqrt{3} \cdot 5\text{A}} \qquad Z_{BLV} = 13.86\,\Omega$$

$$Z_{BHV} := \frac{345\text{kV}}{\sqrt{3} \cdot 800\text{A}} \qquad Z_{BHV} = 248.98\,\Omega$$

$$Z_{pu} := \frac{Z_{line\_secondary}}{Z_{BLV}} \qquad Z_{pu} = 0.02 + 0.2i$$

$$Z_{pu} \cdot Z_{BHV} = (5 + 50i)\,\Omega$$

$MVA := 1000kW$

Incorrect way:

$Sb := 100MVA \qquad Z_{bLV} := \frac{(120V)^2}{Sb} \qquad Z_{bLV} = 1.44 \times 10^{-4}\,\Omega$

$$Z_{bHV} := \frac{(345kV)^2}{Sb} \qquad Z_{bHV} = 1190.25\,\Omega$$

$$Z_{line\_secondary} \cdot \frac{Z_{bHV}}{Z_{bLV}} = \left(2.3 \times 10^{6} + 2.3i \times 10^{7}\right)\Omega$$

They are in secondary ohms. Because we have two different transformer ratios (that are determined independently based on primary voltage and current), the normal practice of finding impedance bases from a MVA base and a voltage base is not accurate.