# Per-Unit and Primary/Secondary Calculations

## Per-Unit Basics

A per-unit value is the actual value of some quantity divided by the base value of that quantity. The basic equation for calculating a per-unit value is shown below.

$$\text{Value}_{\text{perUnit}} = \frac{\text{Value}_{\text{Actual}}}{\text{Value}_{\text{Base}}}$$

Equations used for finding base quantities of impedance, current, and power are shown in Table 1, where the base voltage ($kV_B$) is the nominal phase-to-phase voltage of the system in kilovolts, and the base power ($MVA_B$) is traditionally 100 MVA. In order to convert any per-unit value back to its actual units, simply multiply the per-unit quantity by its base value.

**Table 1. Base Calculations for Per-Unit Conversions**

| Base Quantity | Equation |
|---|---|
| Impedance ($Z_B$) | $Z_B = \frac{kV_B^2}{MVA_B}$ |
| Current ($I_B$) | $I_B = \frac{MVA_B \cdot 1000}{\sqrt{3} \cdot kV_B}$ |
| Power ($MVA_B$) | $MVA_B = \frac{\sqrt{3} \cdot kV_B \cdot I_B}{1000}$ |

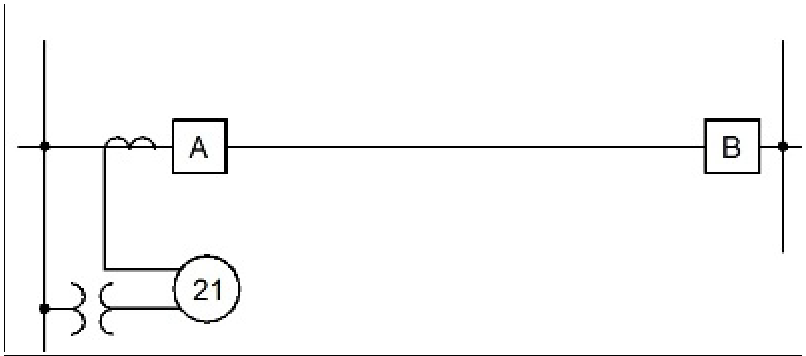
## Primary/Secondary Conversions

Some fundamental primary/secondary conversions can be found in Table 2, along with brief descriptions of their use. The following example should help to illustrate the use of the equations in Tables 1 and 2.

**Table 2. Primary/Secondary Conversions**

| Equation | Description |
|---|---|
| $I_{A\,sec} = \frac{I_{Apri}}{CTR}$ | Convert primary amps to secondary amps |
| $I_{Apri} = I_{A\,sec} \cdot CTR$ | Convert secondary amps to primary amps |
| $V_{sec} = \frac{1000 \cdot kV_{pri}}{PTR}$ | Convert primary kV to secondary volts |
| $kV_{pri} = \frac{V_{sec} \cdot PTR}{1000}$ | Convert secondary volts to primary kV |
| $Z_{\Omega sec} = Z_{\Omega pri} \cdot \frac{CTR}{PTR}$ | Convert primary ohms to secondary ohms |
| $Z_{\Omega pri} = Z_{\Omega sec} \cdot \frac{PTR}{CTR}$ | Convert secondary ohms to primary ohms |

**Example.** Line AB is operating at a line-to-line voltage of 230 kV and has positive-sequence impedance $Z_L = 0.024\angle 85°$ per unit on a 100 MVA base. The CT ratio is 1200/5 and the PT ratio is 2000/1. If phase distance relays at Bus A are to reach 80% of Line AB, what should the relay reach be set to in secondary ohms?




$V_{Base} = 230$ kV

$MVA_{Base} = 100$ MVA

$Z_{Base} = (230 \text{ kV})^2 / 100$ MVA

$Z_{Base} = 529\ \Omega$

$Z_{Lactual} = (0.024\angle 85°) * 529\ \Omega$

$Z_{Lactual} = 12.7\angle 85°\ \Omega$

$Z_{Reachpri} = 0.80 * 12.7\angle 85°\ \Omega$

$Z_{Reachpri} = 10.16\angle 85°\ \Omega$

$Z_{Reachsec} = 10.16\angle 85°\ \Omega * (1200/5) / 2000$

$Z_{Reachsec} = 1.22\angle 85°\ \Omega$ secondary

The relay reach should be set to $1.22\angle 85°\ \Omega$ secondary.

The ability to work comfortably with primary/secondary conversions and per-unit calculations is important when working with protective relays. Quick reference tables, like the ones shown above, can be very convenient in the field for making simple conversions. Where a more comprehensive collection of formulas and general reference material is needed, take a look at a pocket reference such as Protective Relaying Quick Reference.