

## 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.

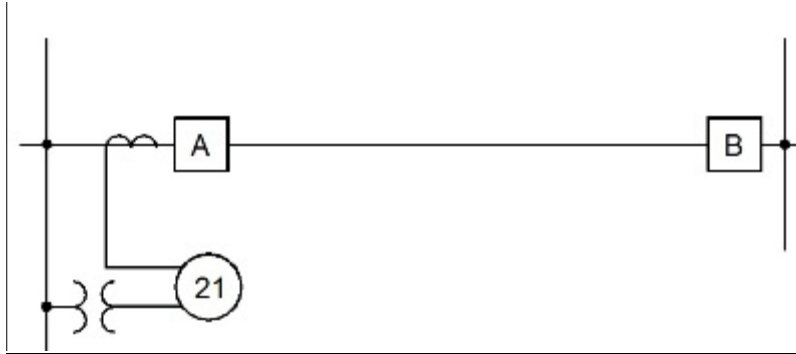
Table 1. Base Calculations for Per-Unit Conversions	
Base Quantity	Equation
Impedance ( $Z_B$ )	$Z_B = \frac{kV_B^2}{MVA_B}$
Current ( $I_B$ )	$I_B = \frac{MVA_B \cdot 1000}{\sqrt{3} \cdot kV_B}$
Power ( $MVA_B$ )	$MVA_B = \frac{\sqrt{3} \cdot kV_B \cdot I_B}{1000}$

### 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
$I_{A \text{ sec}} = \frac{I_{A \text{ pri}}}{CTR}$	Convert primary amps to secondary amps
$I_{A \text{ pri}} = I_{A \text{ sec}} \cdot CTR$	Convert secondary amps to primary amps
$V_{\text{sec}} = \frac{1000 \cdot kV_{\text{pri}}}{PTR}$	Convert primary kV to secondary volts
$kV_{\text{pri}} = \frac{V_{\text{sec}} \cdot PTR}{1000}$	Convert secondary volts to primary kV
$Z_{\Omega \text{ sec}} = Z_{\Omega \text{ pri}} \cdot \frac{CTR}{PTR}$	Convert primary ohms to secondary ohms
$Z_{\Omega \text{ pri}} = Z_{\Omega \text{ sec}} \cdot \frac{PTR}{CTR}$	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  $Z_L = 0.024 \angle 85^\circ$  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?



$$V_{\text{Base}} = 230 \text{ kV}$$

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

$$Z_{\text{Lactual}} = (0.024 \angle 85^\circ) * 529 \Omega$$

$$Z_{\text{Reachpri}} = 0.80 * 12.7 \angle 85^\circ \Omega$$

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

$$\text{MVA}_{\text{Base}} = 100 \text{ MVA}$$

$$Z_{\text{Base}} = 529 \Omega$$

$$Z_{\text{Lactual}} = 12.7 \angle 85^\circ \Omega$$

$$Z_{\text{Reachpri}} = 10.16 \angle 85^\circ \Omega$$

$$Z_{\text{Reachsec}} = 1.22 \angle 85^\circ \Omega \text{ secondary}$$

The relay reach should be set to  $1.22 \angle 85^\circ \Omega$  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](#).