1 POWER DISTRIBUTION

Section 1.1 Per Unit System

Most power systems calculations are done with the values of voltage, current, impedance, and power normalized to a common power and voltage base. Using this technique reduces the complexity of the circuit calculations when transformers are involved. The voltage bases selected for the normalized calculation are usually the same as the rated voltage of the transformers in the system. Selecting these values effectively removes the need to multiply and divide the ohmic values of circuit impedances by the turns ratio of the transformers when computing the voltage and current in the system.

Computing per-unit values (pu) requires selection of power and voltage bases. The base quantities of current and impedance are then computed from the power and voltage base. **The per unit value of any quantity is the ratio of the actual value of that quantity to the base value for that quantity.** To convert a pu value to a percentage, multiply the per unit value by 100. The nameplate of most power systems equipment gives the impedance of the equipment in either pu or percent. The base for this value is the rated power and voltage of the device.

A single-phase model represents balanced three-phase systems in most power systems calculations. The load flow and short circuit models reduce the three-phase model to a single-phase representation of the system when balanced operation is assumed. Both of these problems traditionally represent the system data in pu to simplify the storage of the data and computation of the solution.

Per Unit Formulae for Single Phase Systems

For single-phase circuits, or three phase circuits analyzed on a per phase basis, the following formulae give the base quantities.

Define the power units used in the equations.

$$VA \equiv V \cdot A \qquad KVA \equiv 1000\ VA$$

To illustrate the per unit system calculations, let the single-phase power and voltage base be

$$S_{base} := 100000\ KVA$$

$$V_{base} := 69\ KV$$

The derived base quantities for single-phase or per-phase calculations are

$$I_{base} := \frac{S_{base}}{V_{base}}$$ Use for Sbase in KVA and Vbase in kV. **(1.1.1)**

$$Z_{base} := \frac{V_{base}}{I_{base}}$$ Use for Ibase in KVA and Vbase in kV. **(1.1.2)**

$$Z_{base} := \frac{V_{base}^{\ 2} \cdot 1000}{S_{base}}$$ Use for Sbase in KVA and Vbase in kV. **(1.1.3)**

$$Z_{base} := \frac{V_{base}^{\ 2}}{S_{base}}$$ Use for Sbase in MVA and Vbase in kV. **(1.1.4)**

$$P_{base} := S_{base}$$

The following equations compute the pu values of voltage, current, impedance, and power from the corresponding actual values.

$$Z_{pu}\left(Z_{act}\right) := \frac{Z_{act}}{Z_{base}}$$ **(1.1.5)**

$$I_{pu}\left(I_{act}\right) := \frac{I_{act}}{I_{base}}$$ **(1.1.6)**

$$V_{pu}\left(V_{act}\right) := \frac{V_{act}}{V_{base}}$$ **(1.1.7)**

$$P_{pu}\left(P_{act}\right) := \frac{P_{act}}{S_{base}}$$ **(1.1.8)**

Per Unit Quantities for Three Phase Systems

Equations 1.1.1-1.1.8 establish the normalized circuit values for single-phase circuits. Using these equations on three-phase circuits requires that the current refer to line current, the voltages to line-to-neutral voltage, and the power to per phase power.

Data in three-phase power systems are customarily given as total power and line-to-line voltage. Specifying the line-to-line voltage and the total power results in the same per unit quantities as the single phase relationships from above. Computations done in pu are valid for both single-phase and three-phase equivalents. Converting to actual circuit values requires the multiplication of the pu value by the proper base values to obtain either the three-phase or single-phase quantities.

Redefining the equations above in terms of the three-phase power and the line-to-line voltage results in the following per unit values.

$$I_{base} := \frac{S_{base}}{\sqrt{3} \cdot V_{base}}$$ Sbase is total KVA and Vbase is the line-to-line voltage. **(1.1.9)**

$$Z_{base} := \frac{\left(\frac{V_{base}}{\sqrt{3}}\right)^2 \cdot 1000}{S_{base}}$$ Sbase is total KVA and Vbase is line-to-line voltage. **(1.1.10)**

$$\frac{S_{base}}{3}$$

$$Z_{base} := \frac{V_{base}^{\,2} \cdot 1000}{S_{base}}$$ Sbase is total KVA and Vbase is the line-to-line voltage. **(1.1.10a)**

$$Z_{base} := \frac{V_{base}^{\,2}}{S_{base}}$$ Use for Sbase in total MVA and Vbase in kV line-to-line. **(1.1.11)**

The relationships for converting the actual circuit values to pu are the same as the single-phase relationships.

Changing Bases in the Per Unit System

For per unit calculations to be correct, all circuit variables must be converted using the same power and voltage bases. The rated line-to-line transformer voltage in a section of a system usually is the base voltage for that section of a system. The power base is usually selected to be a 100 MVA for most system studies on high voltage systems. Equipment connected to the system has a per unit or percent impedance value on the nameplate. This nameplate impedance is computed using the device power rating as the base power. The voltage base is the rated operating voltage of the equipment. It is often necessary to change the base of impedance values of equipment to match the base values used in analysis. Equation 1.1.12 gives the relationship for converting the equipment impedance in ohms to a pu impedance.

Suppose

$$S_{base} := 100000 \ \boldsymbol{KVA}$$

$$V_{base} := 69 \ \boldsymbol{KV}$$

$$Z_{act} := 47.6 \ \boldsymbol{\Omega}$$

$$Z_{pu} := \frac{Z_{act} \cdot S_{base}}{V_{base}^{\,2}}$$ **(1.1.12)**

If the equipment impedance is given in per unit, Equation 1.1.13 allows the direct conversion of the per unit value to different voltage and power bases. The given values of voltage and power refer to the power and voltage ratings of the equipment. The new value of voltage and power refer to the base values used in the power system calculation.

For

$$Z_{given} := 0.01$$ given pu impedance of a piece of equipment

$$V_{given} := 69 \ \boldsymbol{KV}$$ the given and new values of base voltages

$$V_{new} := 34.5 \ \boldsymbol{KV}$$

$S_{given} := 10000\ \mathbf{KVA}$ 	the given and new values of base power

$S_{new} := 100000\ \mathbf{KVA}$

The new pu value of impedance is

$$Z_{new} := Z_{given} \cdot \left(\frac{V_{given}}{V_{new}}\right)^2 \cdot \frac{S_{new}}{S_{given}} = 0.4 \qquad \textbf{(1.1.13)}$$