Per Unit Systems

Presentation By

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# CHAPTER 1   Per Unit Calculations

## 1. Power System Representation

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<tr>
<th>Power Component</th>
<th>Symbol</th>
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<th>Symbol</th>
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</thead>
<tbody>
<tr>
<td>Generator</td>
<td>![Generator Symbol]</td>
<td>Circuit breaker</td>
<td>![Circuit Breaker Symbol]</td>
</tr>
<tr>
<td>Transformer</td>
<td>![Transformer Symbol]</td>
<td>Transmission line</td>
<td>![Transmission Line Symbol]</td>
</tr>
<tr>
<td>Motor</td>
<td>![Motor Symbol]</td>
<td>Feeder + load</td>
<td>![Feeder + Load Symbol]</td>
</tr>
<tr>
<td>Busbar (substation)</td>
<td>![Busbar Symbol]</td>
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Power components and symbols
Interconnections among these components in the power system may be shown in a so-called one-line diagram or single-line diagram. Single-line diagram represents all 3-φ of balanced system. For the purpose of analysis, the single-line diagram of a particular power system network is represented to its equivalent reactance or impedance diagram. A sample of a interconnected of individual power component is shown in Figure 1.1. This represent a circuit diagram of a power network which is referred to as a single-line diagram.

Figure 1.1 – Single-line diagram
Impedance diagram

In power system fault calculations it is often that a single-line diagram representing a typical power network in 3-φ be converted into its per phase impedance diagram. Some assumptions for converting from single-line diagram into its equivalent impedance diagram needed to be considered.

(i) A generator can be represented by a voltage source in series with an inductive reactance. The internal resistance of the generator is assumed to be negligible compared to the reactance.
(ii) The loads are usually inductive represented by resistance and inductance.
(iii) The transformer core is assumed to be ideal, and the transformer may be represented by a reactance only.
(iv) The transmission line is represented by its resistance and inductance, the line-to-ground capacitance is assumed to be negligible.

Let us consider the following on how the single-line diagram of Figure 1.2 converted into its impedance diagram counterpart.
Figure 1.2 – Single-line diagram of a power network
Figure 1.3 – Impedance diagram of Figure 1.2

Station A

Transformer $T_1$

$\jmath X_{T_1}$

$R_{L1}$

$\jmath X_L$  

$G_1$

$G_2$

Station B

Transformer $T_2$

$\jmath X_{T_2}$

Transmission Line $T_L$

$R_{T_L}$

$\jmath X_T$

$G_3$

$G_4$
Per-Unit Quantities

Per unit quantities are quantities that have been normalized to a base quantity. In general,

\[
Z_{pu} = \frac{Z_{actual}}{Z_{base}} \quad \text{per-unit (p.u)}
\]

Choice of the base value \( Z_{base} \) is normally a rated value which is often one of the normal full-load operations of power component in a power network.

Let us look at two of the most common per unit formula which are widely used when per unit calculations are involved.

(i) Base impedance \( (Z_{base}) \)

For a given single-line (one-line) diagram of a power network, all component parameters are expressed in 3-\( \Phi \) quantity whether it is the rating (capacity) expressed as MVA or voltage as kV. Let begin with 3-\( \Phi \) base quantity of

\[
S_{base} = \sqrt{3}V_{base}I_{base} \quad ----- (i)
\]

where \( V_{base} = \) line voltage, \( I_{base} = \) line or phase current

Per phase base impedance,

\[
Z_{base} = \frac{V_{base}}{\sqrt{3}I_{base}} \quad ----- (ii) \quad \text{This is line-to-neutral impedance}
\]
Combining (i) and (ii) yields,

\[
Z_{base} = \frac{V_{base}}{S_{base}} \sqrt{3} \frac{\sqrt{3} V_{base}}{\sqrt{3} V_{base}}
\]

\[
Z_{base} = \left[\frac{kV_{base}}{MVA_{base}}\right]^2
\]

where \( kV_{base} \) and \( MVA_{base} \) are 3-\( \phi \) qualities

(ii) Changing base impedance \((Z_{new})\)

Sometimes the parameters for two elements in the same circuit (network) are quoted in per-unit on a different base. The changing base impedance is given as,

\[
Z_{new \,(pu)} = Z_{old} \times \left[\frac{kV_{base \,old}}{kV_{base \,new}}\right]^2 \times \frac{MVA_{base \,new}}{MVA_{base \,old}}
\]
Example 1

Determine the per-unit values of the following single-line diagram and draw the impedance diagram.

\[ X_{T1} = 0.1 \text{ p.u.} \]

\[ X_{T2} = 0.04 \text{ p.u.} \]

\[ 5 \text{ MVA} \quad X_g = 16\% \]

\[ 100 \text{ MVA} \quad 275 \text{ kV/132 kV} \]

Transmission line \[ j/3.48 \Omega \]

\[ 50 \text{ MVA} \quad 132 \text{ kV/66 kV} \]

Load

40 MW, 0.8 p.f. lagging

Solution:

Chosen base: Always choose the largest rating, therefore \( S_{\text{base}} = 100 \text{ MVA} \), \( V = 66 \text{ kV}, 132 \text{ kV} \) and 275 kV

Per-unit calculations:

Generator G1:

\[ Z_{\text{NEW \ (pu)}} = Z_{\text{OLD \ (pu)}} \times \frac{\left[ \frac{kV_{\text{base \ OLD}}}{kV_{\text{base \ NEW}}} \right]^2 \times \frac{\text{MVA}_{\text{base \ NEW}}}{\text{MVA}_{\text{base \ OLD}}}} \]

\[ X_g (pu) = 0.16 \times \frac{100}{50} = 0.32 \text{ p.u.} \]

Transformer T1:

\[ X_{T1} (pu) = 0.1 \text{ p.u.} \]
Transmission line TL:

\[ Z_{\text{base}} = \frac{[kV_{\text{base}}]^2}{\text{MVA}_{\text{base}}} \]

\[ Z_{pu} = \frac{Z_{\text{actual}}}{Z_{\text{base}}} \]

\[ X_{TL}(pu) = \frac{3.4 \times 100}{132^2} = 0.0195 \text{ p.u.} \]

Inductive load:

\[ Z_{\text{actual}} = \frac{66 \times 10^3}{40 \times 10^6 / \sqrt{3}} = 87.12 \angle 36.87^\circ \Omega \]

\[ Z_L(pu) = \frac{87.12 \angle 36.87^\circ \times 100}{66^2} = 2 \angle 36.87^\circ \text{ or } (1.6 + j1.2) \text{ p.u.} \]

Transformer T2:

\[ X_{T2}(pu) = 0.04 \times \frac{100}{50} = 0.08 \text{ p.u.} \]
Now, we have all the impedance values in per-unit with a common base and we can now combine all the impedances and determine the overall impedance.