3-ϕ BASICS

Δ – Y Transformation

for balanced load

\[ Z_\Delta = 3Z_Y \]

Balanced 3-ϕ Systems

\[ \angle V_{ab} - 120° = \angle V_{bc} \]
\[ \angle V_{ab} - 240° = \angle V_{ca} \]
\[ \angle I_a - 120° = \angle I_b \]
\[ \angle I_a - 240° = \angle I_c \]

\[ |V_{ab}| = \sqrt{3} |V_{an}| \]
\[ |I_a| = \sqrt{3} |I_{ab}| \]

\[ \angle V_{ab} - 30° = \angle V_{an} \]
\[ \angle I_{ab} - 30° = \angle I_a \]

\[ S_{3-ϕ} = 3\overline{V}_{an}\overline{T}_a^* \]
\[ S_{3-ϕ} = 3\overline{V}_{ab}\overline{T}_{ab}^* \]

\[ S_{3-ϕ} = \sqrt{3}\overline{V}_{ab}\overline{T}_a^* \angle 30° \]

PER UNIT SYSTEM

\[ S_B = V_B I_B \]
\[ Z_B = \frac{1}{Y_B} = \frac{V_B^2}{S_B} \]
\[ S_B^{3ϕ} = 3S_B \]
\[ V_{line-line}^{3ϕ} = \sqrt{3}V_B \]
\[ Z_B^{3ϕ} = Z_B = \frac{(V_{line-line}^{3ϕ})^2}{S_B^{3ϕ}} \]

MAGNETIC CIRCUIT RELATIONS

\[ \mu_0 = 4\pi \times 10^{-7} \]
\[ R = \frac{l}{\mu A} \]
\[ L = \frac{N^2}{R} = N^2 \left( \frac{\mu A}{l} \right) \]
\[ F = NI = \frac{1}{\mu A} \phi = R\phi \]

Faraday’s Law

\[ V(t) = \frac{d\phi(t)}{dt} = N \frac{d\phi(t)}{dt} \]

TRANSFORMERS

Ideal transformer voltage and current relations

\[ \frac{E_1}{E_2} = \frac{N_1}{N_2} = a = \frac{1}{n} \]
\[ \frac{I_1}{I_2} = \frac{N_2}{N_1} = \frac{1}{a} = n \]

Transformer modelling - impedance relations

secondary winding impedance reflected to primary
\[
Z_2 = \left( \frac{N_2}{N_1} \right)^2 Z_2 = a^2 Z_2
\]

primary winding impedance reflected to secondary

\[
Z_1' = \left( \frac{N_2}{N_1} \right)^2 Z_1 = n^2 Z_1
\]

equivalent impedance seen at primary

\[
Z_{in} = Z_1 + a^2 Z_2 + a^2 Z_{load}
\]

**Impedance Diagram Representation**

\[
Z_{1,B} = \frac{V_{1,B}}{S_{B}} \quad \text{and} \quad Z_{2,B} = \frac{V_{2,B}}{S_{B}}
\]

\[
Z_{1,p.u.} = \frac{V_{1}}{S_{p.u.}} \quad \text{and} \quad Z_{2,p.u.} = \frac{V_{2}}{S_{p.u.}}
\]

**Autotransformer - impedance relations**

equivalent impedance seen at primary - step down, neglecting core loss

\[
Z_{in} = Z_1 + (a - 1)^2 Z_2 + a^2 Z_{load}
\]

equivalent impedance seen at primary - step up, neglecting core loss

\[
Z_{in} = (a - 1)^2 Z_1 + a^2 Z_2 + a^2 Z_{load}
\]

conducted and transformed power

\[
S_{capacity} = S_{transformed} + S_{conducted}
\]

capacity increase - step down \((a \geq 1)\)

\[
S_{capacity} \over S_{rating} = \frac{a}{a - 1}
\]

capacity increase - step down \((a \leq 1)\)

\[
S_{capacity} \over S_{rating} = \frac{1}{1 - a}
\]

**Efficiency**

\[
\eta = \frac{P_{out}}{P_{in}} \times 100\% = \left( 1 - \frac{P_{losses}}{P_{in}} \right) \times 100\%
\]

**Voltage Regulation**

\[
VR = \left( \frac{V_{1, \text{rating}}}{V_{1, \text{rated}}} - 1 \right) \times 100\%
\]

**POWER AND ENERGY FUNDAMENTALS**

Energy - power relationship

\[
P = \frac{dW}{dt}
\]

Energy stored in inductor

\[
W = \frac{1}{2} LI^2
\]

Mechanical kinetic energy

\[
W = \frac{1}{2} mv^2
\]