

# dummy

## Student Group

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## Table of Contents

Exercise E1.1 Dot convention and load current direction .....	2
Exercise E2.1 Mutual inductance and leakage from a magnetic path .....	2
Exercise E3.1 Short-circuit voltage from the transformer impedance .....	4
Exercise E4.1 Voltage drop under load using the Kapp approximation .....	5
Exercise E5.1 Concept question: why the magnetizing branch can be neglected in the short-circuit test .....	6

### Exercise E1.1 Dot convention and load current direction

A transformer winding pair is marked with dots. A positive reference current  $(i_1)$  enters the dotted terminal of winding 1.

Assume positive coupling and define  $(u_2)$  positive at the dotted terminal of winding 2.

- What is the polarity of the induced voltage on winding 2?
- If a resistor  $(R_2)$  is connected to winding 2, in which direction does the load current flow?
- Why can the transformer current reference  $(i_2)$  be opposite to the actual load current?

Result

For positive coupling:

$[ \begin{align*} i_1 \text{ enters the dotted terminal} \quad \rightarrow \quad \text{the dotted terminal of winding 2 becomes positive.} \end{align*} ]$

Since  $(u_2)$  is defined positive at the dotted terminal, the induced voltage is aligned with  $(u_2)$ .

If only a resistor  $(R_2)$  is connected to the secondary side, this voltage drives current out of the dotted terminal into the load.

However, in transformer equivalent circuits  $(i_2)$  is often drawn as a passive current entering the transformer port. Then

$[ \begin{align*} i_2 = -i_{\text{load}} \end{align*} ]$

This is not negative coupling. It only means that the secondary side delivers power to the load.

### Exercise E2.1 Mutual inductance and leakage from a magnetic path

Two coils are wound on the same magnetic core. The shared main magnetic path has the reluctance

$[ \begin{align*} R_{\text{mH}} = 1.6 \cdot 10^6 \frac{1}{\text{H}} \end{align*} ]$

The numbers of turns are

$$\left[ \begin{array}{l} N_1=400, \\ \quad N_2=100. \end{array} \right]$$

The leakage inductances are

$$\left[ \begin{array}{l} L_{1\sigma}=4.0 \text{~}\{\text{mH}\}, \\ \quad L_{2\sigma}=0.30 \text{~}\{\text{mH}\}. \end{array} \right]$$

Calculate:

- $(L_{1\text{H}})$
- $(L_{2\text{H}})$
- $(M)$
- the total self-inductances  $(L_1)$  and  $(L_2)$
- the coupling coefficient  $(k=\frac{M}{\sqrt{L_1L_2}})$

Result

The main-flux self-inductances are

$$\left[ \begin{array}{l} L_{1\text{H}} = \frac{N_1^2}{R} = \frac{400^2}{1.6 \cdot 10^6} = 0.100 \text{~}\{\text{mH}\}, \\ L_{2\text{H}} = \frac{N_2^2}{R} = \frac{100^2}{1.6 \cdot 10^6} = 0.00625 \text{~}\{\text{mH}\} = 6.25 \text{~}\{\text{mH}\}. \end{array} \right]$$

The mutual inductance is

$$\left[ M = \frac{N_1 N_2}{R} = \frac{400 \cdot 100}{1.6 \cdot 10^6} = 0.025 \text{~}\{\text{mH}\} = 25 \text{~}\{\text{mH}\}. \right]$$

The total self-inductances are

$$\left[ \begin{array}{l} L_1 = L_{1\text{H}} + L_{1\sigma} = 100 \text{~}\{\text{mH}\} + 4.0 \text{~}\{\text{mH}\} = 104 \text{~}\{\text{mH}\}, \\ L_2 = L_{2\text{H}} + L_{2\sigma} = 6.25 \text{~}\{\text{mH}\} + 0.30 \text{~}\{\text{mH}\} = 6.55 \text{~}\{\text{mH}\}. \end{array} \right]$$

Thus

$$\left[ k = \frac{M}{\sqrt{L_1 L_2}} = \frac{0.025 \text{~}\{\text{mH}\}}{\sqrt{0.104 \text{~}\{\text{mH}\} \cdot 0.00655 \text{~}\{\text{mH}\}}} \approx 0.96. \right]$$

The coupling is strong, but not ideal, because leakage inductances are present.

### Exercise E3.1 Short-circuit voltage from the transformer impedance

A transformer has the rated primary data

$$\begin{aligned} U_{1\{\text{r m N}\}} &= 230 \sim \{\text{r m V}\}, \quad I_{1\{\text{r m N}\}} = 2.0 \sim \{\text{r m A}\}. \\ \end{aligned}$$

The short-circuit equivalent impedance referred to the primary side is

$$\begin{aligned} R_{\{\text{r m k}\}} &= 1.5 \sim \Omega, \quad X_{\{\text{r m k}\}} = 4.0 \sim \Omega. \end{aligned}$$

Calculate:

- $|\underline{Z}_{\{\text{r m k}\}}|$
- the rated short-circuit voltage  $(U_{1\{\text{r m k}\}})$
- the relative short-circuit voltage  $(u_{\{\text{r m k}\}})$
- the prospective continuous short-circuit current  $(I_{1\{\text{r m k}\}})$  for rated primary voltage
- the approximate first peak current  $(i_{\{\text{r m peak}\}} \approx 2.54 I_{1\{\text{r m k}\}})$

Result

The short-circuit impedance magnitude is

$$\begin{aligned} |\underline{Z}_{\{\text{r m k}\}}| &= \sqrt{R_{\{\text{r m k}\}}^2 + X_{\{\text{r m k}\}}^2} = \\ &= \sqrt{(1.5 \sim \Omega)^2 + (4.0 \sim \Omega)^2} = 4.27 \sim \Omega. \end{aligned}$$

The primary voltage required to drive rated current through the short-circuited transformer is

$$\begin{aligned} U_{1\{\text{r m k}\}} &= |\underline{Z}_{\{\text{r m k}\}}| I_{1\{\text{r m N}\}} = \\ &= 4.27 \sim \Omega \cdot 2.0 \sim \{\text{r m A}\} = 8.54 \sim \{\text{r m V}\}. \end{aligned}$$

The relative short-circuit voltage is

$$\begin{aligned} u_{\{\text{r m k}\}} &= \frac{U_{1\{\text{r m k}\}}}{U_{1\{\text{r m N}\}}} \cdot 100 \sim \% = \\ &= \frac{8.54 \sim \{\text{r m V}\}}{230 \sim \{\text{r m V}\}} \cdot 100 \sim \% = 3.71 \sim \%. \end{aligned}$$

The prospective continuous short-circuit current is

$$\begin{aligned} I_{1\{\text{r m k}\}} &= I_{1\{\text{r m N}\}} \cdot \frac{100 \sim \%}{u_{\{\text{r m k}\}}} = \\ &= 2.0 \sim \{\text{r m A}\} \cdot \frac{100}{3.71} = 53.9 \sim \{\text{r m A}\}. \end{aligned}$$

The approximate first peak current is

$$\begin{aligned} i_{\{\text{r m peak}\}} &\approx 2.54 I_{1\{\text{r m k}\}} = 2.54 \cdot 53.9 \sim \{\text{r m A}\} = \\ &= 137 \sim \{\text{r m A}\}. \end{aligned}$$

Even though the rated current is only  $(2.0 \sim \{\text{r m A}\})$ , a short-circuit fault could lead

to a much larger current until protection reacts.

### Exercise E4.1 Voltage drop under load using the Kapp approximation

A transformer has the turns ratio

$$n=10.$$

The short-circuit equivalent parameters referred to the primary side are

$$R_k=2.4\ \Omega, \quad X_k=3.6\ \Omega.$$

The secondary load current is

$$I_2=4.0\ \text{A}.$$

The load has the power factor

$$\cos\varphi=0.8$$

and is inductive.

Estimate the voltage drop on the secondary side using

$$\Delta U_1 \approx I_1 \left( R_k \cos\varphi + X_k \sin\varphi \right)$$

and

$$\Delta U_2 \approx \frac{\Delta U_1}{n}.$$

Result

The primary current magnitude is approximately

$$I_1 = \frac{I_2}{n} = \frac{4.0\ \text{A}}{10} = 0.40\ \text{A}.$$

For an inductive load with  $\cos\varphi=0.8$ ,

$$\sin\varphi = \sqrt{1-\cos^2\varphi} = \sqrt{1-0.8^2} = 0.6.$$

The primary-side voltage drop is

$$\begin{aligned} \Delta U_1 &\approx I_1 \left( R_k \cos \varphi + X_k \sin \varphi \right) \\ &= 0.40 \text{~}\{\text{A}\} \left( 2.4 \text{~}\{\Omega\} \cdot 0.8 + 3.6 \text{~}\{\Omega\} \cdot 0.6 \right) \\ &= 0.40 \text{~}\{\text{A}\} \left( 1.92 \text{~}\{\Omega\} + 2.16 \text{~}\{\Omega\} \right) \\ &= 1.63 \text{~}\{\text{V}\}. \end{aligned}$$

Referred to the secondary side:

$$\begin{aligned} \Delta U_2 &\approx \frac{\Delta U_1}{n} = \frac{1.63 \text{~}\{\text{V}\}}{10} \\ &= 0.163 \text{~}\{\text{V}\}. \end{aligned}$$

The secondary voltage decreases by approximately  $(0.16 \text{~}\{\text{V}\})$  for this operating point.

### Exercise E5.1 Concept question: why the magnetizing branch can be neglected in the short-circuit test

In the short-circuit test of a transformer, the secondary side is shorted. The primary voltage is then increased only until rated current flows.

Explain in two or three sentences why the magnetizing branch  $(R_{\text{Fe}} \parallel jX_{1\text{H}})$  can usually be neglected in this test.

Result

In the short-circuit test, only a small fraction of the rated primary voltage is needed to drive rated current through the short-circuited transformer. Since the main flux is approximately proportional to the applied voltage,

$$\underline{U}_1 \approx j\omega N_1 \underline{\Phi}_{\text{H}},$$

the main flux is also small.

Therefore the magnetizing current through  $(jX_{1\text{H}})$  and the iron-loss current through  $(R_{\text{Fe}})$  are small compared with the short-circuit current through  $(R_k + jX_k)$ . For this reason, the magnetizing branch is usually neglected in the short-circuit equivalent circuit.

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