Math Lab 7 MS 4

Solving “Force” Transformer Problems in Electrical Systems

For best results, print this document front-to-back and place it in a three-ring binder.
Corresponding teacher and student pages will appear on each opening.

TEACHING PATH - MATH SKILLS LAB - CLASS M

RESOURCE MATERIALS

Student Text: Math Skills Lab

CLASS GOALS

Apply appropriate equations to solve force transformer problems that appear in electrical systems.

CLASS ACTIVITIES

1. Take five or ten minutes to go through the Student Exercises. Make sure that students understand the correct answers.
2. Complete as many math problems on "force" transformers in electrical systems as time permits.
3. Before the class ends, ask students to read Lab 7E1/7E2, "Electrical Transformers," as homework. This is a double lab where students will work with a simple voltage transformer.

Problem 1: n_i = 200 turns

n_o = 400 turns

a. $\frac{n_o}{n_i} = \frac{V_o}{V_i}$ Rearrange symbols to isolate "V_o." Then solve.

$$V_o = \left(\frac{n_o}{n_i}\right) V_i = \left(\frac{400}{200}\right)(110 \text{ V AC}) = 220 \text{ V AC}.$$

b. $\text{IEA} = \frac{n_o}{n_i} = \frac{(400)}{(200)} = 2$

Since $\frac{V_o}{V_i}$ = IEA, the step-up voltage ratio "$\frac{V_o}{V_i}$," also is equal to 2.

c. **According to Items 3, 4 and 5 of Table 7-6:**

$$\text{IEA} = \frac{n_o}{n_i} = \frac{V_o}{V_i} = \frac{I_i}{I_o}$$

Thus, $\frac{V_o}{V_i} = 2$, $\frac{I_i}{I_o} = 2$, or $\frac{I_o}{I_i} = 1/2$.

This means that--when voltage is doubled--the current is cut in half if there are no losses. Thus, the ratio of (current out/current in), or I_o/I_i, equals 1/2.

Math Skills Laboratory

Lab 7 MS 4

MATH ACTIVITY

Solving "Force" Transformer Problems in Electrical Systems

MATH SKILLS LAB OBJECTIVES

When you complete these activities, you should be able to do the following:

1. ***Solve and interpret "force" transformer problems in electrical systems.***
2. ***Distinguish between step-up and step-down transformer actions for both voltage and current.***

LEARNING PATH

1. ***Read the Math Skills Lab. Give particular attention to the Math Skills Lab Objectives.***
2. ***Work the problems.***

ACTIVITY

Solving "Force" Transformer Problems in Electrical Systems

In this lab, you'll solve problems that involve "force" transformers in electrical systems. You'll work problems that involve electrical transformers, where both current and voltage may be stepped up or stepped down.

To solve these problems, refer to the formulas in Table 7-6, "Useful Formulas for Voltage Transformers."

Problem 1: Given: Watson Manufacturing produces electrical components. These include capacitors, resistors, transistors, triacs, silicon-controlled rectifiers and small transformers. Rita Baxter works as a technical sales representative for the company. An important part of her job involves matching the company's products to the needs of customers. For one application, Rita suggested that her customer use a transformer that has 200 turns on the primary (input) winding and 400 turns on the secondary (output) winding.

Find:

a. Output voltage of the transformer when the input coil is connected to 110 volts AC.

b. Voltage step-up ratio (ideal electrical advantage) for the transformer.

c. Ratio of Current Out to Current In for the transformer.

Solution:

Problem 2:

a. IEA = $\frac{n_o}{n_i}$, so $n_o = n_i \times$ IEA after rearranging terms
$n_o = n_i \times$ IEA, where $n_i = 50$, IEA = 6
$n_o = 50 \times 6 = 300$
There are 300 turns on the output coil.

b. Since IEA is given as 6, and IEA = $\frac{V_o}{V_i}$, V_o must be 6 times larger than V_i. Hence it is a step-up transformer.

c. IEA = $\frac{V_o}{V_i}$, so $V_o = V_i \times$ IEA after rearranging terms
$V_o = V_i \times$ IEA, where $V_i = 60$ V AC and $n_o = 300$
$V_o = (60 \text{ V AC}) \times 6 = 360$ V AC.

Problem 3:

a. IEA = $\frac{n_o}{n_i}$, where $n_o = 92$ turns, $n_i = 1$ turn

$$\text{IEA} = \frac{92}{1} = 92$$

b. IEA = $\frac{I_i}{I_o}$, where IEA = 92 and $I_i = 15$ A
Rearrange equation to solve for I_o and get

$$I_o = \frac{I_i}{\text{IEA}} = \frac{15\text{ A}}{92} = 0.163\text{ A}$$

c. IEA = $\frac{V_o}{V_i}$, so $V_o = V_i \times$ IEA after rearranging terms
$V_o = V_i \times$ IEA, where $V_i = 220$ V and IEA = 92
$V_o = (220 \text{ V}) \times 92 = 20{,}240$ V AC

Problem 2: Given: One of the products made by Watson Manufacturing is a voltage transformer that has an ideal electrical advantage of 6.

Find:

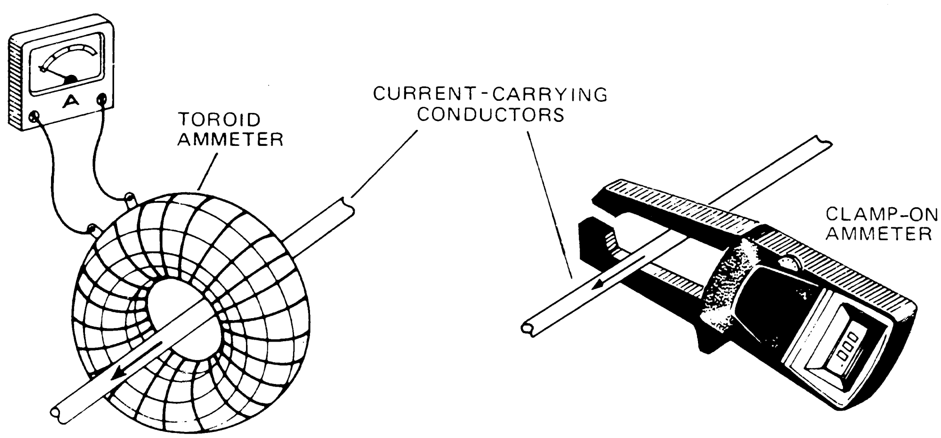
a. Number of turns in the output coil if the input coil has 50 turns.

b. Is this a step-up or step-down voltage transformer?

c. What's the output voltage if the input voltage is 60 V AC?

Solution:

Problem 3: Given: "Toroid" transformers (wire coil transformer) often are used with three-phase power lines to find the current flowing in each line. Some toroids are permanently installed on the individual lines of switch gears. Others—portable types—clamp around the line. The figure shows two of these "ampere meter" transformers. The ammeter is calibrated in terms of the ratio of turns of the wires. This way, a small AC current in the ammeter circuit shows the true AC current in the input conductor.



Find:

a: The ideal electrical advantage for the in-line toroid transformer if the toroid has 92 turns and the input, single-line conductor passing through the toroid is considered to have a turn value of n = 1.

b. The ammeter indicates 15.0 amperes of current in the line. What's the actual output current of the toroid flowing to the ammeter?

c. When the conductor carries 15 amperes, it has a line voltage of 220 volts. Consider this the voltage in the "primary" winding. What's the voltage across the toroid terminals—that is, the voltage across the "secondary" windings?

Solution:

Problem 4: From Table 7-6, Equations 3, 4 and 4 respectively are:

Eq. 3: $IEA = \frac{n_o}{n_i}$; Eq. 4: $IEA = \frac{V_o}{V_i}$; Eq. 5: $IEA = \frac{I_i}{I_o}$.

a. Use Equation 3.

$IEA = \frac{n_o}{n_i}$ where: n_o = 300 turns
n_i = 25 turns

$IEA = \frac{300 \text{ turns}}{25 \text{ turns}} = 12.$

b. Use Equation 5.

$IEA = \frac{I_i}{I_o}$ Solve for "I_o."

$I_o = \frac{I_i}{IEA}$ where: I_i = 3 A
IEA = 12 (from part "a" above)

$I_o = \frac{3 \text{ A}}{12} = 0.25 \text{ A}.$

c. Combine Equations 4 and 5.

$V_i I_i = V_o I_o$ where: V_i = 110 V
I_i = 3 A

Solve for "V_o."

$V_o = \frac{V_i I_i}{I_o} = \frac{110 \text{ V} \times 3 \text{ A}}{0.25 \text{ A}} = \frac{330 \text{ V}\cdot\text{A}}{0.25 \text{ A}} = 1320 \text{ V}$

d. Output power = $I_o V_o$ where: I_o = 0.25 A
V_o = 1320 V

Output power = (1320 V x (0.25 A)
Output power = (1320 x 0.25) (V•A)
Output power = 330 V•A = 330 watts.
Since efficiency is given as 100%, output power should equal input power.
Input power = $I_i V_i$ = 3 A x 100 V = 330 V•A = 330 watts (same as output power).

Problem 5: From Table 7-6, Equations 3 and 4 respectively are:

Eq. 3: $IEA = \frac{n_o}{n_i}$; Eq. 4: $IEA = \frac{V_o}{V_i}$.

a. Tap 1-2:

$IEA = \frac{V_o}{V_i}$ where: $V_o = 120$ V, $V_i = 2400$ V

$IEA = \frac{120 \text{ V}}{2400 \text{ V}} = 0.05.$

Then $IEA = \frac{n_o}{n_i}$. where: IEA = 0.05, $n_o = 300$, n_i = unknown

Solve for "n_i."

$n_i = \frac{n_o}{IEA} = \frac{300 \text{ turns}}{0.05} = 6000$ turns

b. Tap 1-3:

$IEA = \frac{V_o}{V_i}$ where: $V_o = 120$ V, $V_i = 2292$ V

$IEA = \frac{120 \text{ V}}{2292 \text{ V}} = 0.052.$

Then for Tap 1-3, $IEA = \frac{n_o}{n_i}$. where: IEA = 0.052, $n_o = 300$ turns, n_i = unknown

Solve for "n_i."

$n_i = \frac{n_o}{IEA} = \frac{300 \text{ turns}}{0.052} = 5769$ turns.

c. Tap 1-4:

$IEA = \frac{V_o}{V_i}$ where: $V_o = 120$ V, $V_i = 2184$ V

$IEA = \frac{120 \text{ V}}{2184 \text{ V}} = 0.055.$

Then $IEA = \frac{n_o}{n_i}$. where: IEA = 0.055, $n_o = 300$ turns, n_i = unknown

Solve for "n_i."

$n_i = \frac{n_o}{IEA} = \frac{300 \text{ turns}}{0.055} = 5455$ turns.

d. Tap 1-5:

$$IEA = \frac{V_o}{V_i} \qquad \text{where:} \quad V_o = 120\text{ V}, \quad V_i = 2076\text{ V}$$

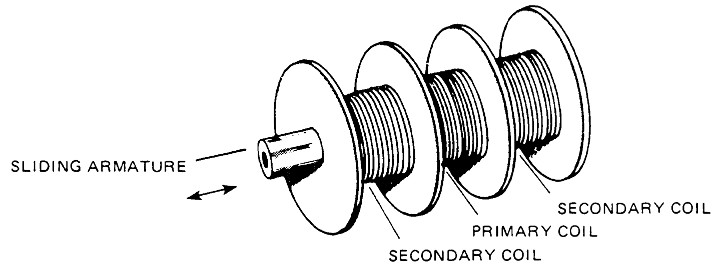
$$IEA = \frac{120\text{ V}}{2076\text{ V}} = 0.058.$$

Then $IEA = \frac{n_o}{n_i}$. where: $IEA = 0.058$
$n_o = 300$ turns
$n_i =$ unknown

Solve for "n_i."

$$n_i = \frac{n_o}{IEA} = \frac{300\text{ turns}}{0.058} = 5172\text{ turns.}$$

Problem 4: Given: A linear variable differential transformer (LVDT) is composed of a primary coil and two secondary coils, as shown in the drawing. Inside the hollow core is a sliding armature that causes a voltage across the primary windings to appear (proportionally) across the secondary windings. The secondary windings produce equal and opposite voltages when the armature is located midway between the coils (null point). At that position, there is no resultant voltage. Moving the armature either way causes an inbalance and a positive or negative voltage across the secondary coils. Thus, measuring the secondary voltage gives a way to determine the position of the sliding armature.



Find:

a. The ideal electrical advantage possible for the LVDT when the primary coil has 25 turns and each secondary coil has 300 turns.

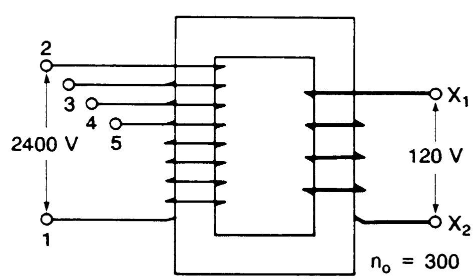
b. The maximum output current if the input voltage is 110 V at 3 amp and the LVDT is 100% efficient.

c. The output voltage for the conditions given in a and b.

d. The output wattage.

Solution:

Problem 5: Given: Line distribution transformers that reduce power-line voltage to house-line voltage must be able to supply 120 volts to the house entrance line. That is the case regardless of the line voltage loss on the input side because of how far the transformer is from the power substation. A 2400 V-to-120 V ratio transformer may not have 2400 V available due to power-line resistance. Multiple taps are provided on the primary (input) windings. These are provided to give different numbers of turns (n_i). That's done to provide 120 volts of house-line voltage even when the distribution-line voltage is less than 2400 V. (See drawing.) Notice that the secondary voltage remains 120 volts and has 300 turns (n_o = 300 turns) in all four cases. The transformer is considered to be 100% efficient.



HV tap	Primary Voltage	Secondary Voltage
1-2	2400 V	120 V
1-3	2292 V	120 V
1-4	2184 V	120 V
1-5	2076 V	120 V

Problem 6: From Table 7-6, Equations 3 and 4 respectively are:

Eq. 3: $IEA = \frac{n_o}{n_i}$; Eq. 4: $IEA = \frac{V_o}{V_i}$.

a. $IEA = \frac{V_o}{V_i}$ where: $V_o = 200$ V
$V_i = 300$ V

$IEA = \frac{200 \text{ V}}{300 \text{ V}} = 0.667.$

Then $IEA = \frac{n_o}{n_i}$. where: $IEA = 0.667$
$n_i = 1000$ turns
n_o = unknown

Solve for "n_o."

$n_o = IEA \times n_i = 0.667 \times 1000$ turns

$n_o = 667$ turns, between taps A and D.

b. $IEA = \frac{V_o}{V_i}$ where: $V_o = 150$ V
$V_i = 300$ V

$IEA = \frac{150 \text{ V}}{300 \text{ V}} = 0.5.$

$IEA = \frac{n_o}{n_i}$ where: $IEA = 0.5$
$n_i = 1000$ turns

Solve for "n_o."

$n_o = IEA \times n_i = 0.5 \times 1000$ turns

$n_o = 500$ turns, between taps A and C.

c. (1) $\frac{n_o}{n_i} = \frac{667}{1000} = 0.667 = 66.7\%$

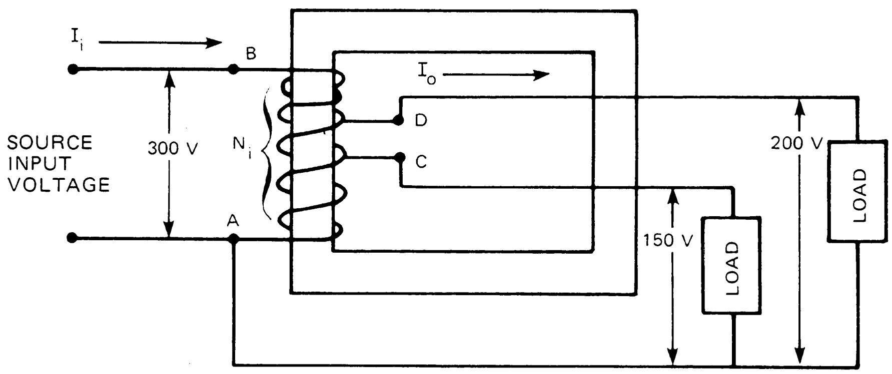
$\frac{n_o}{n_i} = \frac{500}{1000} = 0.5 = 50\%$

Find: The number of turns on the high-voltage (input or primary) side of the transformer for the taps given in Parts a-d below.

a. Tap 1-2
b. Tap 1-3
c. Tap 1-4
d. Tap 1-5

Solution:

Problem 6: Given: In an autotransformer, the secondary winding is really part of the primary winding. In effect, this means there's no need for a separate secondary winding. That makes the transformer lighter, smaller and cheaper than standard transformers of equal power output. Autotransformers are used to start induction motors, to regulate transmission-line voltages and to transform voltages when the ratio is close to 1. Ratios rarely exceed 5 to 1. An autotransformer is shown in the drawing. The primary (input) coil (n_i) contains 1000 turns.



Find:

a. The number of turns in the secondary (output) coil when the input voltage is 300 V and output voltage is 200 V. (Secondary taps are A and D.)
b. The number of turns in the secondary (output) coil when input voltage is 300 V and output voltage is 150 V. (Secondary taps are at A and C.)
c. The percent of the primary coil that's "tapped-off" as a secondary coil in
   (1) Part a above.
   (2) Part b above.

Solution: