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ECE202: CIRCUITS AND SYSTEMS
WEEK 8

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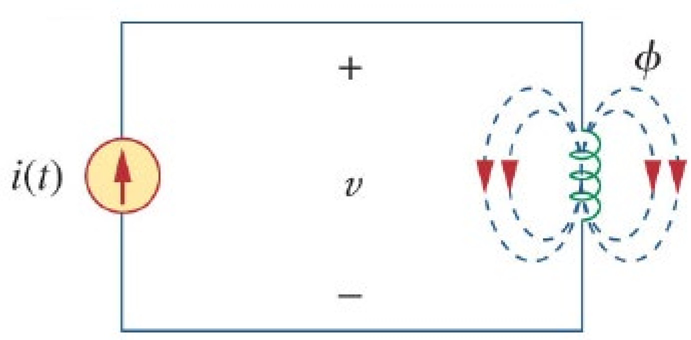
Magnetically Coupled Circuits

Introduction

- Magnetically coupled systems leverage the power of magnetic fields to create efficient and reliable connections between components, enabling seamless energy transfer and communication without direct contact.
- This innovative approach has applications in various fields, including telecommunications, robotics, power transmission, and even medical devices.
- In this session, we will cover the fundamental concepts of magnetism, delve into the different types of magnetic coupling, and discuss their practical applications and advantages over conventional methods.
- I encourage you to engage actively, ask questions, and share your perspectives as we uncover the potential of magnetically coupled systems together. Let's dive in! connected loads have equivalent wye connected loads, and vice versa.

Magnetically Coupled Circuits

- Circuit currents flowing in one mesh, or loop, can be affected by separate currents flowing in adjacent regions, if these are either conductively coupled (common) or magnetically coupled (via mutual inductance).



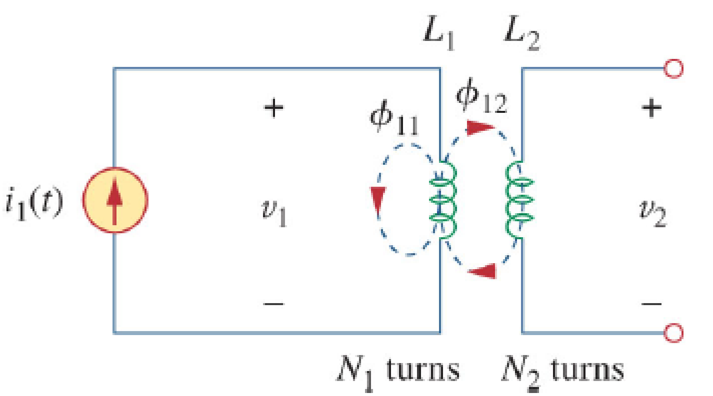
$$v = N\frac{d\phi}{dt}$$

$$v = N\frac{d\phi}{di}\frac{di}{dt}$$

$$L = N\frac{d\phi}{di}$$

Mutual Inductance

- Mutual inductance is the ability of one inductor to induce a voltage across a neighbouring inductor.
- Mutual inductance is measured in Henrys (H).

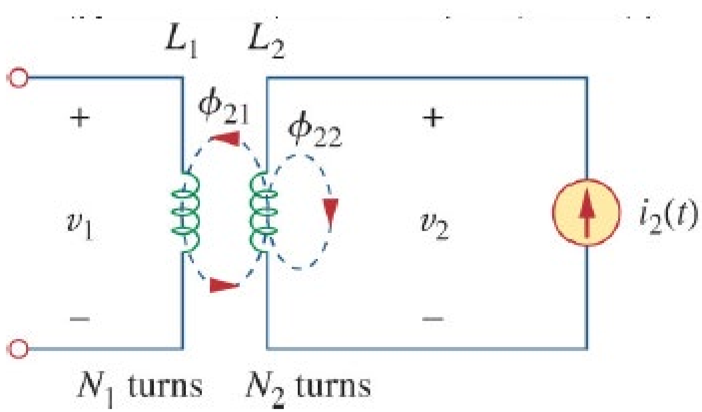


$$v_1 = N_1 \frac{d\phi_1}{dt} = L_1 \frac{di_1}{dt}$$

$$\phi_1 = \phi_{11} + \phi_{12} \qquad v_2 = N_2 \frac{d\phi_{12}}{dt}$$

$$v_2 = N_2 \frac{d\phi_{12}}{di_1}\frac{di_1}{dt} = M_{21}\frac{di_1}{dt}$$

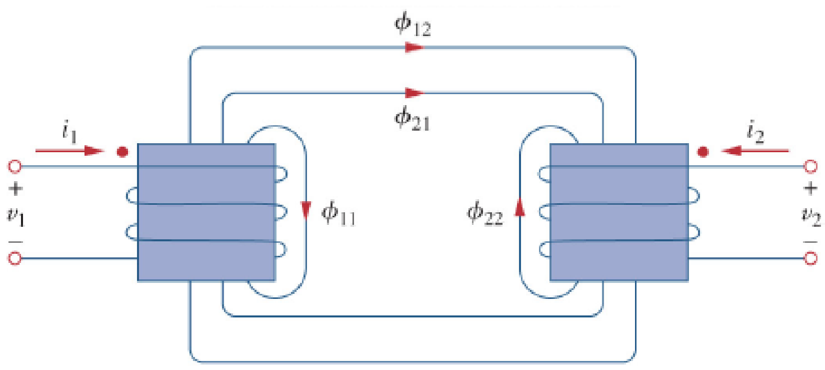
mutual inductance



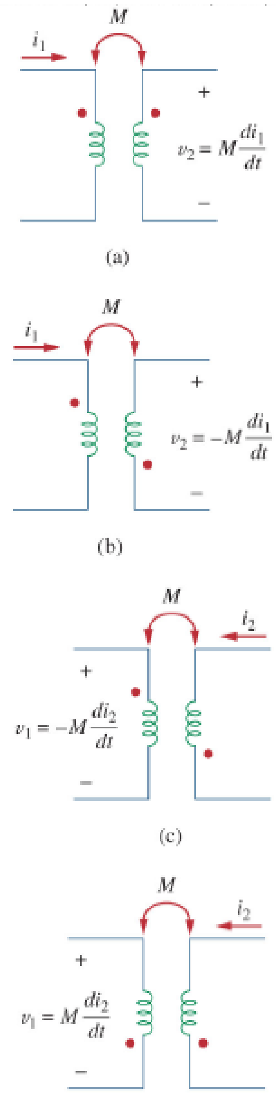
$$v_1 = M_{12}\frac{di_2}{dt} \qquad M_{12} = M_{21} = M$$

Mutual Inductance

- Although mutual inductance is always positive, the resultant mutual voltage (Mdi/dt) may be negative or positive, according to the direction of current flow.



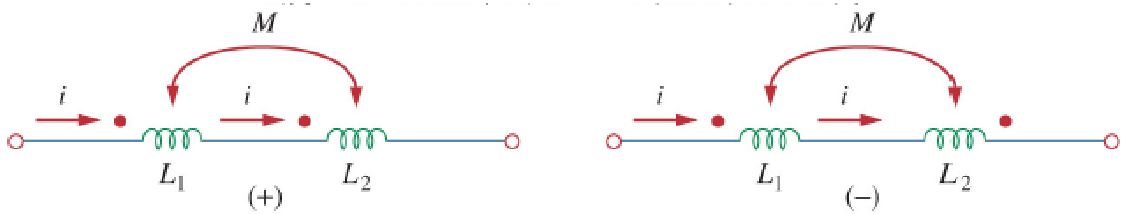
Dot convention: if current enters a dotted terminal of one coil, the reference polarity of the mutual voltage in the second coil will be positive at its respective dotted terminal (& vice-versa)



(d)

Mutual Inductance

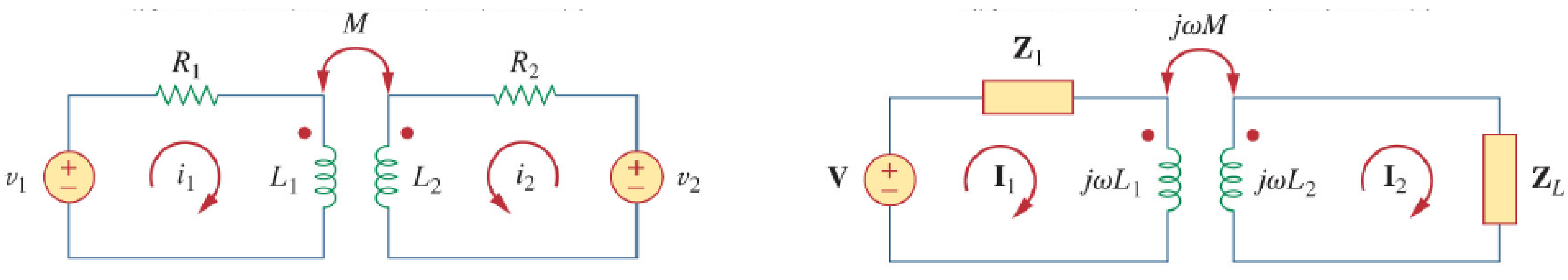
series-aiding



(a) (b)

series-opposing

$$L = L_1 + L_2 + 2M \qquad L = L_1 + L_2 - 2M$$



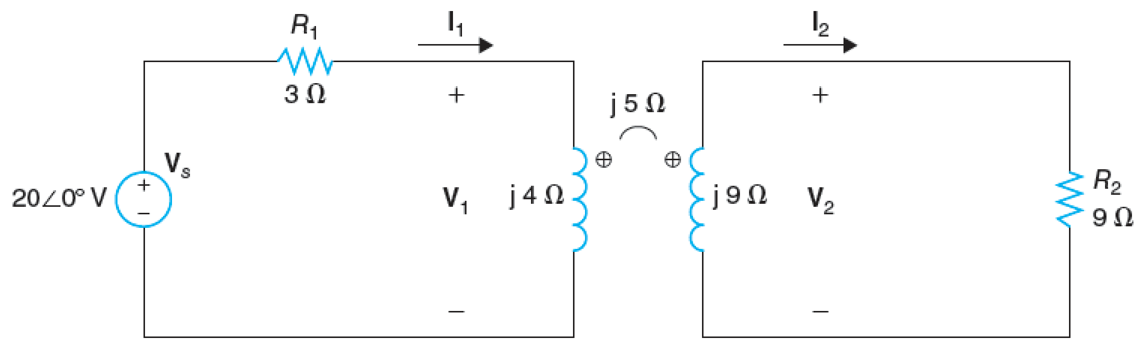
(a) (b)

$$V_1 = (R_1 + j\omega L_1)I_1 + j\omega M I_2$$
$$V_2 = j\omega M I_1 + (R_2 + j\omega L_2)I_2$$

$$V = (Z_1 + j\omega L_1)I_1 - j\omega M I_2$$
$$j\omega M I_1 = (Z_L + j\omega L_2)I_2$$

Example 1

Find $\mathbf{I}_1$, $\mathbf{I}_2$, $\mathbf{V}_1$, and $\mathbf{V}_2$ in the circuit



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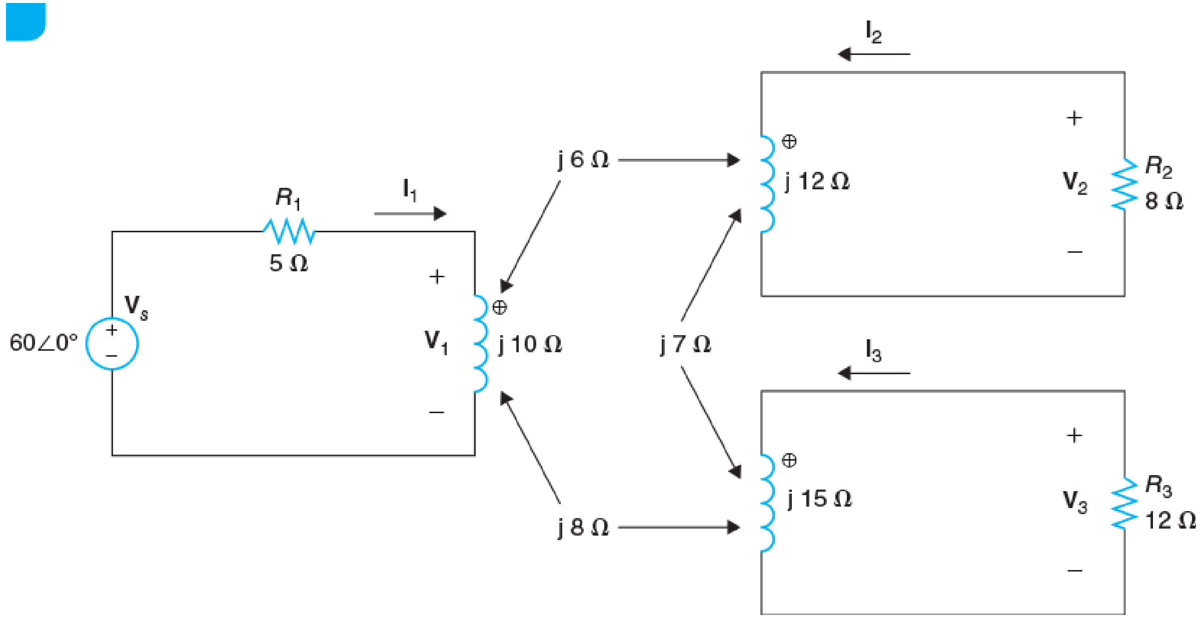
Example 2

Find $\mathbf{I}_1$, $\mathbf{I}_2$, and $\mathbf{I}_3$ in the circuit



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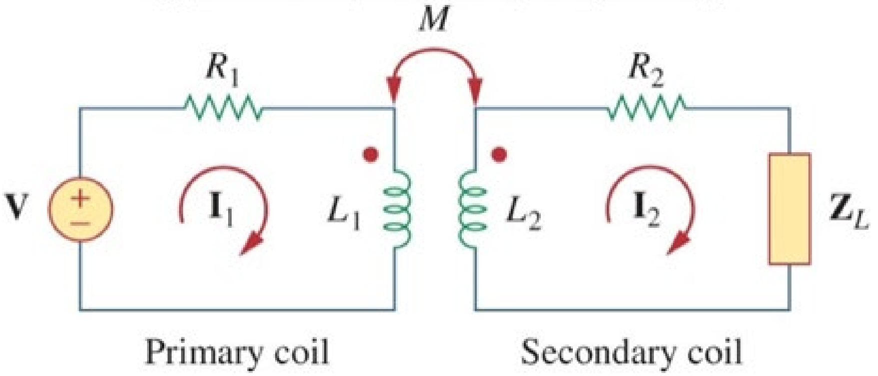
Linear Transformer

- A transformer is a magnetic device that takes advantage of mutual inductance.
- It is generally a four terminal device comprised of two or more magnetically coupled coils.
- The coil that is connected to the voltage source is called the primary, with the one connected to the load called the secondary.
- They are called linear if the coils are wound on a magnetically linear material



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Ideal Transformer

- An ideal transformer is one with perfect coupling.
- It has two or more windings with a large number of turns on a core of high permeability.
- The ideal transformer has:
  - Coils with very large reactance
  - Coupling coefficient is equal to unity
  - Primary and secondary coils are lossless
- Voltages and currents in each winding are related to each other by the turns ratio (n):

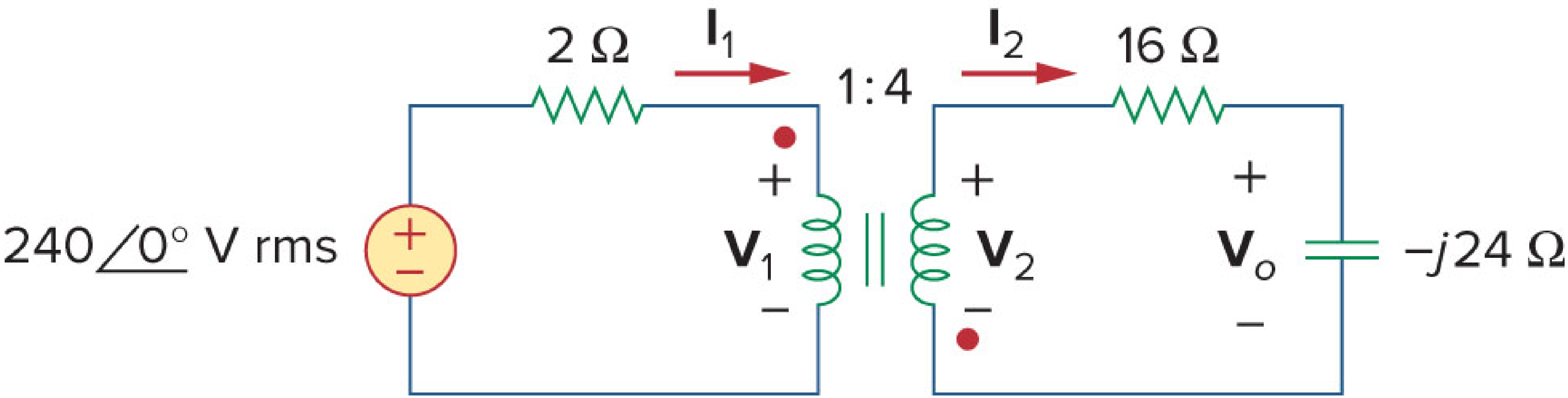
$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = n \qquad\qquad \frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n}$$

- The impedance that appears at the source is called the reflected impedance:

$$Z_{in} = \frac{Z_L}{n^2}$$

Example 3

In the ideal transformer circuit shown, determine both Vo and the complex power supplied by the source.



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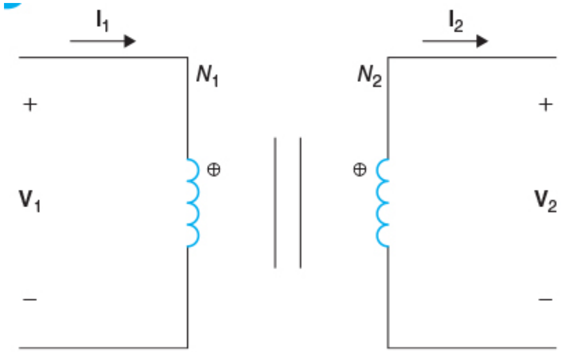
Example 3

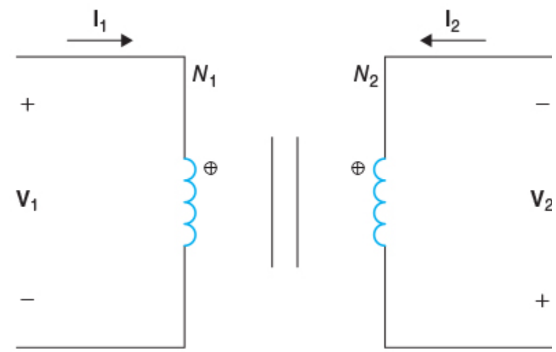
Solution

Ideal Transformer-Dot Convention



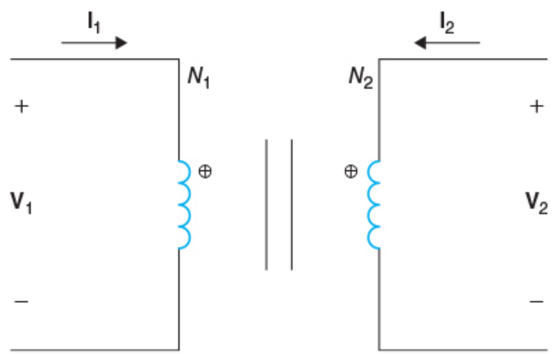
$$\frac{\mathbf{V}_2}{\mathbf{V}_1} = \frac{N_2}{N_1} = n, \quad \frac{\mathbf{I}_2}{\mathbf{I}_1} = \frac{N_1}{N_2} = \frac{1}{n}$$

(a)



$$\frac{\mathbf{V}_2}{\mathbf{V}_1} = -\frac{N_2}{N_1} = -n, \quad \frac{\mathbf{I}_2}{\mathbf{I}_1} = -\frac{N_1}{N_2} = -\frac{1}{n}$$

(c)

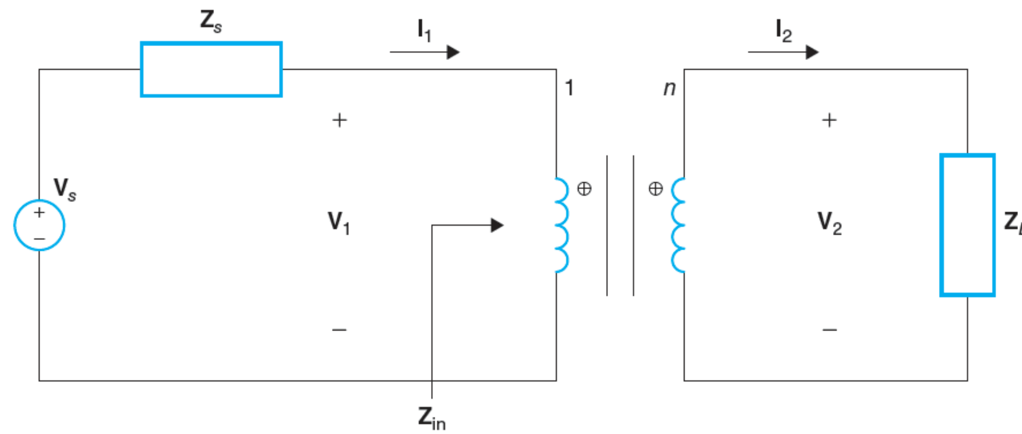


$$\frac{\mathbf{V}_2}{\mathbf{V}_1} = \frac{N_2}{N_1} = n, \quad \frac{\mathbf{I}_2}{\mathbf{I}_1} = -\frac{N_1}{N_2} = -\frac{1}{n}$$

(b)

Example 4

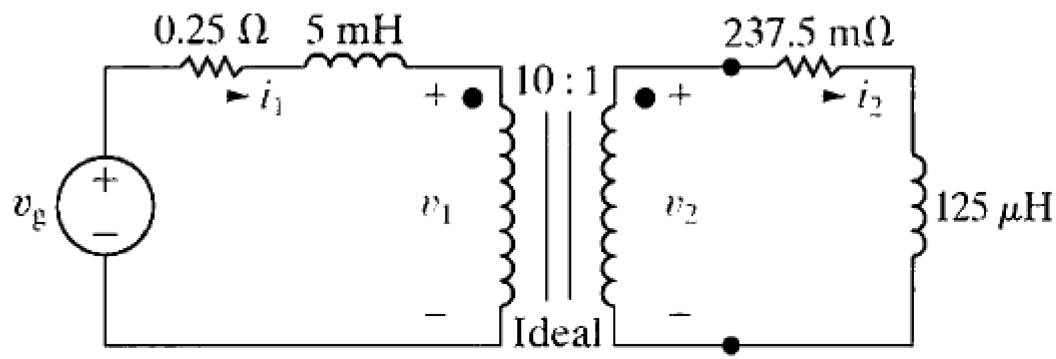
Let $\mathbf{V}_s = 70\angle 0^o$ V, $\mathbf{Z}_L = 5 + j3\ \Omega$, n = 1/5, $\mathbf{Z}_s = 25 + j10\ \Omega$ in the circuit below.
Find $\mathbf{Z}_{in}$, $\mathbf{I}_1$, $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{I}_2$.



Example 5

The load impedance connected to the secondary winding of the ideal transformer in the figure below consists of a 237.5 m_Ohm resistor in series with a 125 Mirco-H inductor. If the sinusoidal voltage source (Vg) is generating the voltage 2500cos(400t) V, find the steady-state expressions for:

a) I1
b) V1
c) I2
d) V2.



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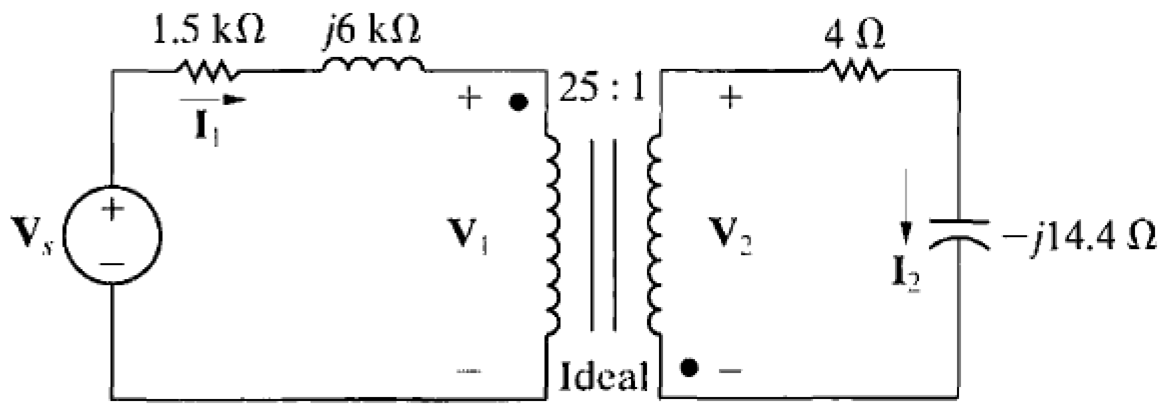
Example 5

Solution

Example 6

The source voltage in the phasor domain circuit in the accompanying figure is 25kV with an angle zero degree. Find the amplitude and phase angle of V2 and I2



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Example 6

Solution