

G A Series Circuit Contains A 1.0-k Resistor, A 5.0-mH Inductor, And An Ideal 25-V Power Supply. What

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Understanding the behavior of electrical circuits is fundamental to electronics and electrical engineering. When dealing with a series circuit comprising a resistor, an inductor, and a voltage source, various parameters such as current, voltage drops, impedance, and phase angles come into play. This article provides a comprehensive overview of such a circuit, exploring its components, calculations, and real-world applications.

Overview of the Series R-L Circuit

A series R-L circuit consists of a resistor (R), an inductor (L), and a power supply (voltage source) connected in a single path. The fundamental characteristics of this circuit include:

- Total Resistance and Reactance: The circuit's impedance combines resistive and reactive effects.
- Current and Voltage Relationships: The current is the same through all components, but the voltage drops differ.
- Phase Difference: Voltage and current are generally out of phase in an R-L circuit.

Components of the Circuit

Before diving into calculations, familiarize yourself with the key components:

Resistor (R)

- Resistance value: 1.0 k Ω (1000 ohms)
- Function: Limits current flow, dissipates energy as heat.

Inductor (L)

- Inductance: 5.0 mH (0.005 Henry)
- Function: Opposes changes in current, stores energy in magnetic fields.

Power Supply

- Voltage: 25 V (ideal source)
- Nature: Provides an alternating or direct voltage (assuming AC for impedance analysis).

Analyzing the Circuit: Step-by-Step Approach

To understand how this circuit behaves, follow these steps:

1. Determine if the Power Supply is AC or DC

- DC sources produce a constant voltage.
- AC sources produce a sinusoidal voltage, often analyzed at a specific frequency.

For the purposes of this analysis, we will assume an AC supply at a standard frequency (e.g., 60 Hz), unless otherwise specified.

2. Calculate the Inductive Reactance (X_L)

The inductive reactance measures the opposition an inductor presents to AC:

$$X_L = 2\pi f L$$

Where:

- f = frequency in Hz
- L = inductance in Henrys

For example, at 60 Hz:

$$X_L = 2\pi \times 60 \times 0.005 = 2\pi \times 0.3 = 1.884 \, \Omega$$

3. Find the Total Impedance (Z)

Impedance combines resistance and reactance:

$$Z = \sqrt{R^2 + X_L^2}$$

Using the above values:

$$[Z = \sqrt{(1000)^2 + (1.884)^2} \approx \sqrt{1,000,000 + 3.55} \approx 1000.0018 \, \Omega]$$

Since (R) dominates, the impedance is approximately $1 \, \text{k}\Omega$, with a small reactive component.

4. Calculate the Circuit Current (I)

Using Ohm's Law:

$$[I = \frac{V}{Z}]$$

At $25 \, \text{V}$:

$$[I = \frac{25}{1000.0018} \approx 0.025 \, \text{A} \, (25 \, \text{mA})]$$

This is the RMS current if the source is AC.

5. Determine Voltage Drops Across Each Component

- Voltage across resistor:

$$[V_R = I \times R = 0.025 \times 1000 = 25 \, \text{V}]$$

- Voltage across inductor:

$$[V_L = I \times X_L = 0.025 \times 1.884 \approx 0.047 \, \text{V}]$$

Note: The voltage across the inductor leads the current by 90° , so it's out of phase with the resistor.

6. Calculate the Power Dissipation

- Power dissipated in resistor:

$$[P_R = I^2 \times R = (0.025)^2 \times 1000 = 0.625 \, \text{W}]$$

- Power in the inductor:

$$[P_L = 0]$$

since an ideal inductor does not dissipate power.

Implications and Practical Considerations

Understanding the above calculations helps in designing and analyzing real-world circuits:

Power Factor

- The power factor indicates how effectively the circuit converts electrical power into useful work.
- It is given by:

$$\text{Power Factor} = \cos \phi = \frac{R}{Z}$$

In our example:

$$\cos \phi = \frac{1000}{1000.0018} \approx 1$$

- Nearly unity, meaning most of the power supplied is used for resistive work; minimal reactive effects at 60 Hz.

Effect of Frequency Variations

- As frequency increases, X_L increases proportionally.
- Higher reactance results in increased impedance, reducing current.
- The circuit behaves differently at various frequencies, which is crucial in tuning and filter design.

Real-World Applications

- Power supplies and filters
- Inductive load analysis in AC circuits
- Signal filtering and tuning circuits
- Designing impedance matching networks

Advanced Topics in R-L Series Circuits

For those interested in deeper understanding, consider the following:

1. Phasor Diagrams

- Graphical representation of voltages and currents in phase and out of phase.

- Useful for visualizing the phase difference between voltage and current.

2. Complex Impedance

- Expressed as:

$$Z = R + jX_L$$

where j is the imaginary unit.

- Facilitates calculations using complex number algebra.

3. Power Calculations

- Real power:

$$P = V_{\text{rms}} \times I_{\text{rms}} \times \cos \phi$$

- Reactive power:

$$Q = V_{\text{rms}} \times I_{\text{rms}} \times \sin \phi$$

- Apparent power:

$$S = V_{\text{rms}} \times I_{\text{rms}}$$

Conclusion

A series circuit with a 1.0 kΩ resistor, a 5.0 mH inductor, and an ideal 25 V power supply presents a fascinating case for analyzing AC circuit behavior. The dominant resistance means the circuit behaves nearly as a resistive load at standard frequencies, with minimal reactive effects. However, understanding the impedance, phase differences, and power calculations is vital for engineers and technicians designing and troubleshooting such circuits.

Whether used in power distribution, signal processing, or electronic device design, the principles outlined here serve as foundational knowledge for analyzing and optimizing R-L circuits. By adjusting parameters such as frequency and component values, engineers can tailor circuit responses to meet specific functional requirements.

Keywords: R-L circuit, impedance, inductive reactance, AC circuit analysis, power factor, phase angle, circuit calculations, inductance, resistance, power dissipation.

Frequently Asked Questions

What is the total impedance of the G A series circuit with a 1.0-k Ω resistor and a 5.0-mH inductor at a given frequency?

The total impedance Z is calculated using $Z = \sqrt{R^2 + (X_L)^2}$, where $X_L = 2\pi fL$. You need the frequency to determine X_L and then find Z .

How do you determine the current flowing through the series circuit with a 25 V supply?

The current I is found using Ohm's law for AC circuits: $I = V / Z$, where Z is the total impedance of the circuit. Calculate Z first, then divide the supply voltage by Z .

What is the phase difference between the voltage and current in this series R-L circuit?

The phase difference ϕ is given by $\phi = \arctangent(X_L/R)$. Since $X_L > R$, the current lags the voltage by this angle.

How does increasing the frequency affect the circuit's impedance and current?

Increasing the frequency increases X_L (since $X_L = 2\pi fL$), which raises the total impedance Z and decreases the circuit's current, assuming other parameters remain constant.

What is the power factor of the circuit, and how is it calculated?

The power factor is $\cos(\phi)$, where ϕ is the phase angle between voltage and current. It indicates how effectively the circuit uses power, with $\cos(\phi) = R / Z$.

If the inductor's inductance is 5.0 mH, what is the inductive reactance at 1 kHz?

$X_L = 2\pi fL = 2\pi \times 1000 \text{ Hz} \times 5.0 \times 10^{-3} \text{ H} \approx 31.4 \text{ } \Omega$.

Additional Resources

G A Series Circuit Contains A 1.0-k Ω Resistor, A 5.0-mH Inductor, And An Ideal 25-V Power Supply. What

Understanding the behavior of electrical circuits is fundamental to both theoretical physics and practical engineering applications. Among various types of circuits, the series circuit—comprising resistors, inductors, and power supplies—serves as a foundational model for analyzing more complex systems. When a series circuit includes a resistor, an inductor, and a voltage source, the interplay between resistance, inductance, and applied voltage leads to fascinating phenomena such as transient responses, phase shifts, and impedance effects.

In this article, we delve into a specific example: a series circuit containing a 1.0 k Ω resistor, a 5.0 mH inductor, and an ideal 25 V power supply. We will explore the circuit's behavior from multiple perspectives, including its steady-state voltage, current, impedance, and transient response, providing a comprehensive understanding suitable for students, educators, and practicing engineers alike.

Fundamentals of Series R-L Circuits

Basic Components and Their Roles

A series R-L circuit consists of a resistor (R), an inductor (L), and a voltage source (V) connected end-to-end. Each component influences the circuit's overall behavior:

- Resistor (R): Offers resistance to current flow, dissipates electrical energy as heat, and introduces a voltage drop proportional to current ($V_R = I \times R$).
- Inductor (L): Opposes changes in current through it due to its stored magnetic energy, leading to a voltage drop (V_L) proportional to the rate of change of current ($V_L = L \times dI/dt$).
- Voltage Source (V): Provides the electrical potential difference driving current through the series components.

Note: An ideal voltage source maintains a constant voltage regardless of the current drawn, with no internal resistance.

Key Concepts in R-L Series Circuits

- Impedance (Z): The total opposition to current in AC circuits, combining resistance and inductive reactance.
- Reactance (X_L): Represents the opposition due to inductance, calculated as $X_L = 2\pi fL$, where f is the frequency of the AC source.
- Phase Shift: The voltage across the inductor lags the current by 90° , leading to phase differences between voltage and current.
- Transient Response: When the circuit is energized or de-energized, the current does not instantaneously reach its steady-state value but evolves over time according to the circuit's time constant.

Analyzing the Given Circuit

The specified circuit parameters are:

- Resistor, $R = 1.0 \text{ k}\Omega = 1000 \text{ }\Omega$
- Inductor, $L = 5.0 \text{ mH} = 5.0 \times 10^{-3} \text{ H}$
- Power supply, $V = 25 \text{ V}$ (assumed DC for initial analysis)

Assumption of DC or AC?

The problem does not specify whether the supply is AC or DC. Given the context and the parameters, we will analyze both cases:

- DC Power Supply (steady-state): The circuit reaches a steady current after transient effects subside.
- AC Power Supply (alternating): Impedance and phase considerations come into play.

For clarity, we will primarily focus on the DC scenario, as the initial question seems to imply a simple power supply. We will also briefly touch upon the AC case for completeness.

DC Circuit Analysis

Steady-State Behavior

When a DC voltage source is applied to an R-L series circuit, the inductor initially opposes the sudden change in current due to its stored magnetic energy, but over time, it behaves like a short circuit (a wire with negligible resistance). The inductor's opposition diminishes as time progresses, and the circuit reaches a steady state where:

- The current is constant.
- The inductor acts as a wire (zero impedance).

Calculating the Steady-State Current:

Using Ohm's law:

$$I_{ss} = \frac{V}{R}$$

Plugging in the values:

$$I_{ss} = \frac{25 \text{ V}}{1000 \Omega} = 0.025 \text{ A} = 25 \text{ mA}$$

Voltage Drops:

- Across the resistor: $V_R = I \times R = 25 \text{ mA} \times 1000 \Omega = 25 \text{ V}$
- Across the inductor: $V_L = 0 \text{ V}$ (since in steady state, the inductor behaves like a short circuit)

Implication:

The entire supply voltage drops across the resistor in the steady state, and the current stabilizes at 25 mA.

Transient Response:

The current does not instantly reach 25 mA. It follows the exponential growth:

$$I(t) = I_{ss} \left(1 - e^{-t/\tau}\right)$$

\]

where the time constant τ is:

\[

$$\tau = \frac{L}{R} = \frac{5.0 \times 10^{-3}}{1000} = 5.0 \times 10^{-6} \text{ s} = 5 \mu\text{s}$$

\]

This extremely small time constant means the circuit reaches near steady-state almost instantaneously for most practical purposes.

AC Circuit Considerations

If the power supply is AC (say, sinusoidal voltage $V(t) = V_{\text{peak}} \sin(\omega t)$), the circuit's behavior becomes more nuanced.

Impedance and Reactance:

- Inductive reactance:

\[

$$X_L = 2\pi f L$$

\]

where f is the frequency of the AC source.

- Total impedance:

\[

$$Z = \sqrt{R^2 + X_L^2}$$

\]

- Phase angle:

\[

$$\phi = \arctan\left(\frac{X_L}{R}\right)$$

\]

The circuit's current amplitude:

\[

$$I_{\text{max}} = \frac{V_{\text{max}}}{Z}$$

\]

and the voltage across each component:

- Resistor: in phase with current.
- Inductor: voltage leads current by 90° .

Example at a Given Frequency:

Suppose the AC source operates at 60 Hz:

- Calculate (X_L) :

$$X_L = 2\pi \times 60 \times 5.0 \times 10^{-3} \approx 1.885 \, \Omega$$

- Total impedance:

$$Z = \sqrt{(1000)^2 + (1.885)^2} \approx 1000 \, \Omega$$

The inductive reactance is negligible compared to resistance at this frequency, so the circuit behaves similarly to a DC circuit.

Implications and Practical Applications

Power Dissipation and Efficiency:

- The resistor dissipates power as heat:

$$P_R = I_{\text{RMS}}^2 R = (25 \times 10^{-3})^2 \times 1000 \approx 0.625 \, \text{W}$$

- The inductor ideally dissipates no power; it stores magnetic energy and releases it back into the circuit.

Real-World Considerations:

- Non-Ideal Inductors: Real inductors have parasitic resistances, leading to additional power loss.
- Transient Effects: In switching applications, the inductor's stored energy can cause voltage spikes, requiring snubber circuits or other protective measures.
- Frequency Response: For AC signals at higher frequencies, the inductive

reactance increases, influencing circuit behavior significantly.

Engineering Significance:

- Filtering: R-L circuits can filter signals, allowing certain frequencies to pass while blocking others.
- Timing Circuits: The inductor's time constant influences the response times in switching and pulse circuits.
- Energy Storage: Inductors are used in energy storage applications, such as in power supplies and transformers.

Summary and Conclusions

The analysis of a series R-L circuit containing a 1.0 kΩ resistor, a 5.0 mH inductor, and a 25 V power supply reveals the fundamental dynamics of resistive-inductive systems. Under DC conditions, the circuit quickly reaches a steady current of 25 mA, with the resistor bearing most of the voltage drop. The inductor resists sudden changes in current but behaves like a short circuit once the transient phase passes.

In AC contexts, the inductor introduces frequency-dependent impedance, affecting both amplitude and phase of the current. At typical power line frequencies, the inductive reactance remains minimal compared to resistance, meaning the circuit behaves similarly to its DC counterpart. However, at higher frequencies, the inductance's effect becomes pronounced, influencing circuit design choices in filtering and signal processing.

Understanding the interplay of resistance, inductance, and voltage in such circuits is essential for designing efficient electrical systems, managing transient phenomena, and optimizing energy transfer. The simplicity of the series R-L circuit serves as an ideal educational tool, illustrating complex electromagnetic principles in a straightforward configuration.

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