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Understanding the behavior of inductors in AC circuits is fundamental in electrical engineering and electronics. When an inductor with a specified inductance, such as $9.95 \text{ millihenries (mH)}$, is connected across an alternating current (AC) source with a voltage amplitude of 50.0 volts , it prompts several questions about how the circuit will respond, what the current will be, and how the inductor influences the overall circuit behavior. This article explores these aspects, providing comprehensive insights into the implications of connecting a 9.95 mH inductor across a 50.0 V AC source, including calculating the current, understanding impedance, phase relationships, and practical applications.

Understanding the Basics of Inductance in AC Circuits

Before diving into calculations, it's essential to understand what an inductor does in an AC circuit and the key parameters involved.

What is an Inductor?

An inductor is a passive electrical component that stores energy in a magnetic field when electrical current flows through it. Its primary characteristic is inductance, measured in henries (H), which quantifies its ability to oppose changes in current.

Inductance and Its Effect on AC Circuits

In AC circuits, inductors oppose changes in current, leading to a phase shift between voltage and current. The opposition to AC is characterized by the circuit's impedance, which depends on the inductance and the frequency of the AC source.

Calculating the Impedance of the Inductor

When an inductor is connected across an AC voltage source, the key parameter to determine is the

impedance (Z), which affects the current flow.

Formula for Inductive Reactance

The inductive reactance (X_L) is given by:

- $X_L = 2\pi fL$

where:

- f = frequency of the AC source (in Hz)
- L = inductance (in Henrys)

This reactance acts as an opposition to current flow, similar to resistance in DC circuits but dependent on frequency.

Calculating Total Impedance

The total impedance of the inductor in the circuit is:

- $Z = jX_L$

where j indicates a 90-degree phase shift between voltage and current.

Since the inductor's impedance is purely reactive, the magnitude of impedance is:

- $|Z| = X_L = 2\pi fL$

Note: Without knowing the frequency, the impedance cannot be precisely calculated. Therefore, to proceed, we consider common frequencies or analyze how the impedance varies with frequency.

Estimating the Current in the Circuit

The current flowing through the inductor when connected to a voltage source depends on the impedance.

Using Ohm's Law for AC Circuits

The current amplitude (I) is given by:

- $I = V_{\text{amplitude}} / |Z|$

where $V_{\text{amplitude}} = 50.0 \text{ V}$.

Example at a Specific Frequency

Suppose the AC source operates at a frequency of 60 Hz, a common power line frequency.

- Inductive reactance:

- $X_L = 2\pi \times 60 \text{ Hz} \times 9.95 \text{ mH}$

- $= 2\pi \times 60 \times 0.00995 \text{ H}$

- $\approx 2\pi \times 0.597$

- $\approx 3.75 \Omega$

- Current amplitude:

- $I = 50.0 \text{ V} / 3.75 \Omega \approx 13.33 \text{ A}$

This example illustrates that at 60 Hz, the inductor would allow a current of approximately 13.33 amperes.

Note: For different frequencies, the reactance and current change proportionally.

Phase Relationship Between Voltage and Current

In an inductor-connected AC circuit, the current lags the voltage by 90 degrees.

Implications of Phase Shift

- The voltage reaches its maximum value before the current does.
- This phase difference affects power calculations and circuit efficiency.

Power Dissipation and Power Factor

Since ideal inductors do not dissipate power (they only store and release energy), the real power consumed in the circuit depends on the resistance present.

Calculating Power in the Circuit

If the circuit is purely inductive:

- Real power (P) = $V_{\text{rms}} \times I_{\text{rms}} \times \cos(\phi)$

where ϕ is the phase angle (90° for ideal inductor), so:

- $\cos(90^\circ) = 0$

meaning no real power is consumed, only reactive power.

However, in real-world circuits, resistance causes some power dissipation, and the power factor becomes a critical parameter.

Practical Applications of Inductors with 9.95 mH

Inductors of this size are common in various electronic and electrical applications:

Filters and Tuning Circuits

- Used in LC filters to block or pass specific frequencies.
- Critical in radio tuning circuits.

Transformers and Inductive Components

- Employed in transformer design where inductance plays a crucial role.
- Used in impedance matching.

Energy Storage and Magnetic Devices

- Serve in energy storage systems like inductive energy storage in power electronics.

Conclusion

Connecting an inductor with an inductance of 9.95 mH across a 50.0 V AC source involves understanding the impedance, phase relationships, and current flow. At a typical frequency such as 60 Hz, the inductive reactance is approximately 3.75Ω , leading to an estimated current of about 13.33 A. The inductor causes the current to lag the voltage by 90° , which influences power calculations and circuit behavior. Recognizing these principles is essential for designing and analyzing AC circuits involving inductors, whether in filtering, tuning, or energy storage applications.

Remember: The actual current and impedance depend on the frequency of the AC source, so always consider the operating frequency when performing such calculations for accurate results.

Frequently Asked Questions

What is the inductance value of the inductor connected across the AC source?

The inductance value is 9.95 mH (millihenrys).

What is the voltage amplitude of the AC source connected to the inductor?

The voltage amplitude of the AC source is 50.0 V.

How do you calculate the inductive reactance (X_L) of the inductor at a given frequency?

The inductive reactance is calculated using the formula $X_L = 2\pi fL$, where f is the frequency and L is the inductance.

What is the significance of the inductive reactance in this circuit?

The inductive reactance determines how much the inductor resists the change in current, affecting the current amplitude and phase in the circuit.

How does the phase of current relate to the voltage in an inductor connected to an AC source?

In an inductor, the current lags the voltage by 90 degrees ($\pi/2$ radians).

If the frequency of the AC source is increased, what happens to the inductive reactance?

The inductive reactance increases proportionally with frequency, making the inductor oppose current changes more strongly.

What is the initial step to analyze this AC circuit with an inductor?

Identify the given values (L and voltage amplitude), determine the frequency of the source, and calculate the inductive reactance to analyze current and phase relationships.

How can you find the current amplitude flowing through the inductor with the given voltage amplitude?

Use Ohm's law for AC circuits: $I = V / X_L$, where V is the voltage amplitude and X_L is the inductive reactance at the given frequency.

What additional information is needed to fully analyze the circuit's behavior?

The frequency of the AC source is needed to compute the inductive reactance and determine the current and phase angle.

How does the inductance value affect the circuit's impedance?

The inductance contributes to the circuit's total impedance, increasing it as the inductance or frequency increases, which affects current flow and phase shift.

Additional Resources

An inductor with $L = 9.95 \text{ mH}$ connected across an AC source that has a voltage amplitude of 50.0 V is a fundamental scenario in the study of AC circuits and electromagnetic induction. Understanding how this inductor behaves under sinusoidal voltage input provides insights into concepts like inductive reactance, impedance, phase relationships, and energy storage in magnetic fields. This guide aims to offer a comprehensive analysis of this setup, detailing the theoretical background, step-by-step calculations, and practical implications.

Introduction to Inductors in AC Circuits

Inductors are passive electrical components that store energy in a magnetic field when electrical current flows through them. They are characterized by their inductance (L), measured in henrys (H), which quantifies their ability to oppose changes in current.

When connected to an alternating current (AC) source, the inductor introduces a frequency-dependent opposition to current flow, known as inductive reactance. Unlike resistors, inductors do not dissipate energy as heat; instead, they temporarily store and release energy, causing phase shifts between voltage and current.

Fundamental Concepts

1. Inductive Reactance (X_L)

Inductive reactance quantifies how much an inductor resists AC current at a given frequency:

$$X_L = 2\pi f L$$

- f : Frequency of the AC source (Hz)
- L : Inductance (H)

Implication: As the frequency increases, the reactance increases, making the inductor more "resistive" to AC.

2. Impedance (Z)

The total opposition to current in an AC circuit that includes resistance (R) and inductive reactance (X_L):

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

- For an ideal inductor with no resistance, ($R = 0$), so:

$$Z = X_L$$

3. Phase Relationship

In a purely inductive circuit:

- Voltage leads current by 90°
- The current lags the voltage

4. Power in Inductive Circuits

The average power dissipated is zero in an ideal inductor because the energy is stored and returned each cycle. The reactive power oscillates between the source and the inductor.

Analyzing the Given Scenario

Given Data:

- Inductance, ($L = 9.95 \text{ mH} = 9.95 \times 10^{-3} \text{ H}$)
- Voltage amplitude, ($V_0 = 50.0 \text{ V}$)
- Frequency, (f): Not specified, so the analysis will include this as a variable.

Step-by-Step Analysis

Step 1: Determine the Inductive Reactance (X_L)

The key to understanding the inductor's behavior is calculating (X_L) , which depends on the frequency of the AC source:

$$\begin{aligned} & \left[\right. \\ X_L &= 2\pi f L \\ & \left. \right] \end{aligned}$$

- Since (L) is known, (X_L) can be expressed as a function of (f) .

Step 2: Calculate Impedance (Z)

Assuming an ideal inductor with no resistance:

$$\begin{aligned} & \left[\right. \\ Z &= X_L = 2\pi f L \\ & \left. \right] \end{aligned}$$

If resistance (R) is present, the impedance would be:

$$\begin{aligned} & \left[\right. \\ Z &= \sqrt{R^2 + (2\pi f L)^2} \\ & \left. \right] \end{aligned}$$

Step 3: Find the Current Amplitude (I_0)

The maximum current in the circuit:

$$\begin{aligned} & \left[\right. \\ I_0 &= \frac{V_0}{Z} \\ & \left. \right] \end{aligned}$$

- For an ideal inductor:

$$\begin{aligned} & \left[\right. \\ I_0 &= \frac{V_0}{2\pi f L} \\ & \left. \right] \end{aligned}$$

Step 4: Phase Difference and Power

In a purely inductive circuit:

- Voltage leads current by 90°
- Instantaneous power oscillates, but average power over a cycle is zero.

Exploring the Frequency Dependence

Because the problem doesn't specify the frequency, let's analyze how the circuit behaves at different frequencies.

Low Frequency ($f \rightarrow 0$)

- $(X_L \rightarrow 0)$
- The inductor acts almost like a short circuit
- Current amplitude:

$$I_0 = \frac{V_0}{X_L} \rightarrow \infty$$

(Practically limited by circuit resistance; in ideal case, current becomes very large)

High Frequency ($f \rightarrow \infty$)

- $(X_L \rightarrow \infty)$
- The inductor acts almost like an open circuit
- Current approaches zero

Practical Examples and Calculations

Suppose the AC source operates at a specific frequency, say $f = 60$ Hz (common mains frequency):

Calculating (X_L) :

$$X_L = 2\pi f L = 2\pi \times 60 \text{ Hz} \times 9.95 \times 10^{-3} \text{ H}$$
$$X_L \approx 2 \times 3.1416 \times 60 \times 9.95 \times 10^{-3}$$
$$X_L \approx 6.2832 \times 60 \times 9.95 \times 10^{-3}$$

$$X_L \approx 6.2832 \times 60 \times 0.00995$$

\]

\[

$$X_L \approx 6.2832 \times 0.597$$

\]

\[

$$X_L \approx 3.755 \, \Omega$$

\]

Impedance:

\[

$$Z \approx 3.755 \, \Omega$$

\]

Current Amplitude:

\[

$$I_0 = \frac{50.0 \, \text{V}}{3.755 \, \Omega} \approx 13.32 \, \text{A}$$

\]

This high current indicates the inductor offers only moderate opposition at 60 Hz.

Implications for Circuit Design

1. Resonance Considerations

In circuits with capacitors, the inductance can lead to resonance at particular frequencies where the inductive reactance equals the capacitive reactance, resulting in maximum current flow.

2. Power Factor and Phase Angle

The phase angle (ϕ) between voltage and current in an inductive circuit:

\[

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

\]

- For an ideal inductor, $(R = 0)$, so $(\phi = 90^\circ)$.

3. Energy Storage and Magnetic Fields

The energy stored in the magnetic field:

$$U = \frac{1}{2} L I^2$$

At maximum current (I_0) , energy stored:

$$U_{\max} = \frac{1}{2} \times 9.95 \times 10^{-3} \times I_0^2$$

Practical Applications and Considerations

- Filters: Inductors are used in filtering applications, blocking high-frequency signals while allowing low-frequency signals.
- Transformers: Variations of inductance are fundamental in transformer operation.
- Energy Storage: Inductors temporarily store energy in magnetic fields, important in power electronics and switching power supplies.
- Impedance Matching: Adjusting the inductance and circuit frequency helps optimize power transfer.

Summary and Key Takeaways

- The inductor with $L = 9.95 \text{ mH}$ exhibits a frequency-dependent reactance, influencing the current amplitude and phase relationship.
- At a typical power line frequency of 60 Hz , the reactance is approximately 3.755Ω , allowing a significant current in the circuit.
- The behavior of the inductor can be tailored by changing the frequency of the AC source, which directly impacts the impedance and circuit response.
- In real-world applications, resistance cannot be neglected, and the total impedance would include resistive components, slightly altering the current and phase.

Final Remarks

Understanding the behavior of an inductor connected across an AC source is fundamental in electrical engineering. Whether designing filters, tuning circuits, or analyzing power systems, grasping how inductance interacts with frequency and voltage is crucial. The scenario of an inductor with $(L = 9.95)$,

mH) connected across a 50 V amplitude AC source illustrates core principles that underpin much of electronic and electrical circuit analysis.

Always consider the operating frequency when analyzing inductive components, as their impedance and effects can vary dramatically across different regimes. With this knowledge, engineers and students can better predict circuit responses and optimize designs for desired performance.

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