



Reactance in AC Circuits - Fundamental Concepts

An Online Continuing Education Course for Engineers

Course Number: E-4005

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Reactance in AC Circuits: Fundamental Concepts

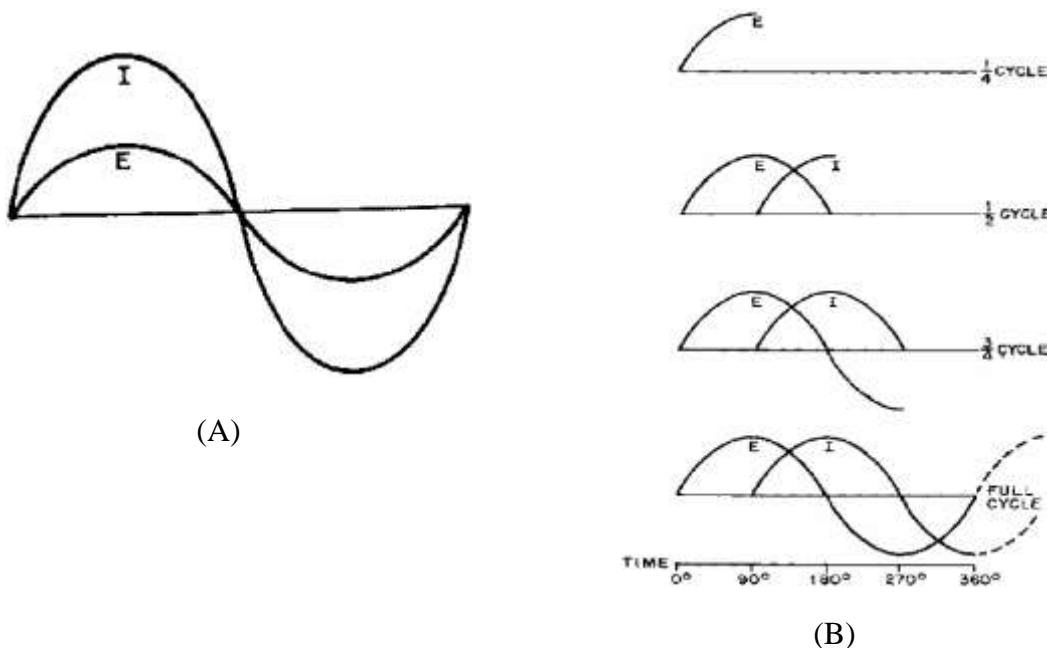
INDUCTANCE AND ALTERNATING CURRENT

When two things are in step, going through a cycle together, falling together and rising together, they are in phase. When they are out of phase, the angle of lead or lag—the number of electrical degrees by which one of the values leads or lags the other—is a measure of the amount they are out of step. The time it takes the current in an inductor to build up to maximum and to fall to zero is important for another reason. It helps illustrate a very useful characteristic of inductive circuits—the current through the inductor always lags the voltage across the inductor.

A circuit having pure resistance (if such a thing were possible) would have the alternating current through it and the voltage across it rising and falling together. This is illustrated in Figure 1(A), which shows the sine waves for current and voltage in a purely resistive circuit having an ac source. The current and voltage do not have the same amplitude, but they are in phase.

In the case of a circuit having inductance, the opposing force of the counter emf would be enough to keep the current from remaining in phase with the applied voltage. In a dc circuit containing pure inductance, the current takes time to rise to maximum even though the full applied voltage is immediately at maximum. Figure 1(B) shows the wave forms for a purely inductive ac circuit in steps of quarter-cycles.

Figure 1.—Voltage and current waveforms in an inductive circuit.

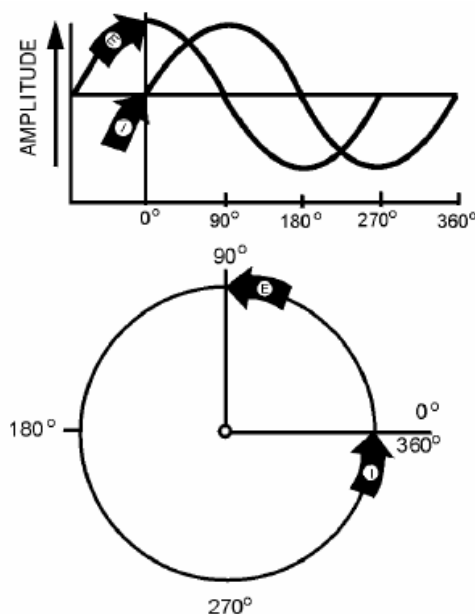


With an ac voltage, in the first quarter-cycle (0° to 90°) the applied ac voltage is continually increasing. If there was no inductance in the circuit, the current would also increase during this first quarter-cycle. You know this circuit does have inductance. Since inductance opposes any change in current flow, no current flows during the first quarter-cycle. In the next quarter-cycle (90° to 180°) the voltage decreases back to zero; current begins to flow in the circuit and reaches a maximum value at the same instant the voltage reaches zero. The applied voltage now begins to build up to maximum in the other direction, to be followed by the resulting current. When the voltage again reaches its maximum at the end of the third quarter-cycle (270°) all values are exactly opposite to what they were during the first half-cycle. The applied voltage leads the resulting current by one quarter-cycle or 90 degrees. To complete the full 360° cycle of the voltage, the voltage again decreases to zero and the current builds to a maximum value.

You must not get the idea that any of these values stops cold at a particular instant. Until the applied voltage is removed, both current and voltage are always changing in amplitude and direction.

As you know the sine wave can be compared to a circle. Just as you mark off a circle into 360 degrees, you can mark off the time of one cycle of a sine wave into 360 electrical degrees. This relationship is shown in Figure 2. By referring to this figure you can see why the current is said to lag the voltage, in a purely inductive circuit, by 90 degrees. Furthermore, by referring to Figures 2 and 1(A) you can see why the current and voltage are said to be in phase in a purely resistive circuit. In a circuit having both resistance and inductance then, as you would expect, the current lags the voltage by an amount somewhere between 0 and 90 degrees.

Figure 2.—Comparison of sine wave and circle in an inductive circuit.



Q1. What effect does an inductor have on a change in current?

Q2. What is the phase relationship between current and voltage in an inductor?

A simple memory aid to help you remember the relationship of voltage and current in an inductive circuit is the word ELI. Since E is the symbol for voltage, L is the symbol for inductance, and I is the symbol for current; the word ELI demonstrates that current comes after (Lags) voltage in an inductor.

INDUCTIVE REACTANCE

When the current flowing through an inductor continuously reverses itself, as in the case of an ac source, the inertia effect of the cemf is greater than with dc. The greater the amount of inductance (L), the greater the opposition from this inertia effect. Also, the faster the reversal of current, the greater this inertial opposition. This opposing force which an inductor presents to the FLOW of alternating current cannot be called resistance, since it is not the result of friction within a conductor. The name given to it is **INDUCTIVE REACTANCE** because it is the "reaction" of the inductor to the changing value of alternating current. Inductive reactance is measured in ohms and its symbol is X_L .

As you know, the induced voltage in a conductor is proportional to the rate at which magnetic lines of force cut the conductor. The greater the rate (the higher the frequency), the greater the cemf. Also, the induced voltage increases with an increase in inductance; the more ampere-turns, the greater the cemf. Reactance, then, increases with an increase of frequency and with an increase of inductance. The formula for inductive reactance is as follows:

$$X_L = 2\pi fL$$

Where:

X_L is inductive reactance in ohms.

2π is a constant in which the Greek letter π , called "pi" represents 3.1416 and $2 \times \pi = 6.28$ approximately.

f is frequency of the alternating current in Hz.

L is inductance in henrys.

The following example problem illustrates the computation of X_L .

$$\begin{aligned} \text{Given: } & f = 60 \text{ Hz} \\ & L = 20 \text{ H} \\ \text{Solution: } & X_L = 2 \pi fL \\ & X_L = 6.28 \times 60 \text{ Hz} \times 20 \text{ H} \\ & X_L = 7,536 \ \Omega \end{aligned}$$

Q3. What is the term for the opposition an inductor presents to ac?

Q4. What is the formula used to compute the value of this opposition?

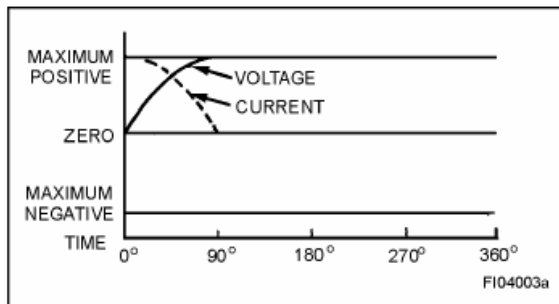
Q5. What happens to the value of X_L as frequency increases?

Q6. What happens to the value of X_L as inductance decreases?

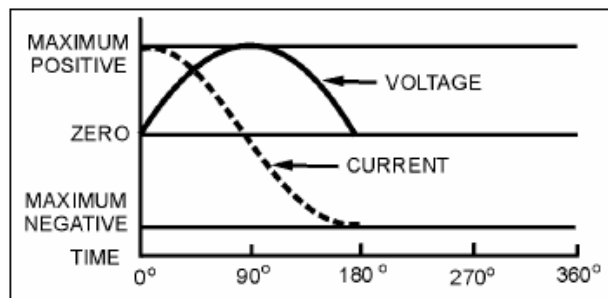
CAPACITORS AND ALTERNATING CURRENT

The four parts of Figure 3 show the variation of the alternating voltage and current in a capacitive circuit, for each quarter of one cycle. The solid line represents the voltage across the capacitor, and the dotted line represents the current. The line running through the center is the zero, or reference point, for both the voltage and the current. The bottom line marks off the time of the cycle in terms of electrical degrees. Assume that the ac voltage has been acting on the capacitor for some time before the time represented by the starting point of the sine wave in the figure.

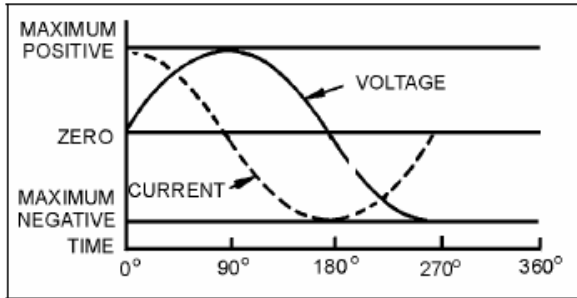
Figure 3.—Phase relationship of voltage and current in a capacitive circuit.



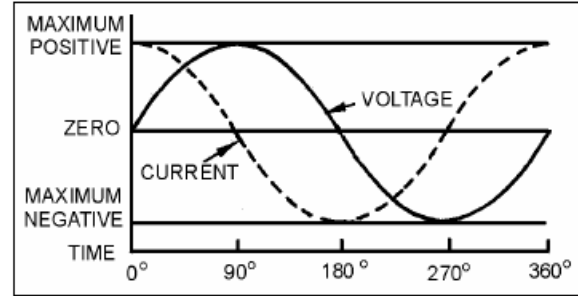
(A)



(B)



(C)



(D)

At the beginning of the first quarter-cycle (0° to 90°) the voltage is just passed through zero and is increasing in the positive direction. Since the rate of change is at its steepest part of the sine wave, the voltage is changing at its greatest rate. The current varies directly with the rate of change of voltage, and therefore the current is at its greatest rate at the beginning of the first quarter-cycle. The number of electrons is moving off the positive plate and onto the negative plate. The current curve in part (D) of the figure shows this.

As the voltage proceeds toward its maximum positive value, the rate of change becomes less and the current decreases. The voltage across the capacitor is at its maximum positive value. The movement of electrons from the positive plate to the negative plate is also at its maximum. At the end of this first quarter-cycle (0° to 90°) the voltage is at its maximum positive value and starts to decrease in the positive direction and starts to build up its maximum negative peak. The current is at its maximum positive value. The current curve in part (A) of the figure shows this.

At 180° degrees the voltage is at its maximum negative value and for a brief instant the electrons are equally distributed between the two plates, the current is maximum because the rate of change of voltage is maximum. Just after 180° degrees the voltage has reversed polarity and starts building up its maximum negative peak which is reached at the end of the third quarter-cycle (180° to 270°). During this third quarter-cycle the rate of voltage change gradually decreases as the charge builds to a maximum at 270° degrees. At this point the capacitor is fully charged and it carries the full impressed voltage. Because the capacitor is fully charged there is no further exchange of electrons; therefore, the current flow is zero at this point. The conditions are exactly the same as at the end of the first quarter-cycle (90°) but the polarity is reversed.

Just after 270° degrees the impressed voltage once again starts to decrease, and the capacitor must lose electrons from the negative plate. It must discharge, starting at a minimum rate of flow and rising to a maximum. This discharging action continues through the last quarter-cycle (270° to 360°) until the impressed-voltage has reached zero. At 360° degrees you are back at the beginning of the entire cycle, and everything starts over again.

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