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Name of the course— B.Sc. (H) Physics

Semester- IV

Name of the paper—Electrical circuits and Network Skills

Paper code-32223903

Lecture Time-- Saturday (10:40 to 12:40)

Topics to be covered:

Unit-2

Electrical Circuits: Basic electric circuit elements and their combination. Rules to analyze DC sourced electrical circuits. Current and voltage drop across the DC circuit elements. Single-phase and three-phase alternating current sources. Rules to analyze AC sourced electrical circuits.

Electrical Circuits: Basic electric circuit elements and their combination

What is an Electric Circuit?

An Electric Circuit is a closed path for transmitting an electric current through the medium of electrical and magnetic fields. The flow of electrons across the loop constitutes the electric current. Electrons enter the circuit through the 'Source' which can be a battery or a generator. The source provides energy to the electrons, by setting up an electrical field which provides the electromotive force.

The electrons leave the circuit through the load, to the earth ground, thus completing a closed path. The load or output can be any simple home appliance like television, lamp, refrigerator, or can be a complex load such as that on a hydroelectric power generating station.

A simple electric circuit consists of a source (such as a battery), wires as conducting medium and a load (such as a light bulb). The battery provides required energy for flow of electrons, to the light bulb.

Basic Circuit Elements

As mentioned above in the introduction, a circuit is an interconnection of elements. These elements are classified into active or passive elements, based on their capability to generate energy.

Active Circuit Elements

Active Elements are those which can generate energy. Examples include batteries, generators, operational amplifiers and diodes. Note that in an electrical circuit, the source elements are the most significant active elements.

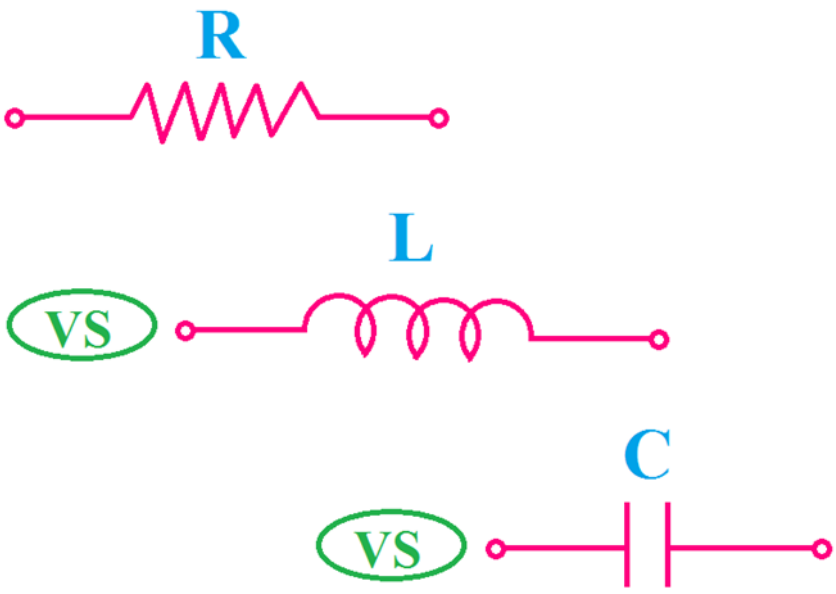
An energy source, whether a voltage or current source, is of 2 types – Independent and Dependent sources. Example of an Independent source is the battery which provides a constant voltage to the circuit, irrespective of the current flowing through the terminals.

Example of a dependent source is a transistor, which provides current to the circuit, depending upon the voltage applied to it. Another example is an Operational Amplifier, which provides voltage, depending upon the differential input voltage applied to its terminals.

Passive circuit Elements

Passive Elements can be defined as elements which can control the flow of electrons through them. They either increase or decrease the voltage. Here are some examples of passive elements.

Resistor: A resistor opposes the flow of current through it. For a linear circuit, Ohm's law is applicable, which states that voltage across the resistor is directly proportional to the current flowing through it, the proportional constant being the resistance.



Inductor: An inductor stores energy in form of the electromagnetic field. The voltage across an inductor is proportional to the rate of change of current flowing through it.

Capacitor: A capacitor stores energy in form of the electrostatic field. The voltage across a capacitor is proportional to the charge.

Rules to analyze DC sourced circuits

All DC circuit analysis (the determining of currents, voltages and resistances throughout a circuit) can be done with the use of three rules.

These rules are given below.

1. Ohm's law. This law states that the current in a circuit is directly proportional to the potential difference across the circuit and inversely proportional to the resistance in the circuit. Mathematically, this can be expressed as

$$I = V R \qquad (1)$$

Ohm's law can be applied to an entire circuit or to individual parts of the circuit.

2. Kirchoff's node rule. This rule states that the algebraic sum of all currents at a node (junction point) is zero. Currents coming into a node are considered negative and currents leaving a node are considered positive.

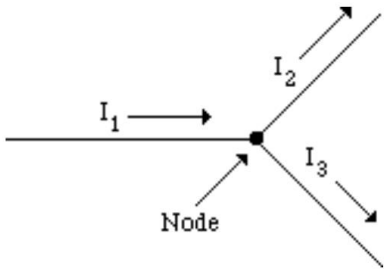


Figure 2.

For the situation in figure 2, we have $-I_1 + I_2 + I_3 = 0$ or $I_1 = I_2 + I_3$

This is a statement of the law of conservation of charge. Since no charge may be stored at a node and since charge cannot be created or destroyed at the node, the total current entering a node must equal the total current out of the node.

3. Kirchoff's loop rule. This rule states that the algebraic sum of all the changes in potential (voltages) around a loop must equal zero. A potential difference is considered negative if the potential is getting smaller in the direction of the current flow.

For the situation in figure 3, we have $+V_1 - V_2 - V_3 = 0$ or $V_1 = V_2 + V_3$

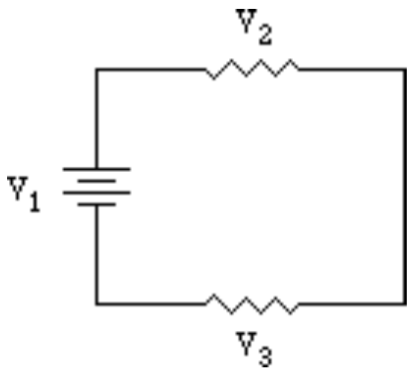


Figure 3.

This is a statement of the law of conservation of energy. Since potential differences correspond to energy changes and since energy cannot be created or destroyed in ordinary electrical interactions, the energy dissipated by the current as it passes through the circuit ($V_2 + V_3$) must equal the energy given to it by the power supply (V_1).

Question: To illustrate the application of these rule, try to solve the following problem to find the total current and voltage drop and individual across each component. (Simplified version of the circuit has been given in the figure b.

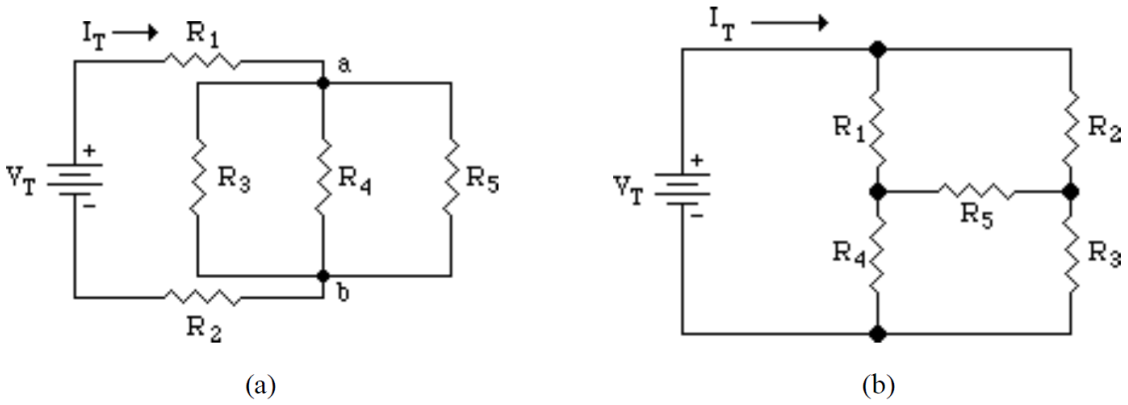


Figure 4.

Current and voltage drop across the DC circuit elements

Voltage drop means the reduction in voltage or voltage loss across a particular element. Due to the presence of the impedance or passive elements, there will be some loss in voltage as the current moves through the circuit. That is, the energy supplied from the voltage source will get reduced as the current flows through the circuit.

The simple idea to calculate the voltage drop across the passive elements is calculated using the ohm's law (make sure the circuit only consist of resistors in the circuit).

Voltage drop across inductor

For the case of inductor, the ohm's law take the form:

$$\mathbf{v = L \frac{di}{dt}}$$

Where,

v = Instantaneous voltage across the inductor

L = Inductance in Henrys

$\frac{\mathbf{di}}{\mathbf{dt}}$ = Instantaneous rate of current change (amps per second)

When a battery is connected to a series resistor and inductor, the inductor resists the change in current and the current therefore builds up slowly. Acting in accordance with Faraday's law and Lenz's law, the amount of impedance to the build-up of current is proportional to the rate of change of the current. That is, the faster you try to make it change, the more it resists. The current builds up toward the value it would have with the resistor alone because once the current is no longer changing, the inductor offers no impedance. The rate of this build up is characterized by the time constant L/R. Establishing a current in an inductor stores energy in the magnetic field formed by the coils of the inductor.

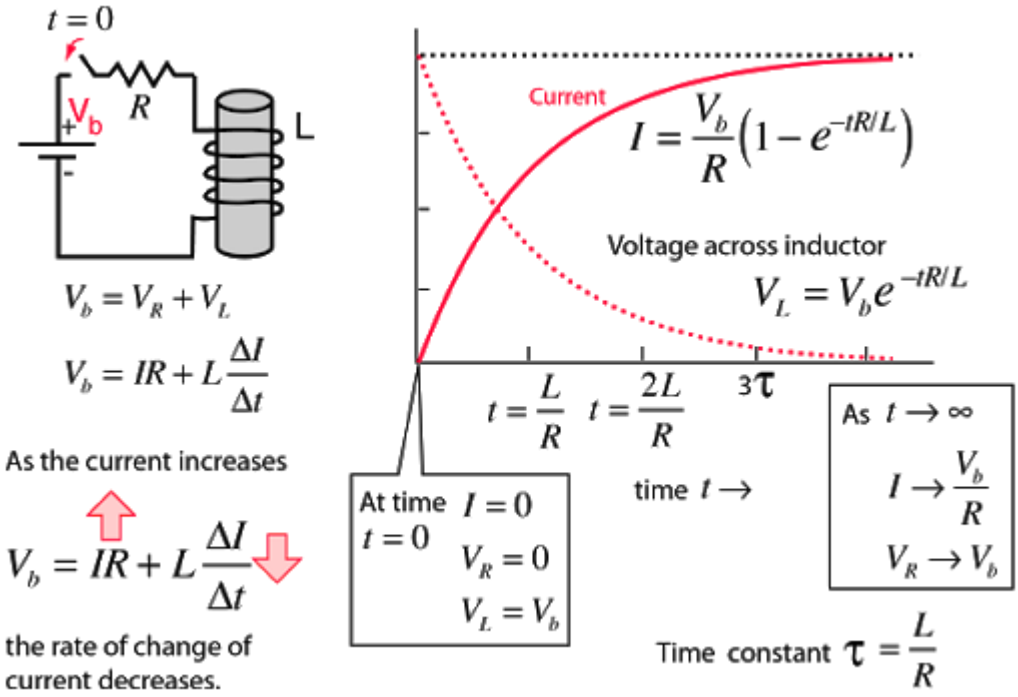


Figure 5.

Voltage across capacitor

For the case of capacitor, the situation is different from both the resistors and inductors. Below we are showing the response of the capacitor for a constant voltage source.

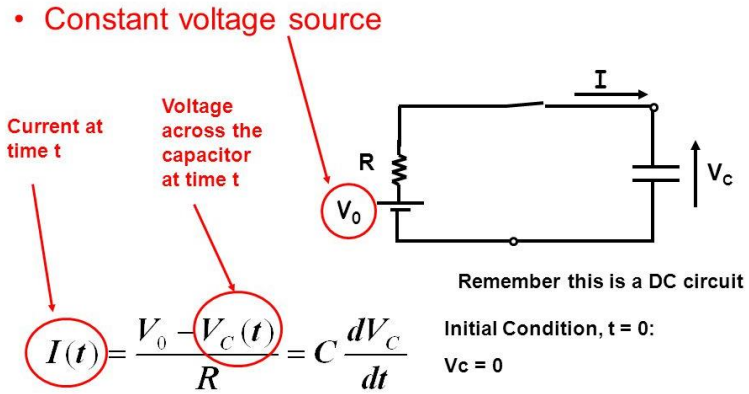


Figure 6.

When a battery is connected to a series resistor and capacitor, the initial current is high as the battery transports charge from one plate of the capacitor to the other. The charging current asymptotically approaches zero as the capacitor becomes charged up to the battery voltage. Charging the capacitor stores energy in the electric field between the capacitor plates. The rate of charging is typically described in terms of a time constant RC.

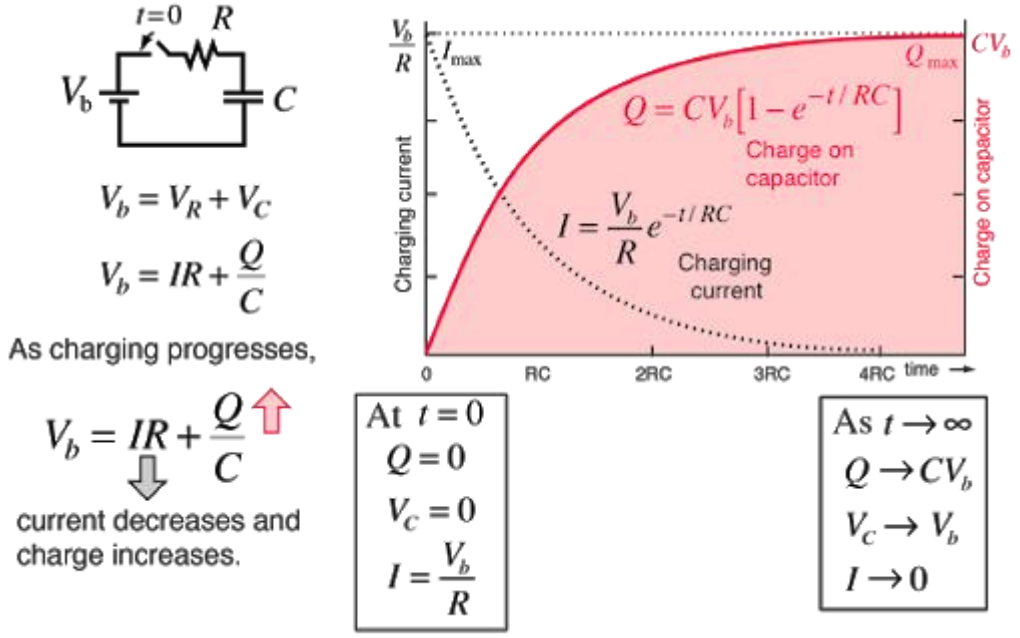


Figure 7.

Single-phase and three-phase alternating current sources

The AC power (alternating current) is a kind of electricity in which the flow of current is frequently changing directions. At the beginning of the 1900 year, AC power supply is used for businesses as well as homes. The system of the power supply is categorized into two type's namely single phase power supply, as well as three phase power supply. For most industrial and businesses settings, three-phase supply is used to run the high loads, whereas homes are generally supplied by a single phase, because home appliances require less power. This article discusses the difference between single phase and three phase power supplies.

What is Phase in Electricity?

Generally, the phase in electricity is the current or the voltage among an existing wire as well as a neutral cable. Phase means the distribution of load, if a single wire is used, an additional load will occur on it & if three wires are used then loads will be separated between them. This can be called as less power for 1-phase and more power for 3-phase. If it is a 1-phase system, it includes two wires as well as if it is a 3-phase system, then it includes 3 wires (or) four wires.

Single Phase Supply

In the field of electrical, single phase supply is the delivery of AC power by a system in which all the supply voltages change in simultaneously. This type of power supply sharing is used when the loads (home appliances) ate generally heat and lighting with some huge electric motors. When a single phase supply is connected to an AC motor doesn't generate a rotating magnetic field, single phase motors require extra circuits for working, but such electric motors are rare over in rating of 10 kW. In every cycle, a single phase system voltage achieves a peak-value two times; the direct power is not stable.

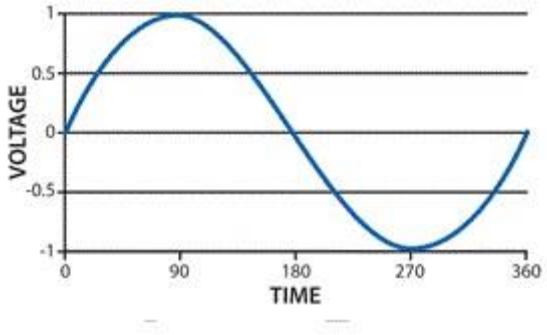


Figure 8.

A load with single-phase can be power-driven from a three-phase sharing transformer in two techniques. One is with the connection between two phases or with connection among one phase and neutral. These two will give dissimilar voltages from a given power supply. This type of phase supply provides up to 230V. The applications of this supply mainly use for running the small home appliances like air conditioners, fans, heater, etc.

Single Phase Supply Benefits

The benefits of choosing a single phase supply include the following.

- The design is less complex
- Design cost is less
- Most efficient AC power supply for up to 1000 watts
- Single Phase AC Power Supply is most competent for up to 1000 watts.
- Wide-range of application uses

Single Phase Supply Applications

The applications of single-phase supply include the following.

- This power supply is applicable for homes as well as businesses.
- Used to supply plenty of power for homes, as well as nonindustrial businesses.
- This power supply is sufficient to run the motors up to about 5 horsepower (hp).

Three Phase Supply

The three-phase power supply includes four wires such as one neutral as well as three conductors. The three conductors are away from phase & space 120º distant from each other. Three phase power supplies are utilized as a single-phase AC power supply. For the small load, 1-phase AC power supply, as well as neutral, can be chosen from the 3-phase AC power supply system. This supply is constant and not at all totally falls to zero. The power of this system can be illustrated in two configurations namely star connection (or) delta connection. The connection of star configuration is used in long-distance communication as it includes a neutral cable to the error current.

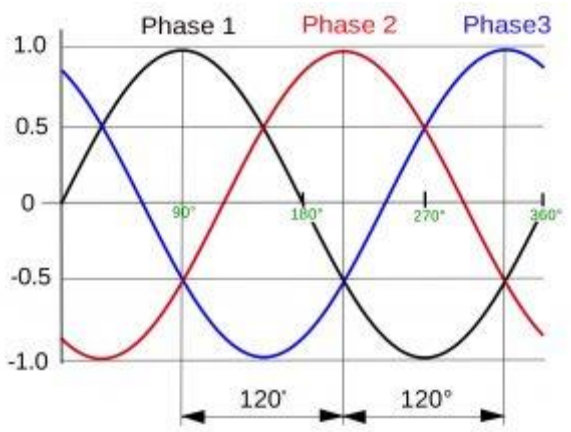


Figure 9.

Below we are showing the star and delta connection used in the three phase power supply.

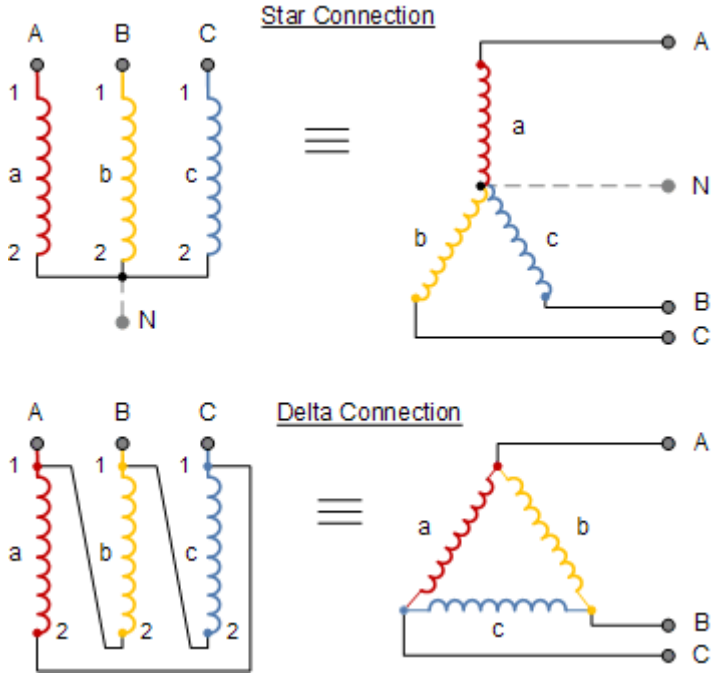


Figure 10.

Three Phase Supply Benefits

The benefits of choosing a three-phase supply include the following.

- Copper Utilization Reduction
- Lessening of Security Risks for Employees
- Labour Treatment Costs
- The efficiency of the Conductor is Greater
- Facility to Run High Power Loads

Three Phase Supply Applications

The applications of the three-phase supply include the following.

- These types of supplies are used in power grids, mobile towers, data centres, aircraft, shipboard, unmanned systems, as well as other electronic loads larger than 1000 watts.
- It is applicable to industrial, manufacturing, and large businesses.
- These are used in power-hungry and high-density data centres.

Key Differences between Single Phase and Three Phase Supplies

The key differences between single phase and three phases include the following.

- The definition of the single-phase power supply is, the power supplies through a single conductor
- The definition of the three-phase power supply is, the power flows through three conductors.
- The single-phase power supply has one distinct wave cycle whereas; three phase has three distinct wave cycles.
- Single phase requires the single wire to connect the circuit whereas; 3-phase needs 3-wires.
- The voltage of the single phase is 230V, whereas three phase voltage is 415V.
- The phase name of the single phase is split phase, whereas three phase has no other name.
- The capacity of power transfer in the single phase is minimum, whereas three phase has the maximum.
- The connection of single phase is simple whereas in 3-phase is complicated.
- The power failure happens in a single phase, but not occurs in three phase.
- The loss in single phase is maximum whereas in three phase is minimum.
- The single-phase efficiency is less whereas in three phase is high.
- The single-phase is inexpensive whereas the 3-phase is expensive.
- The single-phase AC power supply is utilized for home appliances and three phase power supply is used in huge industries to run heavy loads.

From the above information finally, we can conclude that with the right care in the design part of a power supply, the designer can make suitable advice for the highest efficiency & cost savings of your project. Choosing a single phase (or) three-phase system mainly depends on the power requirements of a particular application.

Basic AC Circuits

Unlike DC current, AC voltage or current changes its direction periodically as it increases from zero to maximum, and decreases back to zero, then negatively continue to maximum, and then again back to zero. The frequency of this cycle is about 50 cycles per sec in India. For high-power applications, AC is more predominant and efficient source than DC. The power is not a simple product of voltage and current as in DC, but it depends on the circuit components. Let’s see the AC circuit behavior with the basic components

AC Circuit with a Resistor

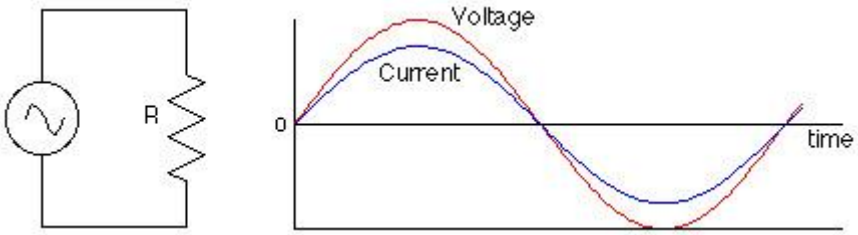


Figure 11.

In this type of circuit, the voltage dropping across the resistor is exactly in phase with the current as shown in the figure. This means that when instantaneous value voltage is zero, the current value at that instant is also zero. And also, when the voltage is positive during the positive half wave of the input signal, the current is also positive, so the power is positive even when they are in negative half wave of the input. This means that the AC power in a resistor is always dissipating as heat while taking it from the source, irrespective of whether the current is positive or negative.

AC Circuit with Inductors

Inductors oppose the change in the current through them not like the resistors that oppose the flow of current. This means when the current is increased, the induced voltage tries to oppose this change of the current by dropping the voltage. The voltage dropped across an inductor is proportional to the rate of change in the current.

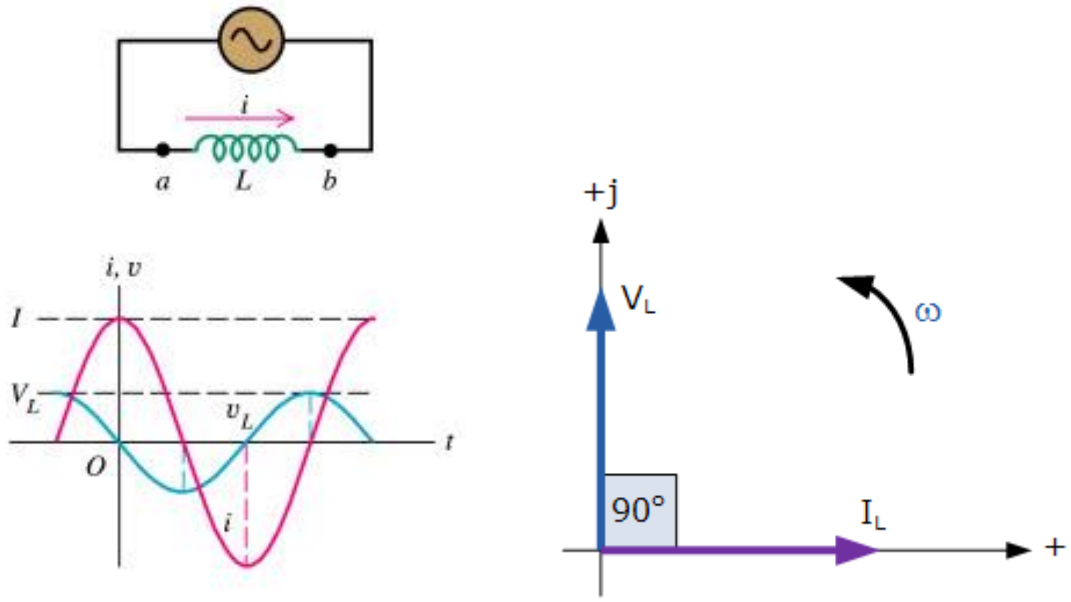


Figure 12.

Therefore, when the current is at its maximum peak (no rate of change in shape), the instantaneous voltage at that instant is zero, and reverse happens when the current peaks at zero (maximum change of its slope), as shown in the figure. So there is no net power dissipation in the inductor AC circuit.

Thus, the instantaneous power of the inductor, in this circuit, is entirely different from the DC circuit, where it is in same phase. But, in this circuit, it is 90 degrees apart so the power is negative, at times, as shown in the figure. Negative power means the power releases back to

the circuit as it absorbs it in the rest of the cycle. This opposition of current change is called as reactance, and it depends on the frequency of the operating circuit.

AC Circuit with Capacitors

A Capacitor opposes a change in the voltage, which is dissimilar to an inductor that opposes a change in the current. By supplying or drawing current, this type of opposition takes place, and this current is proportional to the rate of change of the voltage across the capacitor.

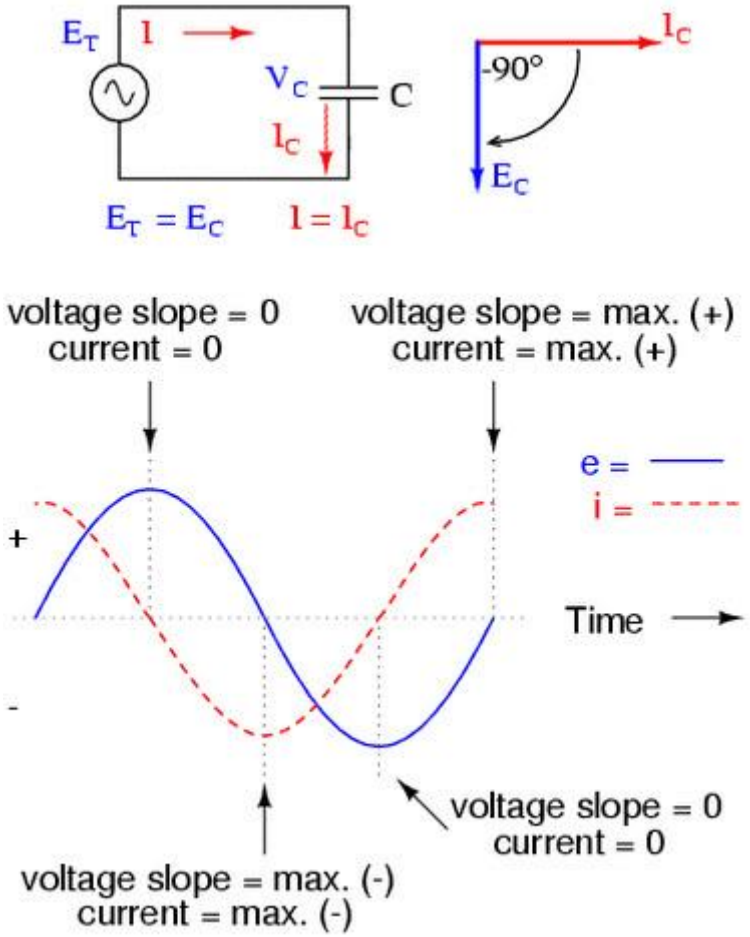


Figure 13.

Here, the current through the capacitor is the result of the change in the voltage in the circuit. Therefore, the instantaneous current is zero when the voltage is at its peak value (no change of voltage slope), and it is maximum when the voltage is at zero, so the power also alternates in positive and negative cycles. This means it does not dissipate the energy but just absorbs and releases the power.

AC circuit behavior can also be analyzed by combining the above circuits like RL, RC and RLC circuits in series as well as in parallel combinations. And also the equations and formulas of the above circuits are exempted in this article to reduce the complexity, but the overall idea is to give a basic concept about the electrical circuits.