UNIT-2 (AC CIRCUITS)

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AC-CIRCUITS

A sinusoidal waveform, or sine wave, is a smooth, repetitive wave that oscillates above and below a central point. Think of it like the ripples spreading out when you drop a pebble in still water. It's the most basic type of wave and is fundamental in many areas of science and engineering.

Key Characteristics of a Sine Wave

There are three main characteristics that define a sinusoidal waveform:

Amplitude

Amplitude is the maximum height of the wave from its center point. It represents the strength or intensity of the wave. A taller wave has a larger amplitude, and a shorter wave has a smaller amplitude. For example, a louder sound wave has a higher amplitude than a quieter one.

Frequency

Frequency is how many times the wave repeats itself in a given amount of time, usually one second. It's measured in **Hertz (Hz)**. A wave with a high frequency has many cycles packed together, while a wave with a low frequency has fewer, more spread-out cycles. Think of it like a heartbeat: a fast heartbeat has a higher frequency than a slow one.

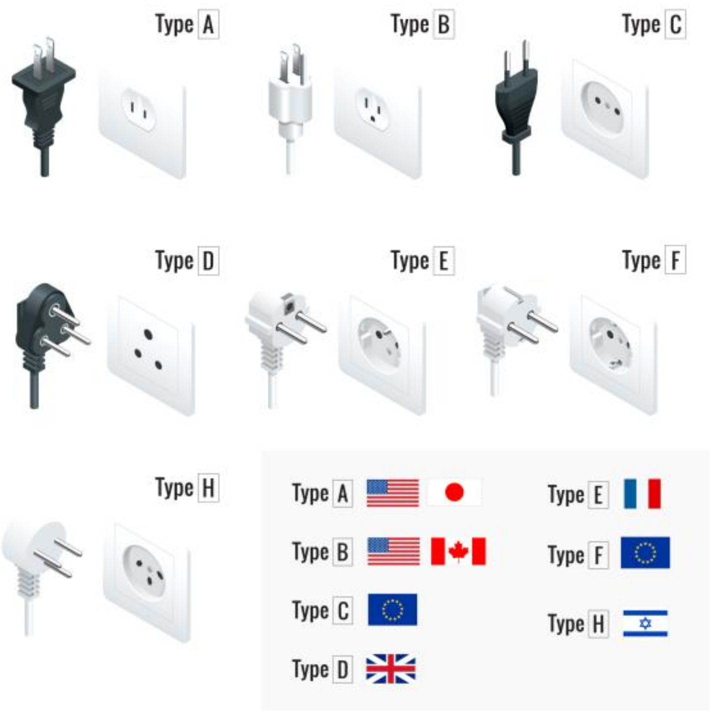
Phase

Phase describes the position of the wave relative to a starting point or another wave. It tells you where the wave is in its cycle at a specific moment in time. If two waves are "in phase," their peaks and troughs line up perfectly. If they're "out of phase," one wave is shifted or delayed compared to the other.

Real-Life Examples

Sine waves are everywhere! Here are a few examples:

- **AC Electricity:** The voltage in the power outlets in your home is a sinusoidal waveform. It's a continuous back-and-forth flow of electricity. This is why it's called **alternating current**.



- **Sound Waves:** When you play a single, pure musical note (like from a tuning fork), the air pressure changes in a sinusoidal pattern.
- **Light:** The electric and magnetic fields that make up light travel as sinusoidal waves.
- **Ocean Waves:** While often more complex, the rise and fall of ocean

waves can be approximated as a sinusoidal motion.

Memory Tip

Think of the word **"A.F.P."** to remember the three key characteristics:

- **A** is for **Amplitude** (the wave's height, like the height of an **A**mplifier's volume).
- **F** is for **Frequency** (how **F**requent the wave is, how many times it cycles).
- **P** is for **Phase** (the wave's starting **P**osition).

Peak value and **RMS value** are two different ways to measure alternating current (AC) or voltage. They're both important for understanding the behavior and power of a waveform, but they tell you different things.

Peak Value (Vp or Ip)

The **peak value** is the absolute maximum value a wave reaches in a single cycle. It's the highest point the wave climbs to before it starts to fall, or the lowest point it dips to.

- **What it tells you:** It's the maximum stress or voltage a component in a circuit will experience. This is crucial for designing and selecting components like capacitors, which must be able to handle the highest voltage they'll encounter without breaking down.
- **Real-life example:** If your home's electricity is 230V, that's the RMS value. However, the voltage actually "peaks" at about 325V. Your electrical devices need to be able to handle that momentary 325V peak, even though the "effective" voltage is lower.

RMS Value (Vrms or Irms)

The **RMS value** stands for **Root Mean Square**. It's the "effective" value of an AC signal. It's a way of comparing AC to DC (direct current) by answering this question: "What constant DC voltage would produce the same amount of heat or power as this varying AC voltage?"

- **What it tells you:** The RMS value is what's used for power calculations and is the number you'll see on most voltmeters. It's a better measure of the energy an AC signal delivers over time.
- **Real-life example:** When you see a light bulb rated for "120V AC," that's its RMS value. This means it will glow with the same brightness and consume the same power as if it were connected to a steady 120V DC source.

Key Relationship & Memory Tip

For a perfect sine wave, there's a simple mathematical relationship between the two values:

Vrms=2

Vpeak≈0.707×Vpeak

This means the RMS value is always a bit smaller than the peak value.

Memory Tip:

- **P**eak is for **P**opping. Think of a circuit "popping" if the voltage gets too high—this is the peak value.
- **R**MS is for **R**esistance/**R**eal power. Think of the real, effective power that heats up a **r**esistor or powers your devices.

Phasor representation is a simplified way to represent a **sinusoidal waveform** (like AC voltage or current). Instead of drawing the entire wave over time, we use a single arrow, or **phasor**, to capture its most important information: its **amplitude** and its **phase**.

A phasor is essentially a rotating vector. We "freeze" this vector at a specific point in time (usually t=0) and draw it on a two-dimensional graph called a **phasor diagram**.

What does the phasor represent?

- **Length:** The length of the arrow represents the **amplitude** of the wave. A longer arrow means a higher amplitude (e.g., a higher voltage).
- **Angle:** The angle of the arrow, measured from the positive x-axis, represents the **phase angle** of the wave. This angle tells you the starting position of the wave in its cycle.

All waveforms in a phasor diagram must have the same **frequency**, but they can have different amplitudes and phases. The phasors all rotate together at the same frequency. The real power of phasors is that they let us use simple algebra and geometry to solve complex AC circuit problems that would otherwise require complicated calculus.

Real-Life Analogy 💡

Imagine a spinning merry-go-round. 🎠 If you take a picture of a single horse on the merry-go-round at a specific moment, you can capture its

distance from the center (amplitude) and its **position on the circle** (phase).

The horse's up-and-down motion as it goes around is like the actual sine wave. The picture of the horse, frozen in time, is the **phasor**. It's a snapshot that gives you all the essential information without having to watch the entire ride.

Memory Tip

Think of a **P**hasor as a **P**icture of a wave. 📸 It freezes the wave's most important information (amplitude and phase) into a simple, static image.

The **impedance triangle** is a right-angled triangle used in AC (alternating current) circuits to visualize the relationship between **resistance**, **reactance**, and **impedance**.

Think of it as a blueprint that shows you the total opposition to current flow in a circuit.

The Three Sides

1. **Resistance (R):** This is the horizontal side (base) of the triangle. It represents the component of the circuit that turns electrical energy into heat. This is the same resistance you learn about in basic DC circuits. Resistance is measured in ohms (Ω).
2. **Reactance (X):** This is the vertical side (height) of the triangle. It represents the opposition to current caused by energy storage

elements like **inductors** and **capacitors**. Unlike resistance, reactance doesn't dissipate energy; it stores and releases it. It's also measured in ohms (Ω).

3. **Impedance (Z):** This is the diagonal side (hypotenuse) of the triangle. It represents the **total** opposition to current flow, combining both the resistance and the reactance. It's the overall "roadblock" the current faces. Impedance is also measured in ohms (Ω).

Here is a visual representation of the impedance triangle:

Real-Life Analogy 🚦

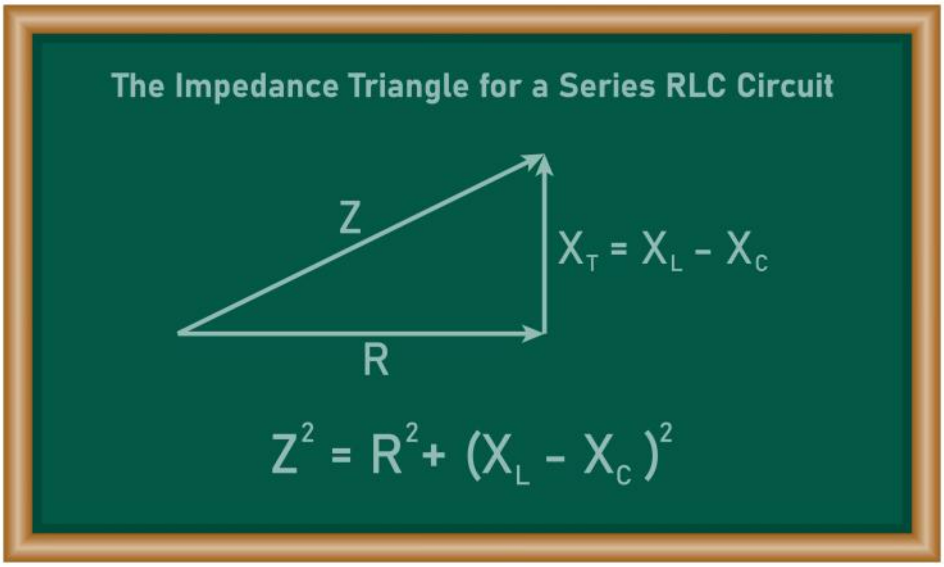
Imagine you are trying to drive through a city.

- **Resistance (R):** This is like the **traffic** on the main roads. It slows you down and generates heat in your engine (a form of energy loss). The traffic is always there, no matter what direction you're going.
- **Reactance (X):** This is like the **detours** and **one-way streets** that force you to change direction. They don't just slow you down, they change the way you have to navigate the city.
- **Impedance (Z):** This is the **total difficulty** of your trip—the combined effect of the traffic and all the detours. It's a single measure of how much your journey is being hindered.

Memory Tip

The impedance triangle is just a geometric representation of the Pythagorean theorem: R2+X2=Z2.

- **R** for **R**oad (Resistance) - the straight path, the base.
- **X** for a "turn" (Reactance) - the change in direction, the height.
- **Z** for **Z**igzag (Impedance) - the total path, the hypotenuse.



In alternating current (AC) circuits, power isn't as simple as in a DC circuit. The three types of power and the power factor help us understand how efficiently an electrical system is using its energy.

The Beer Analogy 🍺

The easiest way to understand this is with an analogy: imagine a glass of beer.

- **Apparent Power (S):** This is the **total contents of the glass** (beer + foam). It's the total power the electricity company has to supply to your house. It's measured in **Volt-Amperes (VA)**.
- **Real Power (P):** This is the **actual beer** 🍻. This is the power that does the useful work, like running your refrigerator, lighting your lamps, or charging your phone. It's what you're billed for on your

electricity statement. It's measured in **Watts (W)**.

- **Reactive Power (Q):** This is the **foam** on top of the beer. It doesn't quench your thirst, but it's necessary for some electrical devices (like motors and transformers) to create the magnetic fields they need to operate. It's power that sloshes back and forth in the circuit without being used for work. It's measured in **Volt-Amperes Reactive (VAR)**.

The Power Triangle

This relationship between the three powers can be visualized as a power triangle.

This is a right-angled triangle where:

- The **base** is the **Real Power (P)**.
- The **height** is the **Reactive Power (Q)**.
- The **hypotenuse** is the **Apparent Power (S)**.

The relationship follows the Pythagorean theorem: S2=P2+Q2.

Power Factor

The **power factor** is a number that tells you how efficiently the supplied power (apparent power) is being used. It's the ratio of **Real Power** to **Apparent Power**.

Power Factor (PF) = Real Power (P) / Apparent Power (S)

- A **Power Factor of 1** (or 100%) is ideal. This means all the power supplied is being used for work (all beer, no foam).
- A **low Power Factor** (less than 1) means you have a lot of reactive

power (a lot of foam). This is bad because the electricity company still has to supply that total apparent power, even though a portion of it isn't being used for work. A low power factor can lead to higher electricity bills for industrial customers and puts more stress on the power grid.

Memory Tip 🧠

Just remember the **beer analogy**:

- **R**eal Power is the **R**eal beer.
- **A**pparent Power is the **A**ll-in-the-glass amount.
- **P**ower **F**actor is a measure of how **F**ull your glass is with beer instead of foam.

When a single-phase AC circuit has multiple components in series, we need to analyze how each component affects the current and voltage. The key is that in a series circuit, the current is the same everywhere, but the voltage is different across each component. The total opposition to current flow is called **impedance (Z)**.

Basic Components in AC Circuits

- **Resistor (R):** A resistor simply opposes current flow, converting electrical energy into heat. In a resistor, the voltage and current are **in phase**, meaning they reach their peaks and troughs at the same time. The opposition to current is its resistance, measured in ohms (Ω).

- **Inductor (L):** An inductor stores energy in a magnetic field. It resists changes in current. This causes the voltage to **lead** the current by 90 ∘ (a quarter of a cycle). The opposition from an inductor is called **inductive reactance (XL)**, also measured in ohms (Ω).
- **Capacitor (C):** A capacitor stores energy in an electric field. It resists changes in voltage. This causes the voltage to **lag** the current by 90 ∘. The opposition from a capacitor is called **capacitive reactance (XC)**, also measured in ohms (Ω).

Series Circuit Combinations

In a series circuit, we use the **impedance triangle** to find the total impedance (Z) by combining the resistance (R) and the total reactance (Xtotal), which is the difference between XL and XC.

1. R-L Circuit (Resistor and Inductor)

An R-L circuit has both resistance and inductive reactance. The total impedance is:

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

The voltage across the inductor leads the current, so the total voltage across the circuit will also **lead** the current, but by an angle less than 90°.

- **Real-life example:** An electric fan or motor. The coil inside is an inductor, and the wires have resistance.

2. R-C Circuit (Resistor and Capacitor)

An R-C circuit has both resistance and capacitive reactance. The total impedance is:

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

The voltage across the capacitor lags the current, so the total voltage across the circuit will also **lag** the current, but by an angle less than 90°.

- **Real-life example:** A simple audio filter that lets high-frequency sounds pass through while blocking low-frequency ones.

3. R-L-C Circuit (Resistor, Inductor, and Capacitor)

This circuit has all three components. Since the inductive and capacitive reactances (X_L and X_C) have opposite effects on the phase, they cancel each other out. The total reactance is the difference between them: $X_{total} = |X_L - X_C|$.

The total impedance is:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

The overall behavior of the circuit depends on which reactance is larger:

- If $X_L > X_C$, the circuit behaves like an R-L circuit, with the voltage leading the current.
- If $X_C > X_L$, the circuit behaves like an R-C circuit, with the voltage lagging the current.
- If $X_L = X_C$, the reactances cancel completely, and the circuit's impedance is just the resistance ($Z = R$). This is a special and important condition called **resonance**.
- **Real-life example:** Tuning a radio. You change the capacitor value to match the frequency of the radio station, causing the circuit to be at resonance, which allows the radio to "tune in" to that specific station's frequency.

Memory Tip 💡

Remember the phrase "**ELI the ICE man**".

- **ELI**: In an inductor (L), the voltage (E) comes before the current (I).
- **ICE**: In a capacitor (C), the current (I) comes before the voltage (E).

A **three-phase balanced circuit** is a key concept in electrical engineering, representing an ideal state for power systems. It consists of a power source that generates three alternating voltages of equal magnitude and frequency, which are precisely separated in phase by 120 degrees.[1] These voltages are then applied to a load where the impedance in all three phases is identical.[2]

Key Characteristics

- **Equal Magnitudes:** The voltage and current in each of the three phases (let's call them Phase A, B, and C) have the exact same RMS value.[3]
- **120-Degree Phase Shift:** The voltage and current waveforms in each phase are shifted by exactly 120° relative to each other.[4] For example, when Phase A's voltage is at its peak, Phase B's is at -0.5 times its peak, and Phase C is at a different value. This precise timing is what allows for smooth and constant power delivery.[5]
- **Equal Impedances:** The load connected to each of the three phases is identical in both magnitude and phase angle.[6] This ensures that the current drawn by each phase is also perfectly balanced.[7]
- **Zero Neutral Current:** A major benefit of a balanced circuit is that the three currents sum to zero at any given instant. This means that if a neutral wire is present, it carries no current. This allows for a smaller neutral wire or, in some cases, no neutral wire at all, which reduces cost and material.[8]

Real-Life Analogy: The Three-Cylinder Engine 🚙

Think of a single-phase circuit like a single-cylinder engine. It delivers power in bursts, and the output is not constant. You feel a "pulsing" effect.

A three-phase balanced circuit is like a three-cylinder engine. Each cylinder (phase) fires in a perfectly timed sequence, 120° apart. This creates a much smoother, more constant delivery of power to the wheels.[9] This constant power is much more efficient and causes less vibration, which is why three-phase power is used for large industrial motors and heavy machinery.[10]

Advantages of Balanced Circuits

- **Higher Efficiency:** Balanced systems minimize power loss and voltage fluctuations, making them more efficient for transmitting large amounts of power.[11]
- **Constant Power:** The total power delivered by a balanced three-phase system is constant and doesn't fluctuate like in a single-phase system, which is ideal for motors and generators.[12]
- **Cost Savings:** The zero neutral current allows for smaller or no neutral conductors, which saves on material and installation costs.[13]
- **Self-Starting Motors:** The rotating magnetic field produced by three-phase power allows AC motors to be self-starting, eliminating the need for extra starting components.

  A **three-phase balanced circuit** is a highly efficient electrical system where three separate AC voltages are generated. These three voltages have the exact same strength and frequency but are perfectly spaced out in time, each one starting its cycle **120 degrees** after the previous one. This balanced timing and equal load on all three phases is what makes the system so effective for power generation and distribution.

Analogy: The Three-Cylinder Engine 🚗

Imagine a single-phase system is like a one-cylinder engine. It delivers power in uneven pulses. A three-phase system is like a three-cylinder engine where each cylinder fires at a precise, staggered time. This creates a much smoother, continuous, and powerful output.

Star (Y) and Delta (Δ) Connections

These are the two main ways to connect a three-phase power source or load. The voltage and current relationships are what make them unique.

Star (Y) Connection

In a **Star** connection, one end of each of the three windings (or loads) is connected to a common central point called the **neutral point**. The other three ends are connected to the power lines (A, B, C). It looks like the letter "Y".

- **Voltage Relation:** The voltage between any two power lines (**line voltage**, V_L) is $\sqrt{3}$ times the voltage measured across a single winding (**phase voltage**, V_P).

$$V_L = \sqrt{3} \times V_P$$

- **Current Relation:** The current flowing in a power line (**line current**, I_L) is the same as the current flowing through a single winding (**phase current**, I_P).

$$I_L = I_P$$

- **Real-life use:** Power distribution. The neutral wire provides a safe return path for unbalanced loads and allows for two different voltage levels: the higher line voltage and the lower phase voltage (which is what you get in your home outlets).

Memory Tip

- **Star (Y) Connection:** Think of the shape. The "Y" has two distinct "arms" connected to a central point. This helps you remember that the voltage is split up (VL>VP), while the current is a single path (IL=IP).
- **Delta (Δ) Connection:** The triangle has no central point, so everything is directly connected. This helps you remember that the voltage is the same (VL=VP), but the current splits up (IL>IP).

Delta (Δ) Connection

In a **Delta** connection, the three windings are connected end-to-end to form a closed loop, shaped like a triangle. There is no central neutral point.

- **Voltage Relation:** The voltage across any single winding (**phase voltage**, V_P) is the same as the voltage between the two lines connected to it (**line voltage**, V_L).

$$V_L = V_P$$

- **Current Relation:** The current flowing in a power line (**line current**, I_L) is $\sqrt{3}$ times the current flowing through a single winding (**phase current**, I_P).

$$I_L = \sqrt{3} \times I_P$$

- **Real-life use:** High-power industrial applications like motors, where a neutral point isn't needed and the load is typically balanced.