



A T M E
College of Engineering



1 BEE303 Electric Circuit Analysis

MODULE 1

1. Fundamentals & Active/Passive Components

Electric Circuit Fundamentals

- Definition: A closed-loop path through which electrons flow to deliver electrical energy from a source to a load.
- Key Metrics: Voltage (potential difference driving current, Volts), Current (rate of charge flow, Amperes), and Resistance (opposition to current, Ohms).
- Fundamental Governing Law: Ohm's Law ($V = IR$), which dictates linear relationship in specific media.

The Mechanism of Charge Flow

- Energy is transferred via electromagnetic wave propagation, while individual electrons drift at slow speeds.

Classification of Components

Active Components (Energy Providers):

- Capable of delivering net power over an infinite duration or providing power gain.
- Examples: Generators, batteries, operational amplifiers, and transistors.

Passive Components (Energy Consumers/Storers):

- Cannot deliver long-term net energy or introduce internal amplification.
- Resistors (R): Dissipate energy permanently as heat thermal energy.
- Inductors (L): Store kinetic energy temporarily in a magnetic field.
- Capacitors (C): Store potential energy temporarily in an electrostatic field.

2. Advanced Classification of Networks

Linear vs. Non-Linear Networks

Linear: Circuit parameters (R , L , C) remain completely constant irrespective of voltage or current variations. Obeys Superposition and Homogeneity (e.g., pure resistive networks).
Non-Linear: Parameters vary with current/voltage fluctuations (e.g., diodes, transistors, saturated magnetic cores).

Bilateral vs. Unilateral Networks

Bilateral: Conduction behavior and properties are identical in both current directions. (e.g., Transmission lines, resistors).
Unilateral: Response alters radically if direction of current is reversed (e.g., Diode circuits, rectifiers allowing one-way conduction).

Lumped vs. Distributed Networks

Lumped: Elements are physically separable, discrete, and concentrated at specific points (e.g., standard PCB circuits analyzed via KVL/KCL).
Distributed: Elements are spread infinitesimally along lengths; cannot be separated physically (e.g., long transmission lines where R , L , C occur per kilometer).

Active vs. Passive Networks

Active Network: Contains at least one internal active source (voltage or current source) capable of injecting net power into the system.
Passive Network: Devoid of any internal power generation sources; consists entirely of loads, attenuators, or energy storage elements.

3. Concept of Ideal and Practical Sources

Voltage Sources (E)

Ideal Voltage Source:

- Delivers a constant terminal voltage completely independent of the load current drawn.
- **Internal Resistance (R_{in}) = 0Ω (Zero internal impedance).**

Practical Voltage Source:

- Terminal voltage drops non-linearly as current load increases due to internal resistance.
- **Modeled as an Ideal Voltage Source in SERIES with an internal resistance (R_s).**
- Governing Equation: $V_{terminal} = E - (I * R_s)$

Current Sources (I)

Ideal Current Source:

- Supplies constant current to the network regardless of terminal voltage across it.
- **Internal Resistance (R_{in}) = $\infty \Omega$ (Infinite internal impedance).**

Practical Current Source:

- Output current decreases slightly as external terminal voltage rises.
- **Modeled as an Ideal Current Source in PARALLEL with an internal shunt resistance (R_{sh}).**
- Governing Equation: $I_{load} = I_{source} - (V_{terminal} / R_{sh})$

4. Independent and Dependent Sources

Independent Sources

- **Characteristics:** Value is entirely autonomous. Not altered by changes in other loop currents or branch voltages within the network.
- **Standard Symbols:** Circular geometry.

Dependent / Controlled Sources

- **Characteristics:** The voltage or current output depends directly on a distinct control voltage (v_x) or control current (i_x) elsewhere in the circuit.
- **Standard Symbols:** Diamond/Rhombus geometry. Crucial for solid-state active modeling.

The 4 Controlled Configurations:

1. VCVS (Voltage-Controlled Voltage Source)

- Output: $V = \mu * V_x$ | μ = Dimensionless Gain Factor

2. CCVS (Current-Controlled Voltage Source)

- Output: $V = r * i_x$ | r = Transresistance Factor (Ohms)

3. VCCS (Voltage-Controlled Current Source)

- Output: $I = g * V_x$ | g = Transconductance Factor (Siemens)

4. CCCS (Current-Controlled Current Source)

- Output: $I = \beta * i_x$ | β = Dimensionless Current Gain



5. Source Transformation & Source Shifting

The Source Transformation Principle

- Mechanism: Allows converting a practical voltage source to a practical current source, or vice versa, without changing external circuit characteristics.
- Mathematical Conversion:
 - Series to Parallel: A voltage source (V) in series with resistor (R) converts to a parallel current source ($I = V/R$) with the identical resistor (R) in parallel shunt.
 - Parallel to Series: A current source (I) in parallel with resistor (R) converts to a series voltage source ($V = I * R$) with the identical resistor (R) in series.
- Applicability: Valid for independent and dependent sources (provided the control parameter location is maintained unaltered).

Advanced Source Shifting (Blakesley's)

Voltage Source Shifting (E-Shift):

- Problem: An ideal voltage source connected directly between two independent nodes cannot undergo normal transformation.
- Action: Shift the voltage source across a common node into all other connected branches meeting at that junction, preserving identical polarity orientation relative to the node.

Current Source Shifting (I-Shift):

- Problem: A current source isolated in a single branch preventing basic loop reductions.
- Action: Can be shifted across a closed loop or node junction by adding identical current sources in parallel with adjacent branches to preserve Kirchhoff's Current Law integrity.

6. Star-Delta (Y- Δ) Transformations

Delta to Star ($\Delta \rightarrow Y$) Conversion

• Scenario: Used when three resistors are arranged in a closed triangle (Delta) loop and need to be simplified into a central-point T-junction (Star).

• Principle: Each derived Star resistance equals the product of the two adjacent Delta branch resistors divided by the sum of all three Delta resistors.

• Exact Mathematical Formulas:

$$R1 = (Rab * Rac) / (Rab + Rbc + Rac)$$

$$R2 = (Rab * Rbc) / (Rab + Rbc + Rac)$$

$$R3 = (Rbc * Rac) / (Rab + Rbc + Rac)$$

Star to Delta ($Y \rightarrow \Delta$) Conversion

• Scenario: Used when three elements radiate from a neutral common node (Star) and must be transformed into an equivalent outer loop delta profile.

• Principle: Each derived Delta resistance equals the sum of all possible pairwise products of the Star resistances divided by the opposite Star branch resistor.

• Exact Mathematical Formulas:

$$Rab = R1 + R2 + (R1 * R2) / R3$$

$$Rbc = R2 + R3 + (R2 * R3) / R1$$

$$Rac = R1 + R3 + (R1 * R3) / R2$$

7. Mesh Current vs. Node Voltage Analysis

Mesh Current Method (Loop Matrix)

- Core Law: Based on Kirchhoff's Voltage Law (KVL) - $\sum V$ around any closed loop = 0.
- Independent Variables: Assign fictitious loop/mesh currents ($I_1, I_2, \dots, I_n$) tracking uniform direction.
- Best Used For: Planar circuits (circuits capable of drawing flat without crossing wires) where number of meshes is lower than nodes.
- Matrix Formulation (DC vs AC):**
 - DC: $[R][I] = [V]$ | Resistance matrix multiplied by current vector.
 - AC: $[Z][I] = [V]$ | Impedance matrix where Z involves real resistance and imaginary inductive/capacitive reactance ($R + jX$).

Node Voltage Method (Nodal Matrix)

- Core Law: Based on Kirchhoff's Current Law (KCL) - $\sum I$ leaving a junction node = 0.
- Independent Variables: Assign individual essential node potentials ($V_1, V_2, \dots, V_n$) relative to a chosen 0V reference/ground node.
- Best Used For: Non-planar circuits or networks containing extensive parallel branches and fewer reference nodes than independent meshes.
- Matrix Formulation (DC vs AC):**
 - DC: $[G][V] = [I]$ | Conductance matrix ($G = 1/R$) solved for nodal voltage vector.
 - AC: $[Y][V] = [I]$ | Admittance matrix ($Y = G + jB$) where components embrace real conductance and imaginary susceptance.

8. Handling Singularities: Super-Mesh & Super-Node

Concept of Super-Mesh Analysis (Constraint Resolution)

- Trigger Condition: Occurs when an ideal current source (either independent or dependent) is shared as a mutual branch between two distinct meshes.
- **Solution Strategy:**
 1. Completely remove the shared current source branch temporarily by open-circuiting it.
 2. Formulate a single unified KVL equation around the remaining macro perimeter loop (Super-mesh).
 3. Formulate an auxiliary constraint equation linking internal mesh currents to the current source value (e.g., $I_2 - I_1 = I_{\text{source}}$).

Concept of Super-Node Analysis (Constraint Resolution)

- Trigger Condition: Occurs when an ideal voltage source (independent or dependent) is connected directly between two non-reference essential nodes.
- **Solution Strategy:**
 1. Enclose the voltage source and its two associated nodes inside a generalized bounded boundary surface (Super-node).
 2. Write a single structural KCL equation for the entire super-node, summing all currents entering or leaving the perimeter surface.
 3. Create an auxiliary algebraic constraint equation defining the fixed potential difference between those two specific nodes (e.g., $V_1 - V_2 = V_{\text{source}}$).

9. Principle of Duality in Networks

The Principle of Circuit Duality

Core Definition: Two networks are said to be duals if the mesh equations of one system are mathematically identical in form to the nodal equations of the other.

- Practical Utility: Solving a dual network means you automatically possess the solution structure for its twin problem. Simplifies deep matrix computations.

- **Geometric Duality Rules:**

- Independent Meshes become independent Junction Nodes.
- Series connections transform systematically to Parallel clusters.
- Internal loop lines translate to lines slicing outward reference paths.

Direct Electrical Dual Mapping:

- Voltage (V) $\leftarrow$ Dual Pair $\rightarrow$ Current (I)
- Resistance (R) $\leftarrow$ Dual Pair $\rightarrow$ Conductance (G)
- Inductance (L) $\leftarrow$ Dual Pair $\rightarrow$ Capacitance (C)
- Mesh Current Method $\leftarrow$ Dual Pair $\rightarrow$ Node Voltage Method
- Kirchhoff's Voltage Law (KVL) $\leftarrow$ Dual Pair $\rightarrow$ Kirchhoff's Current Law (KCL)
- Series Branches $\leftarrow$ Dual Pair $\rightarrow$ Parallel Branches
- Open Circuit Condition $\leftarrow$ Dual Pair $\rightarrow$ Short Circuit Condition
- Impedance (Z) $\leftarrow$ Dual Pair $\rightarrow$ Admittance (Y)