Basic Electrical Engineering

Short notes for B.Tech 1st year · all branches · Diploma

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1. DC Circuit Basics

- **Current (I)** = rate of flow of charge, I = Q / t. Unit: ampere (A).
- **Voltage (V)** = work done per unit charge. Unit: volt (V).
- **Resistance (R)** = opposition to current. R = ρ l / A. Unit: ohm (Ω).
- **Ohm's law**: V = I R (temperature and other physical conditions constant).
- Power P = V I = I^2 R = V^2 / R. Energy = P x t (1 kWh = 1 "unit" = 3.6 MJ).

➤ Active and passive elements

- **Active**: give energy, e.g. voltage source, current source, battery.
- **Passive**: take or store energy, e.g. R, L, C.
- **Ideal voltage source**: zero internal resistance. **Ideal current source**: infinite internal resistance.
- **Linear** element follows V ∝ I. **Bilateral** element behaves the same in both directions (R, L, C). A diode is non-linear and unilateral.

➤ Series and parallel

Item	Series	Parallel
Current	Same in all	Divides
Voltage	Divides	Same across all
R total	R1 + R2 + ...	1/R = 1/R1 + 1/R2 + ...
Divider rule	V1 = V R1 / (R1 + R2)	I1 = I R2 / (R1 + R2)

➤ Kirchhoff's laws

1. **KCL**: sum of currents entering a node = sum of currents leaving it (conservation of charge).
2. **KVL**: algebraic sum of voltages around any closed loop = 0 (conservation of energy).

- **Mesh analysis** uses KVL with loop currents. **Nodal analysis** uses KCL with node voltages.

➤ Star-delta conversion

FORMULA Delta to star: RA = R_AB x R_CA / (R_AB + R_BC + R_CA). Equal resistors: R_star = R_delta / 3.

FORMULA Star to delta: R_AB = RA + RB + RA x RB / RC. Equal resistors: R_delta = 3 x R_star.

2. Network Theorems

Theorem	Statement in short
Superposition	In a linear circuit with many sources, response = sum of responses of each source acting alone
Thevenin	Any linear two-terminal network = Vth in series with Rth
Norton	Any linear two-terminal network = IN in parallel with RN (RN = Rth, IN = Vth / Rth)
Maximum power transfer	Load gets maximum power when RL = Rth
Reciprocity	Ratio of response to excitation stays same when their positions are swapped

- While "killing" sources: voltage source → **short circuit**, current source → **open circuit**.
- Superposition works for voltage and current, not for power (power is not linear).

FORMULA Pmax = Vth^2 / (4 Rth). Efficiency at maximum power transfer = 50%.

EXAMPLE 12 V source with 4 Ω in series, then 12 Ω across terminals A-B. Vth = 12 x 12/16 = 9 V. Rth = 4 || 12 = 3 Ω. With RL = 6 Ω: I = 9/(3 + 6) = 1 A. For max power RL = 3 Ω, Pmax = 81 / 12 = 6.75 W.

3. AC Fundamentals

- AC voltage: v = Vm sin ωt, where ω = 2πf. In India supply frequency f = 50 Hz.

- **Time period** $T = 1/f = 20$ ms at 50 Hz.
- **RMS value** = the DC value that gives the same heating effect.
- **Average value** of a full sine wave = 0, so it is taken over half a cycle.

FORMULA Sine wave: $V_{rms} = V_m/\sqrt{2} = 0.707\ V_m$. $V_{avg} = 2V_m/\pi = 0.637\ V_m$.

FORMULA Form factor = Vrms / Vavg = 1.11. Peak (crest) factor = Vm / Vrms = 1.414.

Waveform	RMS	Average (half cycle)	Form factor
Sine	$V_m/\sqrt{2}$	$2V_m/\pi$	1.11
Square	V_m	V_m	1
Triangular	$V_m/\sqrt{3}$	$V_m/2$	1.155
Half-wave rectified sine	$V_m/2$	V_m/π (over full cycle)	1.57

- **Phasor**: a rotating vector showing magnitude (RMS) and phase angle.
- 230 V house supply means 230 V RMS, peak = 230 x 1.414 = 325 V.

4. Single-Phase AC Circuits

Circuit	Impedance	Phase of I w.r.t. V	Power factor
Pure R	R	In phase	1
Pure L	$X_L = \omega L$	Lags by 90°	0 (lag)
Pure C	$X_C = 1/(\omega C)$	Leads by 90°	0 (lead)
R-L series	sqrt(R^2 + XL^2)	Lags by ϕ	R/Z lagging
R-C series	sqrt(R^2 + XC^2)	Leads by ϕ	R/Z leading

REMEMBER "ELI the ICE man": in L, E (voltage) leads I; in C, I leads E.

➤ Power in AC

- **Active power** $P = V\ I \cos\phi$ (W). **Reactive power** $Q = V\ I \sin\phi$ (VAR). **Apparent power** $S = V\ I$ (VA).
- Power triangle: $S^2 = P^2 + Q^2$. Power factor = $\cos\phi = P / S = R / Z$.
- Low power factor → more current for same power → more losses and bigger cables. Improve it with shunt capacitors.

Series RLC and resonance

- Z = sqrt(R^2 + (XL - XC)^2). At resonance XL = XC, so Z = R (minimum) and current is maximum.

FORMULA f0 = 1 / (2π sqrt(LC)). Quality factor Q = (1/R) sqrt(L/C). Bandwidth = f0 / Q = R / (2πL).

- Series resonance = **voltage magnification** (VL = VC = Q x V). Parallel resonance = **current magnification**, impedance is maximum (= L / (CR)).

EXAMPLE Series RLC: R = 30 Ω, XL = 60 Ω, XC = 20 Ω, V = 200 V. Z = sqrt(30^2 + 40^2) = 50 Ω. I = 200/50 = 4 A. pf = 30/50 = 0.6 lagging. P = 200 x 4 x 0.6 = 480 W (check: I^2 R = 16 x 30 = 480 W). Q = 200 x 4 x 0.8 = 640 VAR.

5. Three-Phase Circuits

- Three voltages of equal size, 120° apart. Phase sequence R-Y-B.
- Advantages over single phase: more power for the same conductor material, constant power, self-starting motors.

Quantity	Star (Y)	Delta (Δ)
Line voltage	VL = √3 Vph	VL = Vph
Line current	IL = Iph	IL = √3 Iph
Neutral	Available	Not available
Power	√3 VL IL cos ϕ	√3 VL IL cos ϕ

FORMULA P = √3 VL IL cos ϕ = 3 Vph Iph cos ϕ (balanced load). ϕ = angle between phase voltage and phase current.

EXAMPLE Balanced star load, 400 V line, Z = 10 Ω per phase at 0.8 pf lag. Vph = 400/√3 = 230.9 V. Iph = IL = 23.09 A. P = √3 x 400 x 23.09 x 0.8 = 12.8 kW (check: 3 x 23.09^2 x 8 Ω = 12.8 kW).

Two-wattmeter method

- Measures total power in a 3-phase, 3-wire system (balanced or unbalanced).
- P = W1 + W2. For balanced load: tan ϕ = √3 (W1 - W2) / (W1 + W2).

- pf = 1 → W1 = W2. pf = 0.5 → one wattmeter reads zero. pf < 0.5 → one reads negative.

6. Magnetic Circuits

- **MMF** = N I (ampere-turns). **Flux** Φ in weber (Wb). **Flux density** B = Φ / A (tesla).
- **Reluctance** S = l / (μ0 μr A). μ0 = 4π × 10^-7 H/m.
- **Magnetising force** H = N I / l (AT/m). B = μ0 μr H.

FORMULA Φ = MMF / Reluctance = N I / S (Ohm's law of magnetic circuits).

Electric circuit	Magnetic circuit
EMF (V)	MMF (AT)
Current I	Flux Φ
Resistance R	Reluctance S
Conductivity	Permeability
Current really flows	Flux does not "flow"

- **Faraday's law**: e = -N dΦ/dt. **Lenz's law**: induced EMF opposes the cause (that is the minus sign).
- **Self inductance** L = N Φ / I. Energy stored in an inductor = (1/2) L I^2. Energy in a capacitor = (1/2) C V^2.
- Mutual inductance M = k sqrt(L1 L2), k = coupling coefficient (0 to 1).
- **Hysteresis loss** ∝ f Bm^1.6 (Steinmetz). Reduce with silicon steel. **Eddy current loss** ∝ f^2 Bm^2 t^2. Reduce with thin laminations.

7. Single-Phase Transformer

- Static device that transfers power between two circuits by **mutual induction**, at the same frequency.
- Works only on AC. On DC there is no changing flux, so no EMF, and the primary may burn.

FORMULA EMF equation: E = 4.44 f N Φm. Turns ratio: V1/V2 = N1/N2 = I2/I1.

EXAMPLE f = 50 Hz, N = 200 turns, Φm = 0.01 Wb. E = 4.44 x 50 x 200 x 0.01 = 444 V.

- Losses: **iron (core) loss** = hysteresis + eddy (constant), **copper loss** = I^2 R (varies with load).
- Maximum efficiency when copper loss = iron loss.
- Efficiency = output / (output + iron loss + copper loss).
- Core type vs shell type: in shell type the core surrounds the windings, gives better protection and less leakage.

8. Electrical Machines (introduction)

➤ DC machines

- **Generator**: mechanical → electrical (Fleming's right-hand rule). **Motor**: electrical → mechanical (Fleming's left-hand rule).
- Back EMF in motor: Eb = V - Ia Ra. Speed N ∝ Eb / Φ.
- **Commutator** converts the AC induced in armature into DC at the terminals.
- DC series motor: high starting torque (cranes, traction). Never start a series motor on no load (speed becomes dangerously high).

➤ Induction motor

- Rotating magnetic field from a 3-phase supply. Synchronous speed Ns = 120 f / P.
- Slip s = (Ns - N) / Ns. The rotor always runs a little slower than Ns.

EXAMPLE 4-pole, 50 Hz motor runs at 1440 rpm. Ns = 120 x 50 / 4 = 1500 rpm. s = 60/1500 = 0.04 = 4%.

- Single-phase induction motor is **not self-starting**; a capacitor or auxiliary winding is used to start it.

9. Electrical Installation and Safety

- **Fuse**: thin wire that melts on overcurrent. Rewirable or HRC (high rupturing capacity).

- **MCB** (miniature circuit breaker): trips on overload (thermal) and short circuit (magnetic). Can be reset.
- **ELCB / RCCB**: trips when leakage current to earth flows; protects people from electric shock.
- **Earthing**: connects metal body of equipment to earth, so fault current flows to ground, not through a person. Types: plate earthing, pipe earthing.
- Wiring: casing-capping, conduit (concealed or surface), PVC.
- Cables: conductor (copper or aluminium) + insulation (PVC, XLPE) + sheath.

➤ Batteries

Type	Cell voltage (nominal)	Use
Lead-acid	2 V	Inverters, vehicles, UPS
Nickel-cadmium	1.2 V	Old portable tools
Lithium-ion	about 3.6–3.7 V	Phones, laptops, EVs

- Battery capacity in Ah (ampere-hour). Energy stored = V x Ah (Wh).

> **TIP** In the exam, draw the phasor diagram for every AC numerical; it gives easy marks and avoids sign mistakes.

10. Most Asked Questions (practice)

1. State and prove Thevenin's and Norton's theorems with an example.
2. State maximum power transfer theorem and find Pmax.
3. Derive RMS and average value of a sine wave. Define form factor and peak factor.
4. Solve a series RLC circuit: find Z, I, pf, P and Q. Draw the phasor diagram.
5. Explain series resonance. Derive f0, Q-factor and bandwidth.
6. Relation between line and phase quantities in star and delta.
7. Explain the two-wattmeter method and find pf from the readings.
8. Compare electric and magnetic circuits. Explain hysteresis and eddy current loss.
9. Derive the EMF equation of a transformer. When is efficiency maximum?
10. What is earthing? Compare fuse and MCB.

> **TIP** First-year exams repeat theorems, RLC circuits, 3-phase relations and the transformer EMF equation. Learn these four with one solved numerical each.