Engineering License Exam Study Guide: Basic Electrical and Electronics Engineering (AExE01)

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1. Basic Concepts

1.1 Ohm's Law

Definition: Ohm's Law states that the current flowing through a conductor between two points is directly proportional to the voltage across the two points.

Formula: [V = I \times R] Where:

- (V) = Voltage (Volts)
- (I) = Current (Amperes)
- (R) = Resistance (Ohms)

Explanation:

- **Voltage (V):** The potential difference that drives current through a circuit.
- **Current (I):** The flow of electric charge.
- **Resistance (R):** The opposition to current flow.

Example Problem: *Given a resistor with a resistance of 10 Ω and a voltage of 5 V across it, calculate the current flowing through the resistor.*

Solution: [I = \frac{V}{R} = \frac{5, \text{V}}{10, \Omega} = 0.5, \text{A}]

1.2 Electric Voltage, Current, Power, and Energy

Voltage (V):

- The potential difference between two points.
- Unit: Volt (V)

Current (I):

- The rate of flow of electric charge.
- Unit: Ampere (A)

Power (P):

- The rate at which electrical energy is transferred by an electric circuit.
- **Formula:** [P = V \times I]
- Unit: Watt (W)

Energy (E):

- The capacity to do work.
- **Formula:** [E = P \times t]
- Unit: Joule (J) or Watt-hour (Wh)

1.3 Conducting and Insulating Materials

Conductors:

- Materials that allow easy flow of electric current.

- **Examples:** Copper, Aluminum, Silver

Insulators:

- Materials that resist the flow of electric current.
- **Examples:** Rubber, Glass, Plastic

1.4 Series and Parallel Electric Circuits

Series Circuits:

- Components connected end-to-end.
- **Total Resistance (R_total):** $R_{\text{total}} = R_1 + R_2 + R_3 + \dots$
- **Current (I):** Same through all components.

Parallel Circuits:

- Components connected across the same two points.
- **Total Resistance (R_total):** $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- **Voltage (V):** Same across all components.

1.5 Star-Delta and Delta-Star Conversion

Star (Y) to Delta (Δ) Conversion:

- **Formulae:** $R_{AB} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$ $R_{BC} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}$ $R_{CA} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$

Delta (Δ) to Star (Y) Conversion:

- **Formulae:** $R_1 = \frac{R_{AB} R_{CA}}{R_{AB} + R_{BC} + R_{CA}}$ $R_2 = \frac{R_{AB} R_{BC}}{R_{AB} + R_{BC} + R_{CA}}$ $R_3 = \frac{R_{BC} R_{CA}}{R_{AB} + R_{BC} + R_{CA}}$

1.6 Kirchhoff's Laws

Kirchhoff's Current Law (KCL):

- The algebraic sum of currents entering a node is zero.
- **Formula:** $\sum I_{\text{entering}} = \sum I_{\text{leaving}}$

Kirchhoff's Voltage Law (KVL):

- The algebraic sum of all voltages around any closed loop in a circuit is zero.
- **Formula:** $\sum V = 0$

1.7 Types of Circuits

Linear vs. Non-Linear Circuits:

- **Linear Circuits:** Parameters (resistance, inductance, capacitance) are constant with respect to voltage and current.
- **Non-Linear Circuits:** Parameters change with voltage and current.

Bilateral vs. Unilateral Circuits:

- **Bilateral Circuits:** Circuit properties are the same in either direction.
- **Unilateral Circuits:** Circuit properties change with the direction of current.

Active vs. Passive Circuits:

- **Active Circuits:** Contain active components (can supply energy), e.g., transistors.
- **Passive Circuits:** Contain passive components (cannot supply energy), e.g., resistors, capacitors.

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2. Network Theorems

2.1 Superposition Theorem

Statement: In a linear circuit with multiple independent sources, the response (voltage or current) in any element is the algebraic sum of the responses caused by each independent source acting alone.

Procedure:

1. Select one independent source; replace all other independent voltage sources with short circuits and current sources with open circuits.
2. Calculate the response due to the selected source.
3. Repeat steps 1 and 2 for each independent source.
4. Sum all individual responses.

2.2 Thevenin's Theorem

Statement: Any linear bilateral circuit can be replaced by an equivalent circuit consisting of a single voltage source (V_TH) in series with a resistance (R_TH).

Procedure:

1. Remove the load resistor from the original circuit.
2. Calculate the open-circuit voltage across the load terminals (V_TH).
3. Calculate the equivalent resistance seen from the load terminals with all independent sources turned off (R_TH).
4. Draw the Thevenin equivalent circuit.

2.3 Norton's Theorem

Statement: Any linear bilateral circuit can be replaced by an equivalent circuit consisting of a single current source (I_N) in parallel with a resistance (R_N).

Procedure:

1. Remove the load resistor.
2. Calculate the short-circuit current across the load terminals (I_N).
3. Calculate the equivalent resistance (R_N) same as R_{TH} in Thevenin's theorem.
4. Draw the Norton equivalent circuit.

2.4 Maximum Power Transfer Theorem

Statement: Maximum power is transferred to the load when the load resistance (R_L) equals the Thevenin resistance (R_{TH}) of the source network.

Formula: $R_L = R_{TH}$

Maximum Power: $P_{\text{max}} = \frac{V_{TH}^2}{4 R_{TH}}$

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3. R-L, R-C, and R-L-C Circuits

3.1 Resonance in AC Circuits

Series Resonance:

- Occurs in R-L-C series circuits when the inductive reactance equals the capacitive reactance.
- **Resonant Frequency (f_r):** $f_r = \frac{1}{2\pi\sqrt{LC}}$

Parallel Resonance:

- Occurs in R-L-C parallel circuits under similar conditions.

3.2 Active and Reactive Power

Active Power (P):

- The real power consumed by resistive components.
- **Formula:** $P = V_{\text{rms}} I_{\text{rms}} \cos\phi$
- Unit: Watt (W)

Reactive Power (Q):

- The power stored and released by inductive and capacitive components.
- **Formula:** $Q = V_{\text{rms}} I_{\text{rms}} \sin\phi$
- Unit: Volt-Ampere Reactive (VAR)

Apparent Power (S):

- Combination of active and reactive power.
- **Formula:** $S = V_{\text{rms}} I_{\text{rms}}$
- Unit: Volt-Ampere (VA)

Power Factor (PF):

- The ratio of active power to apparent power.

- **Formula:** $\text{PF} = \cos\phi = \frac{P}{S}$

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4. Alternating Current Fundamentals

4.1 Generation of AC Voltages and Currents

Principle:

- AC voltages are generated by rotating a coil within a magnetic field, inducing an electromotive force (EMF).

4.2 AC Waveforms and Equations

Sinusoidal Waveform:

- **Voltage Equation:** $v(t) = V_{\text{max}} \sin(\omega t + \phi)$
- **Current Equation:** $i(t) = I_{\text{max}} \sin(\omega t + \phi)$ Where:
- V_{max} = Peak voltage
- I_{max} = Peak current
- ω = Angular frequency ($\omega = 2\pi f$)
- ϕ = Phase angle
- f = Frequency in Hz

4.3 Average, Peak, and RMS Values

Peak Value (V_{max} or I_{max}):

- Maximum value of voltage or current.

Root Mean Square (RMS) Value:

- Effective value of AC voltage or current.
- **Formula:** $V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}}$ $I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}}$

Average Value:

- Average over half a cycle.
- **Formula:** $V_{\text{avg}} = \frac{2 V_{\text{max}}}{\pi}$ $I_{\text{avg}} = \frac{2 I_{\text{max}}}{\pi}$

4.4 Three-Phase Systems

Characteristics:

- Consists of three sinusoidal voltages of equal magnitude and frequency but displaced by 120 degrees.

Advantages:

- Constant power delivery.
- More efficient than single-phase systems.

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5. Semiconductor Devices

5.1 Semiconductor Diodes

Characteristics:

- Allows current flow in one direction.
- **Forward Bias:** Conducts current.
- **Reverse Bias:** Blocks current.

I-V Characteristics:

- Exponential relationship in forward bias.

5.2 BJT Configurations and Biasing

Configurations:

- **Common Emitter (CE):** Amplifies voltage and current.
- **Common Base (CB):** High voltage gain.
- **Common Collector (CC):** Voltage follower.

Biasing:

- **Purpose:** To set the transistor's operating point.
- **Methods:**
  - Fixed Bias
  - Voltage Divider Bias
  - Emitter Bias

5.3 MOSFET and CMOS Principles

MOSFET:

- Voltage-controlled device.
- **Types:** Enhancement and Depletion mode.

CMOS:

- Complementary MOSFET (combines n-MOS and p-MOS).
- **Advantages:** Low power consumption.

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6. Signal Generators

6.1 Principles of Oscillators

Oscillator:

- Generates periodic waveforms without external input.

Requirements:

- **Amplifier with Gain (A)**
- **Feedback Network (β)**
- **Barkhausen Criterion:** [A \beta = 1] [\text{Total phase shift} = 0^\circ \text{ or } 360^\circ]

6.2 RC, LC, and Crystal Oscillator Circuits

RC Oscillators:

- Use resistors and capacitors.
- **Example:** Phase Shift Oscillator.

LC Oscillators:

- Use inductors and capacitors.
- **Example:** Hartley and Colpitts Oscillators.

Crystal Oscillators:

- Use quartz crystals for stable frequency.

6.3 Waveform Generators

Types:

- **Sine Wave Generators**
- **Square Wave Generators**
- **Triangle Wave Generators**

Applications:

- Testing and calibration of electronic circuits.

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7. Amplifiers

7.1 Classification of Output Stages

Classes:

- **Class A:** Conduction angle = 360°
- **Class B:** Conduction angle = 180°
- **Class AB:** Conduction angle between 180° and 360°
- **Class C:** Conduction angle < 180°

7.2 Class A, B, and AB Output Stages

Class A Amplifiers:

- Operate over the entire input cycle.
- **Advantages:** Low distortion.
- **Disadvantages:** Low efficiency (~30%).

Class B Amplifiers:

- Operate over half the input cycle.
- **Advantages:** Higher efficiency (~78.5%).
- **Disadvantages:** Crossover distortion.

Class AB Amplifiers:

- Operate over more than half but less than full cycle.
- **Advantages:** Compromise between Class A and B.

7.3 Biasing Techniques

Class AB Biasing:

- Eliminates crossover distortion.
- **Methods:**
  - Diode Biasing
  - VBE Multiplier

7.4 Power BJTs and Transformer-Coupled Push-Pull Stages

Power BJTs:

- Designed to handle high currents and voltages.

Transformer-Coupled Push-Pull Amplifiers:

- Use transformers to combine outputs.
- **Advantages:** Efficient power transfer.

7.5 Tuned Amplifiers and Op-Amps

Tuned Amplifiers:

- Amplify a specific frequency or band.
- **Applications:** Radio frequency amplification.

Operational Amplifiers (Op-Amps):

- High-gain voltage amplifiers.
- **Characteristics:**
  - High input impedance.
  - Low output impedance.
- **Configurations:**

- Inverting
- Non-inverting
- Differential

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8. Practice Questions and Solutions

Question 1

Problem: Calculate the total resistance in a series circuit with three resistors of values 5 Ω, 10 Ω, and 15 Ω.

Solution: $$ R_{\text{total}} = R_1 + R_2 + R_3 = 5, \Omega + 10, \Omega + 15, \Omega = 30, \Omega $$

Question 2

Problem: Using Thevenin's theorem, find the equivalent circuit across terminals A and B for the following circuit: A voltage source of 20 V in series with a resistor of 4 Ω is connected to terminals A and B, which are connected across a load resistor of 6 Ω.

Solution:

1. **Remove the Load Resistor (6 Ω).**
2. **Find V_TH (Open-Circuit Voltage):**
   - Since there's only one voltage source and one resistor, $V_{TH} = 20, \text{V}$.
3. **Find R_TH (Thevenin Resistance):**
   - With voltage source shorted, $R_{TH} = 4, \Omega$.
4. **Thevenin Equivalent Circuit:**
   - Voltage source of 20 V in series with a 4 Ω resistor across terminals A and B.

Question 3

Problem: Determine the resonant frequency of an R-L-C series circuit with L = 50 mH and C = 0.1 μF.

Solution: $$ f_r = \frac{1}{2\pi\sqrt{LC}} $$ $$ f_r = \frac{1}{2\pi\sqrt{50 \times 10^{-3}, \text{H} \times 0.1 \times 10^{-6}, \text{F}}} $$ $$ f_r = \frac{1}{2\pi\sqrt{5 \times 10^{-9}}} $$ $$ f_r = \frac{1}{2\pi \times 7.07 \times 10^{-5}} $$ $$ f_r \approx \frac{1}{0.000444} $$ $$ f_r \approx 2257, \text{Hz} $$

Question 4

Problem: A pure resistive AC circuit has an RMS voltage of 230 V and consumes 10 A of current. Calculate the active power consumed.

Solution: $$ P = V_{\text{rms}} I_{\text{rms}} \cos\phi $$ For a pure resistive circuit, $\cos\phi = 1$. $$ P = 230, \text{V} \times 10, \text{A} \times 1 = 2300, \text{W} $$

Question 5

Problem: In a common-emitter BJT amplifier, if the base current is 20 µA and the current gain (β) is 100, find the collector current.

Solution: $$I_C = \beta I_B$$ $$I_C = 100 \times 20 \times 10^{-6}, \text{A} = 2, \text{mA}$$

Question 6

Problem: An op-amp is configured in an inverting amplifier setup with a feedback resistor $R_f = 100, \text{k}\Omega$ and an input resistor $R_{in} = 10, \text{k}\Omega$. Calculate the voltage gain.

Solution: $$A_v = -\frac{R_f}{R_{in}}$$ $$A_v = -\frac{100, \text{k}\Omega}{10, \text{k}\Omega} = -10$$

Question 7

Problem: A Class B push-pull amplifier has a supply voltage of $V_{CC} = 15, \text{V}$. Determine the maximum output power.

Solution: For Class B amplifier: $$P_{\text{max}} = \frac{V_{CC}^2}{2 R_L}$$ Assuming $R_L = 8, \Omega$, $$P_{\text{max}} = \frac{15^2}{2 \times 8} = \frac{225}{16} \approx 14.06, \text{W}$$
