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Practice the sample paper covered both important questions and exam patterns

Subject: Advanced Electrical Power System (EEE301)   **Full Marks: 70**   **Time: 3 Hours**

Instructions:

- Question No. 1 is compulsory. (7 MCQs, 2 Marks each)
- Answer any FOUR questions from the remaining (Q.2 to Q.7).
- Q.2 to Q.6 carry 14 marks each (Divided into A and B, 7 Marks each).
- Q.7 consists of Short Notes (Answer any FOUR, 3.5 Marks each).

Q.1 Choose the correct option (Compulsory - 7 x 2 = 14 Marks)

i) The base impedance (Z_{base}) of a 3-phase system can be calculated using the formula:

    a. $(kV_{base})^2 / MVA_{base}$

    b. kV_{base} / MVA_{base}

    c. $MVA_{base} / (kV_{base})^2$

    d. $(kV_{base}) / (MVA_{base})^2$

ii) The rate of convergence of the Newton-Raphson method in load flow analysis is:

    a. Linear

    b. Quadratic

    c. Cubic

    d. Exponential

iii) Zero sequence currents can flow in a power system ONLY if:

    a. The system is delta connected

    b. The neutral of a star connection is solidly grounded

    c. There is a 3-phase symmetrical fault

    d. The system operates under normal balanced conditions

iv) In the Swing Equation of a generator, the term 'M' represents:

    a. Mechanical power input

    b. Angular momentum (Inertia constant)

    c. Mass of the rotor

    d. Magnetic flux density

v) At a Load Bus (PQ Bus), which parameters are considered as unknown variables?

    a. Active Power (P) and Reactive Power (Q)

    b. Voltage Magnitude ($|V|$) and Phase Angle (δ)

    c. Active Power (P) and Voltage Magnitude ($|V|$)

    d. Reactive Power (Q) and Phase Angle (δ)

vi) A key characteristic that distinguishes a Smart Grid from a traditional grid is:

    a. Use of electromechanical meters

    b. One-way power flow only

    c. Two-way digital communication and power flow

    d. Lack of distributed generation

vii) A Single Line-to-Ground (LG) fault is classified as a/an:

    a. Symmetric fault

    b. Asymmetric fault

    c. Transient fault

    d. Open circuit fault

Answer any FOUR questions from Q.2 to Q.7

Q.2 A) Derive the expression for Base Impedance (Z_{base}) in a 3-phase power system. How is the Per-Unit (PU) impedance calculated from actual impedance? *(7 Marks)*

Q.2 B) Compare Symmetric and Asymmetric Faults. Why is the method of Sequence Components essential for analyzing asymmetric faults? *(7 Marks)*

Q.3 A) Explain the Newton-Raphson method for Load Flow analysis. Why is it preferred over the Gauss-Seidel method for large interconnected power systems? *(7 Marks)*

Q.3 B) Define Steady-State Stability Limit and Transient Stability Limit. Which limit is generally lower and why? *(7 Marks)*

Q.4 A) Discuss the concept of a Micro-grid. Explain its operation in Grid-connected (Non-autonomous) mode and Islanded (Autonomous) mode. *(7 Marks)*

Q.4 B) Derive the Swing Equation of a synchronous machine. State the significance of the power angle (δ). *(7 Marks)*

Q.5 A) Explain the significance of the Slack Bus (Swing Bus) in Load Flow studies. What parameters are known and unknown at this bus? *(7 Marks)*

Q.5 B) State the adverse effects of power system instability on generating stations and the overall grid network. *(7 Marks)*

Q.6 A) Explain the role and integration of Distributed Energy Resources (DERs) in a modern Smart Grid environment. *(7 Marks)*

Q.6 B) Derive the expression for Maximum Power Flow (P_{max}) under steady-state conditions for a lossless transmission line. *(7 Marks)*

Q.7 Write short notes on any FOUR of the following (4 x 3.5 = 14 Marks)

    A. Advantages of Per-Unit System

    B. Smart Grid Architecture

    C. Positive, Negative, and Zero Sequence Networks

    D. Dynamic State Stability

    E. Classification of buses in Load Flow

MCQ Answer Key

i) a,   **ii)** b,   **iii)** b,   **iv)** b,   **v)** b,   **vi)** c,   **vii)** b

Model Answers for Long Questions

Q.2 A) Base Impedance and Per-Unit System:

Derivation for 3-Phase System:

Let the 3-phase base power be $S_{base(3\Phi)}$ (in MVA) and the line-to-line base voltage be $V_{base(LL)}$ (in kV).

Base Current, $I_{base} = S_{base(3\Phi)} / (\sqrt{3} \times V_{base(LL)})$

Base Impedance, $Z_{base} = V_{base(Phase)} / I_{base}$

Since $V_{base(Phase)} = V_{base(LL)} / \sqrt{3}$, substituting the values:

$Z_{base} = (V_{base(LL)} / \sqrt{3}) / [\ S_{base(3\Phi)} / (\sqrt{3} \times V_{base(LL)})\ ]$

$$Z_{base} = (V_{base(LL)})^2 / S_{base(3\Phi)}$$

(i.e., Z_{base} in Ohms $= (kV_{base})^2 / MVA_{base}$).

Calculating PU Impedance:

$Z_{pu} = Z_{actual}$ (in Ohms) $/ Z_{base}$ (in Ohms).

Q.2 B) Symmetric vs Asymmetric Faults & Sequence Components:

Symmetric Faults: Involve all three phases simultaneously (e.g., LLL or LLLG). The system remains electrically balanced. They are the most severe but least frequent.

Asymmetric Faults: Involve one or two phases (e.g., LG, LL, LLG). They cause unbalanced currents and voltages in the system. LG is the most common fault.

Need for Sequence Components: Traditional circuit analysis is incredibly complex for unbalanced 3-phase systems due to mutual coupling between phases. Fortescue's method of Symmetrical Components resolves the unbalanced asymmetric fault into three decoupled, balanced sequence networks (Positive, Negative, Zero). These independent networks can be solved easily using standard single-phase analysis, and their results are superimposed to find the actual fault currents.

Q.3 A) Newton-Raphson Method for Load Flow:

Explanation: The NR method uses Taylor series expansion to solve the non-linear active and reactive power flow equations. It involves creating a Jacobian Matrix that maps the small changes in real (ΔP) and reactive power (ΔQ) to the small changes in voltage phase angles ($\Delta \delta$) and magnitudes ($\Delta |V|$). The bus voltages are updated iteratively until the power mismatch falls below a specified tolerance.

Why it is preferred over Gauss-Seidel:

1. *Convergence:* NR has a quadratic rate of convergence, meaning it reaches the solution much faster (usually 3 to 5 iterations) compared to the slow linear convergence of Gauss-Seidel.

2. *System Size Independence:* The number of iterations in NR is largely independent of the number of buses, making it highly efficient for massive, interconnected grids.

Q.3 B) Steady-State vs Transient Stability Limits:

Steady-State Stability Limit: The maximum active power that can be transmitted through the system without losing synchronism when subjected to very slow, gradual, and small disturbances (like slow load increments).

Transient Stability Limit: The maximum active power that can be transmitted without losing synchronism when subjected to a sudden, severe disturbance (like a major short circuit, sudden loss of a generator, or line tripping).

Which is lower? The Transient Stability Limit is ALWAYS lower than the Steady-State Stability Limit. This is because sudden, severe shocks impart massive kinetic energy to the rotors, causing large power angle (δ) swings. The system must have a sufficient safety margin (operating well below the steady-state maximum) to absorb this shock without exceeding the critical clearing angle.

Q.4 A) Micro-grid and its Modes of Operation:

Micro-grid Concept: It is a localized, small-scale power grid consisting of Distributed Energy Resources (DERs) like solar, wind, micro-turbines, and energy storage, along with local loads. It can operate in conjunction with the main grid or independently.

Grid-connected (Non-autonomous) Mode: The micro-grid is physically connected to the main utility grid. The main grid dictates the reference voltage and frequency. The micro-grid's generators operate in PQ mode, injecting a specific amount of active and reactive power, while importing/exporting any deficit/surplus to the main grid.

Islanded (Autonomous) Mode: In case of a main grid blackout, the micro-grid disconnects (islands itself) via a static switch. It must now autonomously regulate its own voltage and frequency. The local generators switch to V/f control mode and use droop control to share the local load among themselves.

Q.4 B) Swing Equation Derivation:

Let θ_m be the mechanical angle of the rotor, ω_m the synchronous speed, and J the moment of inertia. Mechanical Torque (T_m) drives the rotor, Electrical Torque (T_e) acts as a brake.

$J (d^2\theta_m / dt^2) = T_m - T_e$

Multiply both sides by ω_m:

$\omega_m J (d^2\theta_m / dt^2) = P_m - P_e$ (Since $P = T \times \omega$)

The rotor angle θ_m can be expressed as $\omega_m t + \delta$, where δ is the power angle (the deviation from synchronous reference).

Thus, $d^2\theta_m / dt^2 = d^2\delta / dt^2$.

Let $M = \omega_m J$ (Angular Momentum).

$$M (d^2\delta / dt^2) = P_m - P_e$$

Significance of δ: The power angle δ dictates the stability and the exact amount of electrical power transferred over the lines. A rapidly increasing δ indicates impending loss of synchronism.

Q.5 A) Significance of the Slack (Swing) Bus:

In load flow studies, the active power losses (I^2R) in the transmission lines are unknown until the currents (and thus voltages and phase angles) are fully calculated. Because total generation must equal total load plus total losses, we cannot pre-specify the active power generation for all buses.

Therefore, one generator bus is designated as the **Slack or Swing Bus**. It acts as an infinite bus that absorbs all the system losses and balances the active and reactive power mismatch in the network.

Parameters:

- **Known:** Voltage magnitude ($|V|$ usually 1.0 pu) and Phase Angle (δ usually 0°).
- **Unknown:** Active Power (P) and Reactive Power (Q).

Q.5 B) Adverse Effects of Power System Instability:

1. **Pole Slipping:** Generators lose synchronism and their rotors "slip" poles, causing violent fluctuations in power output.
2. **Mechanical Damage:** Rapid power swings cause severe torsional stress and twisting forces on turbine-generator shafts, potentially snapping them.
3. **Voltage Collapse:** Large reactive power imbalances lead to severe voltage dips across the grid, stalling industrial motors.
4. **Relay Tripping & Blackouts:** Overcurrent and distance relays detect the massive current swings as faults and trip transmission lines. This causes a cascading failure effect, eventually leading to a partial or total system blackout.

Q.6 A) Distributed Energy Resources (DERs) in Smart Grids:

Role & Integration: DERs include rooftop solar panels, wind turbines, micro-hydro, and battery energy storage systems (BESS) located close to the consumer load.

In a Smart Grid, DERs shift the paradigm from centralized generation to decentralized generation. Smart inverters and two-way communication allow the grid operator to monitor and control these DERs in real-time. They help in peak load shaving (reducing demand on main power plants during peak hours), provide localized voltage support, reduce transmission line losses, and significantly lower the carbon footprint of the grid.

Q.6 B) Maximum Power Flow (P_{max}) Derivation:

Consider a lossless transmission line of reactance X connecting a Sending end ($V_S \angle \delta$) and a Receiving end ($V_R \angle 0°$).

Current $I = (V_S \angle \delta - V_R \angle 0°) / jX$

Complex Power at receiving end $S_R = P + jQ = V_R \times I^*$

$S_R = V_R \times [(V_S \angle -\delta - V_R \angle 0°) / -jX]$

Resolving the real part (Active Power):

$$P = (|V_S| \times |V_R| / X) \times \sin(\delta)$$

For maximum steady-state power transfer, the power angle δ must be 90° (since $\sin(90°) = 1$).

Therefore, $\mathbf{P_{max} = (|V_S| \times |V_R|) / X}$.

Short Answer Solutions (Q.7)

A) Advantages of Per-Unit System: Normalizes equipment parameters of different ratings, eliminates ideal transformers from impedance diagrams, simplifies hand and computer calculations, and makes spotting data errors easier as PU values lie in a narrow expected range.

B) Smart Grid Architecture: Comprises intelligent generation (DERs), smart transmission (PMUs and FACTS devices), automated distribution, and Advanced Metering Infrastructure (AMI) at the consumer end, all tied together by robust, secure two-way IT communication networks.

C) Positive, Negative, and Zero Sequence Networks:
- Positive: Models normal balanced operation; contains voltage sources.
- Negative: Models reverse phase sequence components; contains NO voltage sources.
- Zero: Models in-phase components; depends heavily on transformer and generator grounding connections.

D) Dynamic State Stability: Refers to the power system's ability to survive continuous, small disturbances (like varying loads) over a long period (seconds to minutes) with the help of automatic control systems like AVRs and governors, which prevent growing oscillations.

E) Classification of buses in Load Flow:
1. PQ (Load) Bus: P, Q known; |V|, δ unknown.
2. PV (Generator) Bus: P, |V| known; Q, δ unknown.
3. Slack (Swing) Bus: |V|, δ known; P, Q unknown.