PROBLEM SET MINGGU 10

Kontrol Tegangan dan Daya Reaktif

Mata Kuliah: Dasar-Dasar Sistem Tenaga Listrik
Program: Teknik Elektro, Fakultas Teknik
Institution: Universitas Bengkulu

Instructions

This problem set contains questions at various cognitive levels (C1-C6) based on Bloom's Taxonomy. Answer all questions to demonstrate your understanding of voltage control and reactive power management concepts and applications.

- **C1 (Remember):** Recall facts and basic concepts
- **C2 (Understand):** Explain ideas or concepts
- **C3 (Apply):** Use information in new situations
- **C4 (Analyze):** Draw connections and distinguish between parts
- **C5 (Evaluate):** Justify decisions or conclusions
- **C6 (Create):** Produce new or original work

1 C1: Remember (Knowledge)

Question 1

List the main methods of voltage control in power systems. For each method, specify whether it provides continuous or discrete control and its typical response time.

Question 2

What is the acceptable voltage range for transmission and distribution systems according to standard practice? State your answer in both percentage and per unit terms.

Question 3

Write the equation that relates voltage drop to active and reactive power flow in a transmission line. Identify each term.

2 C2: Understand (Comprehension)

Question 4

Explain why reactive power has a stronger influence on voltage magnitude than active power in transmission systems. Use the relationship $\Delta V \approx \frac{PR+QX}{V}$ to support your explanation.

Question 5

Describe how an On-Load Tap Changer (OLTC) controls voltage. Why is a time delay and deadband incorporated in OLTC control logic?

Question 6

Explain the difference between a Static VAR Compensator (SVC) and a STATCOM. What makes STATCOM superior in certain applications?

3 C3: Apply (Application)

Question 7

A 132 kV transmission line with impedance $(2 + j20)$ ohms supplies a load of 80 MW at 0.8 power factor lagging. Calculate:

a) The reactive power of the load

b) The voltage drop across the line

c) The sending end voltage

d) The size of shunt capacitor required to improve the power factor to 0.95 lagging

Question 8

A transformer with an OLTC has the following specifications:

- Nominal ratio: 132/33 kV
- Tap range: $\pm 10\%$ in 17 steps (including nominal)
- Primary voltage: 128 kV (measured)
- Desired secondary voltage: 33 kV

Calculate the tap position required and the actual secondary voltage achieved.

Question 9

A 20 kV radial distribution feeder serves a uniformly distributed load of 8 MW with power factor 0.75 lagging along 12 km. The line impedance is $(0.3 + j0.5)$ Ω/km.

a) Calculate the voltage at the end of the feeder without compensation

b) Determine the optimal location and size of a capacitor bank to maintain voltage within 5% of nominal

c) Calculate the reduction in line losses after compensation

4 C4: Analyze (Analysis)

Question 10

Analyze the voltage control challenges in a distribution system with high penetration of rooftop solar PV installations. Consider:

- Bidirectional power flow effects
- Daily voltage variation patterns
- Impact on OLTC operation
- Coordination with conventional voltage control devices

Question 11

Compare and contrast the following reactive power compensation devices for a 230 kV transmission system:

- Fixed shunt capacitor banks
- Mechanically switched capacitor banks
- SVC (Static VAR Compensator)
- STATCOM

Analyze them in terms of:

- Cost
- Response time
- Operational flexibility
- Maintenance requirements
- Harmonic performance

5 C5: Evaluate (Evaluation)

Question 12

A distribution utility is facing voltage problems in rural areas with long feeders. Three solutions are proposed:

- Option A: Install line voltage regulators at mid-feeder points
- Option B: Install additional OLTCs at distribution substations with upgraded controls
- Option C: Deploy distributed capacitor banks with automated switching

Evaluate each option considering:

- Technical effectiveness
- Capital and operational costs
- Reliability and maintenance
- Scalability for future load growth
- Compatibility with distributed generation integration

Justify which solution or combination you would recommend.

Question 13

The grid operator in Bengkulu is planning to integrate PLTP Hululais (geothermal) with significant reactive power capability and multiple small PLTMH (micro-hydro) units with inverter interfaces. Evaluate the voltage control strategy that should be implemented, considering:

- Generator voltage control coordination

- Use of geothermal plant reactive power capability
- Inverter control modes for PLTMH
- Dynamic voltage support requirements
- System stability implications

Provide a justified recommendation for the coordinated voltage control architecture.

6 C6: Create (Synthesis/Creation)

Question 14

Design a comprehensive voltage and reactive power control scheme for a distribution system with the following characteristics:

- 5 feeders ranging from 8-15 km in length
- Mix of urban and rural loads (total 50 MW)
- 10 MW of distributed solar PV (scattered across feeders)
- 2 MW of PLTMH installations
- One 150/20 kV substation with OLTC

Your design should include:

1. Hierarchical control structure (primary, secondary, tertiary)
2. Selection and placement of voltage control devices
3. Coordination strategy between devices
4. Setpoints and operating ranges
5. Communication and monitoring requirements
6. Protection coordination considerations

Present your design with justification for each decision.

Question 15

Develop a detailed algorithm for optimal capacitor placement in a radial distribution system to minimize losses while maintaining voltage constraints. Your algorithm should:

- Define the objective function
- Specify constraints
- Describe the solution methodology
- Include implementation steps
- Provide pseudocode or flowchart

Additionally, create a MATLAB/Octave implementation outline for your algorithm.

7 Advanced Applications

Question 16: Sensitivity Analysis

Derive the voltage sensitivity with respect to reactive power ($\partial V/\partial Q$) from the power flow equations. Explain how this sensitivity can be used to:

a) Identify weak voltage buses

b) Determine optimal locations for reactive compensation

c) Assess voltage stability margins

Question 17: FACTS Applications

A 500 kV transmission corridor experiences voltage fluctuations due to heavy loading variations. Analyze the suitability of different FACTS devices (SVC, STATCOM, TCSC, SSSC) for this application. Recommend the most appropriate solution with technical justification.

8 Computational Exercise

Question 18: MATPOWER Analysis

Using MATPOWER, perform a comprehensive voltage control study on the IEEE 14-bus system:

a) Run base case power flow and identify voltage violations (buses outside 0.95-1.05 pu)

b) Implement reactive power compensation at appropriate buses

c) Adjust generator voltage setpoints

d) Modify OLTC tap settings

e) Compare system losses before and after optimization

Document your methodology, MATLAB code, and results with plots of voltage profiles.

```
% MATPOWER Voltage Control Analysis
% Load the case file
mpc = loadcase('case14');

% Run base case
results_base = runpf(mpc);

% Identify voltage violations
bus_voltages = results_base.bus(:, 8);  % VM column

% Add your optimization implementation here
% ...

% Run optimized case
results_opt = runpf(mpc_optimized);

% Plot voltage profiles
% ...

% Calculate loss reduction
% ...
```

Question 19: Optimal Power Flow

Extend the previous exercise to solve an Optimal Power Flow (OPF) problem using MATPOWER's `runopf` function. The objective is to minimize generation cost while:

- Maintaining voltages within $\pm 5\%$
- Respecting generator reactive power limits
- Minimizing transmission losses

Compare the OPF solution with manual voltage control adjustments. Analyze the trade-offs.

9 Case Studies

Question 20: Bengkulu Distribution Network

A rural distribution feeder in Bengkulu has the following characteristics:

- Length: 25 km, impedance: $0.4 + j0.6\ \Omega/\text{km}$
- Load: 3 MW at 0.7 pf lagging (at feeder end)
- Two PLTMH units (500 kW each) at 10 km and 18 km from substation
- Substation voltage: 20 kV with OLTC (±10%, 17 steps)

Analyze the voltage profile under different operating scenarios:

a) Maximum load, no PLTMH generation

b) Maximum load, maximum PLTMH generation

c) Minimum load, maximum PLTMH generation (potential overvoltage)

Propose a coordinated control strategy using:

- OLTC settings
- PLTMH inverter reactive power control
- Strategic capacitor placement

Question 21: Smart Grid Voltage Control

Design a smart voltage control system for a distribution network with:

- Real-time monitoring (smart meters, sensors)
- Advanced communication infrastructure

- Controllable distributed energy resources (DER)
- Dynamic load management capability

Your design should address:

1. System architecture and data flow
2. Control algorithms and decision-making logic
3. Integration with existing SCADA systems
4. Cybersecurity considerations
5. Performance metrics and validation methods

10 Bonus Challenge

Bonus Question 1: Voltage Stability Assessment

Develop a methodology for assessing voltage stability margins in a power system using PV curves. Create a MATLAB function that:

- Generates PV curves for specified buses
- Identifies the critical point (nose of the curve)
- Calculates loading margin
- Visualizes results

Include the code implementation and example results.

Bonus Question 2: Coordinated Voltage Control Optimization

Formulate and solve a multi-objective optimization problem for voltage control that simultaneously:

1. Minimizes active power losses
2. Minimizes reactive power generation costs
3. Maximizes voltage stability margin
4. Minimizes number of control actions (tap changes, capacitor switching)

Use appropriate weights or constraints to handle the multiple objectives. Implement your solution using MATPOWER or another suitable tool.

11 Research and Development

Question 22: Future Voltage Control Technologies

Research and report on emerging voltage control technologies and strategies:

- Grid-forming inverters for voltage support
- Coordinated control using machine learning
- Blockchain-based distributed voltage control
- Vehicle-to-Grid (V2G) voltage support services

For each technology:

a) Explain the working principle

b) Analyze potential benefits and challenges

c) Assess readiness for deployment in Indonesia

d) Propose pilot implementation scenarios for Bengkulu

Question 23: Regulatory and Economic Aspects

Analyze the regulatory framework for voltage control and reactive power management in Indonesia:

- Current PLN standards and grid codes
- Reactive power pricing mechanisms
- Requirements for DER interconnection
- Voltage quality standards

Propose improvements to the regulatory framework to facilitate:

- Better voltage control with high renewable penetration
- Fair compensation for reactive power services
- Incentives for voltage support from DER

End of Problem Set

Good luck with voltage control optimization!

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