9.5 Power networks and the per-unit system

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS per-unit

Objective

Normalise impedances on a chosen base, move them between bases and voltage levels, and read one per-unit answer back in amperes at any level.

1 Key knowledge and worked examples

■ **The base quantities**

$Z_{base} = V_{base}^2/S_{base}$, $I_{base} = S_{base}/(\sqrt{3}V_{base})$ (three-phase). Impedances are $Z_{pu} = Z_{actual}/Z_{base}$; ratings in % are just 100 × pu. Changing the MVA base scales pu impedances by S_{new}/S_{old}.

■ **Worked example: one number, two levels**

100 MVA base, 11/132 kV transformer Z = 8%, line 40 Ω: $Z_{base}(132) = 132^2/100 = 174.2\Omega \rightarrow$ line `40/174.24 = 0.230 pu`; total `0.310 pu` → fault `3.23 pu` – readable as 1410 A at 132 kV OR 16 900 A at 11 kV with each level's own base current.

■ **Worked example: bases must match**

An 8% impedance on 50 MVA is $0.08 \times 100/50 = 0.16pu$ on a 100 MVA base – never add pu values computed on different bases.

2 Practice

2.1 A 13.8 kV, 50 MVA base: compute Z_{base} and express an 8 Ω reactor in pu. [3]

2.2 Compute the base current of a 132 kV, 100 MVA system. [3]

2.3 A transformer is 8% on a 50 MVA base. Express it in pu on a 100 MVA base. [3]

3 Exam-style questions

3.1 A 60 MVA base is chosen for a system: a generator (11 kV, $X = 0.15pu$), a 11/132 kV transformer (8% on 60 MVA) and a 132 kV line of 50 Ω feeding a three-phase fault at its far end. Pre-fault voltage 1.0 pu, load neglected.

Convert the line to pu on the 60 MVA base. Compute the total pu reactance to the fault and the pu fault current. Convert the fault current to amperes at BOTH 132 kV and 11 kV, and verify the two readings agree in pu. [8]

3.2 A 33 kV, 20 MVA transformer has an impedance of 5% on its own rating.

Compute its impedance in ohms per phase. Re-express it in pu on a 100 MVA, 33 kV base, and convert that pu value back to ohms to prove the two routes agree. Explain why pu values, not ohms, are printed on nameplates. [7]

Solutions

2.1

- $Z_{base} = 13.8^2/50 = 3.809\Omega$.
- $Z_{pu} = 8/3.809 = 2.10pu$.

2.2

- $I_{base} = 100 \times 10^6/(\sqrt{3} \times 132 \times 10^3) = 437.4A$.

2.3

- $0.08 \times 100/50 = 0.16pu$.

3.1

- $Z_{base}(132) = 132^2/60 = 290.4\Omega \rightarrow$ line `50/290.4 = 0.172 pu`.
- Total `0.15 + 0.08 + 0.172 = 0.402 pu`.
- $I_{pu} = 1/0.402 = 2.49pu$.
- At 132 kV: $I_{base} = 60 \times 10^6/(\sqrt{3} \times 132 \times 10^3) = 262.4A \rightarrow 2.49 \times 262.4 = 653A$.
- At 11 kV: $I_{base} = 60 \times 10^6/(\sqrt{3} \times 11 \times 10^3) = 3149A \rightarrow 2.49 \times 3149 = 7830A$.
- Agreement: both are the SAME 2.49 pu – the per-unit system routes the transformer's turns-ratio current scaling into the base quantities, so one result serves every level.

3.2

- $Z_{base} = 33^2/20 = 54.45\Omega \rightarrow Z = 0.05 \times 54.45 = 2.7225\Omega$ per phase.
- On 100 MVA: $0.05 \times 100/20 = 0.25pu$.
- Back to ohms: $0.25 \times (33^2/100) = 0.25 \times 10.89 = 2.7225\Omega$ ✓ identical.
- Nameplates quote pu/% because the physical ohms depend on which side you measure (the ratio-squared rule) while the pu value is one number valid through the transformer for any study base.