EE4010
Electrical Power Systems

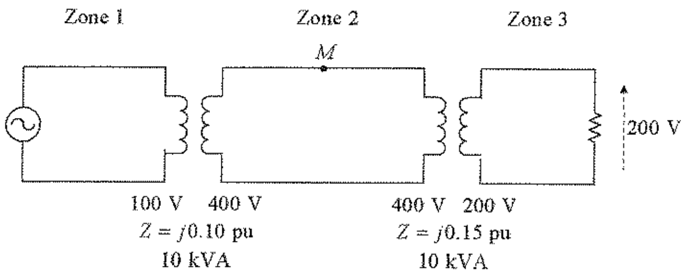
Problems on Transformers and the Per-Unit System

1. An 11 kV/132 kV, 50 MVA, 50 Hz, three-phase transformer bank has an inductive reactance of $j0.005\ \Omega$ per phase referred to the low voltage winding. Calculate the per-unit value of reactance of the transformer evaluated on both the low voltage and high voltage sides of the device.

   [$j0.0021$ pu , $j0.0021$ pu]

2. A three-phase, star-connected load is supplied from a three-phase, 400 V source. Each branch of the load consists of a $20\ \Omega$ resistor. Using 400 V and 10 kVA, calculate the per-unit value of current and power drawn by the load. [0.8 pu, 0.8pu]

3. A single-phase power distribution network which is used to supply a 10 kVA resistive load consists of two single phase transformers in series as shown below.



   Using the per-unit system, calculate the voltage at point M in the network. [$404.5\angle 8.53°$ V]

4. Three single-phase, two-winding transformers, each rated at 25 MVA, 34.5 kV/13.8 kV, are connected to form a three-phase delta-delta bank. Balanced, positive sequence voltages are applied to the high voltage terminals and a balanced three-phase resistive load connected to the low voltage terminals absorbs 75 MW at 13.8 kV. If one of the transformers is removed and the load is reduced to 43.3 MW, calculate the MVA supplied by the two remaining transformers and determine if these devices are overloaded?

   [$(21.65 + j12.5)$ MVA , $(21.65 - j12.5)$ MVA]

5. Three single-phase, 50 Hz, two-winding transformers, each rated at 50 kVA, 2300 V/230 V, are connected to form a three-phase 4000 V/230 V transformer bank. The equivalent impedance of each transformer referred to the low voltage winding is $(0.012 + j0.016)\ \Omega$. The transformer bank supplies a three-phase, 120 kVA, 230 V, 0.85 power factor lagging load.

   (a) Draw a schematic diagram of the transformer connection.
   (b) Calculate the transformer winding currents
   (c) Calculate the primary voltage required to provide the load
   (d) Estimate the voltage regulation of the device.

   [$I_{LVphase} = 173.9$ A, $I_{HVphase} = 17.39$ A, $\overline{V}_{line} = 4039.8\angle 0.31°$ V, Regulation = 1.41%]

6. Two identical 10 MVA, 6.6 kV/33 kV, three-phase, star-star transformers are connected by a 33 kV underground cable. One transformer is located at a power station and the second at a remote substation. The series resistance of the cable per conductor is $7.17\ \Omega$ and the series inductive reactance is $2.0\ \Omega$. Each transformer has an equivalent series resistance of $0.04\ \Omega$ per phase and an equivalent leakage reactance of $0.4\ \Omega$ per phase, referred to the low voltage side. If 5 MW at 6.0 kV and 0.8 power factor lagging is delivered to a load on the low voltage busbars at the substation transformer, calculate the line voltage on the low voltage busbars at the power station.

   [6.875 kV]

7. A small power distribution system is fed by a generator which supplies power to a feeder line of impedance $(0.15 + j1.0)\ \Omega$ per phase. The line voltage of the generator is set at 4.16 kV. At its remote end, the feeder line supplies three single-phase, 50 Hz, 50 kVA, 2.4 kV/240 V transformers which are connected star/delta in a three-phase, 150 kVA bank to step down the voltage to that which is required by the load.

   On the secondary side, the transformer bank feeds a balanced three-phase load through a low voltage feeder line the impedance of which is $(0.0005 + j0.0020)\ \Omega$ per phase. Find the line voltage at the load when the load draws rated current from the transformers. The power factor of the load is 0.8 lagging, measured at the generator terminals. For each single-phase transformer, the short circuit test readings are 48 V, 20.8 A and 617 W when measured on the high voltage side. [233 V]

8. A three-phase transformer is connected in star on both the primary and secondary sides. The secondary is connected to a balanced three-phase load via a transmission line. Each transmission line conductor has a series impedance of $(4+j6)\ \Omega$ per phase. The load has an equivalent per-phase series impedance of $(400+j600)\ \Omega$. The secondary winding of the transformer has three times as many turns per phase as the primary. The parameters of the transformer are as follows:

   Primary impedance: $(0.5+j2.5)\ \Omega$/phase   Secondary impedance: $(5.0+j25.0)\ \Omega$/phase.

   If the primary voltage is 11 kV, calculate the line voltage on the transformer secondary terminals.

   [31.1 kV]

9. A three-phase, 230 V, 50 Hz, 27 kVA, 0.9 lagging power factor load is supplied by three 10 kVA, 1330 V/230 V, 50 Hz transformers connected in a star/delta configuration via a feeder line whose impedance is $(0.003+j0.015)$ Ω/phase.

   The transformer bank is fed via a high voltage feeder line whose impedance is $(0.8+j5.0)$ Ω/phase.

   The equivalent series impedance of one transformer referred to the low voltage side is $(0.12+j0.25)$ Ω/phase. Calculate the required high voltage magnitude if the load voltage is to be maintained at 230 V.

   [2437 V]

10. Two three-phase, 10 kV, 50 Hz power transformers *A* and *B* with equal turns ratios, and each star-connected on both the primary and secondary sides, operate in parallel to supply a load.

    Transformer *A* has a primary current of 100 A and its power factor on the primary side is 0.7 lagging. Calculate the power factor and current on the primary side of Transformer *B*.

    Calculate also the current flowing in the secondary load. The primary line voltage is 10 kV. Both transformers have a step-up transformation ratio of three. The equivalent series impedance of transformer *A* is measured to be $\bar{Z}_{eq\,A}=(0.5+j1.5)$ Ω/phase while that of phase *B* is measured at $\bar{Z}_{eq\,B}=(0.6+j1.8)$ Ω/phase.

    [83.3 A 0.7 lagging, 61.1 A, 0.7 lagging]