ORDRE DES INGÉNIEURS DU QUÉBEC

NOVEMBER 2018 SESSION

Open-book examination
Calculators : only authorized models
Duration : 3 hours

16 – MK – A7

POWER SYSTEMS AND MACHINES

Question 1 (25 points): Three-phase circuits

Two balanced three-phase loads are fed from a 400 V / 60 Hz three-phase source. The first is resistive inductive (R = 24 Ω and L = 48 mH) and is connected in Δ. The second absorbs 16 kVA with a power factor (PF) of 0.8 leading and is connected in Y.

a) Determine the elements (R and C, in series) that represent the second load. **(5 points)**
b) Present the per-phase equivalent circuit: Source and load impedances (with their parameters). **(5 points)**
c) Present the phasor diagram of the per-phase equivalent circuit: Source voltage and current, current of load #1 and current of load #2. **(10 points)**
d) Calculate the apparent power delivered by the three-phase source. **(5 points)**

Question 2 (25 points): Single-phase transformers

A single-phase 2.4 kV/240 V, 50 kVA, 60 Hz transformer presents the following parameters: R_1 = 1.5 Ω, R_2 = 0.015 Ω, X_1 = 3.0 Ω, X_2 = 0.03 Ω, R_c = 33333 Ω and X_m = 5000 Ω.

a) Determine the efficiency of the transformer when it provides a resistive load with 50 kVA, at V_2 = 240 V. **(10 points)**
b) Determine the voltage regulation of the transformer when it provides a resistive load with 50 kVA at V_2 = 240 V. **(5 points)**
c) Compute the short-circuit current of the transformer, in the primary side (I_1). **(5 points)**
d) What is the maximum apparent power that can be delivered by the transformer to a load at 50 Hz? **(5 points)**

Question 3 (25 points): Three-phase induction motor

A 4-pole, 400 V, 60 Hz three-phase induction motor presents the following parameters in a per-phase basis: $R_1 = 1.21\ \Omega$, $X_1 = 3.1\ \Omega$, $X_m = 65.6\ \Omega$, $R_c = \infty$, $R'_2 = 0.8\ \Omega$, $X'_2 = 2.5\ \Omega$. The rated slip is 5%. The frictions and windage losses amount to 500 W.

a) Determine the power factor (PF) of the motor when it is fed with rated voltage and it operates with rated speed. **(5 points)**
b) Find the stator copper losses at rated shaft speed and voltage. **(5 points)**
c) Calculate the mechanical power and torque at the shaft of the machine when it is fed with rated voltage at it operates with rated speed. **(10 points)**
d) Determine the shaft speed at half-load and rated voltage. **(5 points)**

Question 4 (25 points): Synchronous machine

A 8-pole, 120 MVA, 13.8 kV, 60 Hz, Y-connected three-phase synchronous generator presents a negligible stator resistance and a synchronous reactance of 0.82 Ω, per phase. It is connected to an "infinite bus."

a) Determine the shaft speed. **(5 points)**
b) Calculate the magnitude and angle of the internal induced voltage when the generator supplies rated power to the grid with unity power factor (PF = 1). **(10 points)**
c) Present the phasor diagram of the system: Internal induced voltage, grid voltage and current injected into the grid. **(5 points)**
d) Explain the operation of a synchronous machine as a "synchronous compensator." **(5 points)**