

EE3124 Assignment 1 (Solution)

Name:

Student No.:

Q1 - Please summarize the differences and similarities between Turbogenerator (Thermal Power Plants) and Hydroelectric Generator (Hydropower Plants).

Solution

Features: Turbogenerator (50 Hz)

High rotating speed: 3000 r/min for 2-pole machine in Coal plant, 1500 r/min for 4-pole machine in Nuclear plant.

Round rotor (turbo generator).

Generator with long shaft but small diameter size due to higher speed and less pole-pair.

Features: Hydroelectric Generator (50 Hz)

Low rotating speed: 150 r/min for 40-pole, 300 r/min for 20-pole. In general, less than 1000 r/min.

Salient pole (hydro generator).

Generator with short shaft but big diameter size due to lower speed and more pole-pair.

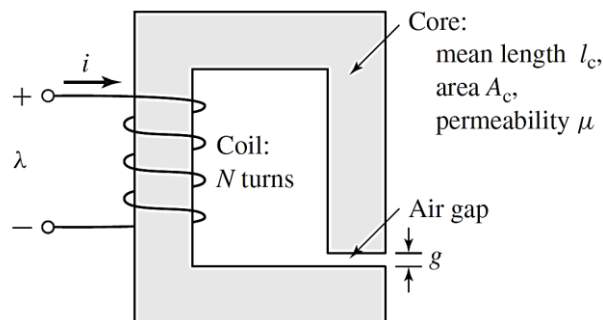
Q2 - An inductor of the form of the following figure has dimensions

Cross-sectional area $A_c = 3.8 \text{ cm}^2$

Mean core length $l_c = 19 \text{ cm}$

$N = 122$ turns

Assuming a core permeability of $\mu = 3240 \mu_0$ and neglecting the effects of leakage flux and fringing fields, calculate the air-gap length required to achieve an inductance of 6.0 mH.



Solution

$$g = \frac{\mu_0 N^2 A_c}{L} - \left(\frac{\mu_0}{\mu} \right) l_c = 1.126 \text{ mm}$$

Q3 - A DC series motor takes 40 A at 220 V and runs at 800 rpm. If the armature and field resistances are 0.2 Ω and 0.1 Ω , respectively and the iron and friction losses are 0.5 kW, find the torque developed in the armature. What will be the output power of the motor?

Solution

Armature torque is given by $T_a = \frac{E_a I_a}{2\pi N}$
 $E_a = V - I_a(R_a + R_{se}) = 220 - 40(0.2 + 0.1) = 208V$
 $N = \frac{800}{60} = \frac{40}{3} \text{ r.p.s}; T_a = 208 \times \frac{40}{2\pi(40/3)} = 99.3 \text{ Nm}$
Copper loss in armature and series – field resistance = $40^2 \times 0.3 = 480W$
Iron and friction losses = 500W; Total losses = $480 + 500 = 980W$
Motor input power = $220 \times 40 = 8800W$
Motor output power = $8800 - 980 = 7820W$

Q4 - A shunt-connected, 75-kW, 250-V dc motor has an armature resistance of 45 m Ω and a field resistance of 185 Ω . When operated at 250 V, its no-load speed is 1850 r/min.

a) The motor is operating under load at a terminal voltage of 250 V and a terminal current of 290 A. Calculate (i) the motor speed in r/min, (ii) the load power in kW, and (iii) the load torque in Nm.

b) Assuming the load torque remains constant as a function of speed at the value calculated in part (a), calculate (i) the motor speed and (ii) the terminal current if the terminal voltage is reduced to 200 V.

c) Repeat part (b) if the load torque of part (a) varies with the square of the speed.

Solution

If we write $E_a = \omega_m K_a I_f$, we can find K_a . At no load given no-load condition with $E_a = V_a = 250 \text{ V}$, $I_f = 250/185 = 1.35 \text{ A}$ and $\omega_m = 1850 \times \pi/30 = 193.7 \text{ rad/sec}$. Thus,

$$K_a = 0.956$$

Part (a): Here $I_f = 1.35 \text{ A}$, $I_L = 290 \text{ A}$ and $I_a = I_L - I_f = 288.6 \text{ A}$. Thus

$$E_a = V_a - I_a R_a = 237 \text{ V}$$

(i)

$$\omega_m = \frac{E_a}{K_a I_f} = 183.6 \text{ rad/sec}$$

corresponding to a speed of 1754 r/min.

(ii)

$$P_{\text{load}} = E_a I_a = 68.40 \text{ kW}$$

(iii)

$$T_{\text{load}} = \frac{P_{\text{load}}}{\omega_m} = 372.5 \text{ N} \cdot \text{m}$$

Part (b): If the terminal voltage is 200 V, $I_f = 200/185 = 1.08 \text{ A}$.

$$T_{\text{load}} = \frac{E_a I_a}{\omega_m} = (V_a - E_a) \left(\frac{K_a I_f}{R_a} \right)$$

and thus

$$E_a = V_a - \frac{T_{\text{load}} R_a}{K_a I_f} = 183.5 \text{ V}$$

from which (i)

$$\omega_m = \frac{E_a}{K_a I_f} = 177.7 \text{ rad/sec}$$

corresponding to a speed of 1697 r/min.

(ii)

$$I_L = \frac{V_a - E_a}{R_a + I_f} = 367.8 \text{ A}$$

Part (c): Let $T_0 = 372.5 \text{ N} \cdot \text{m}$ and $\omega_{m0} = 183.6 \text{ rad/sec}$. We can write

$$T_0 \left(\frac{\omega_m}{\omega_{m0}} \right)^2 = k_a I_f I_a = K_a I_f (V_a - K_a \omega_m I_f)$$

from which we find that $\omega_m = 178.8 \text{ rad/sec}$ corresponding to 1707 r/min.

$$I_L = \frac{V_a - \omega_m K_a I_f}{R_a} + I_f = 344.6 \text{ A}$$

Q5 - A three-phase Y-connected 60-Hz two-pole synchronous machine has a stator with 5000 turns of wire per phase. What rotor flux would be required to produce a terminal (line-to-line) voltage of 13.2 kV?

Solution

The phase voltage of this machine should be $V_\phi = V_L / \sqrt{3} = 7621 \text{ V}$. The induced voltage per phase in this machine (which is equal to V_ϕ at no-load conditions) is given by the equation

$$E_A = \sqrt{2} \pi N_c \phi f$$

so

$$\phi = \frac{E_A}{\sqrt{2} \pi N_c f} = \frac{7621 \text{ V}}{\sqrt{2} \pi (5000 \text{ t})(60 \text{ Hz})} = 0.0057 \text{ Wb}$$

Q6 - The simple loop is rotating in a uniform magnetic field shown as follows has the following characteristics:

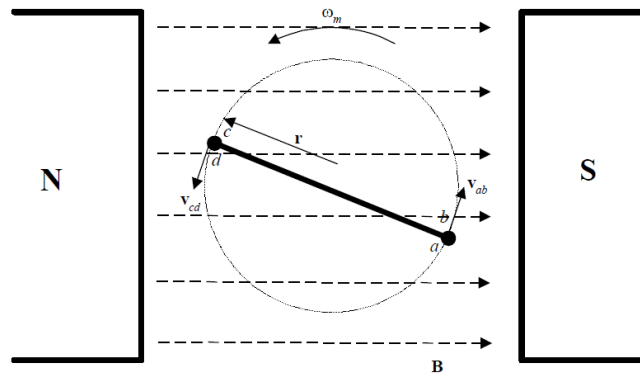
$$B = 1.0 \text{ T to the right}$$

$$r = 0.1 \text{ m}$$

$$l = 0.3 \text{ m}$$

$$\omega_m = 377 \text{ rad/s}$$

- Calculate the voltage $e_{tot}(t)$ induced in this rotating loop.
- What is the frequency of the voltage produced in this loop?
- Suppose that a 10Ω resistor is connected as a load across the terminals of the loop. Calculate the current that would flow through the resistor.
- Calculate the magnitude and direction of the induced torque on the loop for the conditions in (c).
- Calculate the instantaneous and average electric power being generated by the loop for the conditions in (c).
- Calculate the mechanical power being consumed by the loop for the conditions in (c). How does this number compare to the amount of electric power being generated by the loop?



B is a uniform magnetic field, aligned as shown.

Solution

- (a) The induced voltage on a simple rotating loop is given by

$$e_{ind}(t) = 2r\omega B l \sin \omega t$$

$$e_{ind}(t) = 2(0.1 \text{ m})(377 \text{ rad/s})(1.0 \text{ T})(0.3 \text{ m}) \sin 377t$$

$$e_{ind}(t) = 22.6 \sin 377t \text{ V}$$

- (b) The angular velocity of the voltage produced in the loop is 377 rad/s. Frequency is related to angular velocity by the equation $\omega = 2\pi f$, so

$$f = \frac{\omega}{2\pi} = \frac{377}{2\pi} = 60 \text{ Hz}$$

- (c) If a 10Ω resistor is connected as a load across the terminals of the loop, the current flow would be:

$$i(t) = \frac{e_{ind}}{R} = \frac{22.6 \sin 377t \text{ V}}{10 \Omega} = 2.26 \sin 377t \text{ A}$$

(d) The induced torque would be:

$$\tau_{\text{ind}}(t) = 2rilB \sin \theta$$

$$\tau_{\text{ind}}(t) = 2(0.1 \text{ m})(2.26 \sin \omega t \text{ A})(0.3 \text{ m})(1.0 \text{ T}) \sin \omega t$$

$$\tau_{\text{ind}}(t) = 0.136 \sin^2 377t \text{ N} \cdot \text{m}, \text{ counterclockwise}$$

(e) The instantaneous power generated by the loop is:

$$P(t) = e_{\text{ind}} i = (22.6 \sin 377t \text{ V})(2.26 \sin 377t \text{ A}) = 51.1 \sin^2 377t \text{ W}$$

The average power generated by the loop is

$$P_{\text{ave}} = \frac{1}{T} \int_T 51.1 \sin^2 \omega t \, dt = 25.55 \text{ W}$$

(f) The mechanical power being consumed by the loop is:

$$P = \tau_{\text{ind}} \omega = (0.136 \sin^2 377t \text{ N} \cdot \text{m})(377 \text{ rad/s}) = 51.3 \sin^2 \omega t \text{ W}$$

Note that the amount of mechanical power consumed by the loop is equal to the amount of electrical power created by the loop (within roundoff error). This machine is acting as a generator, converting mechanical power into electrical power.