23-DC Generators Part 1

ECEGR 450
Electromechanical Energy Conversion

Overview

- Induced emf Equation
- Power
- Torque
- Armature Reaction

Induced emf

- Recall for a single coil with one turn that is rotating in a uniform magnetic field the average emf is:

$$e_c = \frac{2}{\pi}E_m = \frac{P}{\pi}\Phi_p\omega_m$$

  - E_c: average induced emf in a single coil (V)
  - ω_m: mechanical speed of the rotor (rad/s)
  - ϕ_p: flux per pole
- Frequency of e_c in Hz is:

$$f = \frac{P}{4\pi}\omega_m$$

Induced emf

- emf at the terminals of the machine must account for number of turns per coil and number of coils arranged in series (or in parallel)

$$N_a = \frac{C}{a}N_c$$

  - N_a: number turns between positive and negative terminals
  - C: total number of coils
  - a: number of parallel paths (lap winding: a = P)
  - N_c: number of turns per coil

Induced emf Equation

- Therefore

$$e_a = \frac{PN_a}{\pi}\phi_p\omega_m = \frac{PCN_c}{\pi a}\phi_p\omega_m$$

  - e_a: average emf between the brushes (V)

let

$$K_a \triangleq \frac{PCN_c}{\pi a} \quad \text{(machine constant)}$$

therefore

$$e_a = K_a\phi_p\omega_m$$

Example

Consider a 24-slot, lap wound, 2 pole dc generator with 18 turns per coil. Find the average induced emf if ϕ_p = 0.05 Wb and the rotor rotates at 183.2 rad/s.

"slot" refers to the notches in the rotor for armature windings. Number of slots = number of coils.

Example

Consider a 24-slot, lap wound, 2 pole dc generator with 18 turns per coil. Find the average induced emf if ϕ_p = 0.05 Wb and the rotor rotates at 183.2 rad/s.

$$e_a = \frac{PCN_c\phi_P\omega_m}{\pi a} = \frac{2 \times 24 \times 18 \times 0.05 \times 182.3}{\pi \times 2} = 1259.6V$$

Question

- For a lap-wound machine with constant C, N_c and ω_m, how does increasing the number of poles P affect the terminal voltage?

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- For a lap-wound machine with constant C, N_c and ω_m, how does increasing the number of poles P affect the terminal voltage?
- It has no effect on induced voltage. For lap-wound machines, a = P so that:

$$e_a = \frac{PCN_c}{\pi a}\phi_P\omega_m = \frac{PCN_c}{\pi P}\phi_P\omega_m = \frac{CN_c}{\pi}\phi_P\omega_m$$

Induced emf Equation

- Electrical power to the load:

  $P_d = e_a i_a = K_a\phi_P\omega_m i_a$

  - P_d: power developed by the generator (W)
  - i_a: armature current, assumed to be constant (A)

Induced emf Equation

- Developed mechanical torque:

  $P_d = T_d\omega_m$

  $T_d = K_a\phi_P i_a$

  - T_d: torque(Nm)
- For stable operation, the electrical power developed must equal the mechanical power

  $P_d = T_d\omega_m$
- Next examine the torque developed using a fields approach

Developed Torque

- Recall the torque developed by a single turn coil rotating in a uniform magnetic field

  $T_e = 2BiLr$

  - L : length of one conductor along the side of the rotor (m)
  - r: radius at which each conductor is located (m)
- The average torque on a single turn-coil is

  $T_c = 2Bi_cLr$

  - i_c: average current in the coil (current is full wave rectified)

Developed Torque

- The total torque developed by the machine is:

$$T_d = 2BLri_a \frac{CN_c}{a}$$

- Let A_p be the area of each pole (m^2), then

$$A_p = \frac{2\pi rL}{P}$$

$$T_d = \frac{2CN_cP}{2\pi a} BA_p i_a = K_a \phi_p i_a$$

This is exactly the same as the torque derived from examining the electrical power

recall that: $K_a \triangleq \frac{PCN_c}{\pi a}$

Magnetization Characteristic

- Induced emf is a function of flux per pole and armature speed
  - from $e_a = K_a \phi_P \omega_m$
- Assume the armature is open-circuited and is rotating at the rated speed of the machine
  - Induced emf is then proportional to flux per pole
- Flux per pole is dependent on the mmf provided by the field current

Magnetization Characteristic

- Flux per pole is dependent on and proportional with the mmf provided by the field current
- Mathematically

  $\phi_P = k_f i_f$
  - k_f: constant of proportionality
  - i_f: field current (A)
- Is k_f always the same value for a given machine?

Magnetization Characteristic

- Is k_f always the same value for a given machine?
  - k_f relates flux to field current
  - Since the machine is made of ferromagnetic material, it can saturate
  - When it saturates, it requires more current to produce an incremental amount of flux
  - So, k_f is a function of field current

Magnetization Characteristic

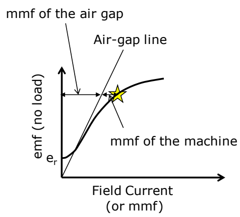
- Combining $E_a = K_a \phi_P \omega_m$ and $\phi_P = k_f i_f$
  - yields $E_a = K_a \omega_m k_f i_f$
- Assuming speed is constant, the induced emf is proportional to the field current
- Remember that k_f is dependent on the field current due to saturation
- We therefore expect a non-linear current-to-induced emf relationship
  - This is the <u>magnetization curve</u> of the machine

Magnetization Characteristic

- The magnetization curve will reflect that:
  - Magnetic circuit of the flux passes through a ferromagnetic material and an air gap
  - Ferromagnetic material (non-linear B-H curve)
  - Air-gap (linear B-H curve)
  - Residual magnetism in material will give rise to a residual emf in the armature at zero field current
  - Hysteresis effect

Magnetization Characteristic

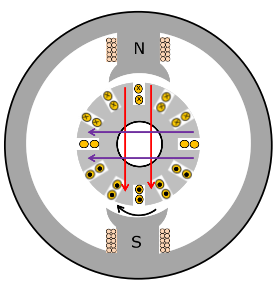
- e_r: residual induced emf (volts)



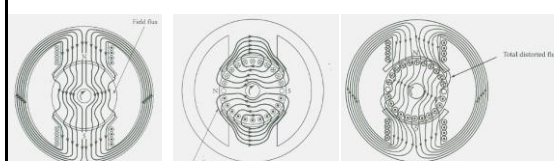
Armature Reaction

- Flux in the armature is from two sources:
  - field winding
  - armature current (when connected to a load)
- Fluxes are perpendicular to each other
- Resulting distortion can have a profound effect on the operation of the machine
- Read 5.8 of the text

Armature Reaction

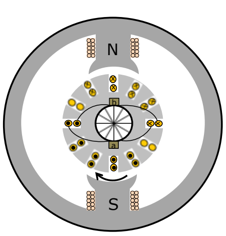


Armature Reaction



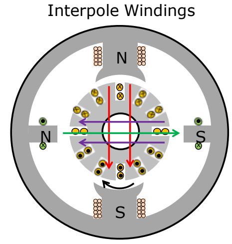
Armature Reaction

Current-carrying conductors are shorted. Excessive sparking occurs.

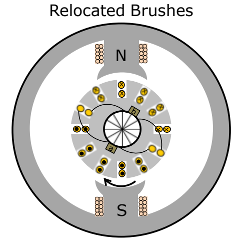


Armature Reaction

Interpole Windings



Relocated Brushes



Summary

- Terminal voltage for DC generator:
  $e_a = \frac{PCN_c}{\pi a} \phi_P \omega_m$
- Non-linear relationship between field current and terminal voltage due to saturation
- Interaction between flux generated by field winding and armature winding is "Armature Reaction", and decreases performance of machine