

23-DC Generators Part 1

ECEGR 450
Electromechanical Energy Conversion



Overview

- Induced emf Equation
- Power
- Torque
- Armature Reaction

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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:

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

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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

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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

$$e_a = K_a \phi_p \omega_m$$

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Example

Consider a 24-slot, lap wound, 2 pole dc generator with 18 turns per coil. Find the average induced emf if $\phi_p = 0.05$ 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.

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Example

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

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

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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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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?
- It has no effect on induced voltage. For lap-wound machines, $a = P$ so that:

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

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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)

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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

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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
 - $T_c = 2Bi_c Lr$
 - i_c : average current in the coil (current is full wave rectified)

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Developed Torque

- The total torque developed by the machine is:

$$T_d = 2BLr_a \frac{CN_c}{a}$$
- Let A_p be the area of each pole (m^2), then


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

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

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

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


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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

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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?


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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


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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 magnetization curve of the machine

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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

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Magnetization Characteristic

- e_r : residual induced emf (volts)

The graph plots induced emf (no load) on the y-axis against Field Current (or mmf) on the x-axis. A straight line labeled 'mmf of the air gap' is drawn from the origin. A curve labeled 'mmf of the machine' starts at a point on the y-axis labeled e_r and curves upwards. The intersection of the air gap line and the machine mmf curve is marked with a yellow star and labeled 'Air-gap line'.

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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

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Armature Reaction

The diagram shows a synchronous motor with North (N) and South (S) poles. The main field flux is represented by a vertical red line. The armature current is shown as a horizontal purple line. The resulting total flux is shown as a diagonal blue line, indicating the distortion of the main field flux.

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Armature Reaction

The three diagrams show the progression of flux line distortion. The first shows the 'Field flux' as straight vertical lines. The second shows the 'Armature flux' as horizontal lines. The third shows the 'Total distorted flux' as curved lines that are bowed out on the leading pole and bowed in on the lagging pole.

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Armature Reaction

The diagram shows a synchronous motor where the armature reaction has significantly distorted the main field flux. A text box on the left states: "Current-carrying conductors are shorted. Excessive sparking occurs."

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Armature Reaction

The two diagrams show solutions to armature reaction. The first, 'Interpole Windings', shows additional poles (interpoles) between the main poles, with their flux lines opposing the armature reaction. The second, 'Relocated Brushes', shows the brushes moved to the new positions of the magnetic neutral axis.

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Summary

- Terminal voltage for DC generator:

$$e_a = \frac{PCN}{\pi a} \phi_f \omega_m$$

- 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