Electrical Power and Machines
Lecture 4

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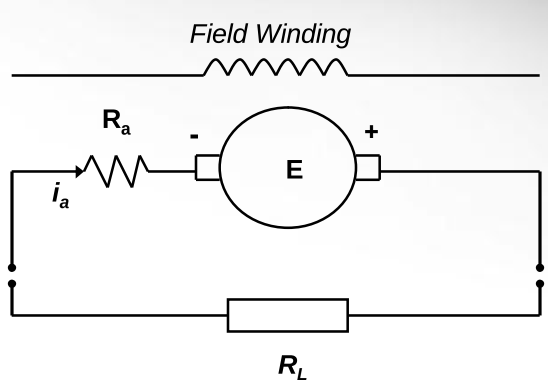
DC Generators

Electric Equivalent Circuit of a DC Generator

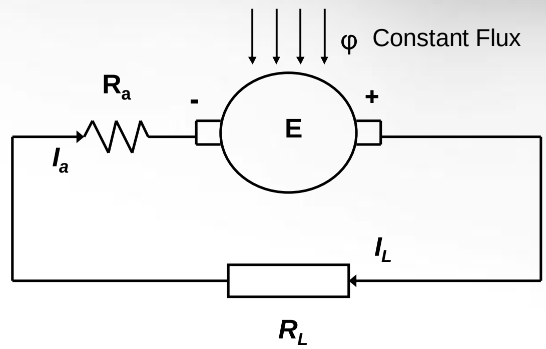


Field winding is responsible of setting up a flux

Types of DC Generators

1. *Permanent Magnet Generators*

$I_a = I_L$

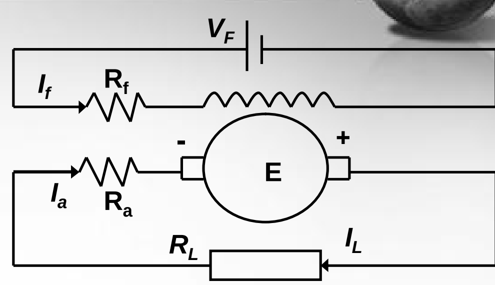


This type is characterized by being smaller, lighter and more efficient compared to wound generators

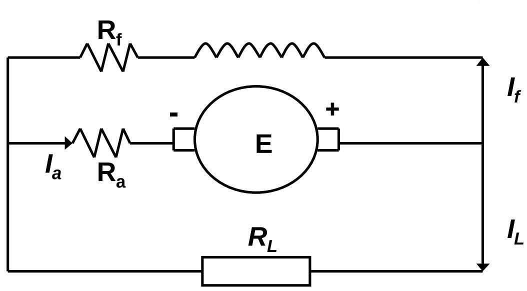
2. *Electro-magnet Generators*

a. Separately Excited

$I_a = I_L$



b. Self Excited



$I_a = I_f + I_L$

Induced E.M.F Equation

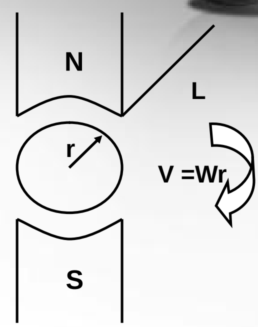
e.m.f "E_C" is generated in armature windings

$$E_C = BLV$$

B: Flux density (T)

L: length of conductor (m)

V: velocity of conduction motion



$B = \varphi / A = \varphi / \ L A_p = \varphi / [L(\pi D/P)]$

$V = Wr = (2\pi N/60)r$ *(N: rev/min)*

Then $$E_c = \frac{\phi}{L(\pi D/P)} \times L \times \frac{WD}{2} = \frac{\phi PW}{2\pi}$$

Machine e.m.f "E_a" = E_C (total no. of conductors/no. of parallel paths)

$$E_a = \frac{\phi PW}{2\pi} \times \frac{Z}{a} = K_a \phi_p W$$

Where $K_a = ZP/2\pi a$ ……………….. Machine constant

And $Z = 2\,C\,N_C$ *(C:no. of coils, N_C : no. of turns)*

Example

Calculate the voltage generated by a six pole dc machine if its windings are: 1) lap wound 2) Wave wound, if the flux per pole is 0.05 wb. and the generator speed is 120 rev/min, 200 armature coils with 15 turns each

Solution

$Z = 2CN_C = 2\times200\times15 = 6000$ *conductors*

1)Lap wound

$a = P = 6$

$E_a = K_a\, \varphi_p\, w = [6000\times6/2\pi\times6]\times0.05\times[2\pi\times120/60] = 600\ V$

2)Wave wound

$a=2$

$E_a = K_a\, \varphi_p\, w = [6000\times6/2\pi\times2]\times0.05\times[2\pi\times120/60] = 1800\ V$

Torque Equation

$$P = E_a I_a = K_a \varphi_p w I_a = T \times w$$

Then the developed torque is given by: $T_d = P/w = K_a \varphi_p I_a$

Example

A 24 slot, 2 pole Dc machine has 18 turns per coil, the average flux density per pole is 1T. The effective length is 20 cm and the armature radius is 10 cm. the magnetic poles are designed to cover 80 % of the armature periphery. If the armature velocity is 183.2 rad/sec and the armature current is 25 A, determine:

- the current in each conductor
- the developed torque
- the developed power

Solution

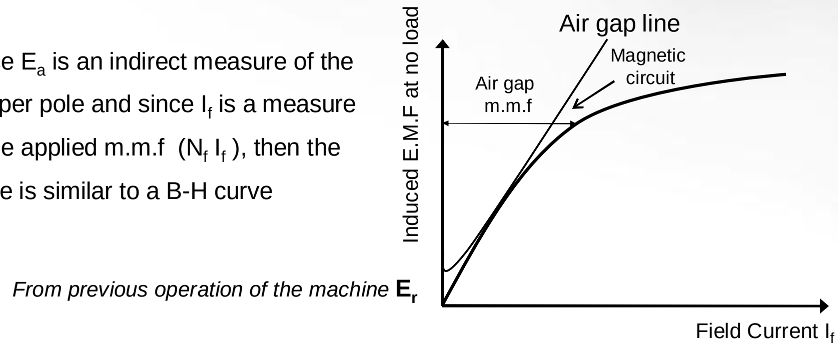
- As the machine is a 2 pole,
- then $I_C = I_a / 2 = 25/2 = 12.5\ A$
- $A_p = 2\pi rL/p = 2\times3.14\times0.1\times0.2/2 = 0.063\ m^2$,
- as $A_e = 0.8\ A_p$,
- then $A_e = 0.8\times0.063 = 0.05\ m^2$,

- then $\varphi_p = B\ A_e = 1\times0.05 = 0.05$ wb
- and $K_a = (Zp/2\pi a) = (2\times24\times18)\times2/2\Pi\times2 = 137.51$
- $T_d = K_a I_a \varphi_p = 137.51\times25\times0.05 = 171.89$ N.m
- $P_d = T_d \times w = 171.89\times183.2 = 31490$ W

Magnetization characteristics of DC machine

As $E_a \; \alpha \; \varphi_p \, w$, now if the armature circuit is left open, and armature is rotated at rated speed, then $E_a = K_1 \varphi_p = K_a w_m \varphi_p$ and since $\varphi_p = K_f I_f$ (flux per pole depend on the m.m.f provided by current I_f) then $E_a = K_1 K_f I_f$

Since E_a is an indirect measure of the flux per pole and since I_f is a measure of the applied m.m.f ($N_f I_f$), then the curve is similar to a B-H curve



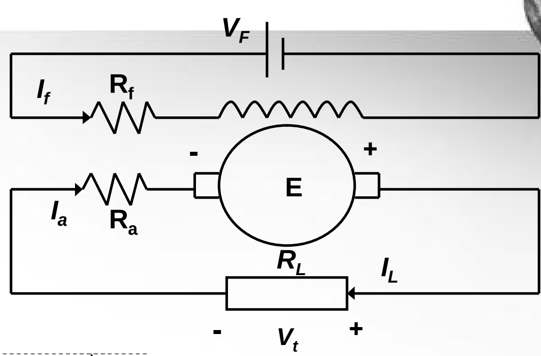
m.m.f required for magnetic material is almost negligible at small values of flux density

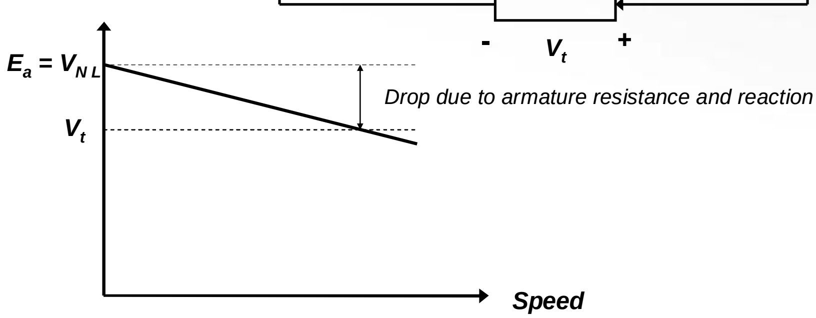
Separately Excited Dc Generator

$$E_a = V_t + I_a R_a$$

$$I_L = I_a$$

$$V_f = I_f R_f$$



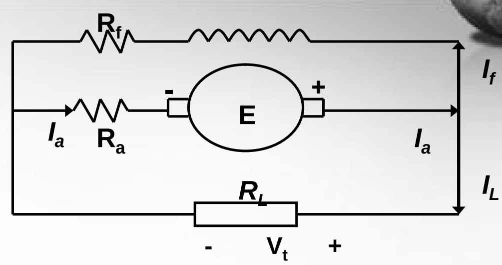


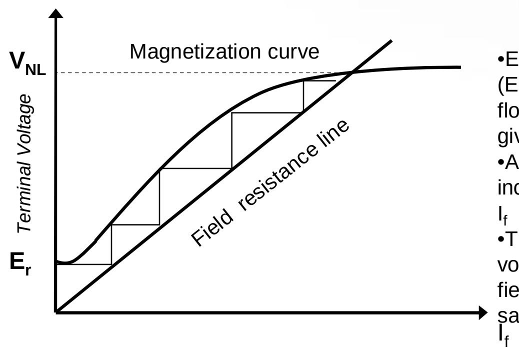
Shunt Generator

$$I_f = V_t / R_f$$

$$I_a = I_L + I_f$$

$$V_t = E_a - I_a R_a = I_L R_L$$

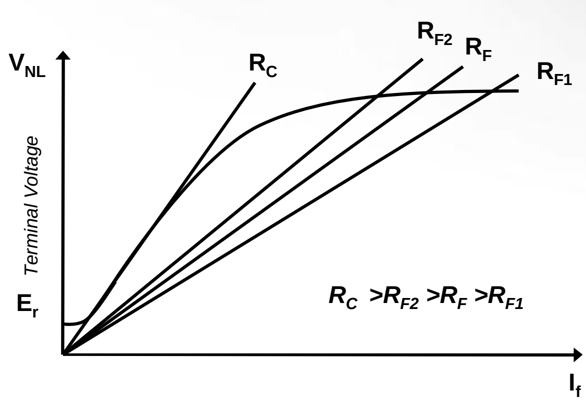




- E_r induces an e.m.f in armature winding (E_r) and as the field is parallel then a small I_f flows giving a m.m.f that sets up a flux giving aid to the residual flux.
- An increase in the flux per pole will increase the induced e.m.f thus increasing I_f
- The shunt generator continues to build up voltage until the point of intersection of the field resistance line and the magnetization saturation curve

Note :

A decrease in the field circuit resistance will cause the shunt generator to build up faster to a higher voltage, the generator will not build up if the field resistance is greater than or equal the critical resistance

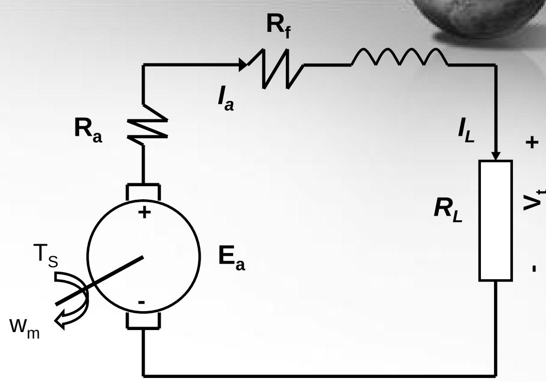


Series Generator

$$I_L = V_t / R_L$$

$$I_a = I_L = I_f$$

$$V_t = E_a - I_a R_a - I_a R_f$$



•Series generators are used to supply a constant load current

•R_f should be small to reduce voltage drop (so it is made of thick wire)

Voltage Regulation

Voltage regulation is a measure of the terminal voltage drop at full load

$$V.R\ \% = 100\times(V_{NL} - V_{FL})/V_{FL}$$

V_{NL}: NO load terminal voltage

V_{FL} : Full load terminal voltage

Losses in DC Generators

Input | ***Mechanical Power***

Rotational losses "P_r"

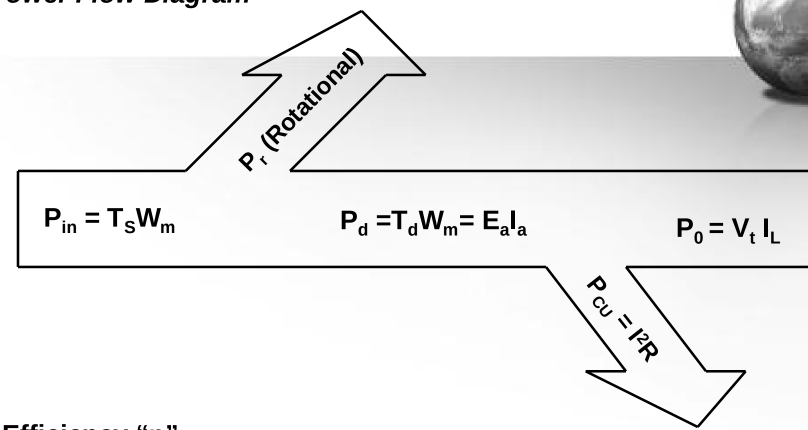
Mechanical Losses:
- Windage (drag on armature caused by air)
- Friction (brushes-commutator , bearing-shaft)

Magnetic Losses:
- Hysteresis losses
- Eddy losses

Developed Power "P_d" = $E_a I_a$

- ***Output Power "P_o" =$V_t I_L$***
- ***Copper Losses "P_{CU}" = I^2R***

Power Flow Diagram



Efficiency "η"

$\eta\ \% = (P_0 / P_{in}) \times 100$

Example:

The d.c Separately-excited generator shown in Fig produces an open circuit emf E of 220 V. Calculate the Terminal voltage V when generator supplies a current of 10 A. The armature resistance is 1 ohm

$V_t = E_a - R_a I_a$

Where $E_a = 220\ V$ $I_a = 10\ A$ $R_a = 1\ ohm$

$V_t = 220 - (10)(1)$
$= 210\ V$

Example:

A separately-excited d.c. generator produces an open-circuit voltage of 250 V with field current of 1.5 A. If the field current is increased to 2 A, calculate

a) The new open-circuit emf.

b) The terminal voltage if the generator supplies a current of 5 A. Assume armature resistance- 0.8 ohm and the speed remains constant.

Solution:

a) Since the speed is constant

b)

$$\frac{E_1}{E_2} = \frac{I_{f1}}{I_{f2}}$$

Where

E_1=250 V, I_{f1}= 1.5 A and I_{f2} = 2A

E_2=250 (2/1.5)=333 V

b) $V_t = E_a - R_a I_a$

Where

E_a=333 V, I_a= 5 A and R_a = o.8 ohm

$V = 333 - (5)(0.8)$

$= 333 - 4$

$= 329\ V$

Example

A separately excited DC generator has a field resistance of 50 ohm, armature resistance of 0.125 ohm and brush drop of 2V. At no load the generated voltage is 275 V, and the full load current is 95 A. the field excitation voltage is 120 V and the friction windage and core losses are 1500 watt. Calculate :

- The rated terminal voltage and output power
- the efficiency at full load

Solution

$V_t = E_a - I_a R_a - V_B = 275\text{-}95 \times 0.125\text{-}2 = 261.13\ V$

$P_0 = V_t I_a = 26.13 \times 95 = 24.81\ Kw$

$P_{in} = P_0 + P_{losses}$

$= 24.81 \times 10^3 + 1500 + 95^2 \times 0.125 + 120^2/50$

$= 27.913\ Kw$

$\eta = (24.81/27.913) \times 100 = 88.88\ \%$