Module - 5

~~Single Phase Transformer.~~

DC Machines

Principle of operation of DC Generator -

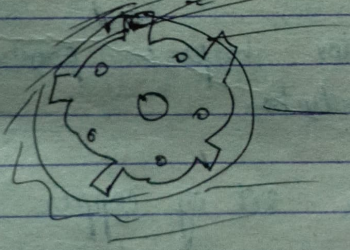
All the generator work on the principle of dynamically induced emf. This principle is nothing but Faraday's Law of EM induction. Whenever no. of mag lines of force i.e flux linking with conductor of a coil changes an emf is set up in conductor or coil.

An induced emf which is due to physical movement of coil or conductor wrt flux or movement of flux wrt coil / conductor is called dynamically induced emf.

Armature

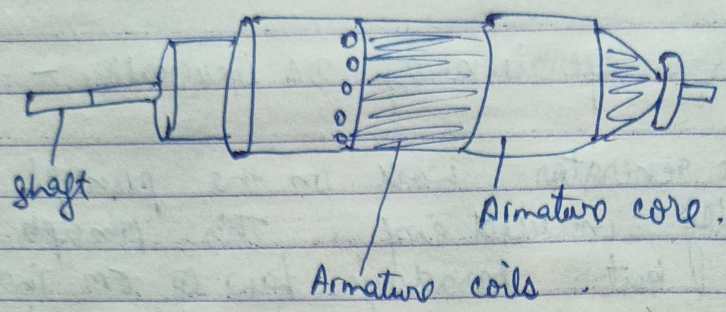
① Armature core ② Armature winding

Armature core → It is rotor of dc machine
→ Cylindrical in shape with slots to carry armature winding.



Armature Winding → It is usually former wound copper coil which rest in armature slots.

The armature conductors are insulated from each other & also from armature core.



Functions of Armature :-

① Its purpose is to rotate the conductors in uniform magnetic field.

② Most imp function is to provide a path of very low reluctance to magnetic flux.

Commutator & Brushes :-

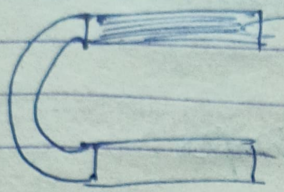
⇒ Physical connection to the armature winding is made through a commutator brush arrangement.

→ Function of commutator in DC generator is to collect the current generated in armature conductors.
Where as
in DC motor, commutator helps in providing current to armature conductors

Commutator consists of a set of copper segment insulated from each other.
No. of segments = no. of armature coil.

→ Each segment of copper is connected to armature coil & commutator is keyed to shaft.

→ Brushes are usually made of carbon or graphite.



copper segment.

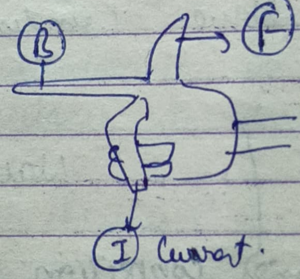
Commutator func. is to convert AC → DC & vice versa

Armature winding

Lap winding | Wave winding.

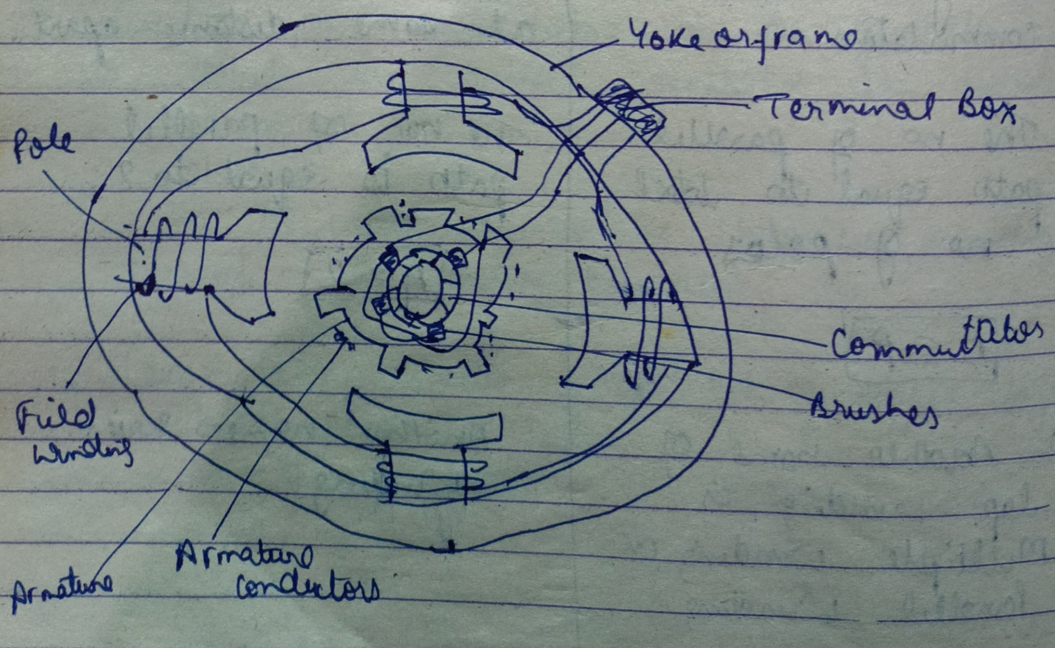
Lap Winding	Wave Winding
① Connection of Lap winding is the armature coil end is connected to nearby section on commutators.	Connection of wave winding is the armature coil ~~end~~ end is connected to commutator sections at same distance apart.
② The no of parallel path equal to total no of poles $\boxed{A = P}$	The no. of parallel path is equal to 2. $\boxed{A = 2}$
③ Another name of lap winding is multiple winding or Parallel Winding.	Another name → series winding.

(4) Emf of Lap winding is less.	Emf of wave winding is more.
(5) No. of brushes is equivalent to no. of parallel paths.	No. of Brushes is equivalent to two.
(6) costly due to more conductor	Cheaper.

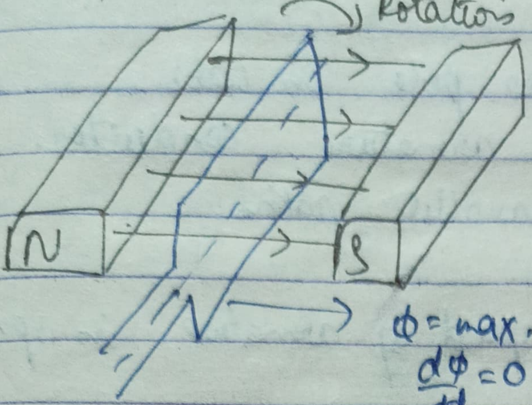


Fleming's Right Hand Rule.

Construction of DC machines



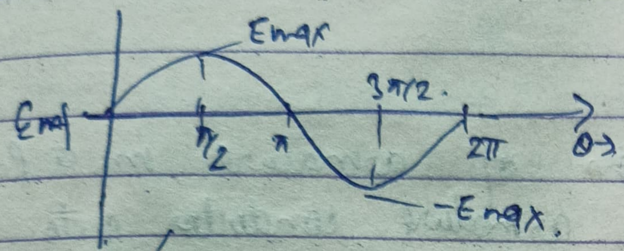
Simple Loop Generator



$\phi = BA\cos\theta$.

$\phi = max$.

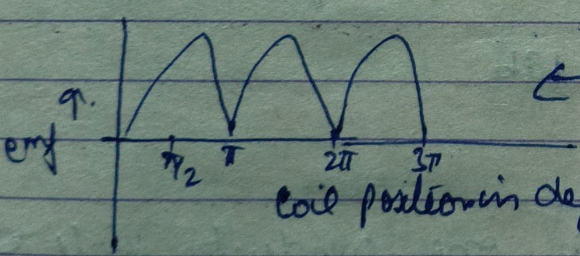
$\frac{d\phi}{dt} = 0$.



(AC) Gener.

induced emf in a coil rotated in uniform mag^n field

AC Generator	DC Generator
→ Slip Ring	→ split Ring → Known as commutator.



← (DC) generator.

Emf Equation→

Let ϕ be flux per pole in Wbs.
Z = Total no. of armature conductor.
A = No. of parallel paths.
P = no. of poles.
N = Rotational speed of armature in rpm.

$$e = -\frac{d\phi}{dt}$$

During 1 revolution of armature in a P-pole generator each armature conductor cuts the magⁿ flux P times, so flux cut by 1 conductor in one revolution = $P\phi$ Wb.

Since no. of revolution made by armature per minute is N, no. of revolution made per second is $N/60$ & flux cut by each conductor per second = Flux cut by one conductor per rev × no. of revol. of armature/second

$$= \left(\phi P \times \frac{N}{60}\right) \text{ Wb}$$

Average emf induced in one conductor will be

$$\boxed{e = \frac{\phi P N}{60} \text{ V}}$$

The no. of conductors in series btw +ve & -ve brush. is equal to total no. of conductors divided by number of parallel paths
i.e. [no. of armature conductors per parallel path = $\frac{Z}{A}$]

$A^* = 2$ (in wave winding)
$A^* = P$ (in lap winding)

Total emf generated btw terminals, E = avg emf induce on one conductor X no. of conductors in each circuit

$$= \left(\frac{\phi P N}{60} \times \frac{Z}{A} \right) V$$

For given machine, no. of poles & no. of armature conductors per parallel path (Z/A) are - const.

$$E = K \phi N$$

$$\boxed{E \propto \phi N}$$

or $E \propto \phi \omega$ $\left(\omega = \frac{2\pi N}{60} \right)$

induced emf is directly proportional to flux per pole ϕ & speed N.

When machine is operating as generator, induced emf is called [generated emf, E_g].

When machine is operating as a motor it is called [counter or back emf, E_b]

eg 1. $I_a = 250\,A$ $P = 12$.

For wave wound:-

No. of parallel paths, $A = 2$.

$$\text{Current per path} = \frac{250}{2} = 125\,A.$$

For simplex lap wound.

$$A = P = 12.$$

$$\text{Current per path} = \frac{250}{12} = 20.83\,A$$

eg 2. flux ⇒ 20% reduced. speed ⇒ 20% increas.

emf eqⁿ of dc generator = ? , change in emf?

$$\phi' = \left(1 - \frac{20}{100}\right)\phi = \frac{80\,\phi}{100} = 0.8\,\phi$$

$$N' = \left(1 + \frac{20}{100}\right)N = \left(\frac{120}{100}\right)N = 1.2\,N$$

$$E \propto \phi N.$$

$$\frac{E_1}{E_2} = \frac{\Phi_1 N_1}{\Phi_2 N_2} = \frac{\cancel{\phi_1 N_1}}{(0.8\cancel{\phi_1})\,1.2(\cancel{N_1})}$$

$$\frac{E_1}{E_2} = \frac{1}{0.8 \times 1.2}$$

$$\frac{E_2}{E_1} = 0.96.$$

$$\text{change in emf} = \frac{E_1 - E_2}{E_1} \times 100 = \left(\frac{E_1 - .96E_1}{E_1}\right) \times 100$$

= 4% decrease.

eg 3. $P = 6.$ $Z = 720.$ $\phi = 80 \times 10^{-3}$ per pole.

→ lap wound so $A = P$

$N = 1000.$

$E_g = \frac{\phi P N}{60} \times \frac{Z}{A}$

$E_g = \frac{80 \times 10^{-3} \times 6 \times 1000}{60} \times \frac{720}{6} = 960V$

eg 4. $E_g = 100V$ $\phi = 20 \times 10^{-3} Wb$ $N = 800.$

$E_g = ?$ (i) with same flux & speed $= 1000$ rpm.

(ii) with flux per pole $= 24 \times 10^{-3} Wb$ & $N = 900$ rpm.

$E_1 = 100V$

$\Phi_1 = 20 \times 10^{-3}$

$N_1 = 800$ rpm.

$E \propto \Phi N.$

$\frac{E_2}{E_1} = \frac{\Phi_2 N_2}{\Phi_1 N_1}$

(i) $E_2 = \frac{100 \times \cancel{\phi_2} \times 1000}{\cancel{\phi_1} \times 800} = 125V$

(ii) $E_2 = \frac{100 \times 24 \times 10^{-3} \times 900}{20 \times 10^{-3} \times 800} = 135V$

x/00

eg 5. $P = 4$ lap wound $\rightarrow \boxed{A = P = 4}$

Slots = 144. no. of coils = 2. no. of turns in each coil = 2.

$\phi = 20 \times 10^{-3}$ wb $N = 720$ rpm, Voltage ind = ?

No. of armature conductors, $Z = 144 \times 2 \times 2$
$= 576$.

$$E = \left(\frac{\phi P N}{60}\right) \times \left(\frac{Z}{A}\right)$$

$$E = \frac{20 \times 10^{-3} \times 4 \times 720}{60} \left(\frac{576}{4}\right) = 138.24V$$

eg 6. $P = 8$ $Z = 500$ $\phi = .05$

$N = 1200$ rpm. in lap-connected.

$N = ?$ when wave wound with same Emf = ?

$$E = \frac{\phi P N}{60} \times \frac{Z}{A}$$

$$\text{Emf} = \frac{.05 \times 8 \times 1200}{6\cancel{0}} \times \frac{50\cancel{0}}{\cancel{8}} = 500 V.$$

$$500 = \frac{\phi P N'}{60} \times \frac{Z}{A}$$

(wave wound)
$\Downarrow$
($A = 2$)

$$N' = \frac{500 \times 60 \times 2}{500 \times .05 \times 8} = 300 \text{ rpm.}$$

eg 7. $P = 4$. $N = \cancel{1000}\ 600\ rpm$,
$E = 220V$.
Z, (no of armature conductor) = $2 \times$ no. of turns
$= 2 \times 100 = 200$.
$\phi = ?$
(i) Lap connected
$A = P = 4$.

$$E = \frac{\phi P N}{60} \times \frac{Z}{A}$$

$$\frac{\cancel{220}^{11} \times \cancel{60} \times 4}{4 \times \cancel{600}_{100} \times \cancel{200}} = \phi$$

$\phi = .11\ Wb$

(ii) Wave connected
$A = 2$, $P = 4$.

$$\frac{2 \times 60 \times \cancel{220}^{11}}{\cancel{4}_{2} \times \cancel{600} \times 200} = \phi.$$

~~.00505~~ $.055\ Wb. = \phi$.

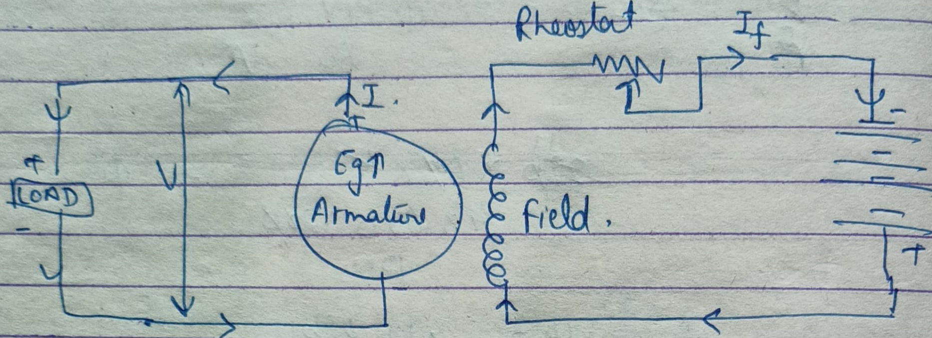
Types of DC generators:

MMF necessary to establish flux in magn circuit of a dc generator can be obtained by means of
(i) Permanent magnet.
(ii) field coils excited by some external source.
(iii) field coils excited by generator itself.

Permanent magnet used to establish flux - called Permanent magnet generator.

(i) Separately excited DC generator.

DC generator whose field winding is excited from an independent external dc source (like battery), the generator is called separately excited generator.



$I_a \Rightarrow$ Current flowing through armature.
I_L = " through Load.
V = Terminal voltage.
$E_g \Rightarrow$ Generated Emf.

$R_a \Rightarrow$ armature Resistance

$I_a = I_L = I$ (say.

$V = E_g - IR_a$.

Power developed, $P_g = E_g I$.

Power deliver to Load, $P_L = VI$.

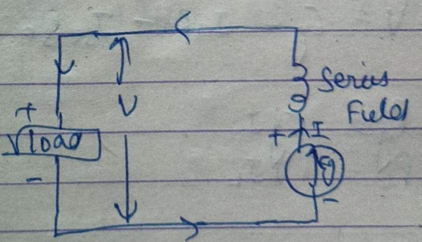
(ii). Self Excited DC generator – A dc generator whose field winding is excited by the current supplied by the generator itself is called Self Excited DC generator.

→ Field coils are interconnected with armature winding.
→ Field coils may be connected in series or Parallel with armature.

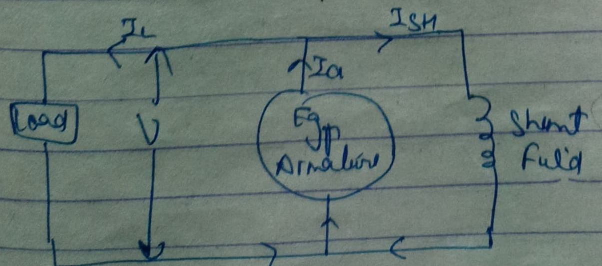
Its Further classified as :–
(a) Series wound generators.
(b) Shunt "
(c) Compound "

Series Wound Generator → R_{SE} → Resistance of series field winding.

$I_a = I_L = I_{se} = I$ (say).
$V = E_g - I(R_a + R_{se})$
$P_g = E_g I$.
$P_L = VI$.



Shunt Wound Generator.

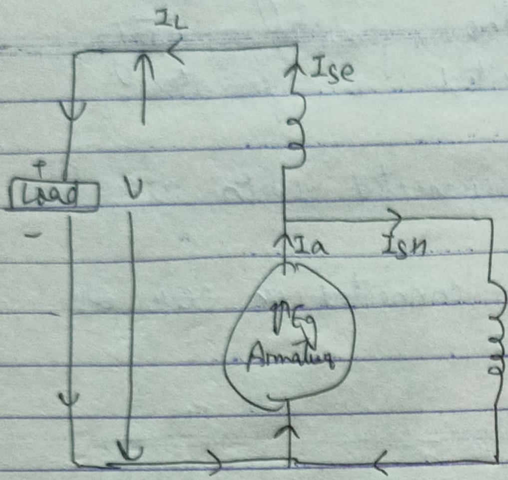


$\boxed{I_a = I_L + I_{SH}}$

$I_{sh} = \frac{V}{R_{SH}}$

$V = E_g - I_a R_a$
$P_g = E_g I_a$
$P_L = V I_L$

Compound Wound Generators.



⇒ Short shunt Compound wound.

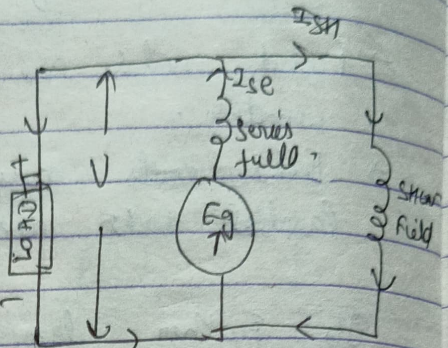
$$I_{se} = I_L$$

$$I_{SH} = \frac{V + I_{se}R_{se}}{R_{SH}}$$

$$\boxed{I_a = I_{SH} + I_L}$$

$$V = E_g - I_aR_a - I_{se}R_{se}$$

$$P_g = E_g I_a$$
$$P_L = V I_L$$



Long Shunt Compound wound.

$$I_{SH} = \frac{V}{R_{sh}}$$

$$I_a = I_{se}$$

$$\boxed{I_a = I_L + I_{SH}}$$

$$V = E_g - I_aR_a - I_{se}R_{se}$$

$$V = E_g - I_a(R_a + R_{se})$$

$$P_g = E_g I_a$$
$$P_L = V I_L$$

eg 8. $P = 4$. lap wound. $I = 100A$

$Z = 728$ (active conductors).

$N = 1800$ rpm

$\phi = 30 \times 10^{-3}$ Wb.

Voltage induced, $E = \frac{\phi P N}{60} \times \frac{2}{A}$

$= \frac{30 \times 10^{-3} \times \cancel{4} \times \cancel{1800}^{30} \times 728}{\cancel{60} \quad \cancel{4}}$

$= 655.2V$.

Power developed by armature $= 655.2 \times 100$

$= 65520 W$

eg 9. $P = 20 kW$ $\qquad$ $R_a = 0.05 \Omega$.

$V = 200$ $\quad$ Shunt generator

$R_{sh} = 200\Omega$.

$P_g = ?$

$P = V I_L$.

$20000 = 200 I_L$

$I_a = I_L + I_{sh}$.

$P_g = E_g I_a$.

$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{200}$

$I_a = 1A + 100A = 101A$.

$V = E_g - I_a R_a$

$200 + I_a R_a = E_g$.

$E_g = 200 + 101(.05)$

$E_g = 205.05 V$

$P_g = E_g I_a$

$P_g = 205.05(101) = 20710 W$

eg10. (Pole) $P = 8$ (shunt generator) wave convertor

$Z = 778$ $V = 250\,V$

$R_L = 12.5\,\Omega$ $R_a = 0.24\,\Omega$

$R_{SH} = 250\,\Omega$ $N = 500\,rpm$

$I_a = ?$ $E_g = ?$ $\phi = ?$

$I_{sh} = \frac{V}{R_{SH}}$

$V = E_g - I_a R_a$

$\left[I_{SH} = \frac{250}{250} = 1A \right]$

$I_a = I_L + I_{SH}$

$I_L = \frac{V}{R_L} = \frac{250}{12.5} = 20A$

$\boxed{I_a = 21\,A}$

$E_g = 250 + 21 \times .24$

$E_g = 255.04\,V$

$E_g = \frac{\phi P N}{60} \times \frac{Z}{A}$

$\phi = \frac{E_g \times 60 \times A}{P N \times Z} = \frac{255.04 \times 60 \times 2}{8 \times 500 \times 778}$

$(\phi = 9.834\,mWb)$

eg4. Pole $= 4$ lap connected Brush drop $= 2$

$R_{SH} = 80$ $R_a = 0.1\,\Omega$

Power (Load) $= 50 \times 60 = 3000\,W$

$V = 100\,V$

$I_L = \frac{P_L}{V} = \frac{3000}{100} = 30A$

$I_{sh} = \frac{10\cancel{0}}{8\cancel{0}} = 1.25A$

$I_a = I_L + I_{sh}$

$I_a = 30 + 1.25 = 31.25A$

$V = E_g - I_aR_a - \text{Brush drop}$

$E_g = V + I_aR_a + \text{Brush drop}$

$= 100 + 31.25(0.1) + 2$

$E_g = 105.125V$

eg 12. Pole = 4. wave wound.

slots = 40. having 12 conductors.

$R_a = 1\Omega$. $R_{SH} = 200\Omega$.

$\phi = 25 \times 10^{-3} Wb$.

$R_L = 50\Omega$. $N = 1000$ rpm.

(i) $V_L = ?$

(ii) V_L if Lap wound.

(i) $E_g = \frac{\phi PN}{60} \times \frac{Z}{A}$

$E_g = \frac{25 \times 10^{-3} \times 4 \times \cancel{1000}}{\cancel{60}} \times \frac{\cancel{40} \times \cancel{12}}{\cancel{2}} = 400V$

$V = E_g - I_aR_a$

$I_a = I_L + I_{sh}$

$I_L = \frac{V}{R_L}$ $I_{sh} = \frac{V}{R_{SH}}$

$\left[I_a = \frac{V}{50} + \frac{V}{200} = \frac{V}{40} A \right]$

$E_g = V + I_aR_a$

$400 = V + \frac{V}{40} \times 1 = \frac{41}{40} V$

$$V = \frac{400 \times 40}{41} = 390.24\,V$$

(ii) Lap wound.

$$E_g = \frac{\cancel{25\times10^{-3}} \times \cancel{4} \times \cancel{1000}}{\cancel{60}} \times \frac{\overset{2}{\cancel{12}} \times \cancel{40}}{\cancel{4}} = 200\,V$$

$$V = \frac{200 \times 40}{41} = 195.12\,V$$

eg13. Pole $= 4$. wave-connected.
41 slots with 12 conductors / slot.
$R_a = 0.5\,\Omega$ $\quad R_{sh} = 200\,\Omega$
$\phi = 125 \times 10^{-3}\,wb$ $\quad N = 1000\,rpm$.
$R_L = 10\,\Omega$ $\quad V = ?$

$Z = 41 \times 12$.

$$E_g = \frac{\phi P N}{60} \times \frac{2}{A} = \frac{\cancel{12} \times \overset{25}{\cancel{125}} \times \overset{5}{\cancel{10^{-3}}} \times \cancel{4} \times \overset{2}{\cancel{1000}} \times 41}{\underset{5}{\cancel{60}} \times \cancel{2}}$$

$E_g = 2050\,V$

$V = E_g - I_a R_a$.

$I_a = I_L + I_{SH}$.

$$I_a = \frac{V}{10} + \frac{V}{200} = \frac{21\cancel{0}}{\cancel{200}} = \left(\frac{21\,V}{200}\right) A.$$

$$E_g = V + \frac{21\,V}{200}\left(\frac{0.5}{10}\right).$$

$$2050 = \frac{(2000 + 105)\,V}{2000}$$

$$V = \frac{2050 \times \overset{400}{\cancel{2000}}}{\underset{421}{\cancel{2105}}} = 1947.7\,V.$$

eg 14. Pole = 4 long shunt lapwound.

$V = 500V$. $P_L = 25kW$

$R_a = .03\,\Omega$ $R_{se} = 0.04\,\Omega$

$R_{sh} = \cancel{0.04\,\Omega}$ $200\,\Omega$.

Brush drop = 1 V. Emf generated = ?

$P_L = 25000W$.

$$I_{sh} = \frac{V}{R_{sh}} = \frac{5\cancel{00}}{2\cancel{00}} = 2.5\,A.$$

$I_a = I_L + I_{sh}$.

$= 50 + 2.5$

$I_a = 52.5\,A$

$P_L = V I_L$.

$$\frac{\overset{50}{\cancel{25000}}}{\cancel{500}} = I_L$$

$E_g = V + I_aR_a + I_aR_{se} +$ Brush drop.

$= 500 + 52.5(.03) + 52.5(.04) + 1$.

$$\boxed{E_g = 504.675\,V}$$