Synchronous Generators

Synchronous generator = Alternator

To obtain electrical power:-
1. loop rotating , B fixed
or 2. loop fixed , B rotating

• المهم أن تتقطع خطوط المجال ليتولد جهد (فرق جهد) كهربائي ≡ V induced

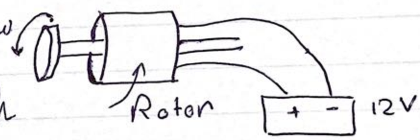
• اشكال الـ Rotor
1. Salient
2. nonsalient

▶ Alternator is composed from:-
Rotor and Stator

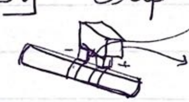
▶ Bearings are used to split Rotor from Stator

▶ Prime mover gives a mechanical Rotational energy
It takes it from a turbine

▶ Electrical magnet is used and It is given a power source (Battery)
Given 12 volt
Resulting Voltages is much higher



▶ The Battery wires are connected by Slip rings and brushes (مادة كربونية موصلة)

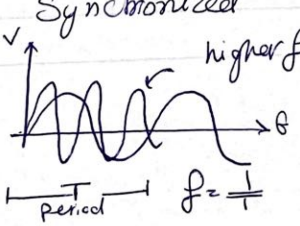


Why is it called synchronous?

$n_m = \frac{120 f_e}{P}$

Synchronized

There is Synchronization between mechanical energy (ω) and electrical frequency (f_e)



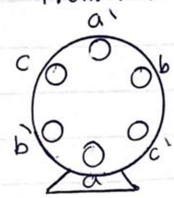
$f = \frac{1}{T}$

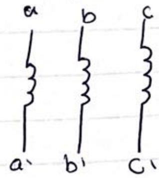
▸ For 3-phase generator

→ large ω will produce centrifugal force that will cause failure

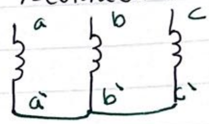
→ we increase number of Poles (F_c ↓) and so ω will decrease

Front view

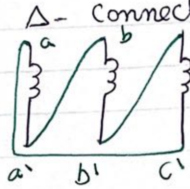




Y-connection :- (star)



Δ- Connection:-



Slides:-

Synchronous generator : synchronous machines that are used to convert mechanical power to electrical power

Dc current → rotor winding → rotor magnetic field (stationary)

Then rotor is turned (Prime mover) producing rotating magnetic field → 3 phase induced voltage

تقطع خطوط
مجال

Winding on a machine

1. field windings : rotor windings that produces main magnetic field

2. Armature windings : Stator windings that produces induced magnetic field

Rotor

- large electromagnet or natural magnet
- Poles are
  1. non salient
  2. Salient

  } → steel laminations are used for Both

To Supply Dc source:-

1. External (Slip Rings) and Brushes → Block of graphite like carbon compound that conducts electricity freely but has low friction to prevent wear from rings.

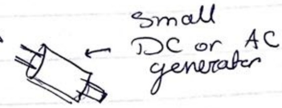
   Slip Rings ↓ Electromechanical device that allows the transmission of power and Electrical signals from a stationary to a rotating structure

Problems :- 1. maintance (Brushes wear)
2. Brush voltage drop can cause significant power losses on machines with larger field currents

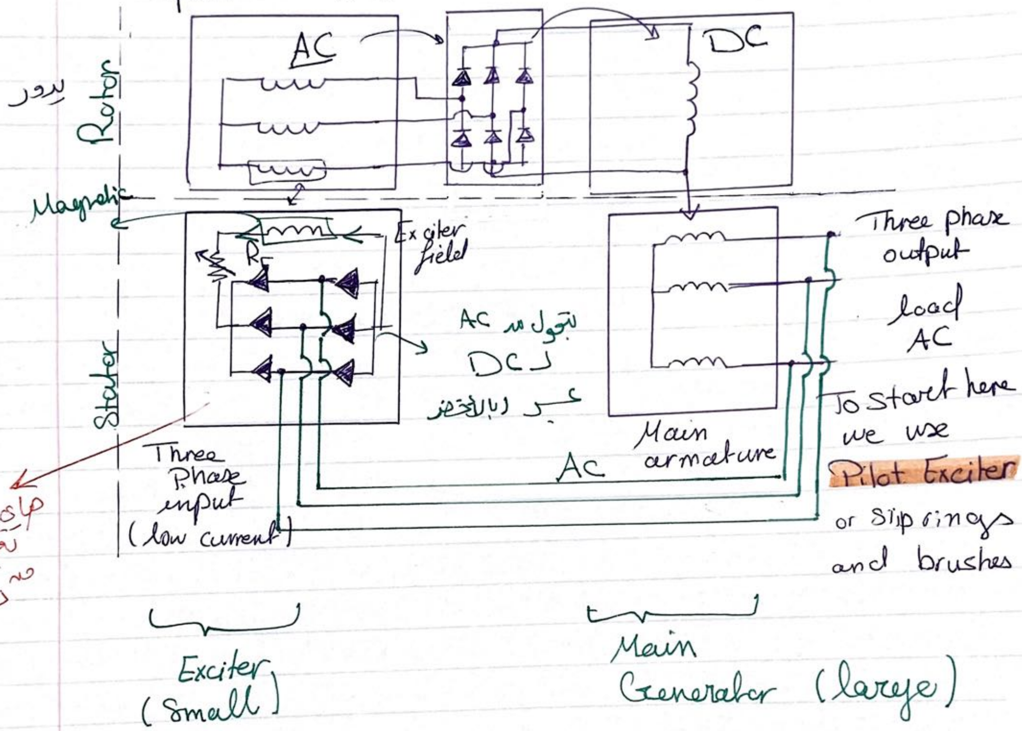
3. Used on small Synchronous generators

2. Special Dc source mounted on the shaft (for larger machines)

Brushless exciters



• requirs much less maintanance

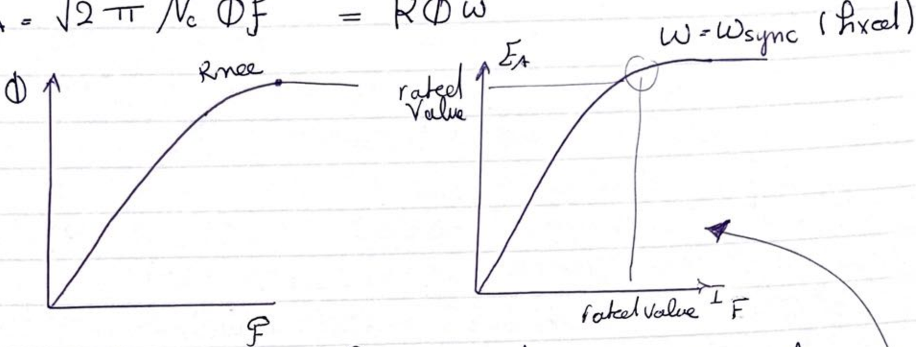


Pilot Exciter : No External power source
A small AC generator with permanent magnets mounted on the rotor shaft
These produce power for the field circuit of the exciter and so produces the field current of the main machine

• We use sliprings & brushes as a back up DC sources in generators

Induced voltage of the Generator

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



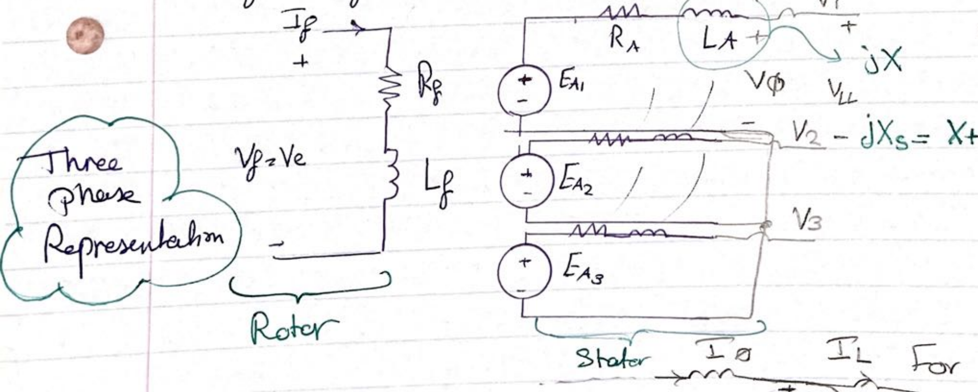
Magnetization curve for synchronous generator

If ω is constant : E_A = Constant ϕ so $E_A \propto \phi$

$E_A \propto N i$ (N constant)

$E_A \propto i$ I_F field current

• **Notice** : that there will be a current passing in the stator → magnetic field. This is considered to be a noise for main magnetic field and It is called **Armature reaction**



Y connection

$V_\phi = V_1$

$V_{LL} = V_1\sqrt{3}$

$-jX_s = X + X_A$ (Armature reaction)

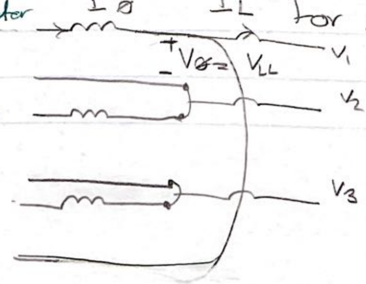
$I_L = I_\phi$

For Δ connection

$V_\phi = V_{LL}$

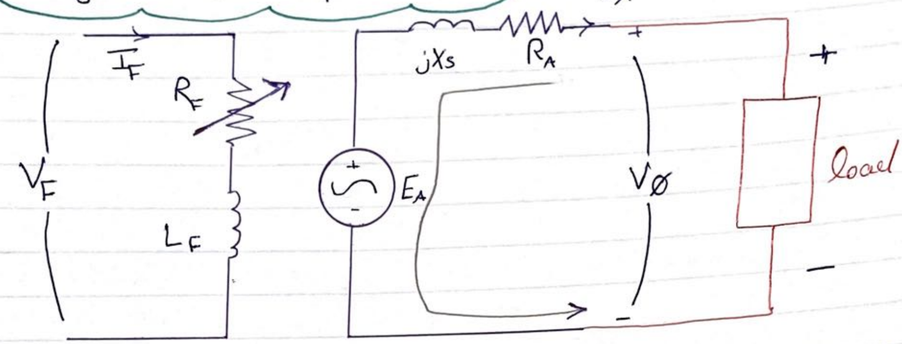
$I_\phi = \frac{I_L}{\sqrt{3}}$

These are Important to know



V_ϕ: Terminal (6)
$= E_A$ if open circuit

Single line representation



KVL

$$-V_\phi - I_A(R_A + X_s j) + E_A = 0$$

$$E_A = V_\phi + I_A(R_A + jX_s)$$

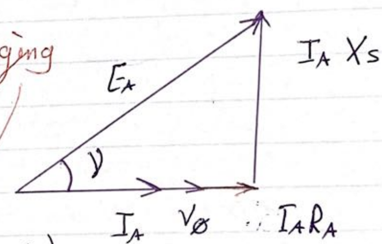
- المقاومة المتغيرة تكون للتحكم بـ I_F لأنه V_F ثابتة
- اذا بدنا نزيد V_ϕ نقلل I_F
- اذا بدنا نقلل V_ϕ نزيد I_F
- Reactive Power ≡ Magnetization current ولا عكسه كوليه لـ source احسبو

▶ If a load is inserted I_A changes

Load can be:-

1. Resistive : R_L → unity

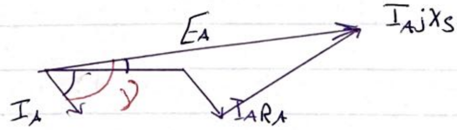
$$\vec{E}_A = \vec{V}_\phi + \vec{I}_A(R_A + X_s j)$$



lagging

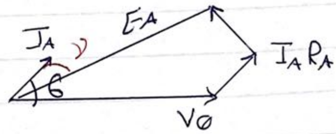
2. Inductive : R_L, jX_L (اكثر شيوعاً)

$$\vec{E}_A = \vec{V}_\phi + \vec{I}_A(R_A + X_s j)$$



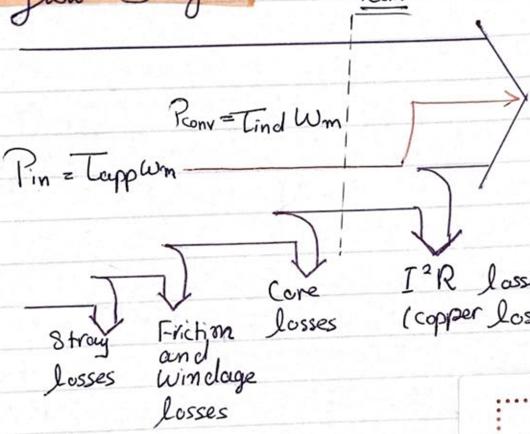
3. Capacitive load R_L, jX_L leading

$$\vec{E}_A = \vec{V}_\phi + \vec{I}_A (R_A + X_s j)$$



- If $V_{Load} > V_{generator}$
  power flow will be reversed

Power flow Diagram



$$P_{out} = \sqrt{3}\, V_L I_L \cos\theta$$
$$= 3 V_L I_A \cos\theta$$
$$= 3 V_\phi I_A \cos\phi$$

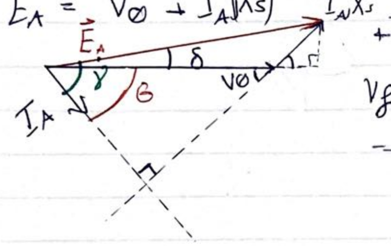
$$I_A = \frac{I_L}{\sqrt{3}}$$

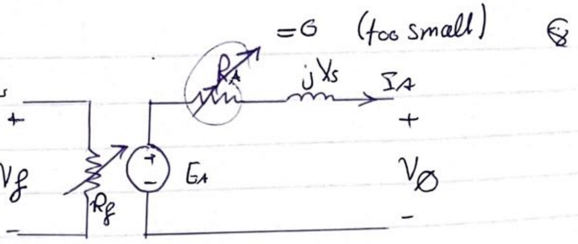
$P_{conv} = 3 E_A I_A \cos\delta$ — see three shapes

Since Three phase :-

- Copper losses $= 3 R_A (I_A)^2$
- Core losses = Hysteris; + Eddy
- Windage losses & friction: stator, Rotor صد الهواء بين
- Stray losses = الخسارة الي ليس لها تفسير

$$\vec{E}_A = \vec{V}_\phi + I_A(jX_s)$$





δ : Between E_A, V_ϕ
γ : Between E_A, I_A
θ : Between V_ϕ, I_A

$V_{LL} = V_T$
$V_\phi = V_{LN}$

$E_A \sin\delta$ on y-axis
$E_A \cos\delta$ on x-axis

$$E_A \sin\delta = X_s I_A \cos\theta$$

$$I_A \cos\theta = \frac{E_A \sin\delta}{X_s}$$

So $P = 3 V_\phi I_A \cos\theta$

$P = \frac{3 V_\phi E_A \sin\delta}{X_s}$ ← Another formula considering $R_A = 0$

In this case

$$P_{conv} = P_{out}$$

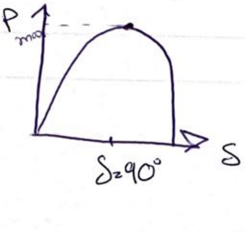
$$\tau_{ind}\,\omega_m = \frac{3 V_\phi E_A \sin\delta}{X_s}$$

$$\tau_{ind} = \frac{3 V_\phi E_A}{X_s \omega_m} \sin\delta$$

when δ = 90, τ is Max and Power is Maximized

$$\tau_{max} = \frac{3 V_\phi E_A}{X_s \omega_m} \sin\delta$$ ← ①

δ is called Torque Angle



- **If load is increased on a generator alone**

$\vec{E}_A = V_T + \vec{I}_A (jX_s)$

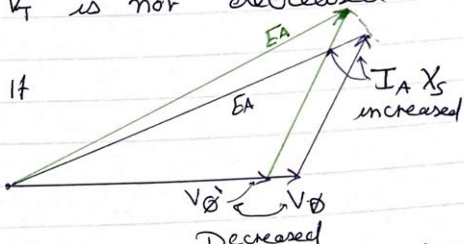
$\vec{E}_A$ constant (ω constant, R_f constant); V_T ↓; $\vec{I}_A$ ⇑

Load ↑ :- real and reactive power ↑ and I_A will ↑

▶ Goal: make sure that V_T is not decreased

But first, Analyze how V_T decreases

lagging power factor load



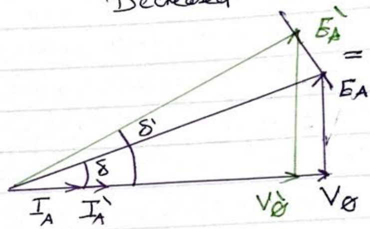
PF lagging (θ negative)

I_A ↑ , V_ϕ ↓

Unity power factor load

PF = 1

I_A ↑ and V_ϕ ↓

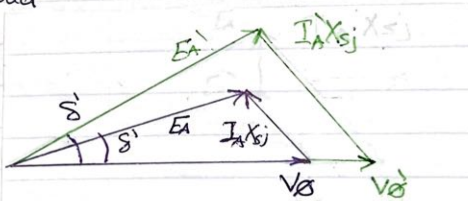


leading Power factor load

In this case:

I_A will ↑

V_ϕ will ↑ why?



(Storage)

capacitor: Charging element so it will increase the voltage of load

- If V_T is increasing and $> E_A$, I_A will be reversed

This occurs at No load or light load (عكس الحمل الأقل)

So company needs to be careful for that not to happen

Voltage Regulation

$$VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

- lagging load: $VR > 0$ (large)
- unity loads: $VR > 0$ (small)
- leading load: $VR < 0$ (large)

- It is prefferred to keep V_T constant so E_A must be controlled by controlling I_F which controls flux
- I_F can be controlled by controlling R_F

$$\downarrow R_F \rightarrow \uparrow I_F \rightarrow \uparrow \phi \rightarrow \uparrow E_A \rightarrow \uparrow V_\phi$$

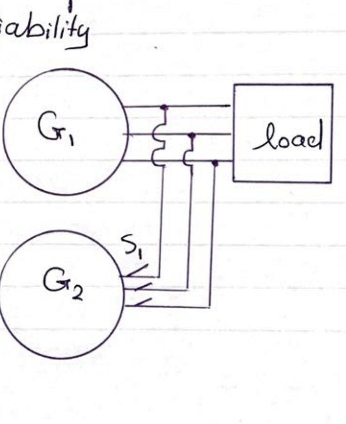
$$\uparrow R_F \rightarrow \downarrow I_F \rightarrow \downarrow \phi \rightarrow \downarrow E_A \rightarrow \downarrow V_\phi$$

Parallel operation of Generators

Why Parallel?

- Handling large loads
- Maintance without power disruption
- Increasing power system reliability
- Increasing efficiency

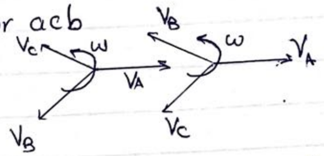
G_1 : main Generator
G_2 : ncoming Generator



- Conditions needed to be checked to close S_1

1- RMs equal (for line voltages)
2- Same phase sequences abc or acb
3- Same phase Angle
4- f_2 a little bit higher

for G_1 to know that G_2 is helping



- If Different sequences were used : High currents will flow in b,c and machine is damaged

- Any unchecked condition will damage the device