Energy conversion I

Lecture 13:

Topic 4: Synchronous Machines (S. Chapman ch. 5&6)

- **Introduction**
- **Synchronous Generators Construction**
- **Steady state equivalent circuit**
- Power and Torque
- Grid connected Synchronous machines
- Synchronous motors
- Power factor correction
- Start-up of synchronous motors

Introduction

Synchronous Machines

Synchronous Generators / Alternators:

The most common Electric Generator coupled to: Steam / Gas / Hydro Turbines, Diesel Engines, …

- **Can operate in inductive / capacitive mode**
  - **Needs DC current as rotor excitation**
  - **additional maintenance for brushes**

Synchronous Motors:

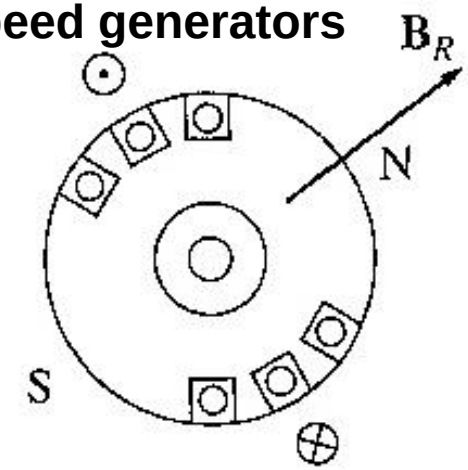
In PM or wounded rotor type, used for constant speed or servo drives (speed/position control).

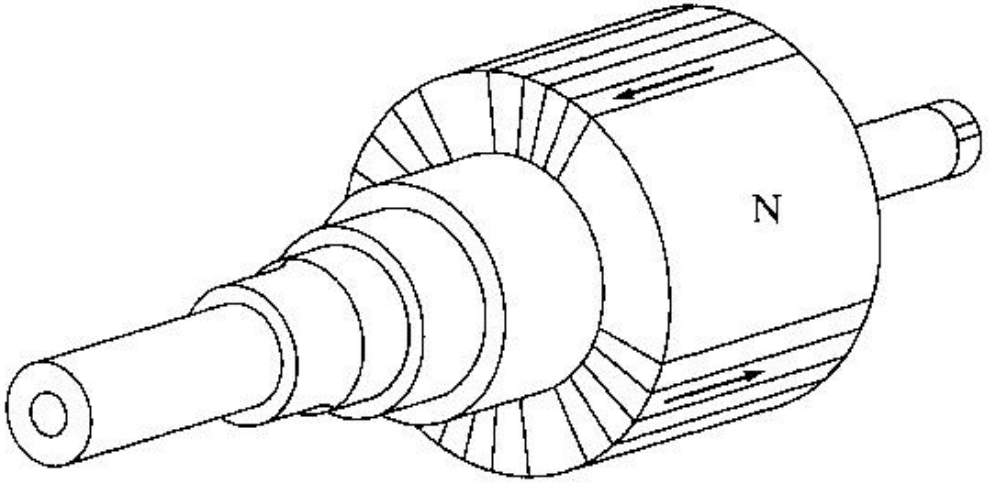
- **Speed is controlled with frequency**
- **Precise control of speed**
- **Can operate in inductive / capacitive mode**
  - **No start-up torque**
  - **The same problems of generators if wound rotor**

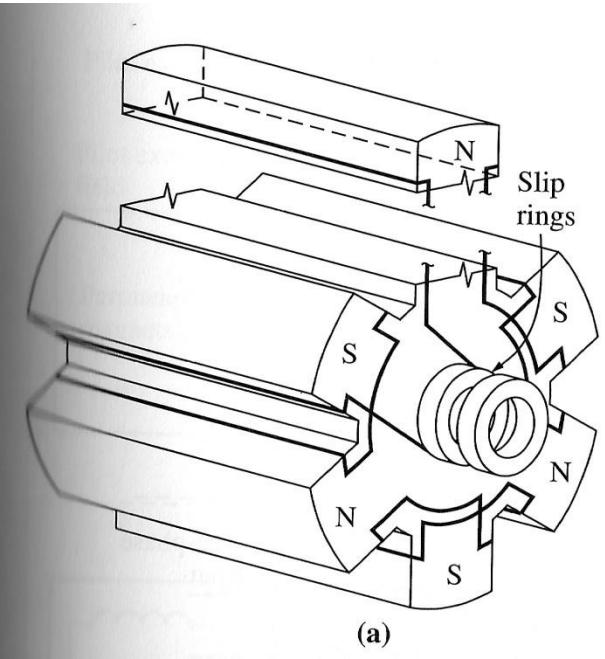
Synchronous Generators Construction

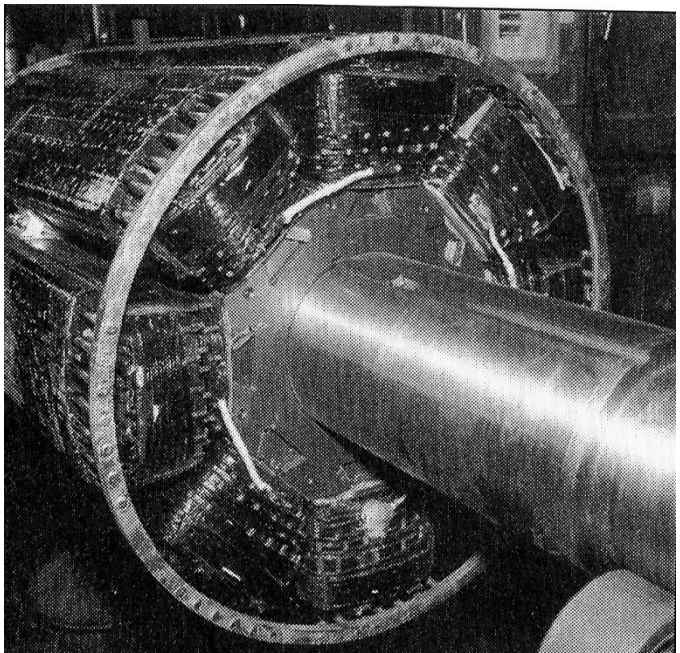
Rotor Magnetic field is generated by DC current in wound rotor machines / Permanent Magnet (mainly for motors)

Rotor is cylindrical in high speed (2 or 4 pole) generators or salient pole in low speed generators



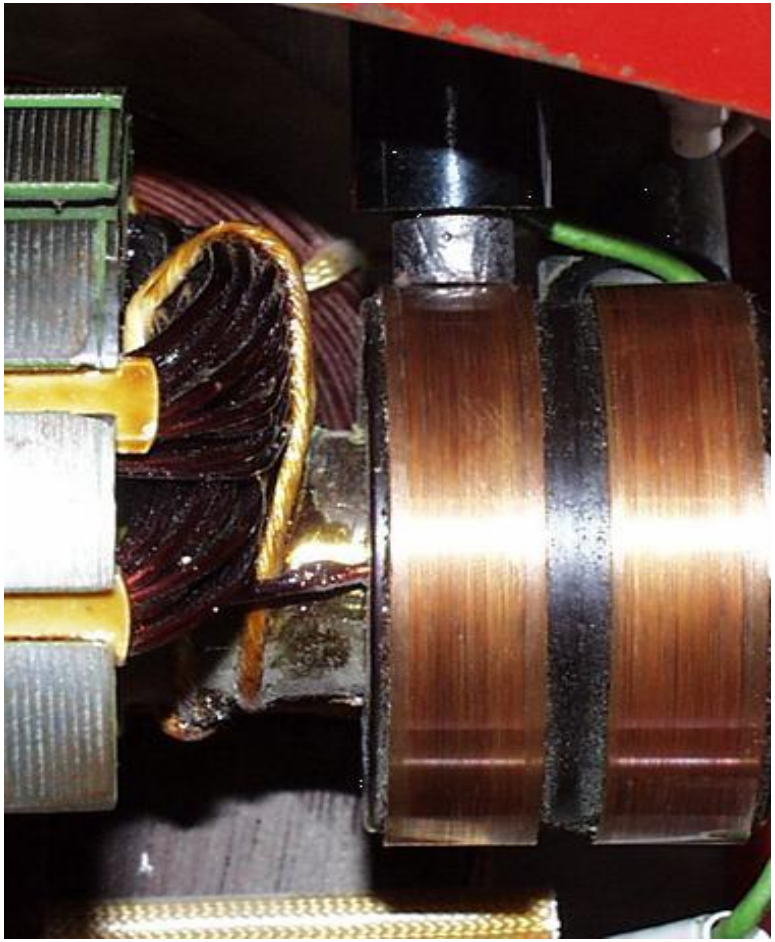


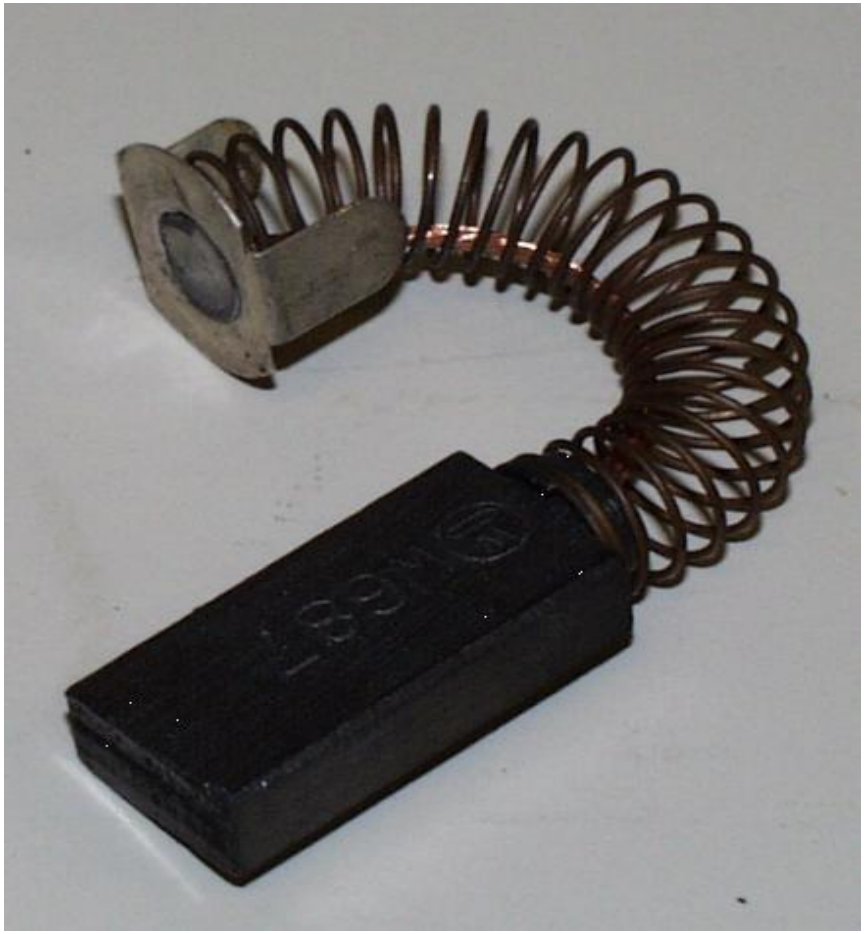




Synchronous Generators Construction

Rotor DC current can be supplied through Slip rings and brushes.





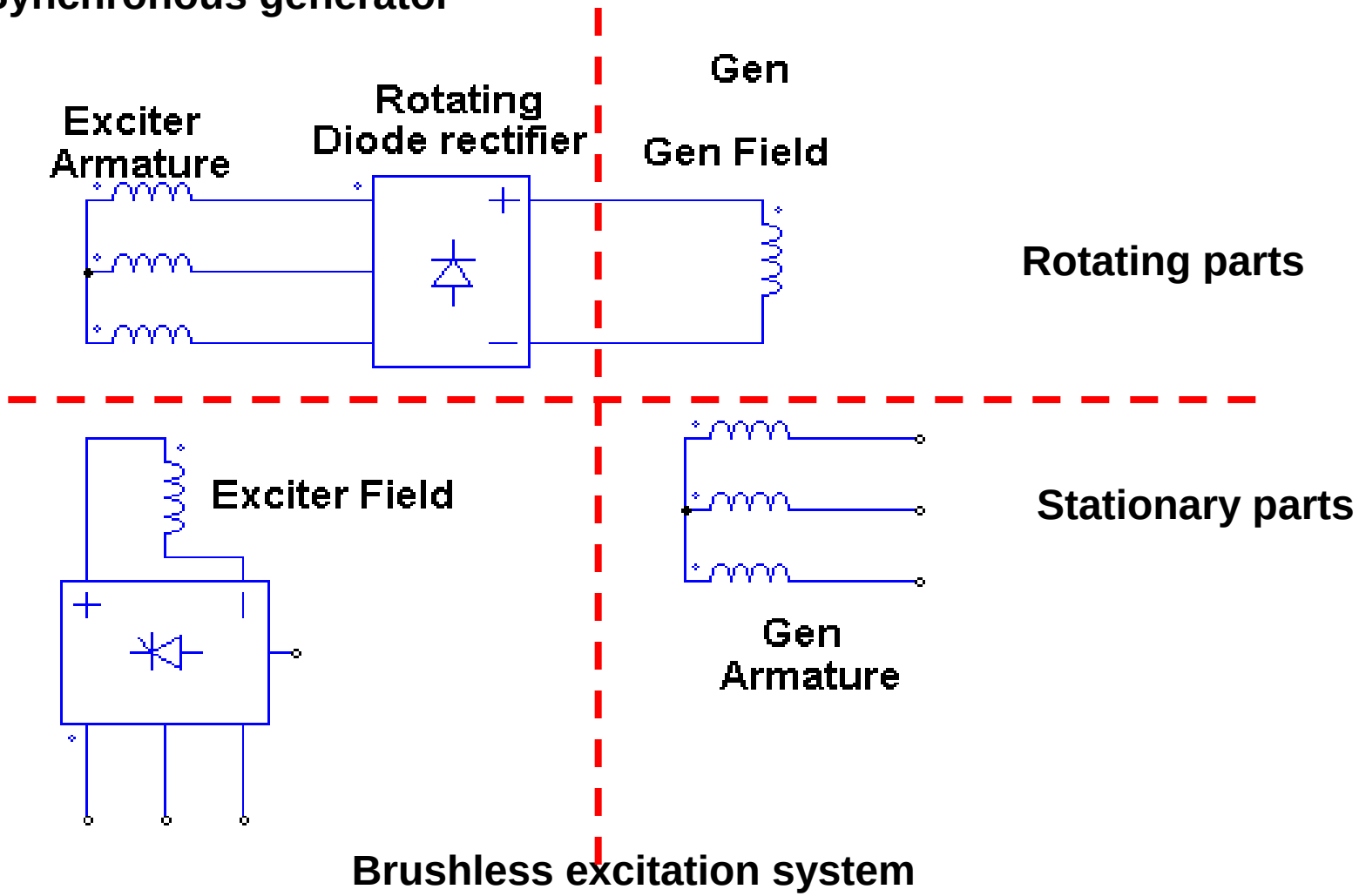
Needs high power controllable DC power

Increases maintenance

Brushes problem for high current applications

Synchronous Generators Construction

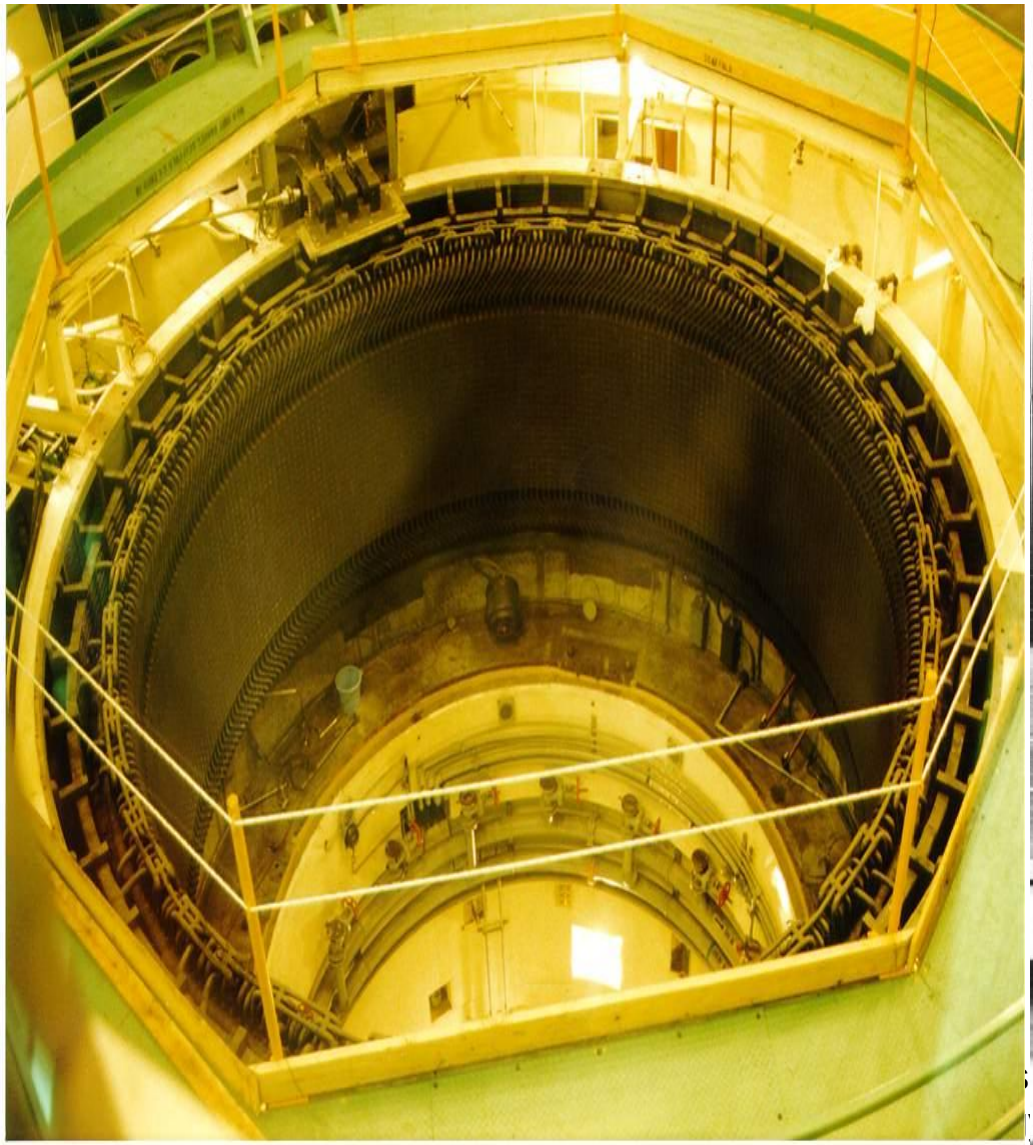
Rotor DC current can be supplied through rotating diode rectifier fed by an inverted Synchronous generator



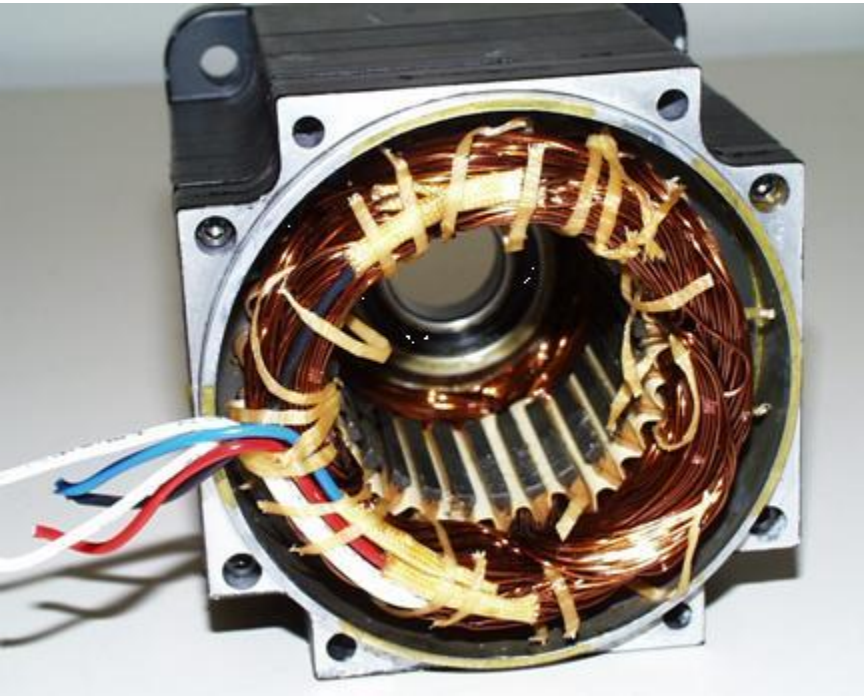
Complex control

Synchronous Generators Construction

Stator winding is a distributed three phase winding.



Synchronous Generators Construction



Steady state equivalent circuit

Steady state operation:

Rotor rotates with synchronous speed ($n_s = 2/p \times f_s \times 60$ rpm)

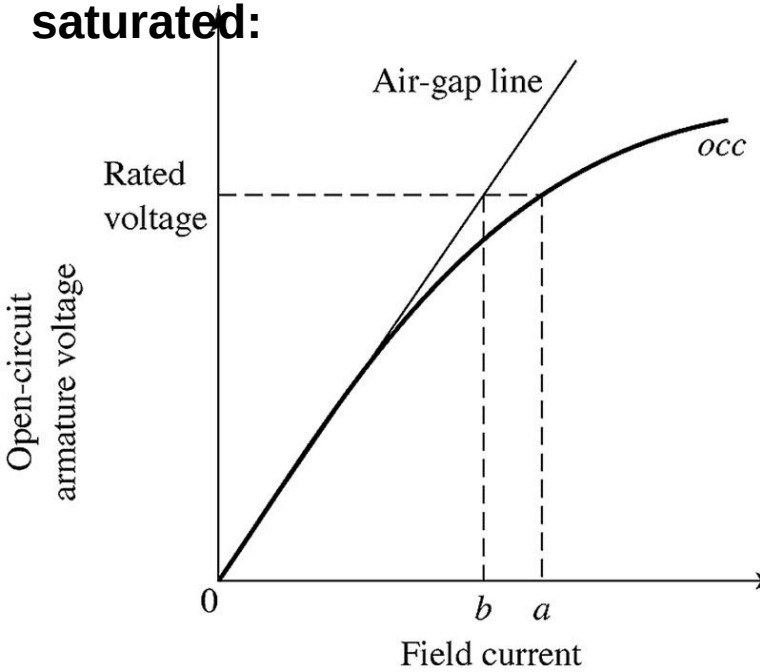
Rotor (/ field) current is reached to its steady state value ($I_f = V_f / R_f$)

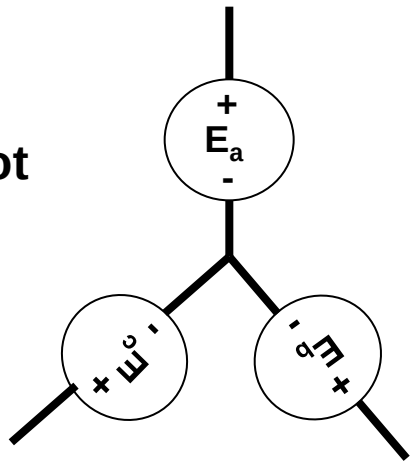
Stator (/ armature) currents reached to its steady state value (three phase current)

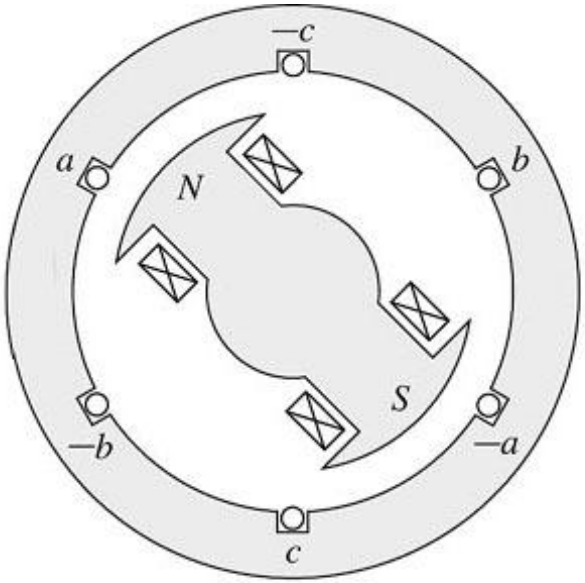
Rotating rotor flux induces three phase voltages in stator three phase winding:

$$E_a = K\varphi\omega$$

E_a is a linear function of I_f if core is not saturated:







E_a is open circuit armature voltage

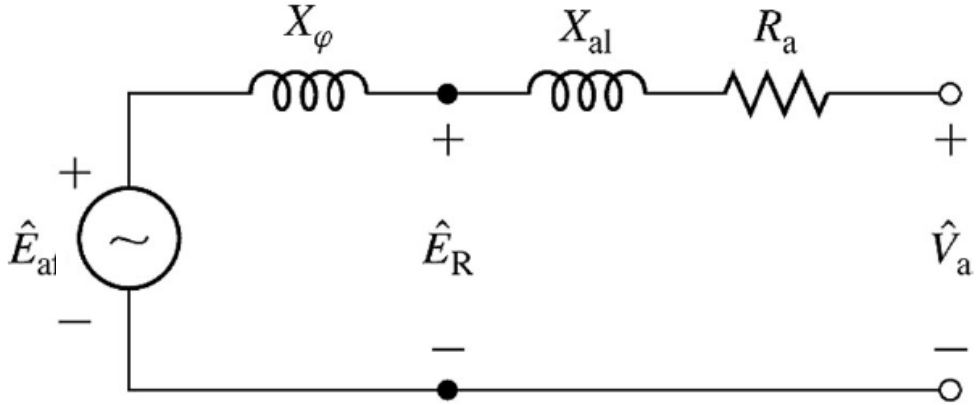
Think about Δ connected windings!!

Steady state equivalent circuit

Rotating stator flux induces three phase voltages in stator three phase winding too (armature reaction).

This induced voltage is similar to the induced voltage in inductances.

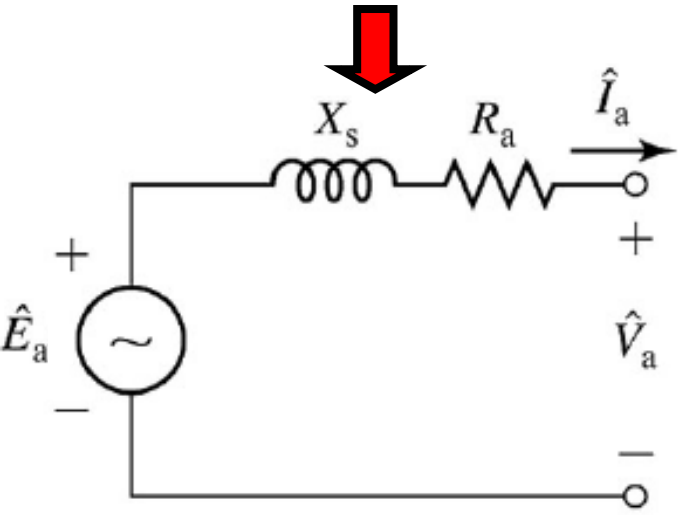
Using Single phase equivalent circuit:



$B_r \rightarrow E_a$, $B_g = B_r + B_s \rightarrow E_R = E_a + E_{stat}$

Flux leakage can be modeled by L_{al}

Winding resitance by R_a



Using generator form for equivalent circuit:

$V_a = E_a - jX_s I_a - R_a I_a$

Think about equivalent circuit of Rotor in steady state!!

What about salient pole machines?