Lecture-43

Synchronous Generator

Lecture delivered by:

Topics

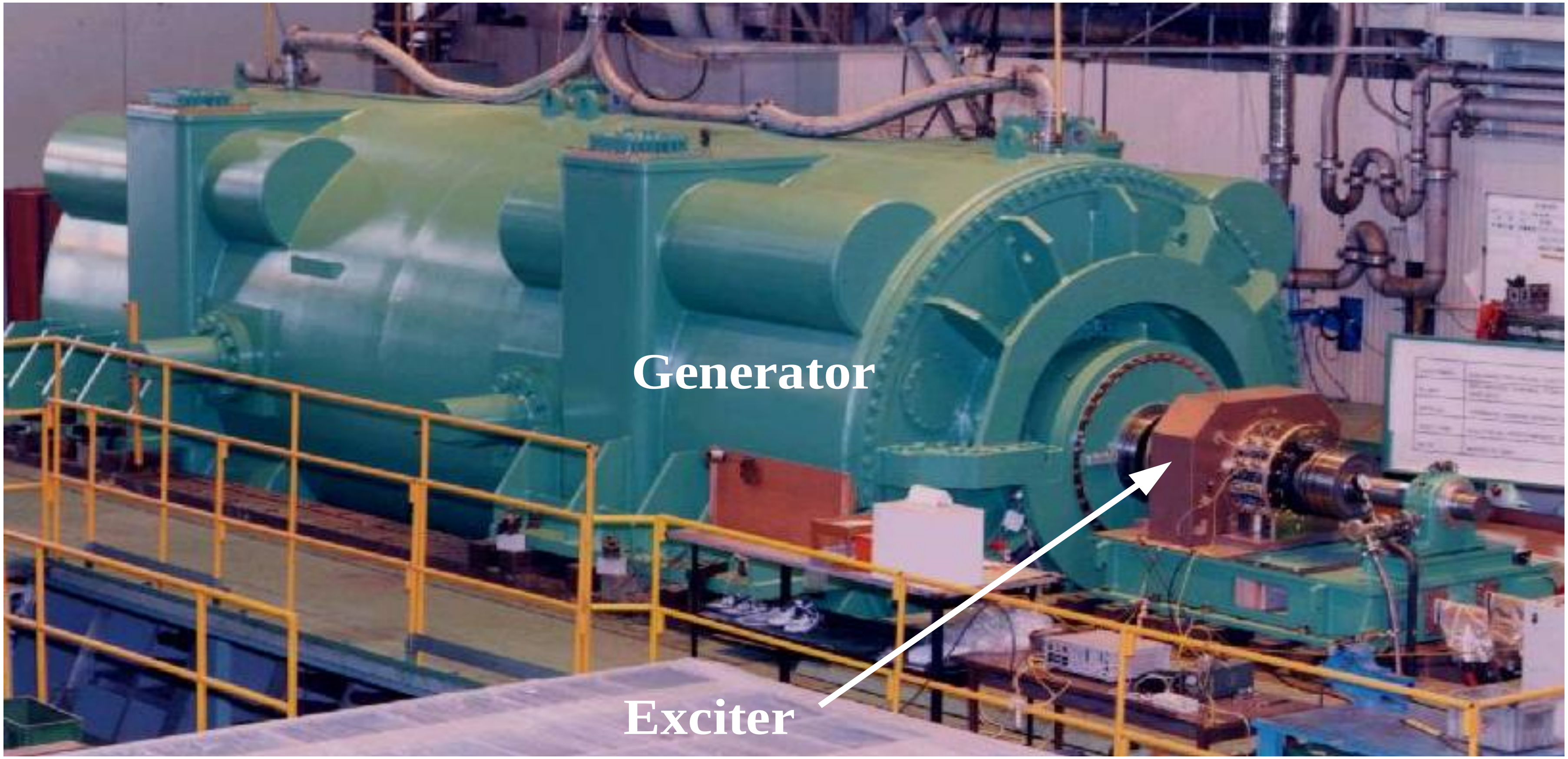
- Synchronous Generator Introduction
- Construction Details of Synchronous Generator
- Principle of operation of Synchronous Generator
- Expressions for Speed and Induced Voltage
- Equivalent Circuit of Synchronous Generator

Objectives

At the end of this lecture, student will be able to:

- Discuss the constructional details of Synchronous Generator
- Describe the principle of operation of Synchronous Generator
- Derive the expressions for Speed and Induced Voltage
- Develop the Equivalent Circuit of Synchronous Generator

Synchronous Generator



View of a two-pole round rotor generator and exciter

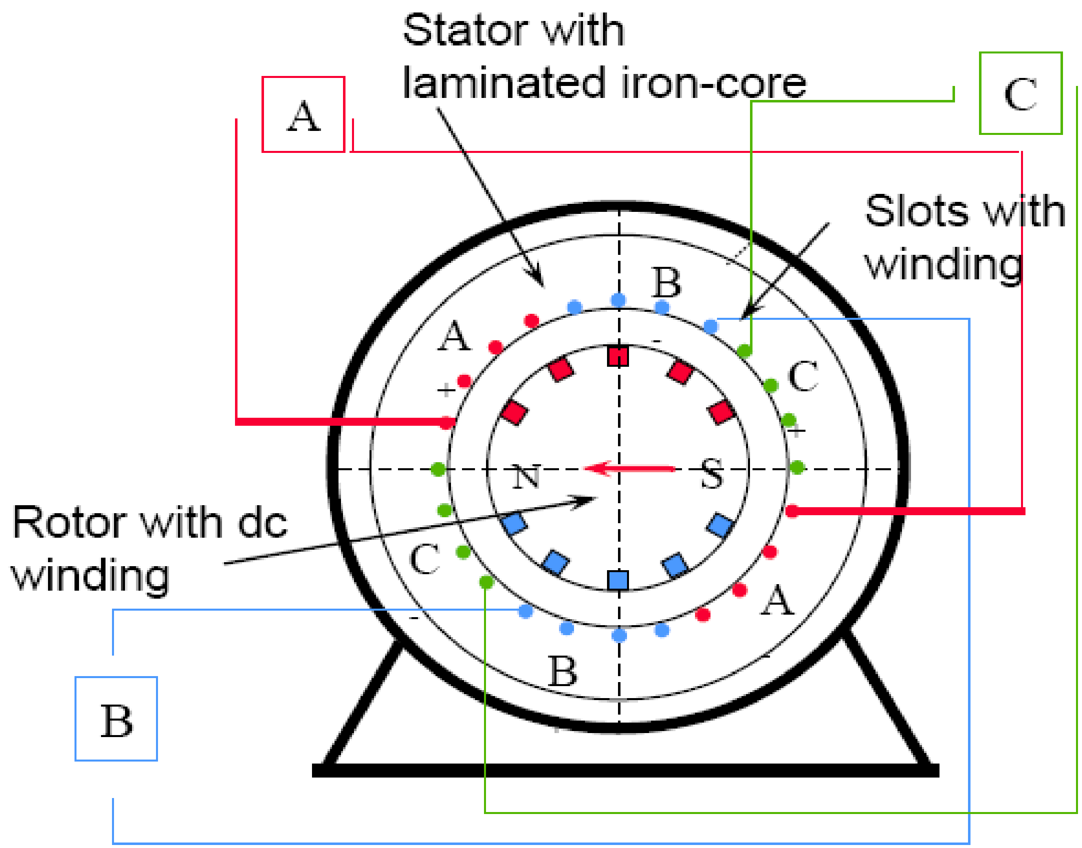
Introduction

- Unlike the induction machines, rotating air gap field and the rotor rotate at the same speed, called the synchronous speed.
- Synchronous machines are used primarily as generators of electrical power, called synchronous generators or alternators.
- synchronous generators are usually large machines generating electrical power at hydro, nuclear, or thermal power stations.
- Application as a motor: pumps in generating stations, electric clocks, timers, and so forth where constant speed is desired.

Applications of Synchronous Machines

Round Rotor Machine

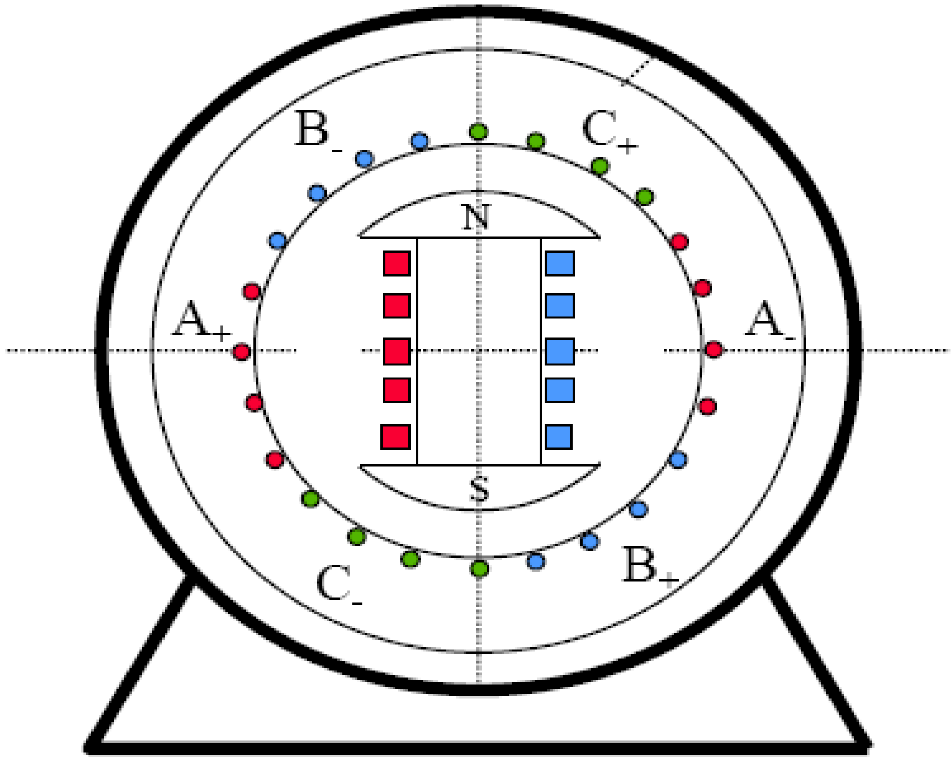
- The stator is a ring shaped laminated iron-core with slots.
- Three phase windings are placed in the slots.
- Round solid iron rotor with slots.
- A single winding is placed in the slots. Dc current is supplied through slip rings.



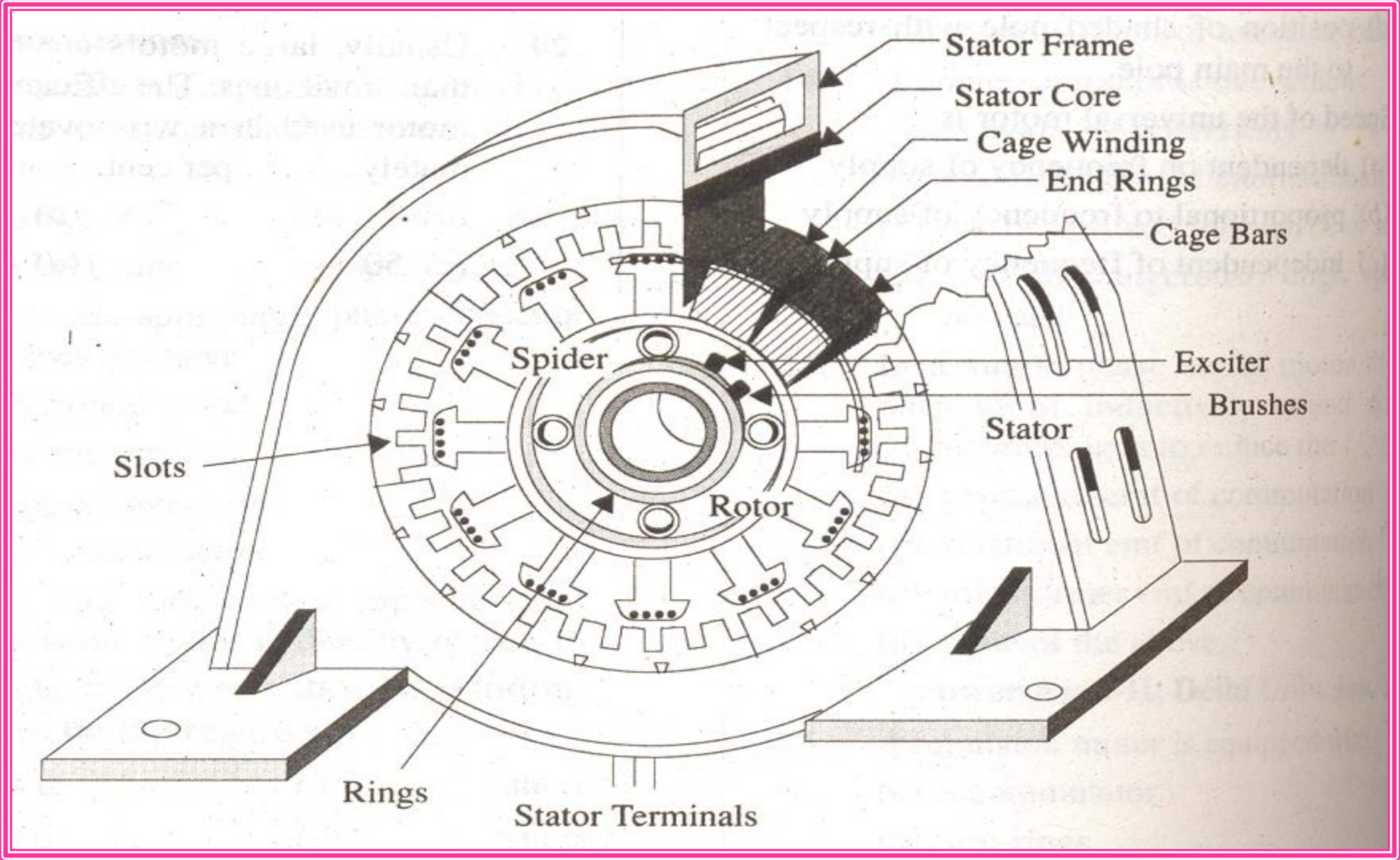
Actual View of Round Rotor Machine

Salient Rotor Machine

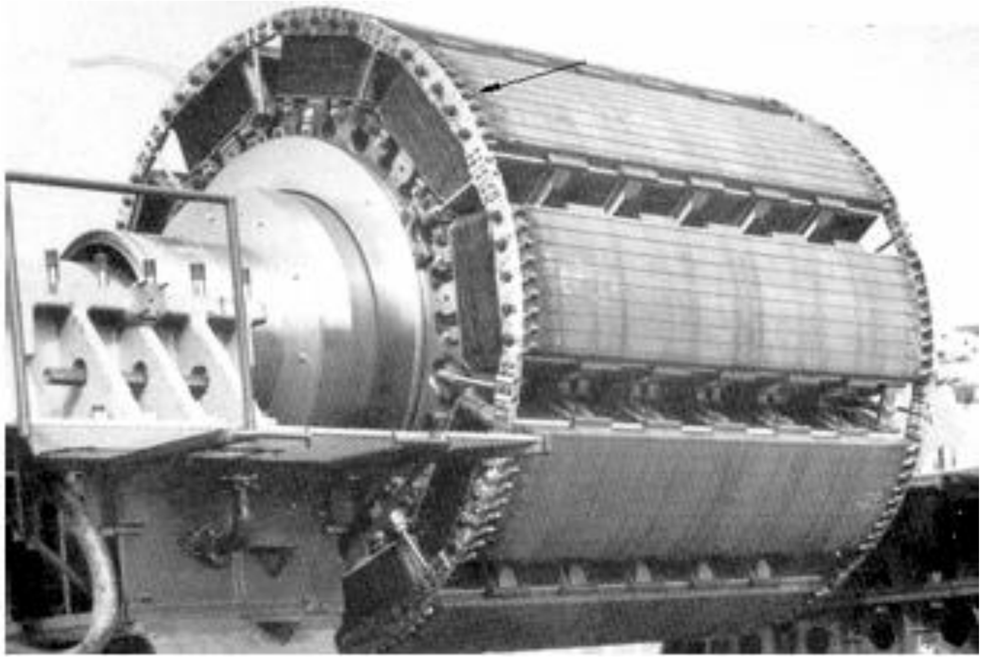
- The stator has a laminated iron-core with slots and three phase windings placed in the slots.
- The rotor has salient poles excited by dc current.
- DC current is supplied to the rotor through slip-rings and brushes.



Construction Details of Synchronous Generator



Actual View of Salient Rotor Machine



Synchronous Generator

- In Synchronous Generator, a DC current is applied to rotor winding (produce rotor magnetic field).
- The rotor is turned by prime mover producing a rotating magnetic field.
- The rotating magnetic field produce three phase sets of voltages within the stator.
- It has:

    - Armature winding [in stator]

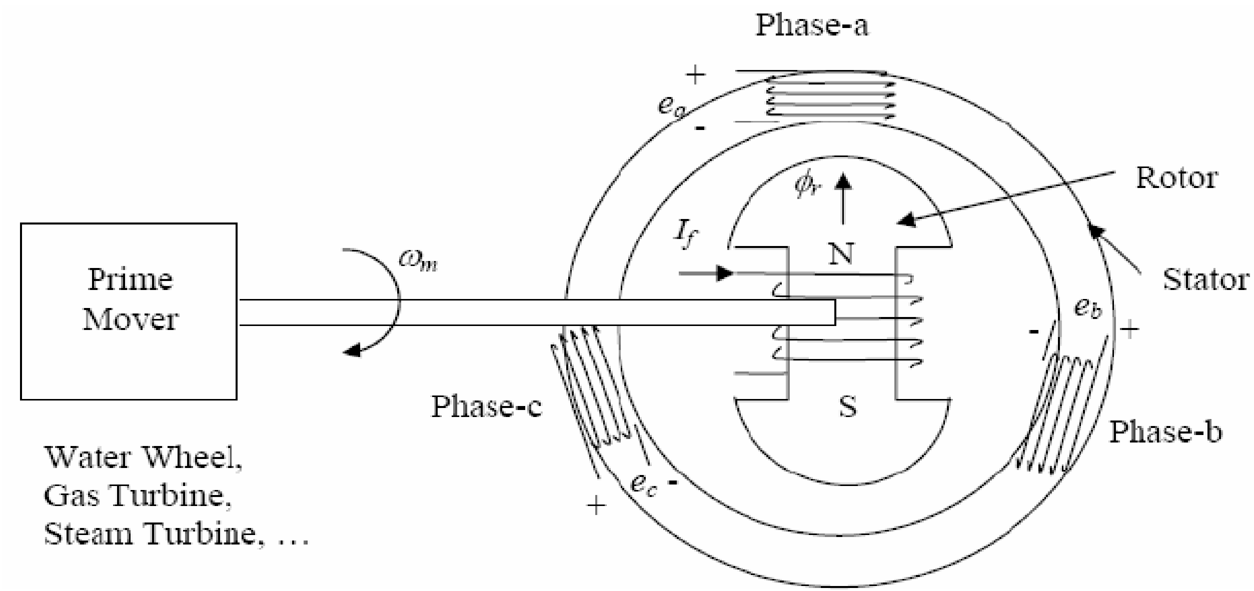
    - Field winding [in rotor]

Synchronous Generator

Principle of Operation

1) From an external source, the field winding is supplied with a DC current -> excitation.

2) The rotating magnetic field produced by the field current induces voltages in the outer stator (armature) winding. The frequency of these voltages is in synchronism with the rotor speed.



Synchronous Generator

Principle of Operation

The rotor of the generator is driven by a prime-mover

↓

A dc current is flowing in the rotor winding which produces a rotating magnetic field within the machine

↓

The rotating magnetic field induces a three-phase voltage in the stator winding of the generator

Generated Voltage of Synchronous Generator

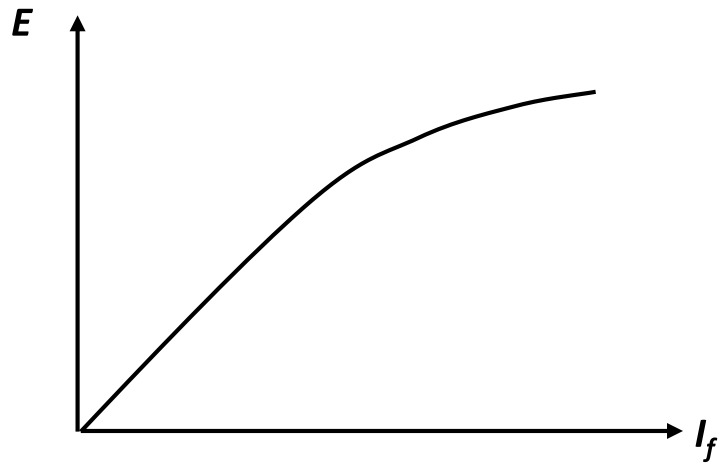
The generated voltage of a synchronous generator is given by

$$E = K_c \phi \; f_e$$

where ϕ = flux in the machine (function of I_f)

f_e = electrical frequency

K_c = synchronous machine constant



Saturation characteristic of a synchronous generator.

Speed of Rotation of Synchronous Generator

- Synchronous means that the electrical frequency produced is locked with the mechanical rate of rotation of the generator.

$$f_e = \frac{P}{2} f_m = \frac{P}{2}\left(\frac{n_m}{60}\right) = \frac{P n_m}{120} \Rightarrow$$

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

Example:

- Determine the rotation speed (r/min)for SG consists of :
  - 2 poles, 50 HZ, 2 poles 60 Hz,
  - 4 poles 50 HZ, 4 poles 60 Hz
- Determine number of poles for 50 Hz operation of SG at 1000 r/min ?

Induced voltage of Synchronous Generator

Induced voltage in SG is given by following formula

$$E_A = \sqrt{2}\pi N_c \phi f = 4.444 N_c B A f$$

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

$$E_A = K\phi\omega$$

N = number of turns,
B= flux density,
A = cross sectional area of the magnetic circuit,
f = frequency,
ϕ= flux per pole

K : constant represents construction of machine

ωradian /s

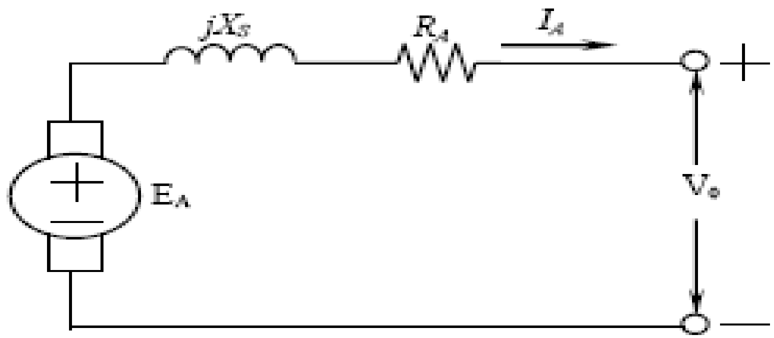
EA: is proportional to flux and speed , flux depend on the current flowing the rotor field circuits field

Per Phase Equivalent Circuit of the Synchronous Generator

$$V_\phi = E_A + E_{stator}$$

$$E_{stator} = -jXI_A$$

$$V_\phi = E_A - jXI_A$$



- X: represents the effect of armature reaction reactance only.

$$X_S = X + X_A$$

$$V_\phi = E_A - jX_SI_A - R_AI_A$$

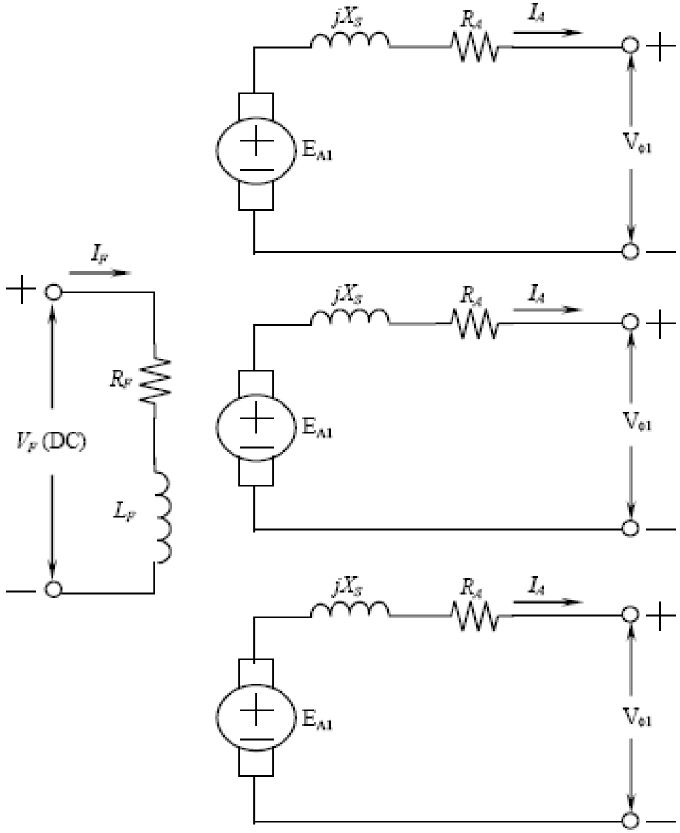
Three Phase Equivalent Circuit of the Synchronous Generator

- The three phases can be either **Y** or **Δ** . If they are **Y** connected, then the terminal voltage **VT** is related to the phase voltage by

$$\boxed{V_T = \sqrt{3}\, V_\phi}$$

If Δ connected :

$$\boxed{V_T = V_\phi}$$



Equivalent circuit of a three-phase synchronous generator

Summary

- Synchronous generators are usually large machines generating electrical power at hydro, nuclear, or thermal power stations.
- Generated voltage of a synchronous generator is $\boldsymbol{E = K_c \phi \ f_e}$
- In Synchronous Generator, a DC current is applied to rotor winding to produce rotor magnetic field.