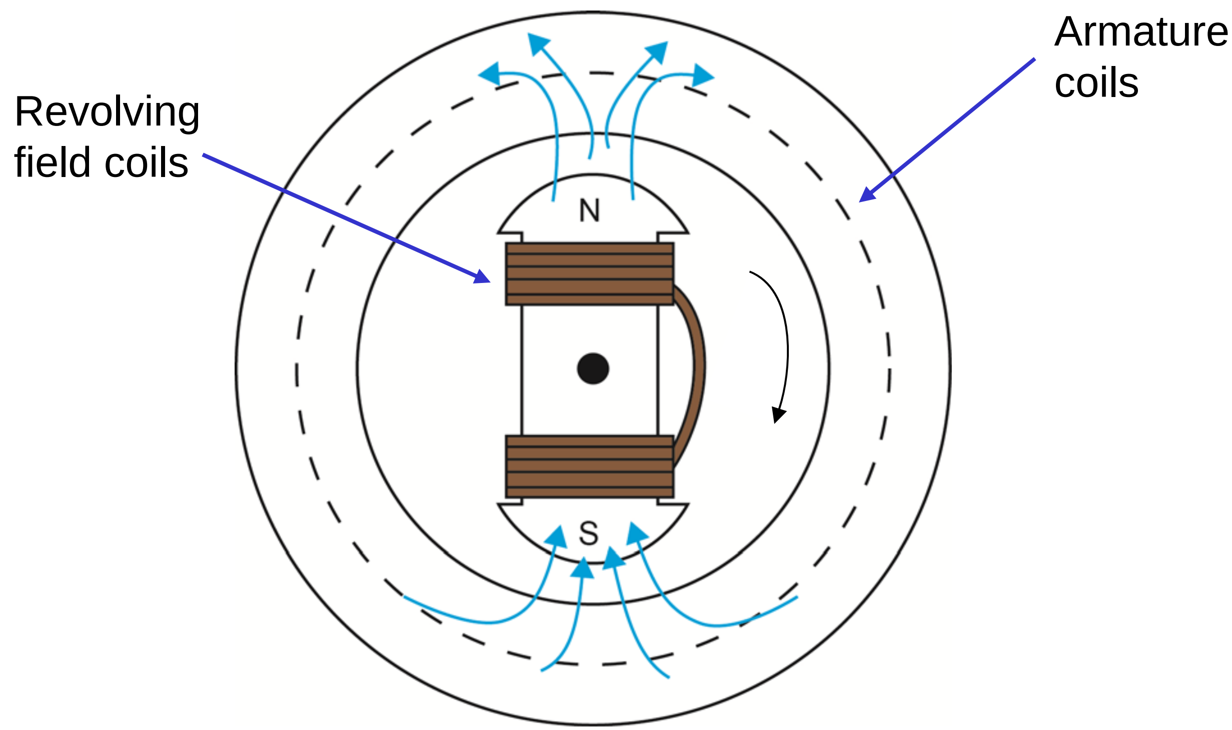
Generator Basics

Basic Power Generation

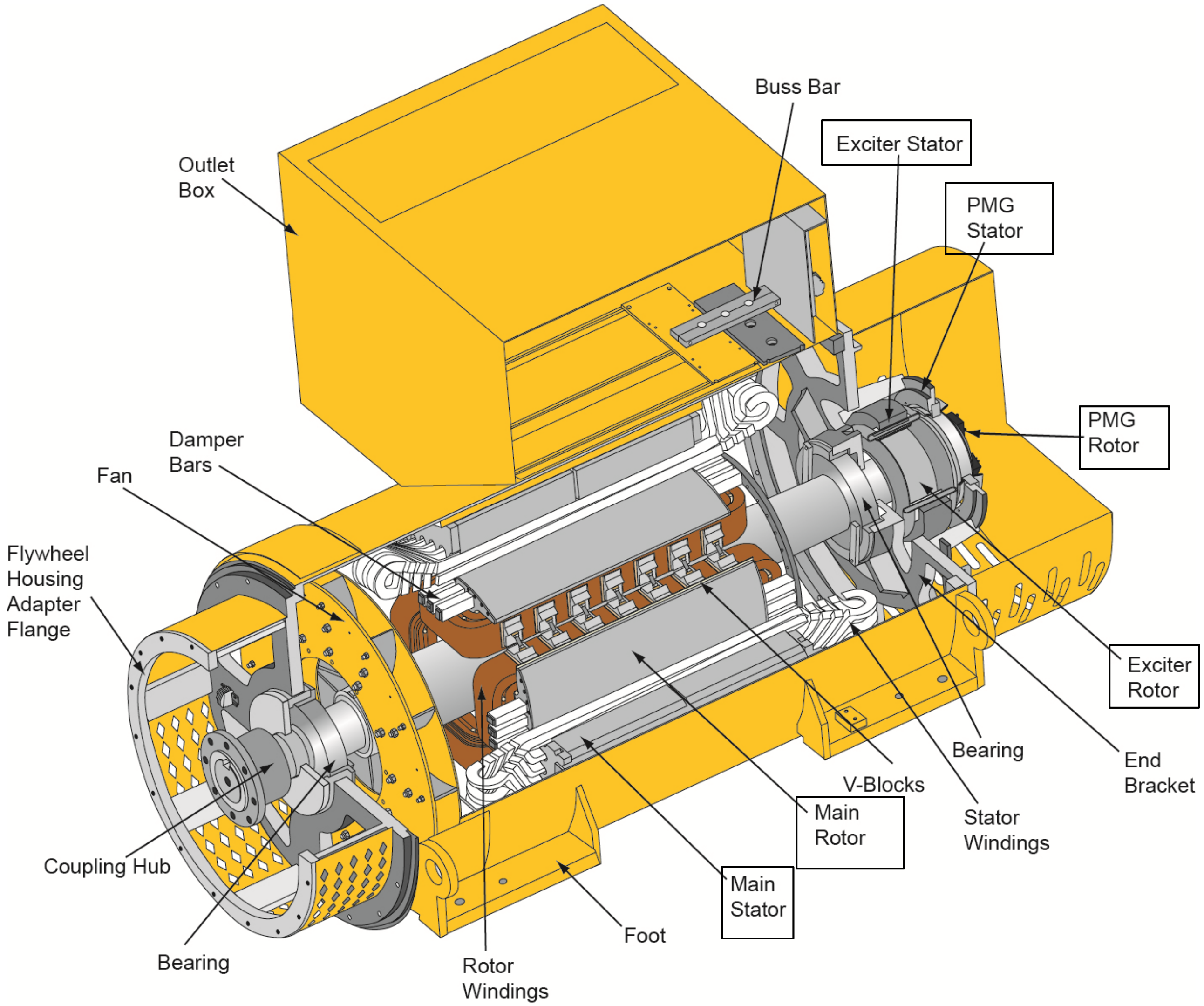
- Generator Arrangement
- Main Components
- Circuit
  - Generator with a PMG
  - Generator without a PMG
  - Brush type
  - AREP
- PMG Rotor
- Exciter Stator
- Exciter Rotor
- Main Rotor
- Main Stator
- Laminations
- VPI

Generator Arrangement

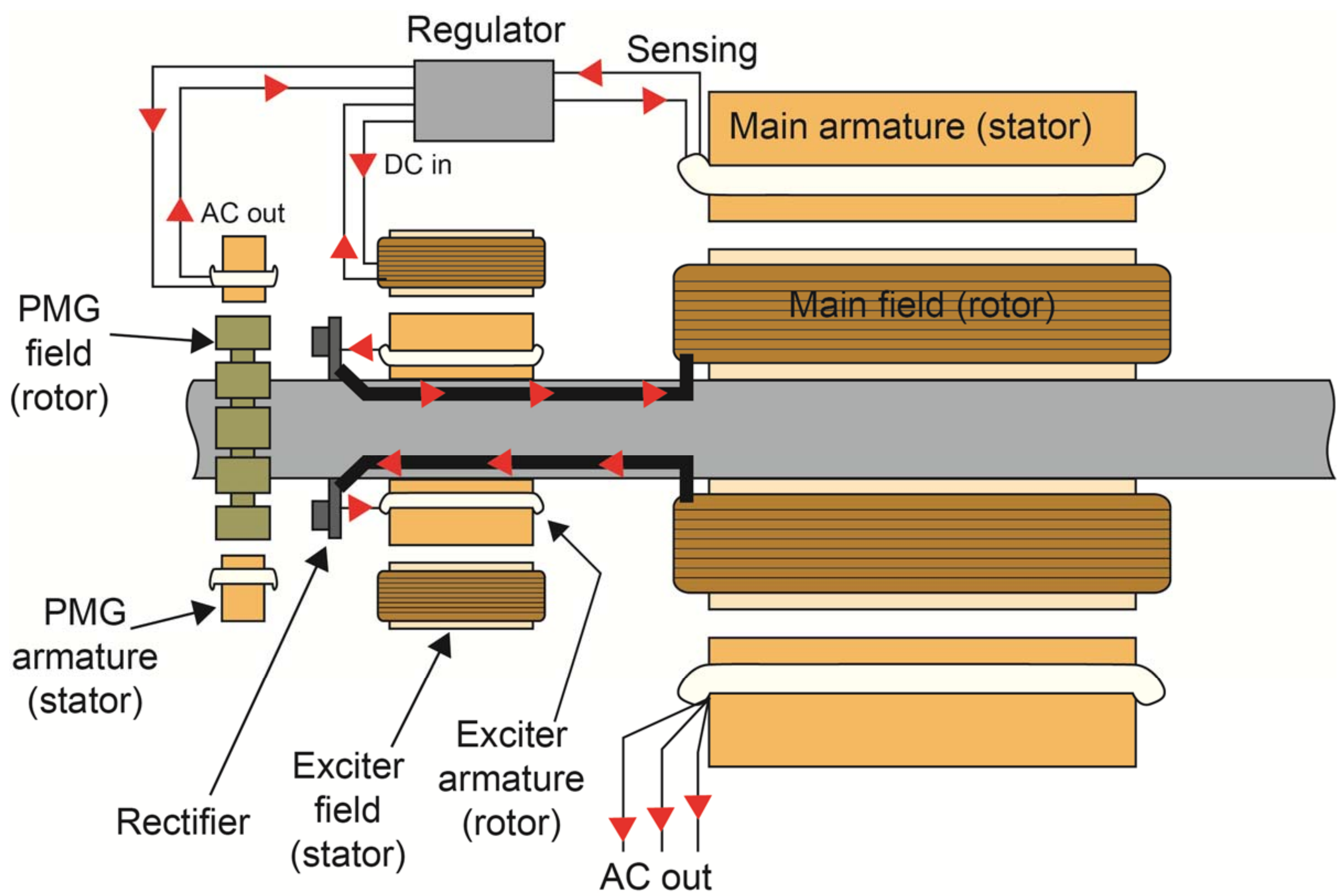
- Most modern, larger generators have a stationary armature (stator) with a rotating current-carrying conductor (rotor or revolving field).



Main Electrical Components: Cutaway

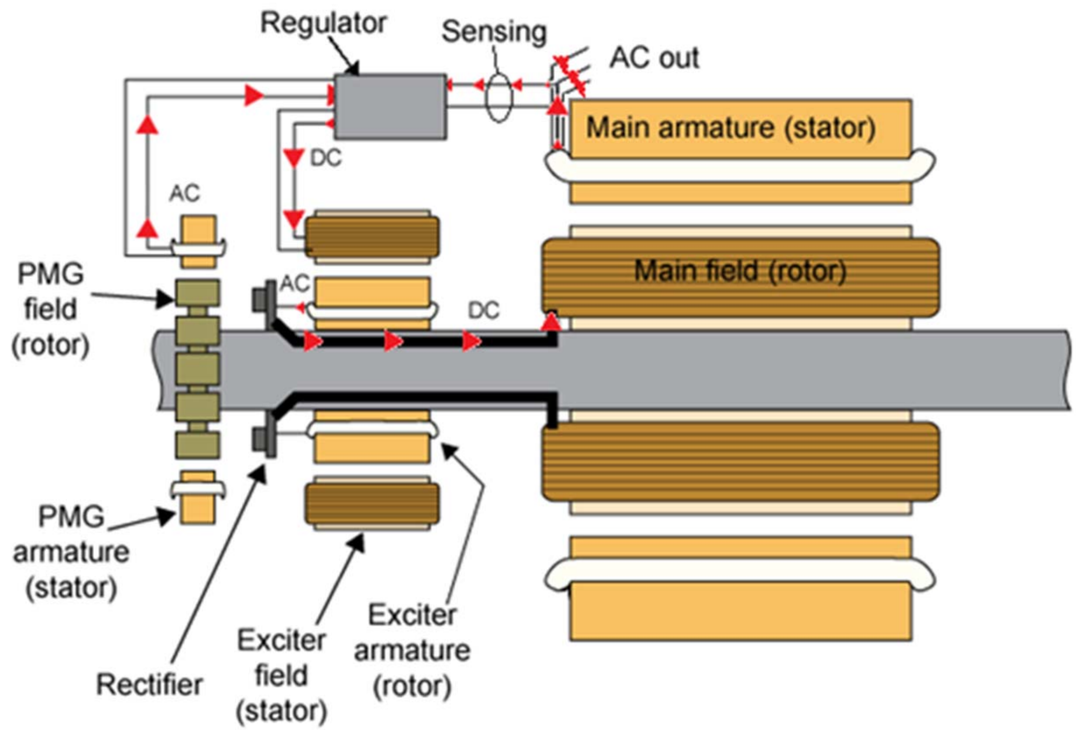


Main Electrical Components: Diagram



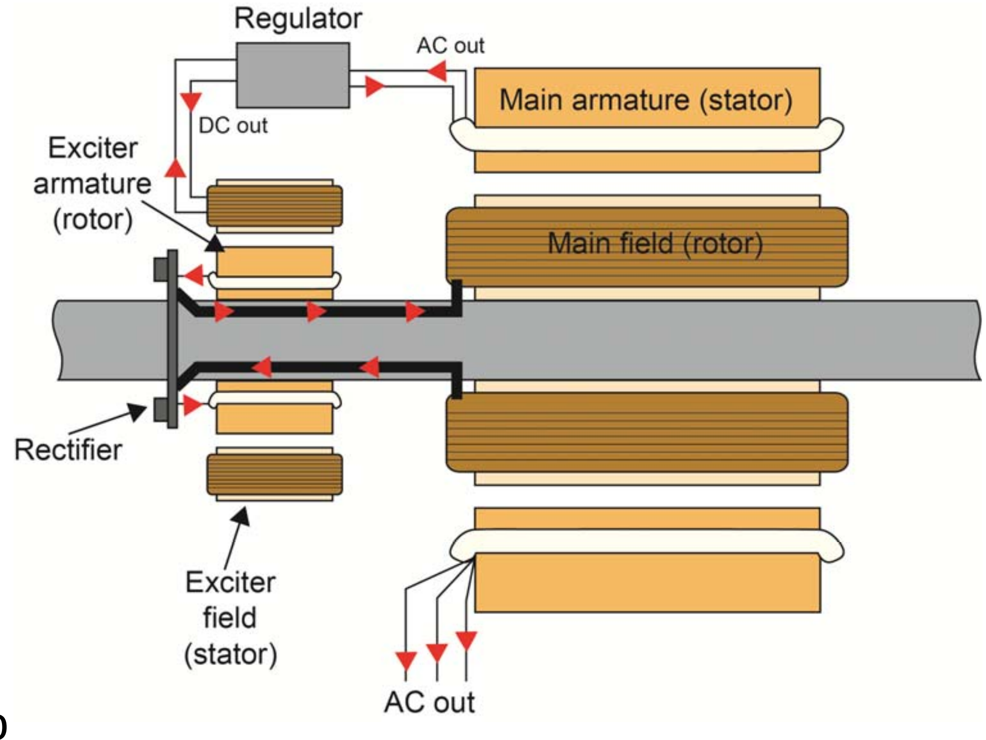
Circuit: Generator with a PMG

- As the PMG rotor rotates, it produces AC voltage in the PMG stator.
- The regulator rectifies this voltage and applies DC to the exciter stator.
- A three-phase AC voltage appears at the exciter rotor and is in turn rectified by the rotating rectifiers.
- The DC voltage appears in the main revolving field and induces a higher AC voltage in the main stator.
- This voltage is sensed by the regulator, compared to a reference level, and output voltage is adjusted accordingly.



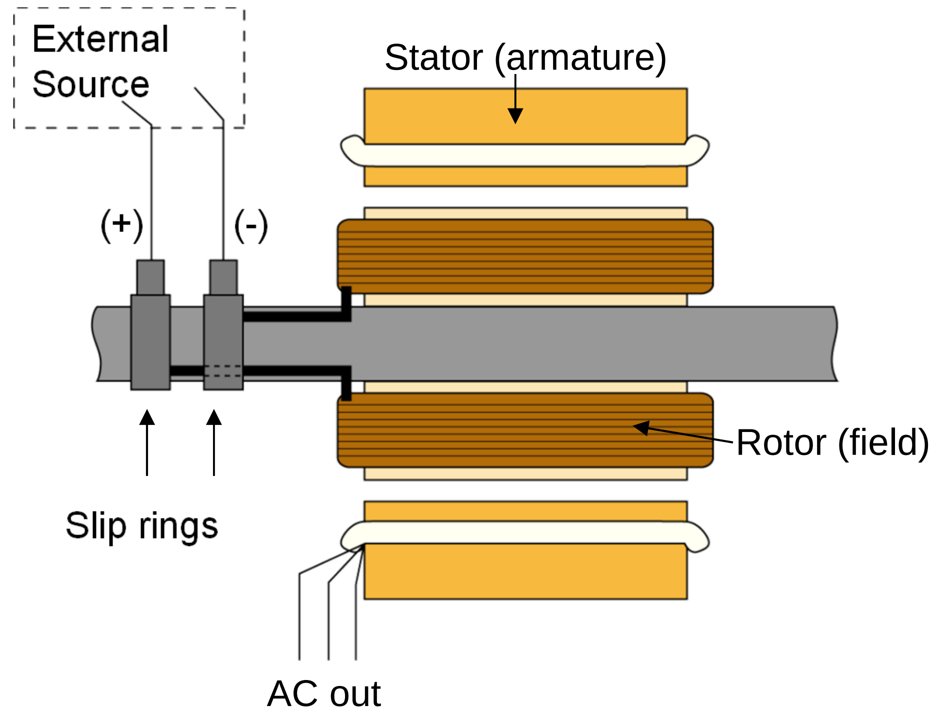
Circuit: Generator without a PMG

- As the revolving field rotates, residual magnetism in it produces a small ac voltage in the main stator.
- The regulator rectifies this voltage and applies dc to the exciter stator.
- A three-phase AC voltage appears at the exciter rotor and is in turn rectified by the rotating rectifiers.
- The magnetic field from the rotor induces a higher voltage in the main stator.
- This voltage is sensed by the regulator, compared to a reference level, and output voltage is adjusted accordingly.



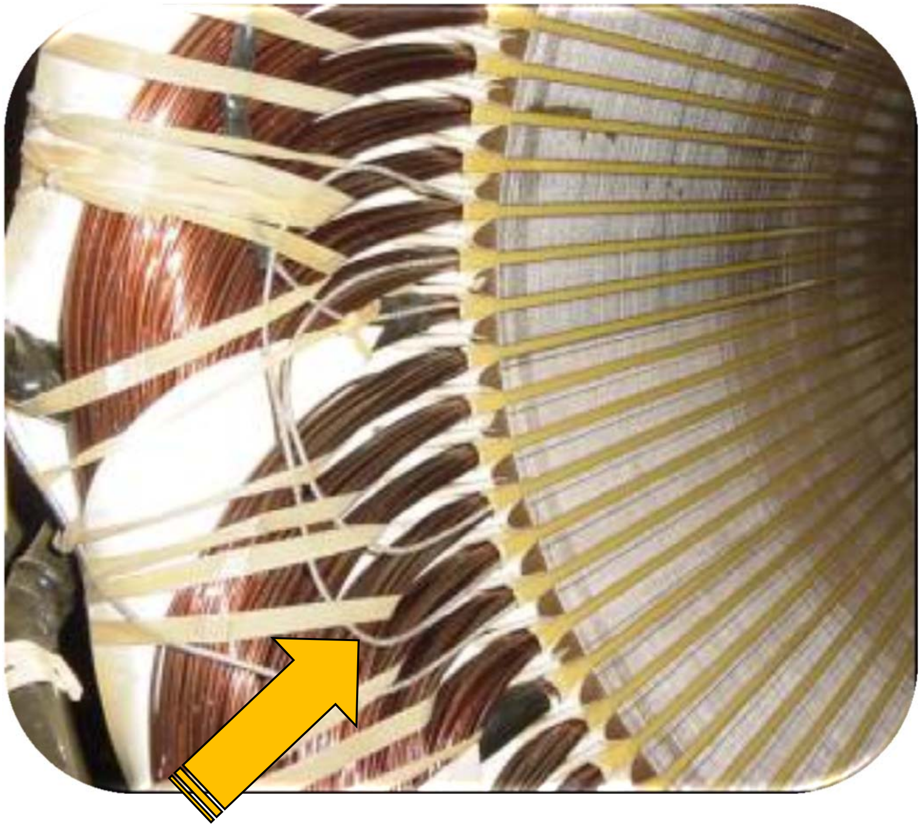
Circuit: Brush Type (Static)

- DC voltage is fed directly to the main revolving field through slip rings.
- Power source for the main revolving field can be very large and expensive.
- Requires brush maintenance.
- Common in variable speed applications.



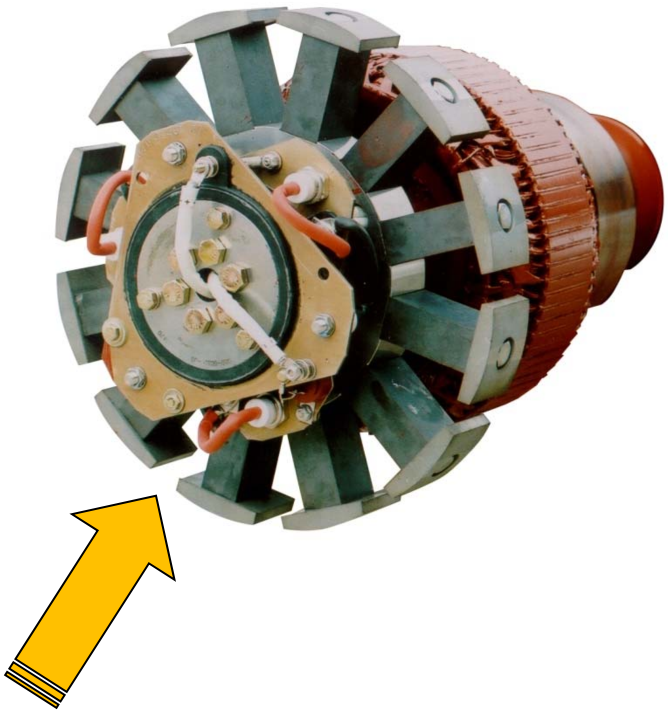
Circuit: AREP

- Auxiliary winding regulation excitation principle.
- Secondary winding in the main stator provides power to the voltage regulator.



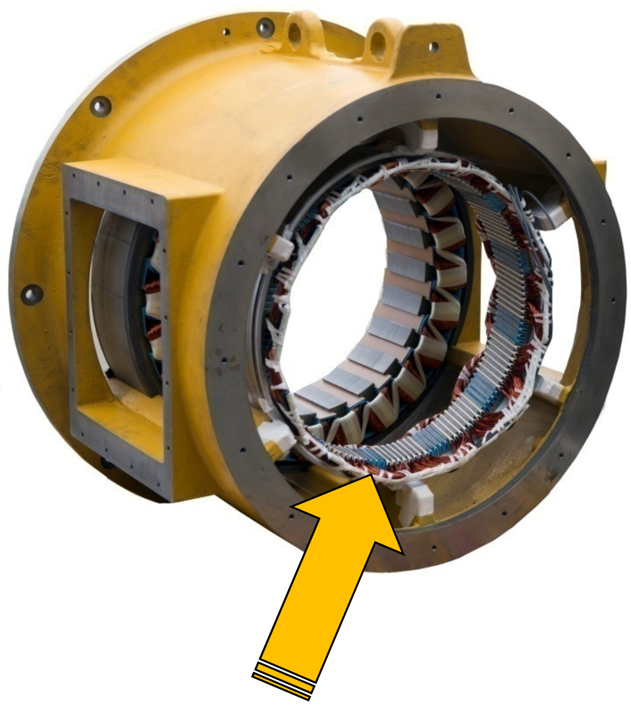
PMG Rotor

- Is a field that induces voltage in the PMG stator.
- Poles are permanent magnets.
- Mounted on the shaft with the main rotor.
- Optional (benefits to be discussed later).



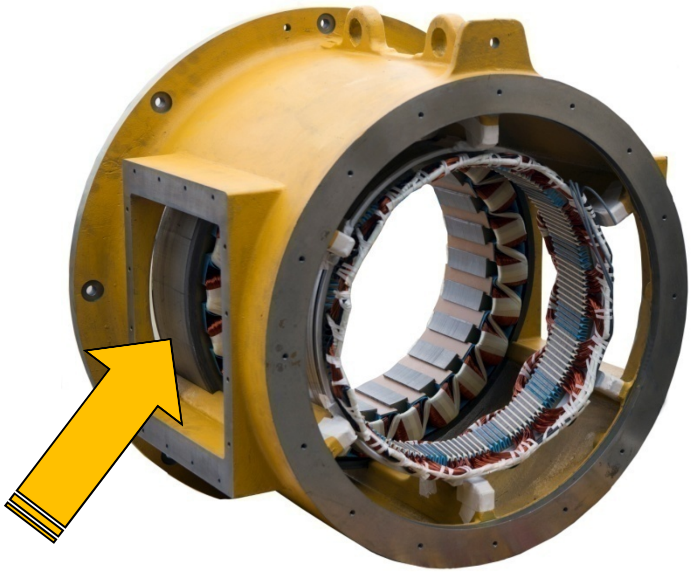
PMG Stator

- Is an armature that provides power to the regulator
- Induced by the PMG rotor.
- Typically has random-wound coils in a laminated steel core.
- Various configurations:
  - Wound cores in a frame
  - Wound cores with no frame
  - Combined with the exciter stator in one frame
- Mounted on an end bracket (opposite side of prime mover).
- Optional



Exciter Stator

- Is a field that induces voltage in the exciter rotor.
- Typically powered by the regulator.
- Typically has random-wound coils in a laminated steel core.
- Various configurations:
  - Wound cores in a frame
  - Wound cores with no frame
  - Combined with the PMG in one frame
- Mounted on an end bracket (opposite side of prime mover).

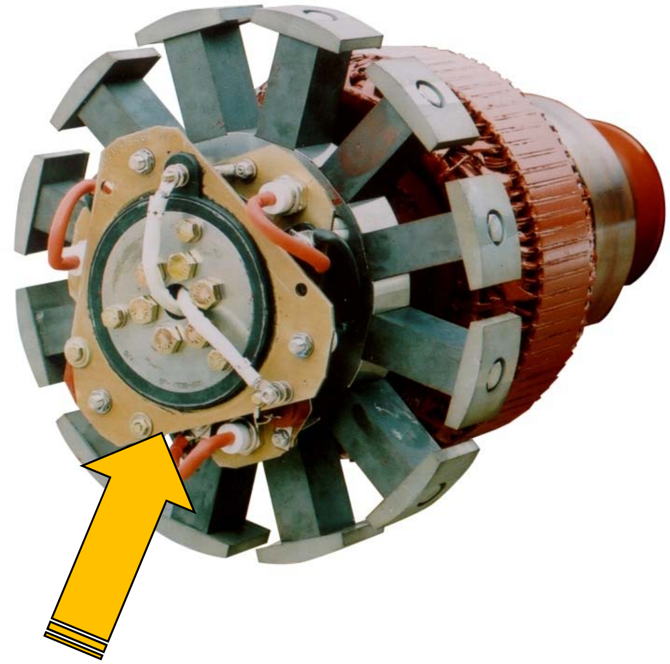


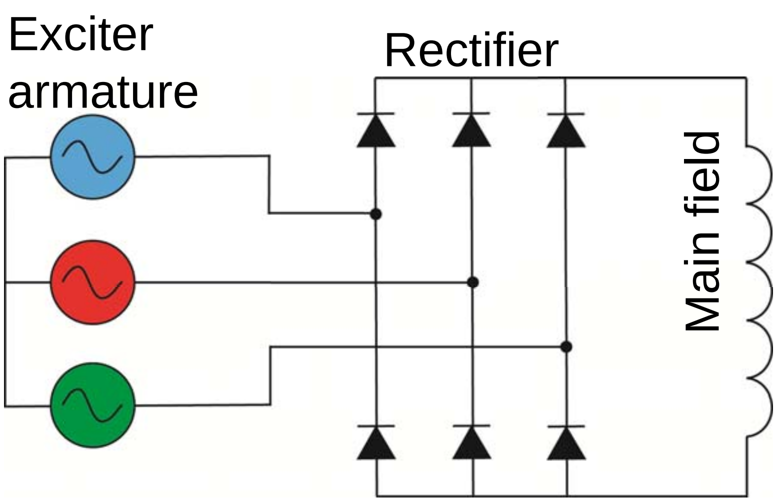
Exciter Rotor

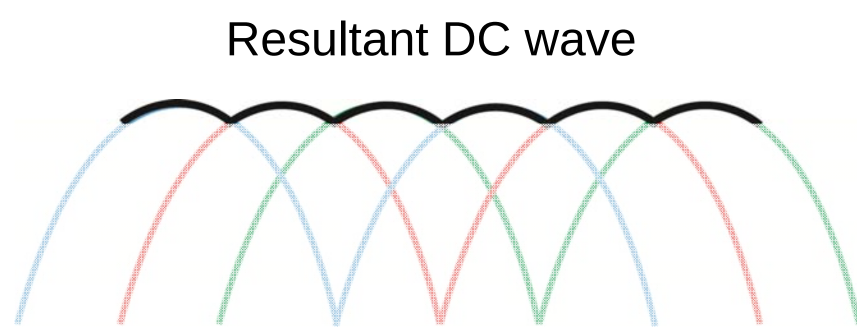
- Is an armature that provides rectified power to the main rotor (revolving field).
- Induced by the exciter stator.
- Three-phase high frequency AC output.
- Typically has random-wound coils in a laminated core.
- Mounted on the shaft with the main rotor.

Rectifier

- Mounted on the exciter (as in previous slide) or PMG.
- Has diodes that full wave rectify the three-phase (three separate voltage) exciter armature AC current to DC before it enters the main rotor.
- Leads connect to the main field (rotor)

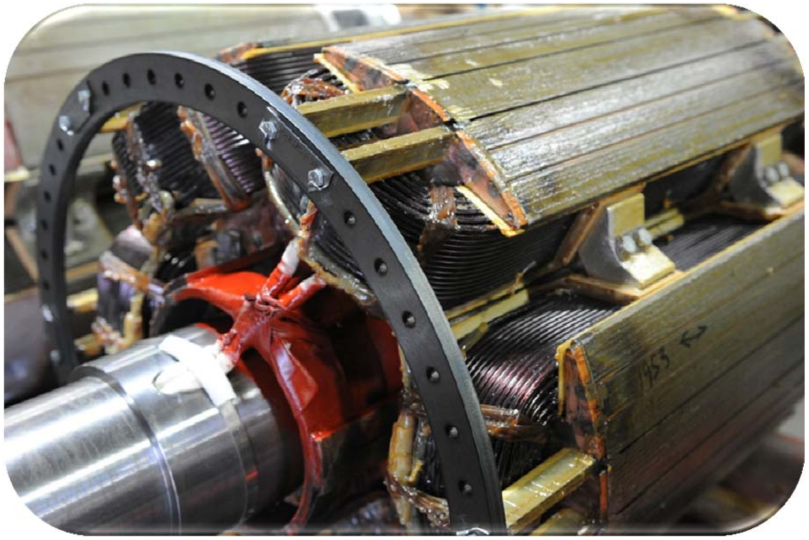


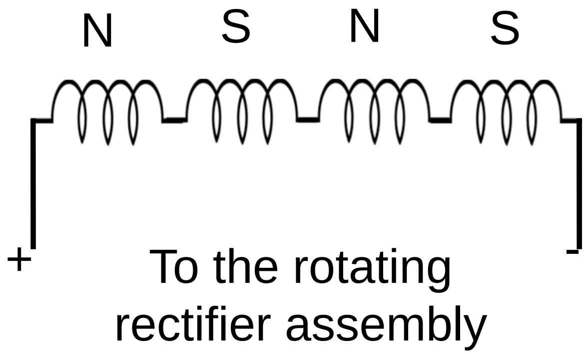




Main Rotor

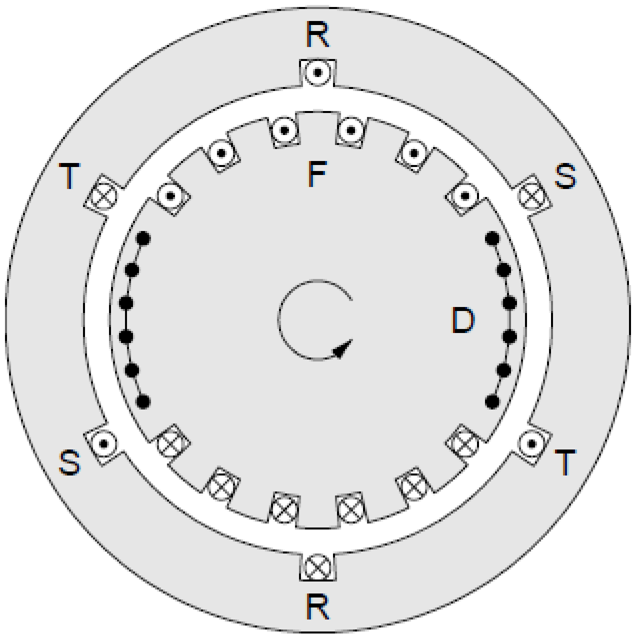
- Is a field that induces voltage in the main stator.
- Powered by the exciter rotor.
- Connected to the (+) and (-) rotating rectifier terminals.
- Coils are connected in series around a core.
  - Laminated core is typical
  - Solid core with large rotors
- Current flow is directed in a clockwise and CCW rotation to create north and south poles.
- Pressed on a shaft.



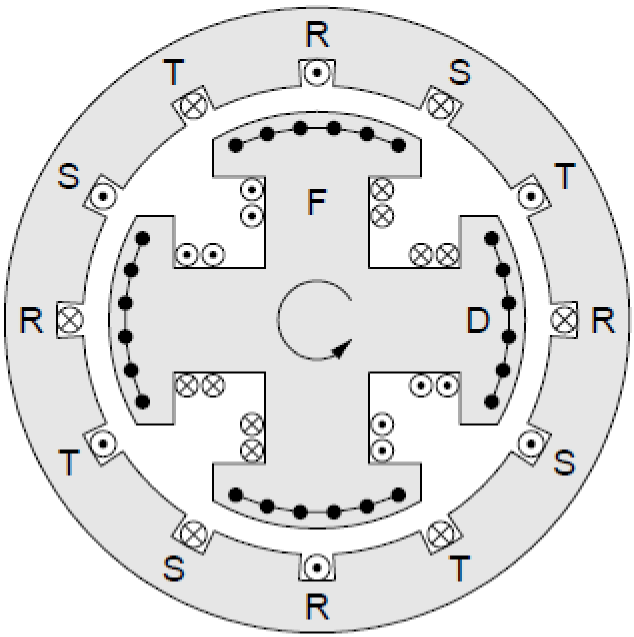


Main Rotor: Types

- Cylindrical
- Salient

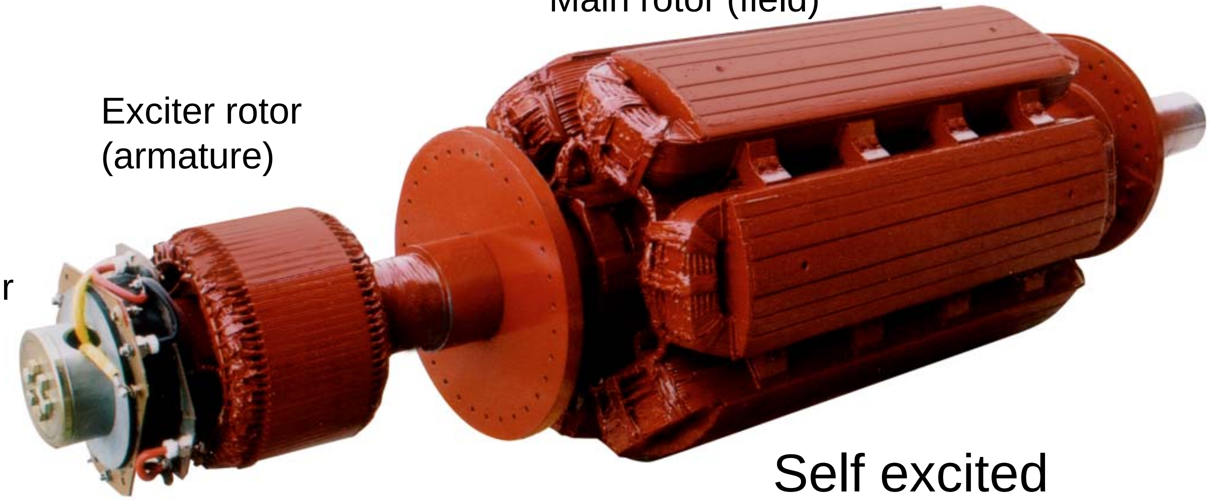


Round rotor
$p = 2,\ n = 3000\,\mathrm{min}^{-1}$ for $f = 50\,\mathrm{Hz}$

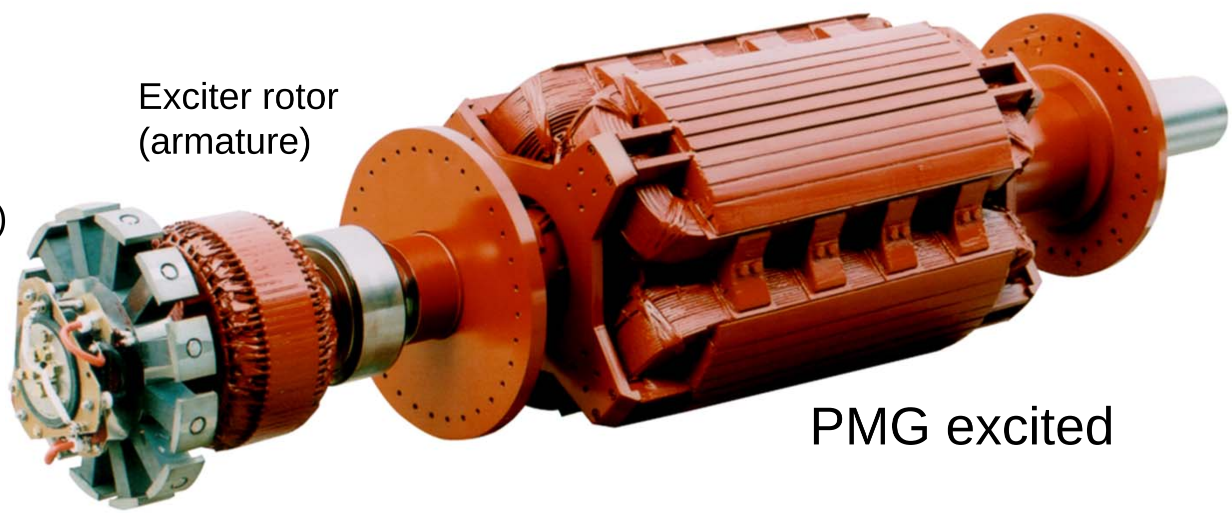


Salient pole rotor
$p = 4,\ n = 1500\,\mathrm{min}^{-1}$ for $f = 50\,\mathrm{Hz}$

Main Rotor: Layout



Self excited



PMG excited

Main Rotor: Frequency, RPM, Pole

$$\text{Frequency} = \frac{\text{RPM} \times \text{number of poles}}{120}$$

If you have a prime mover that runs at 1000 RPM and you wanted 50 Hz, you would need a generator with how many poles?

$$\frac{50\ \text{Hz} \times 120}{1000\ \text{RPM}}$$

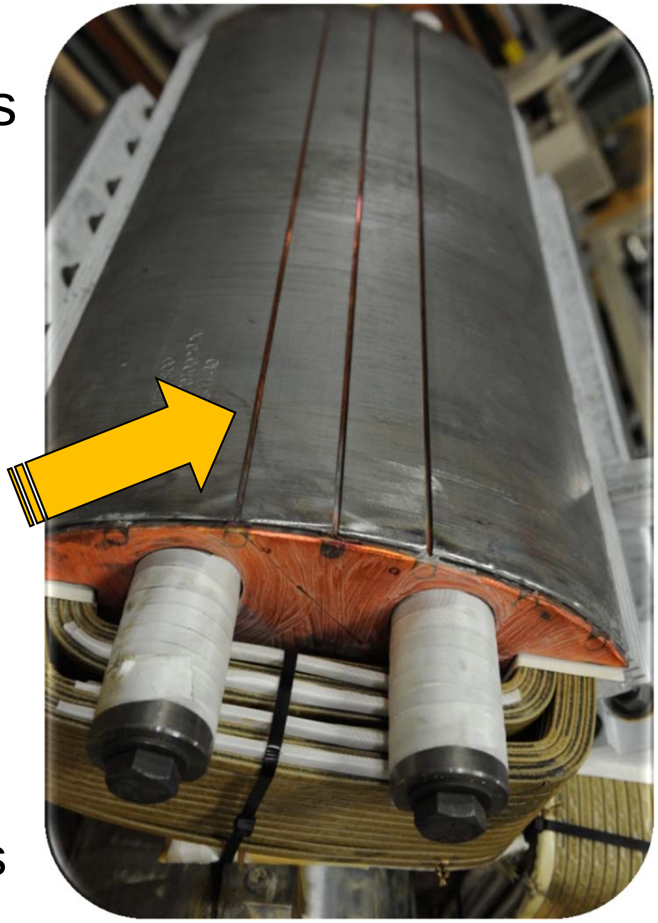
$$= 6\ \text{poles}$$

Main Rotor: Frequency, RPM, Pole

# of Poles	RPM	Hz
4	1800	60
4	1500	50
6	1200	60
6	1000	50
8	900	60
8	750	50
10	720	60
10	600	50

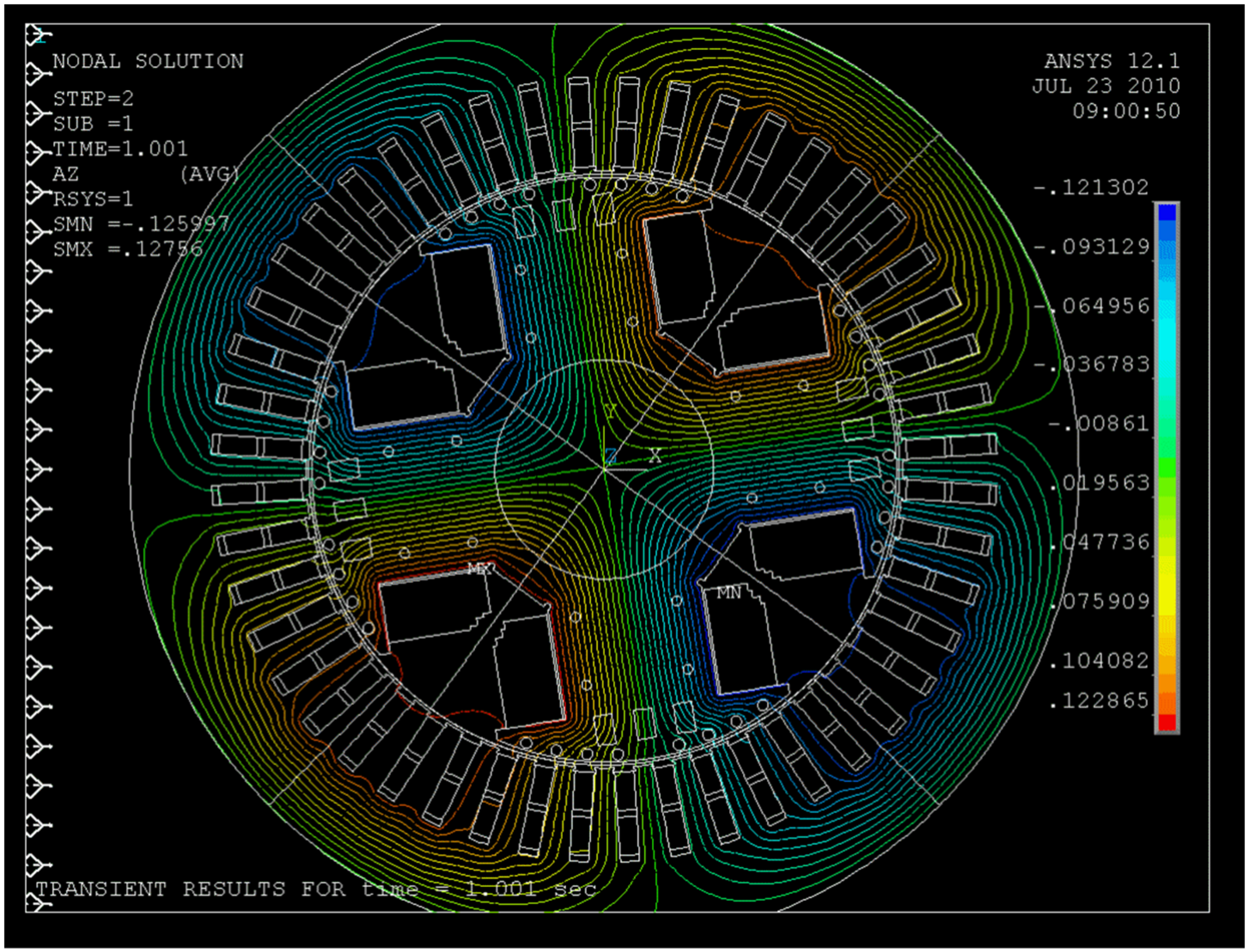
Main Rotor: Damper Cage

- Also called “Amortisseur windings.”
- Copper bars through the pole faces and shorted together by the end plates.
- Standard for all but traction generators, solid rotors.
- Has a very short time constant (effect expressed in datasheets as X”d).
  - Helps with parallel operation
  - Helps with load-induced harmonics (non-linear loads).
- Helps reduce initial voltage dip during motor starting.



Main Rotor: Magnetism

- Magnetic flux paths (i.e. flow of magnetism) for a generator operating at 0.8 PF

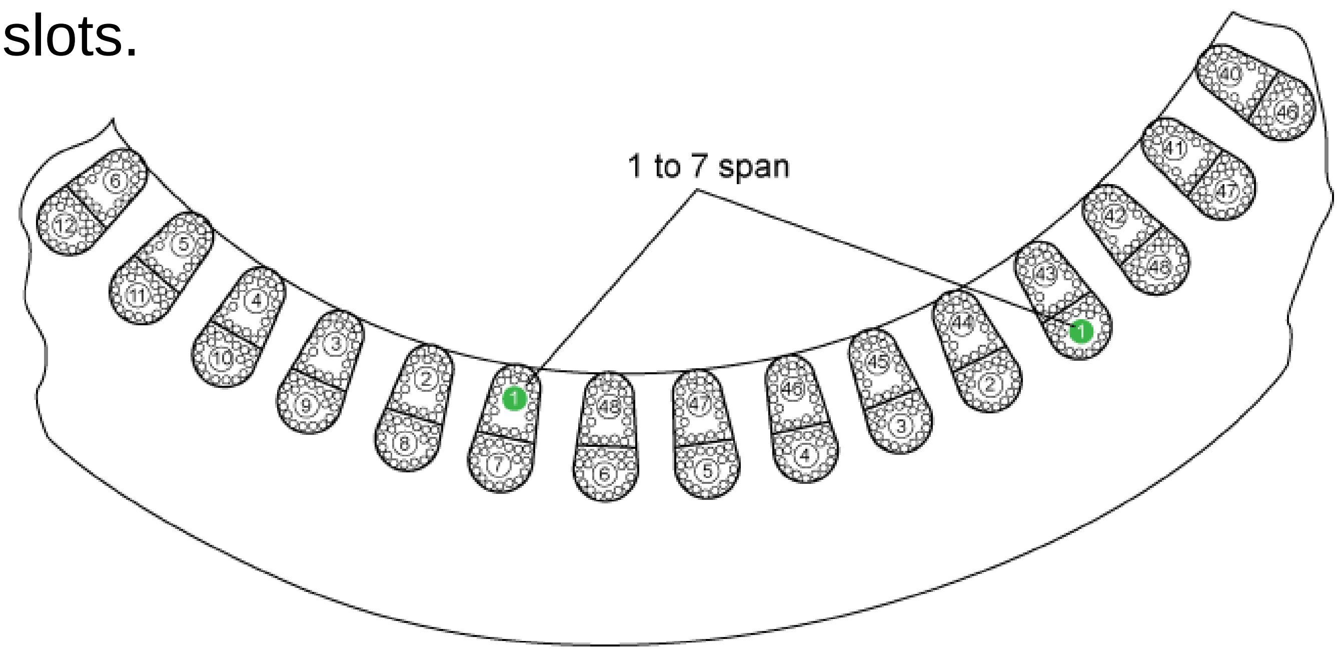


Main Stator

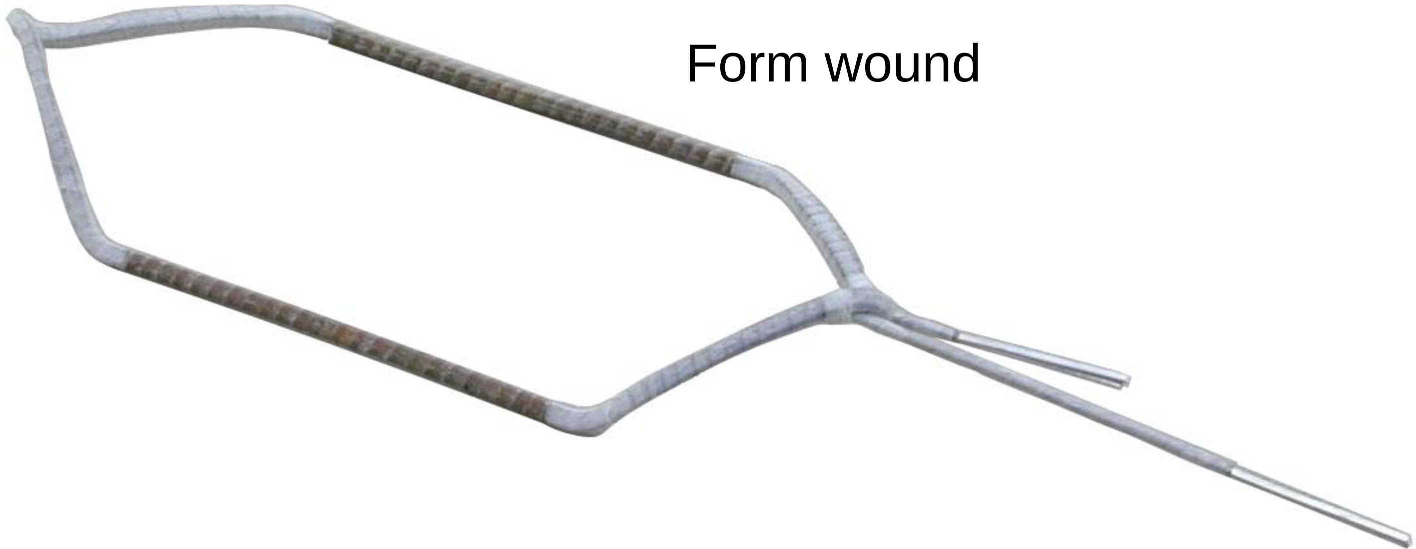
- Is the main armature, the component that delivers power.
- Windings (copper conductors) are either form-wound coils or random-wound coils fitted in core slots.
- Core is laminated steel housed in a metal frame.
- Typically has three phases (three separate windings).

Main Stator: Coils and Slots

- The number of turns and cross section are specific to each frame size, slot combination or design, and voltage.
- Coils typically span into two slots in the core, so there are two coils per slot.
- Pitch = (span -1) × the number of rotor poles / total # of slots.

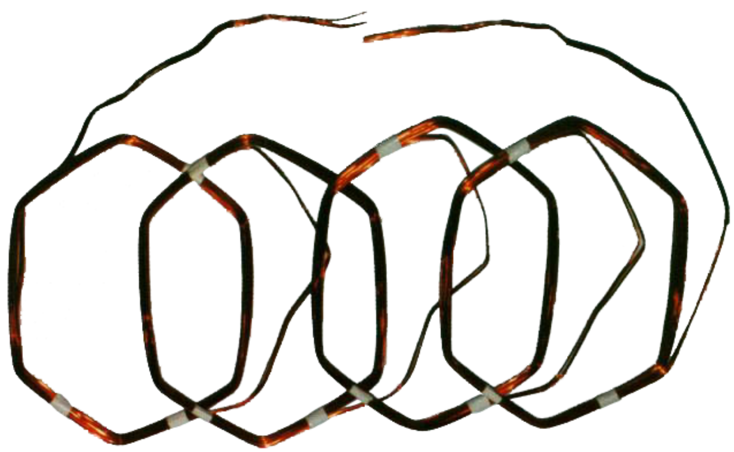


Main Stator: Coil Types

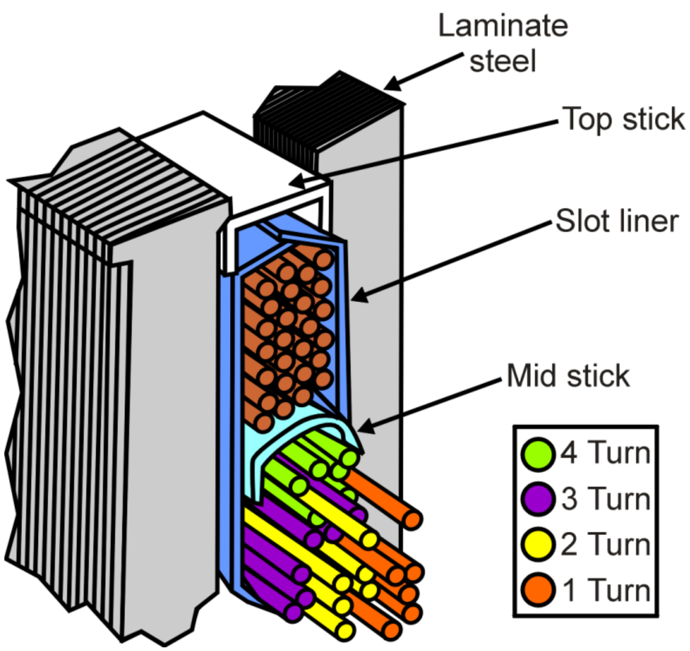


Form wound

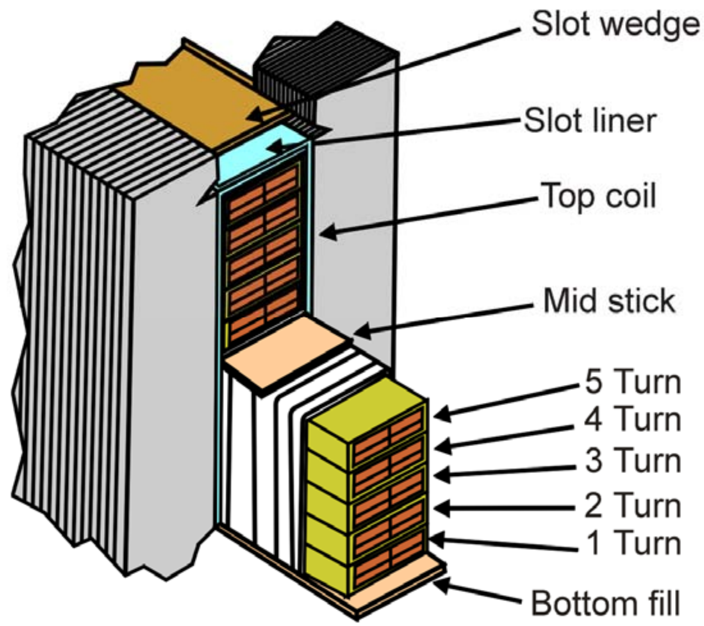
Random wound



Main Stator: Coil Types



Random wound

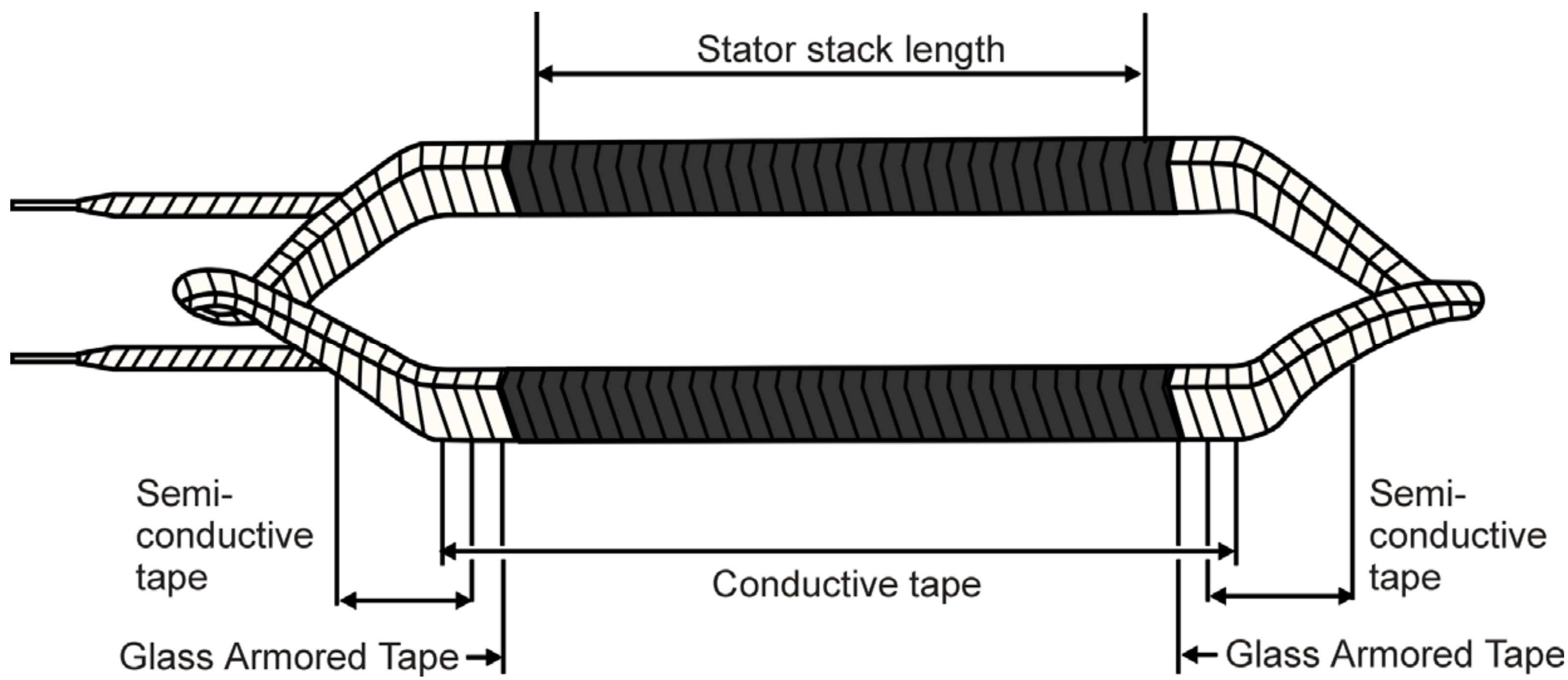


Form wound

Advantages, disadvantages, applications discussed later.

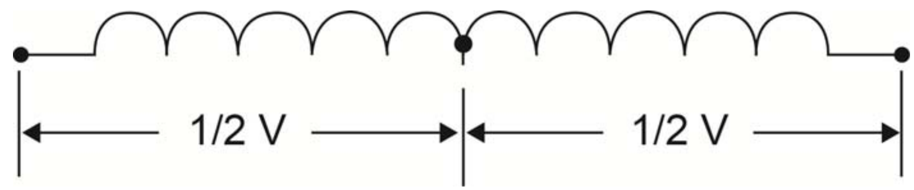
Main Stator: High-Voltage Coil

- Use with voltages above 6000 V
- Has conductive and semi-conductive tape

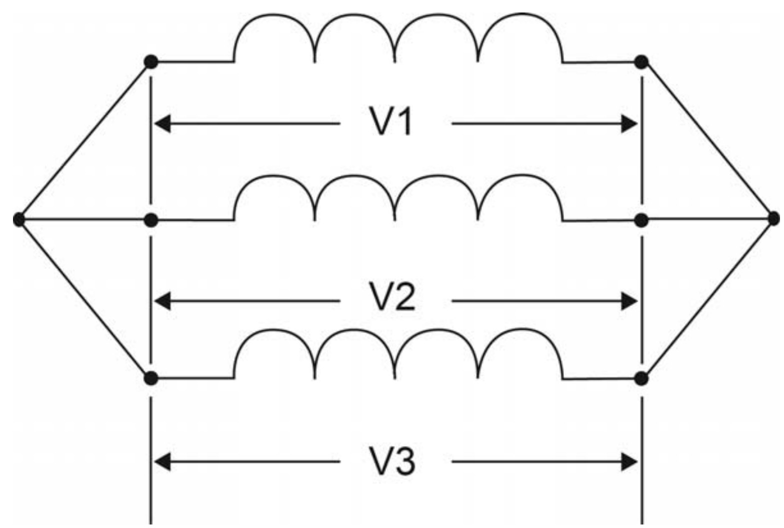


Main Stator: Coil Connection

- Series circuit - coils connected one after another.
  - Voltage additive for each coil.
  - Current capacity is that of any one coil

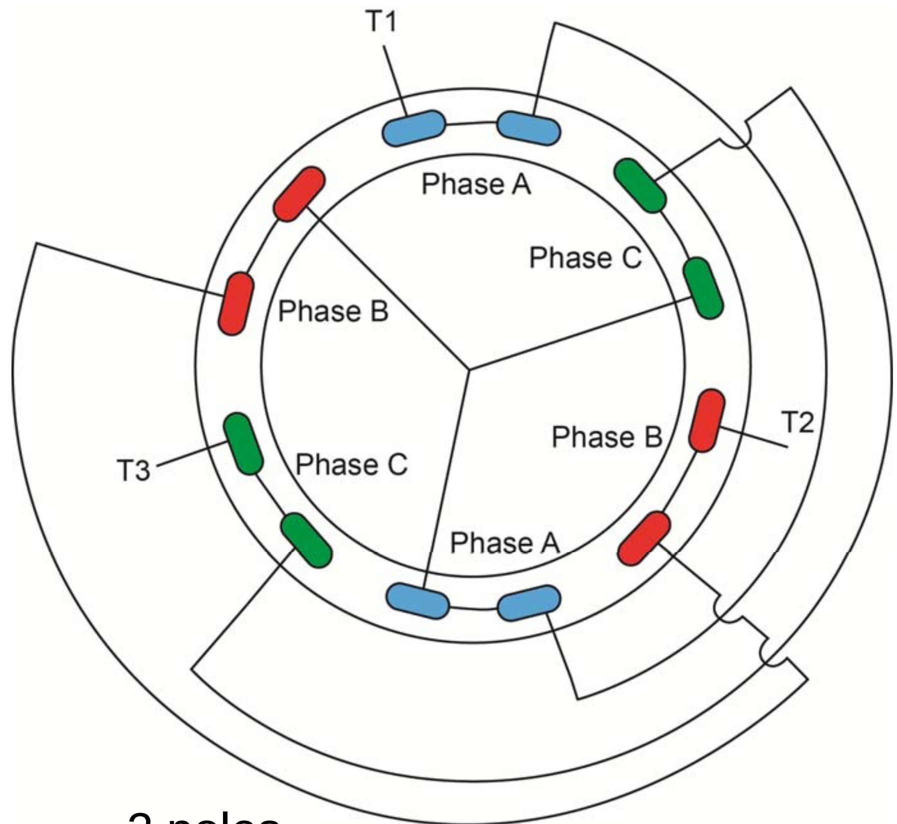


- Parallel circuit - coils connected in parallel
  - Voltage across group is voltage across any one coil.
  - Current capacity is additive for each coil.



Main Stator: Three Phase

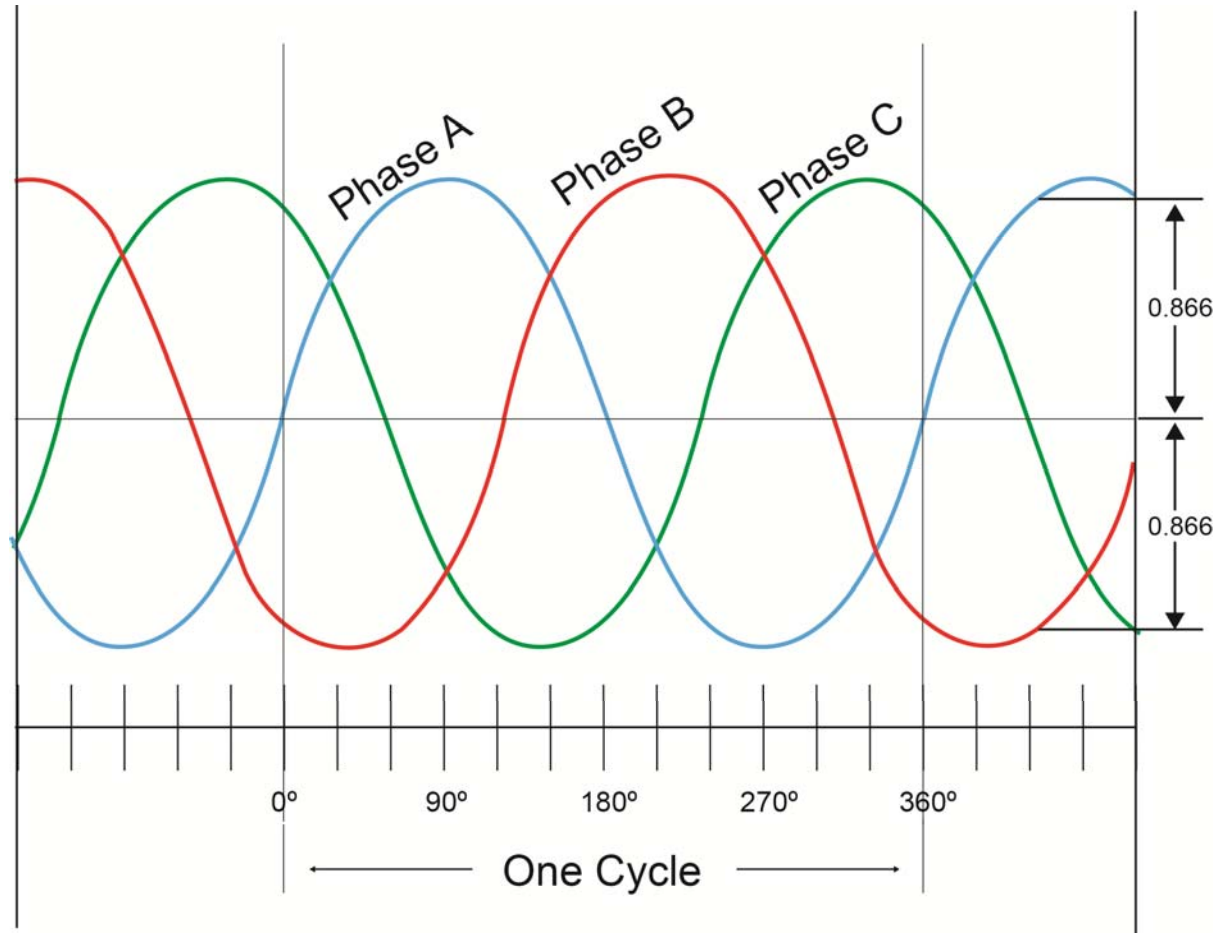
- Three windings.
- For each phase, there is one group (one or more coils) for each rotor pole.
  - A group is interconnected
  - Can be considered as one large coil.
- The leads are typically wye (star) connected. The neutral is usually connected to ground or brought out with single-phase loads.



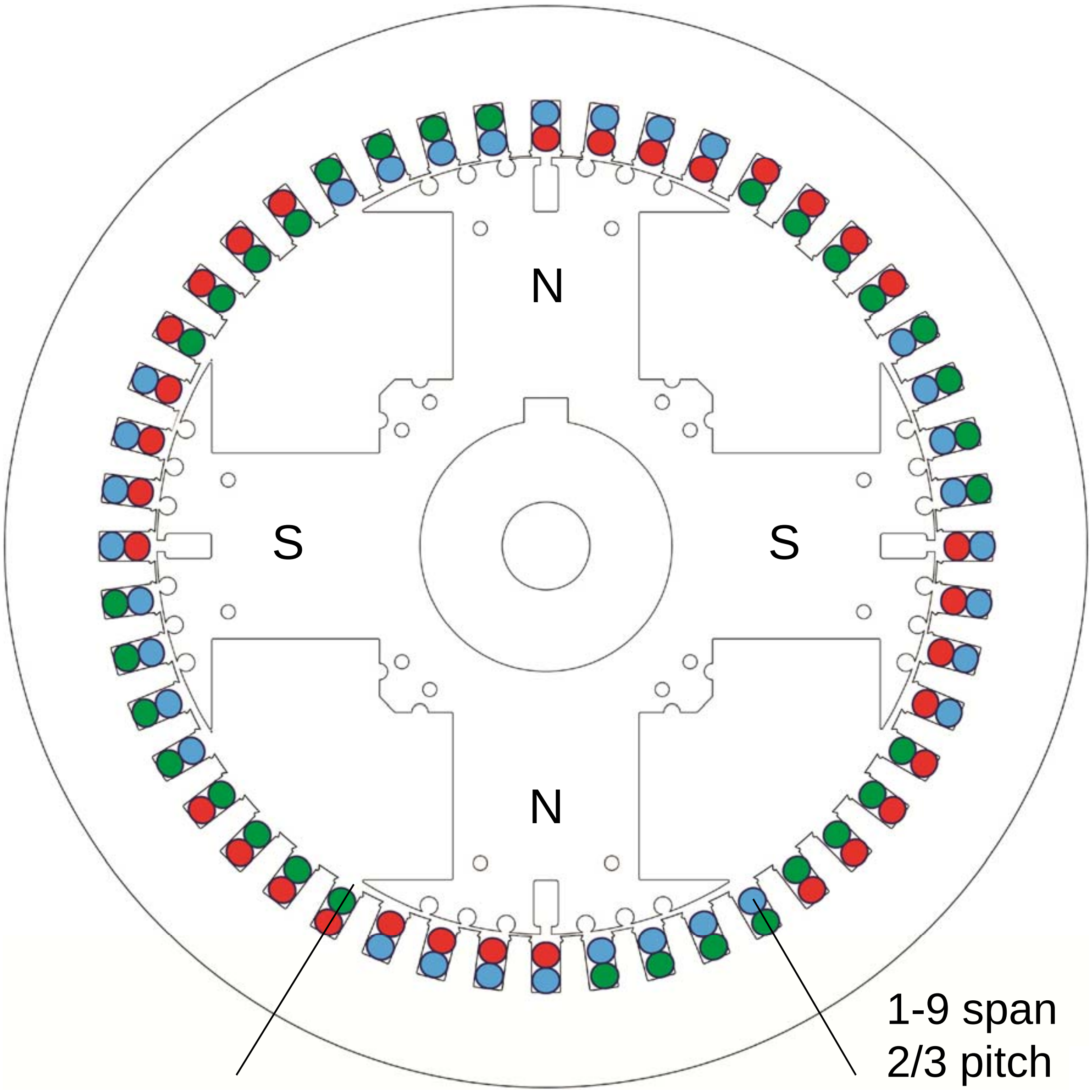
2 poles
6 groups
2 coils/group
(12 coils)
series connected

Main Stator: Three Phase (cont.)

- As the rotor rotates, three separate voltages are created at the stator terminals.

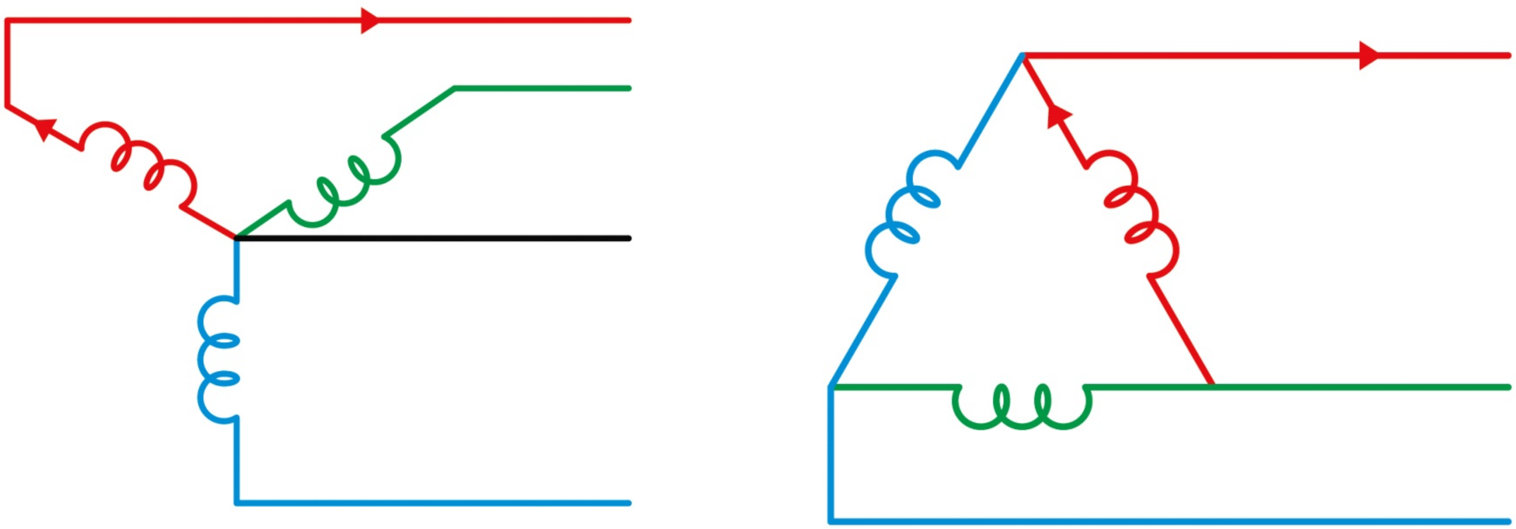


Main Stator: Three Phase (cont.)

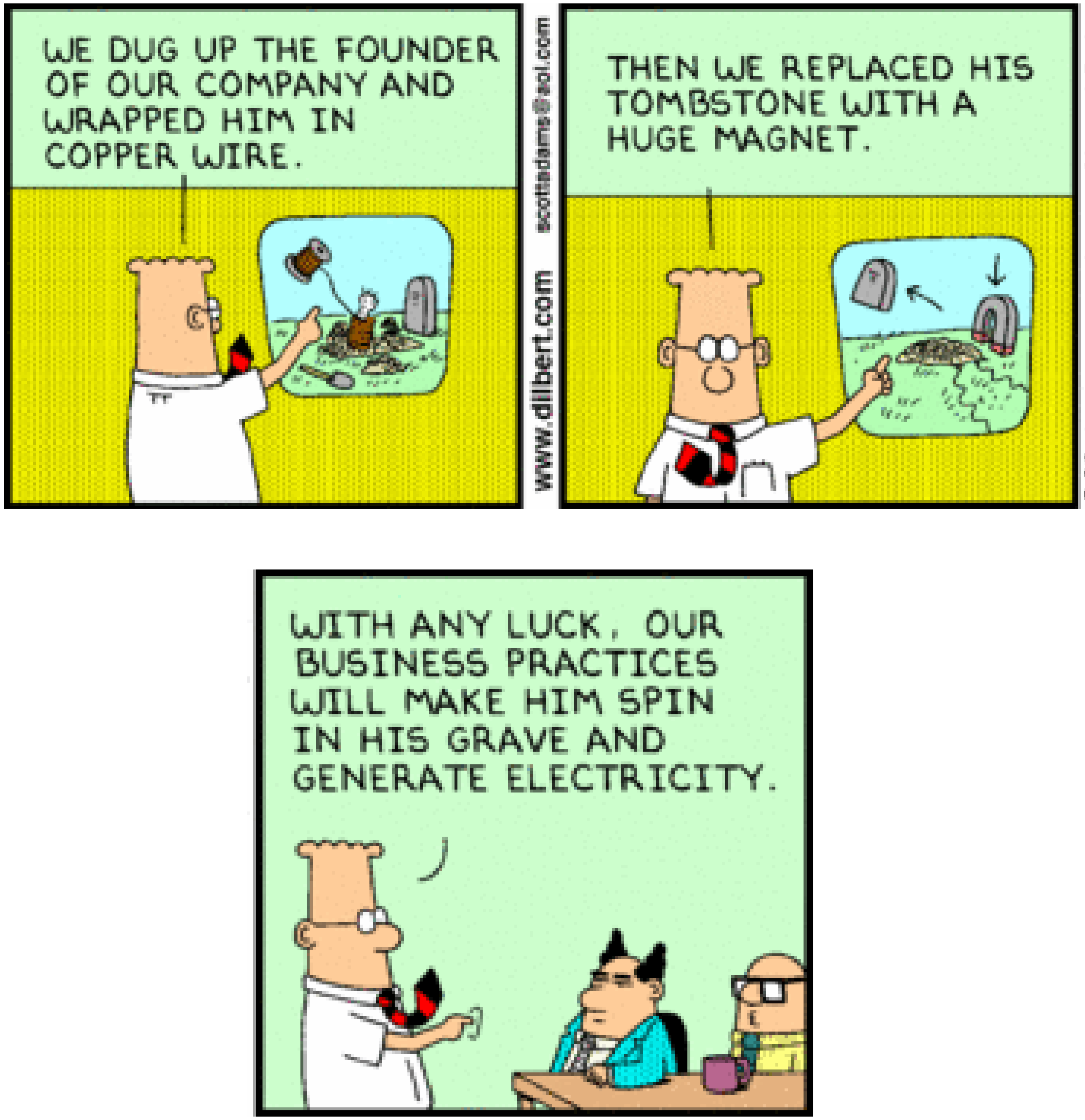


4 poles
12 groups
4 coils/group
(48 coils)

Wye vs. Delta

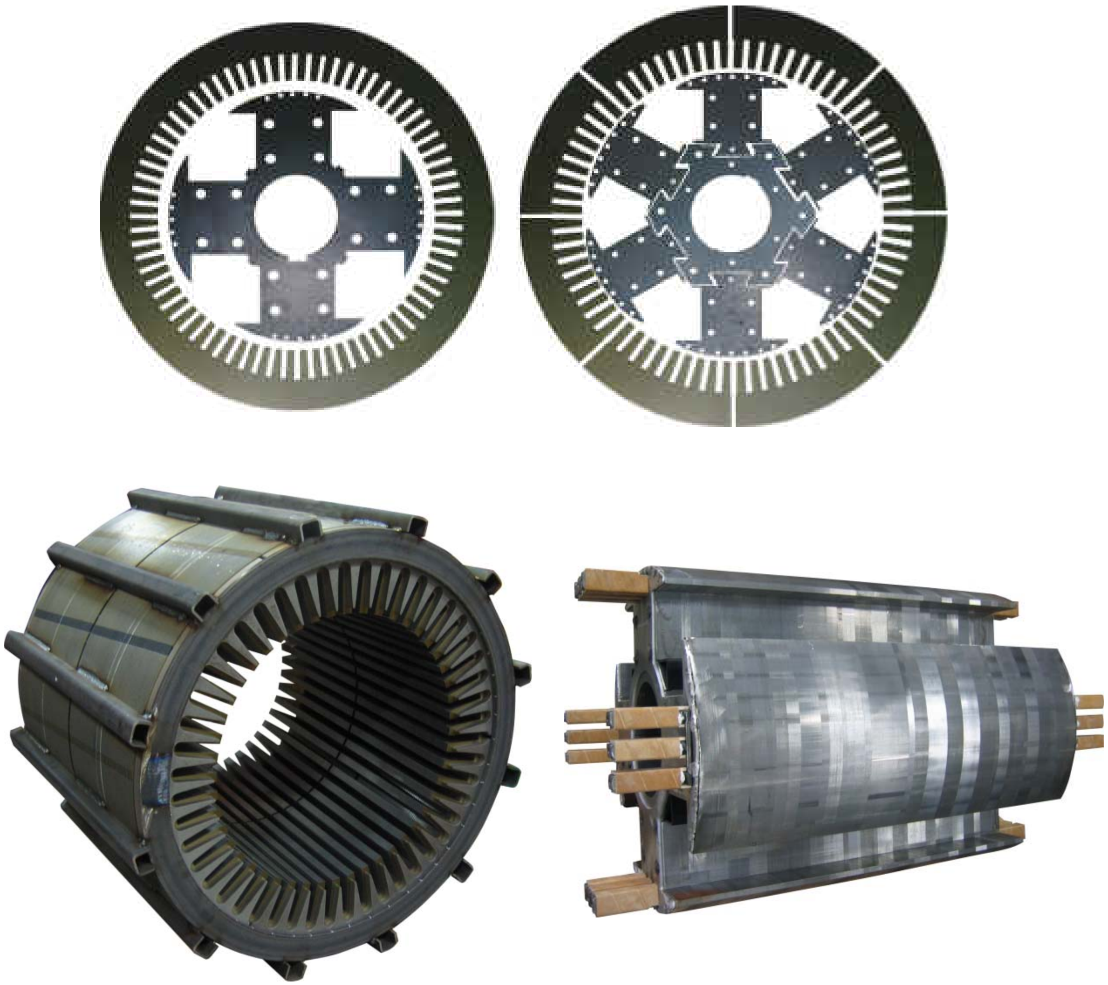


Dilbert's Renewable Energy Idea….



Other Considerations: Laminations

- Magnetic cores (stacks) used in manufacturing generators are typically made from thin steel sheets called laminations.
- Reduce losses due to stray currents.



Other Considerations: VPI

- Vacuum pressure impregnation
- A polyester or epoxy resin is applied to windings.
- Provides mechanical strength, heat transfer, dielectric strength and environmental protection.
- A bake cycle after VPI hardens the resin.