Kron's primitive machine

Day 3

ILOs – Day3

- Derive expressions for statically and dynamically induced EMF in basic 2-pole machine structure
- Describe the development of Kron's primitive machine

Static & Dynamic EMFs

- Statically induced EMF (Transformer EMF)
- Dynamically induced EMF (Speed EMF)

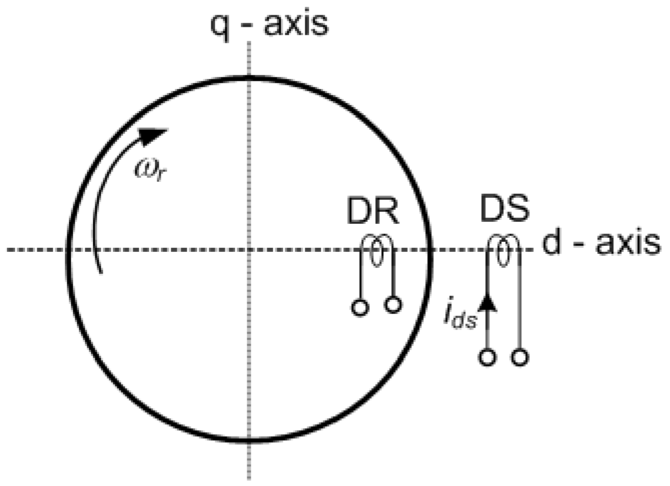
in basic 2-pole generalized machine structure

Static & Dynamic EMFs

- One coil DS in stator along d-axis
  - Flux produced by DS is assumed to be distributed sinusoidally in **space** along the air gap and is **time varying** in nature
- One coil DR in rotor also shown along d-axis

Is this true for DC machine also?

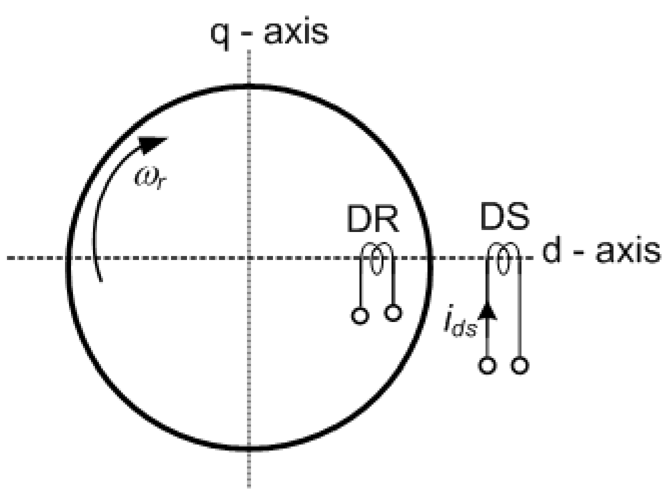
YES



Static & Dynamic EMFs

- Time varying current i_{ds} in DS produces a time varying flux that links with the rotor coil DR due to mutual coupling between them.
- When the two coil are both along d-axis, their mutual coupling is maximum.
- Flux linkage at this instant: $\psi_{md} = M_d i_{ds}$

  M_d is the mutual inductance between coils DS and DR

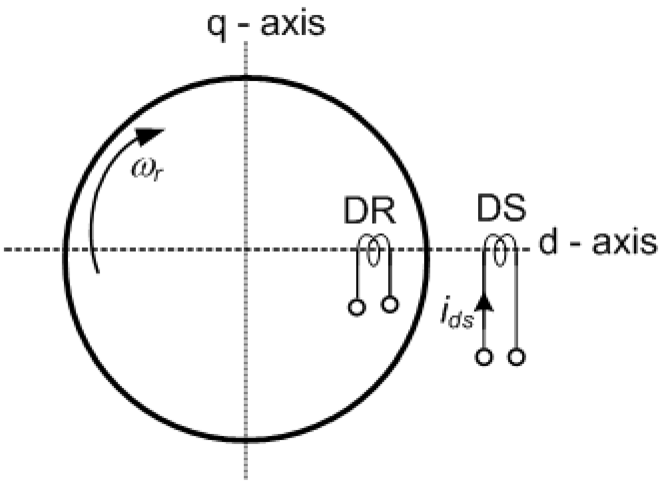


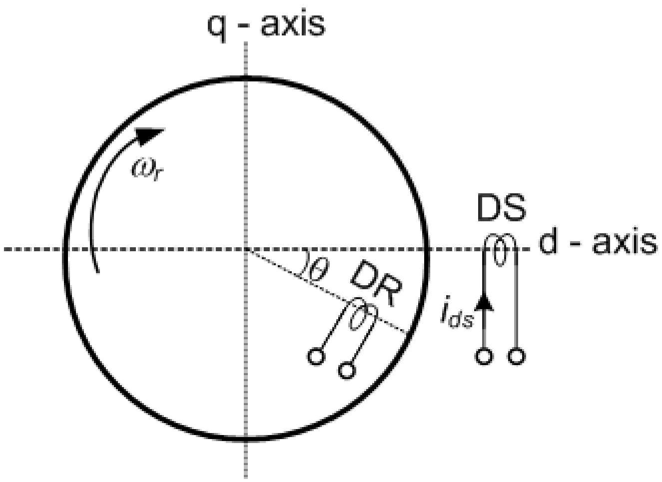
Static & Dynamic EMFs

$$\psi_{md} = M_d i_{ds}$$

- As the rotor rotates, the coil DR takes up different positions w.r.t. DS
- At the instant shown: $\theta = \omega_r t$
- Hence, flux linkage with coil DR after time *t* seconds is:

$$= \psi_{md} \cos\theta = \left(M_d i_{ds}\right)\cos\theta$$





Static & Dynamic EMFs

$$\psi_{md} = M_d i_{ds}$$

- According to Faraday's law, EMF induced in the coil DR due to this flux linkage at this instant is:

$$e = -\frac{d}{dt}\left(\psi_{md}\cos\theta\right)$$

$$= +\psi_{md}\sin\theta\frac{d\theta}{dt} - \cos\theta\frac{d}{dt}\left(\psi_{md}\right)$$

$$= +\psi_{md}\sin\theta\omega_r - \cos\theta p\psi_{md}$$ Here p is the operator $\frac{d}{dt}$

$$= +\psi_{md}\sin\theta\omega_r - \cos\theta M_d\left(pi_{ds}\right) = +M_d i_{ds}\sin\theta\omega_r - \cos\theta M_d\left(pi_{ds}\right)$$

This is the dynamic EMF component since it involves the speed ω_r

This is the transformer EMF component since it involves the time derivative of current i_{ds}

Static & Dynamic EMFs

$$e = +\psi_{md} \sin\theta\omega_r - \cos\theta M_d \left(pi_{ds}\right)$$

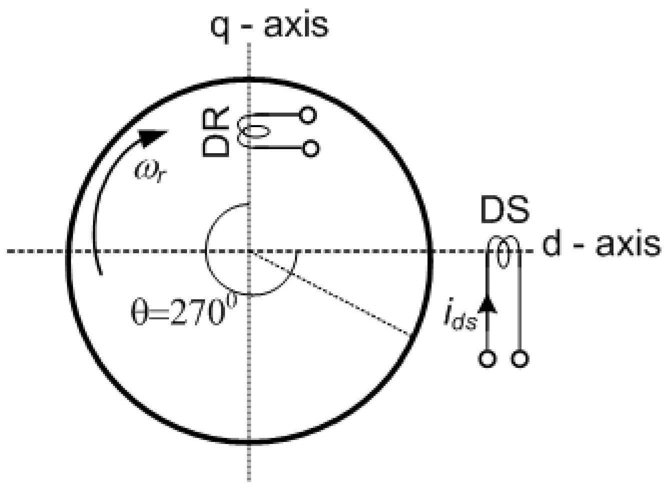
- When $\theta = 270^0$, the coil DR comes along the q-axis
- EMF induced in the rotor coil DR is:

$$e_q = +\psi_{md} \sin 270^0 \omega_r - \cos 270^0 M_d \left(pi_{ds}\right)$$

$$= +\psi_{md} \sin 270^0 \omega_r - 0$$

$$= -\psi_{md}\omega_r = -M_d i_{ds}\omega_r = \text{Dynamic/rotational/speed EMF}$$

Note the suffix q with EMF indicating Q axis



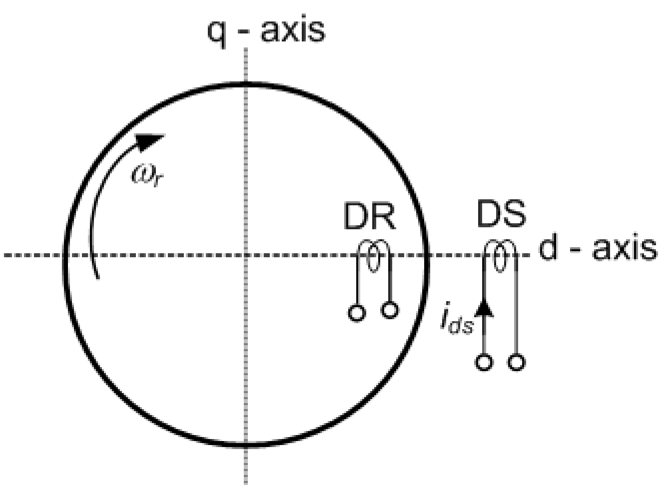
Static & Dynamic EMFs

$$e = +\psi_{md}\sin\theta\omega_r - \cos\theta M_d\left(pi_{ds}\right)$$

- When $\theta = 0^0$, the coil DR comes along the d-axis
- EMF induced in the rotor coil DR is:

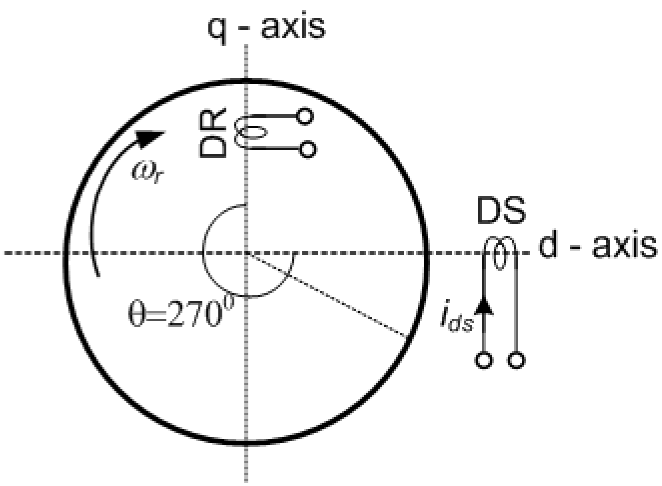
$$\begin{aligned} e_d &= +\psi_{md}\sin 0^0\,\omega_r - \cos 0^0\, M_d\left(pi_{ds}\right) \\ &= 0 - M_d\, p\left(i_{ds}\right) \\ &= -M_d\, p\left(i_{ds}\right) \\ &= -p\psi_{md} = \text{Static/transformer EMF} \end{aligned}$$

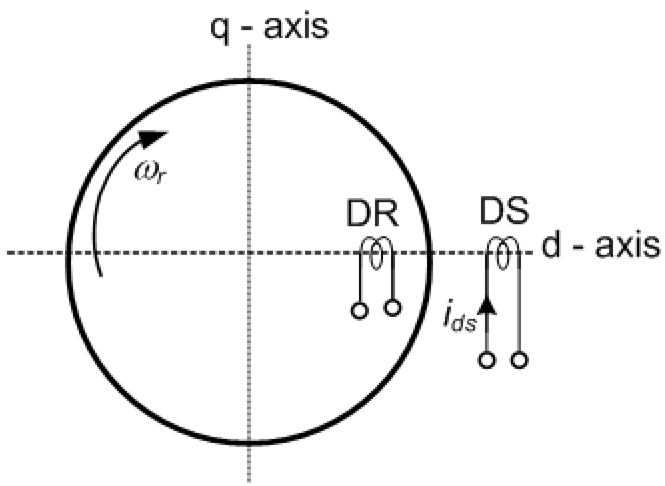
Note the suffix d with EMF indicating D axis



Static & Dynamic EMFs

$$e = +\psi_{md} \sin\theta\omega_r - \cos\theta M_d (pi_{ds})$$





$$e_q = -\psi_{md}\omega_r - 0 = -\psi_{md}\omega_r$$

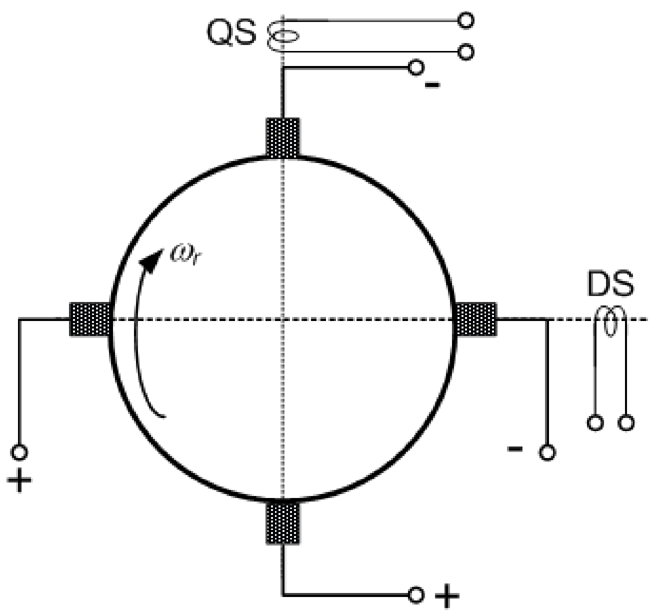
$$e_d = 0 - M_d p(i_{ds}) = -M_d p(i_{ds})$$

- The dynamically induced EMF (speed EMF) is maximum when the moving coil is magnetically perpendicular to the other (static) coil
- The statically induced EMF (transformer EMF) is maximum when the coils are magnetically aligned along the same axis

Kron's primitive machine

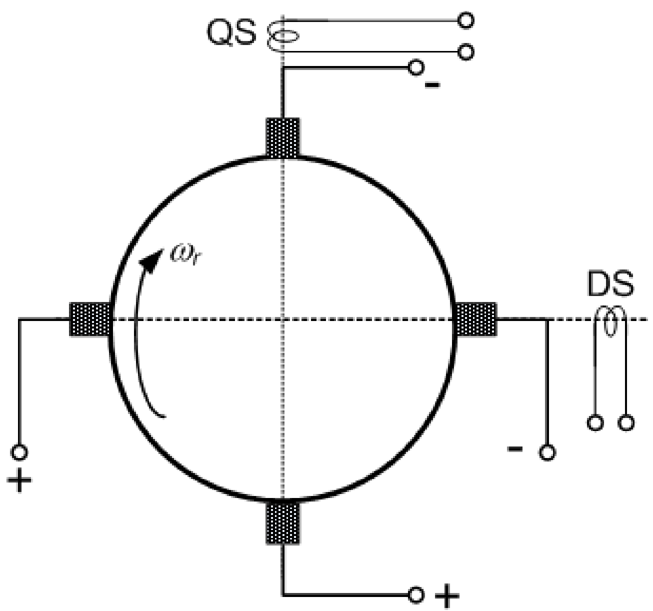
Generalized machine structure

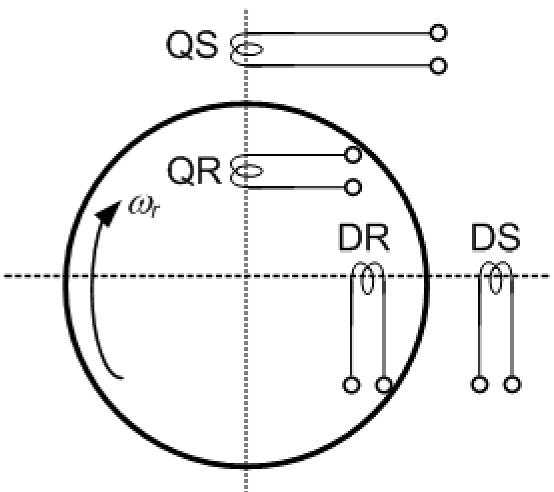
- As per Gabriel Kron, the primitive machine (generalized machine) has:
  - A stationary field coil DS in stator along d-axis
  - An independent field coil QS in stator along q-axis
  - Rotor has a completely closed type winding as in DC machine armature
  - Rotor has commutator
  - Rotor has two sets of brushes that are magnetically perpendicular (one brush set along d-axis, and the other along q-axis)



Generalized machine structure

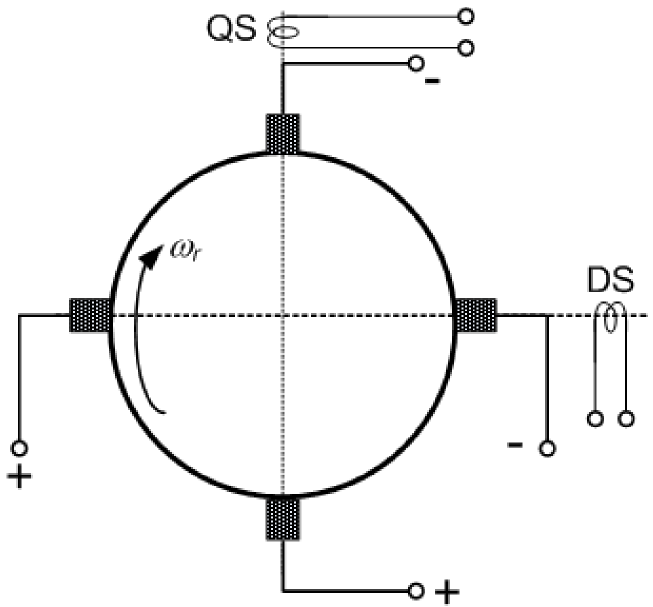
- The two sets of brushes will effectively make the rotor winding into two independent sections, whose axes are at right angles to each other
- Thus, in generalized structure, the rotor will have two coils DR and QR, one along the d-axis, and the other along q-axis
- The idealized or 2-pole generalized structure for this machine will be:
- (*Note that it is not necessary to show the brushes in the equivalent diagram*)

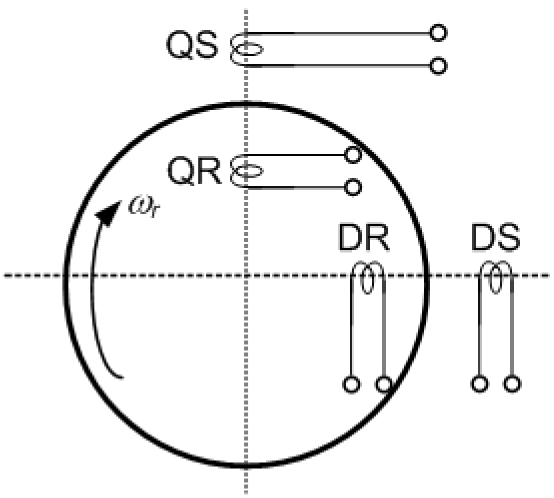




Generalized machine structure

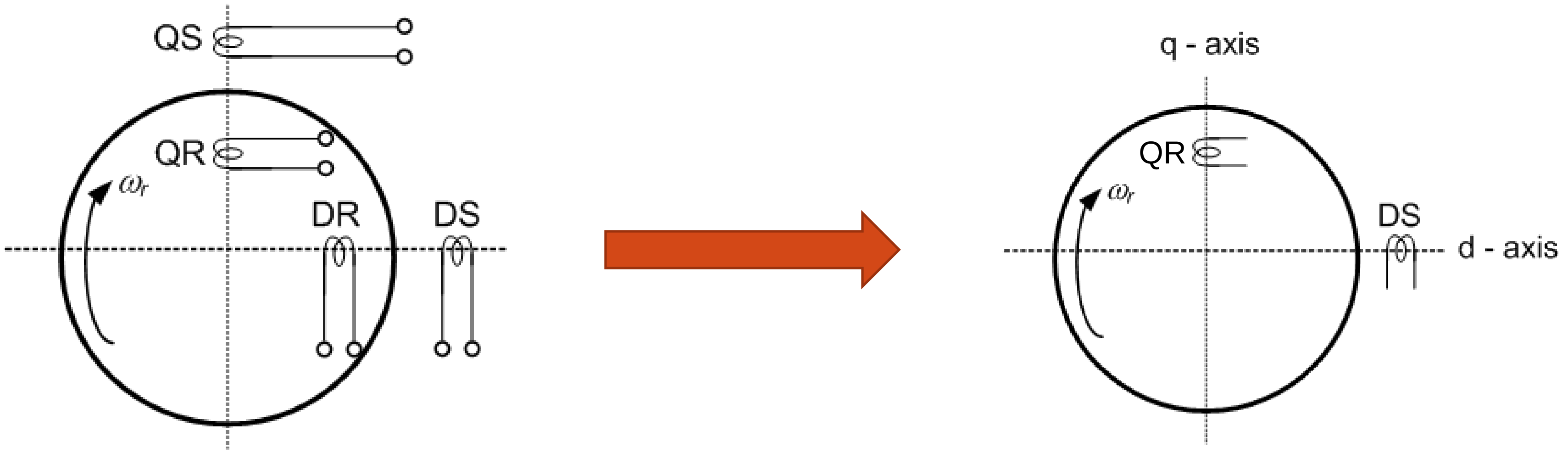
- The second figure is called:
  - Generalized machine
  - Kron's primitive machine
  - Generalized model
  - Two-axis model
- This generalized model is applicable for all rotating machines (with suitable modifications)





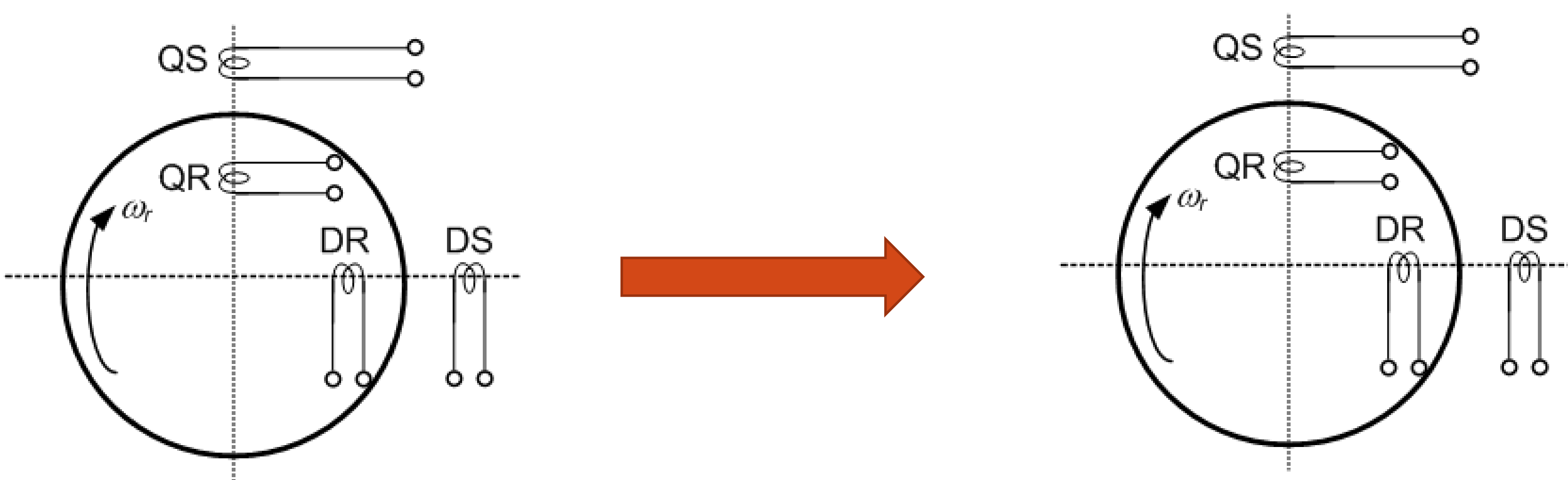
Generalized machine structure

- **DC machine model from generalized model:**
  - DS for the stator (field) coil
  - QR for the rotor (armature) coil



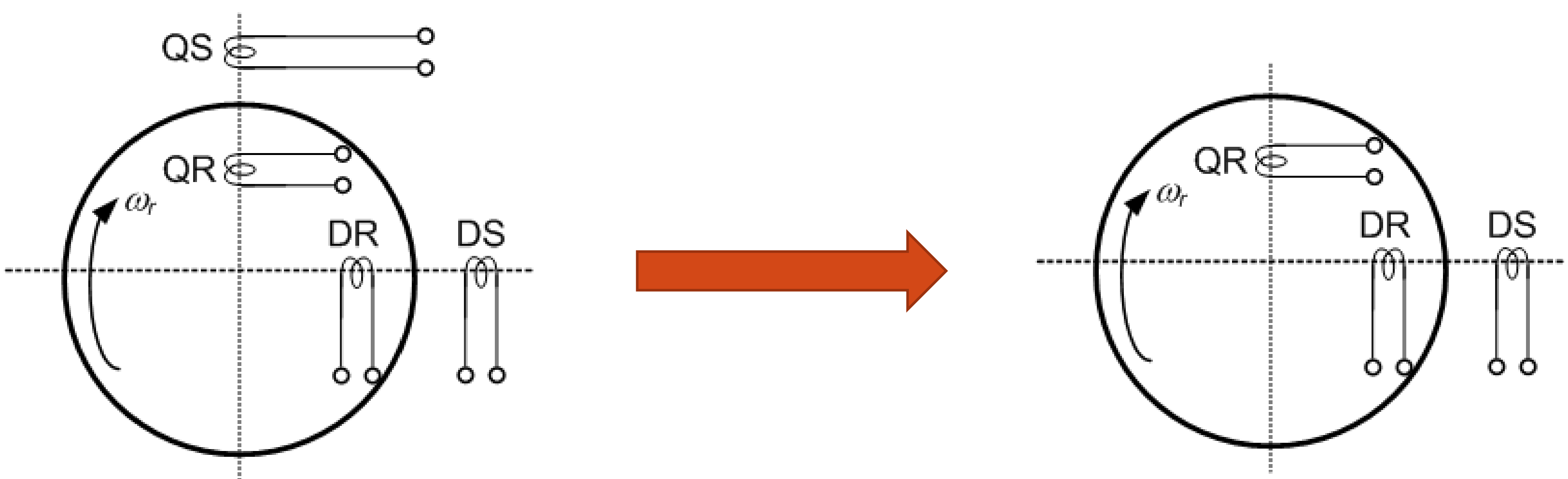
Generalized machine structure

- **3-phase induction machine model from generalized model:**
  - Ideally we could have required 3-coils in stator (and also in rotor) to represent the 3-phase windings
  - But, remember that a set balanced 2-phase coil (90^0 space angle difference) when supplied from a balanced 2-phase supply (90^0 time angle difference), produces the same rotating magnetic field (RMF) as by a 3-phase winding (120^0 space angle difference) supplied from a 3-phase supply (120^0 time angle difference)
  - Thus, both stator and rotor can be represented by two orthogonally placed coils



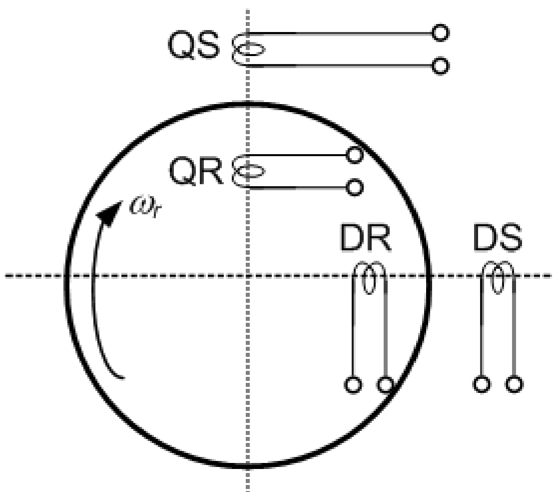
Generalized machine structure

- **3-phase synchronous machine model from generalized model:**
  - The field coil (DC excitation) is assumed to be in stator and is represented by a single coil DS along the d-axis
  - The 3-phase armature coil (assumed to be in rotor), can be represented by two orthogonally placed coils DR and QR that produces similar RMF as would have been produced by a 3-phase winding



Generalized machine structure

- **Fundamental assumptions for the primitive machine:**
  - The MMF distribution along air gap is sinusoidal, i.e. effects of space harmonics can be neglected
  - Saturation and hysteresis are neglected (i.e. magnetic circuit is assumed to be linear)
  - Slots and teeth does not affect reactance of stator and/or rotor



Limitations of Generalized theory

- The generalized theory of machines cannot be applied to machines that have salient structures both in stator and rotor

- The non-salient element of the machine must have balanced windings

- Certain special effects, such as brush contact phenomena, commutation effects, and surge effects cannot be represented in the Kron's primitive machine

- Effects of slotting, skewing, stray load losses, eddy current phenomena, and certain mechanical issues such as noise, vibration etc. cannot be studied directly using the generalize theory.