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Object-oriented modeling of electrical machines: Modelica.Electrical.Machines

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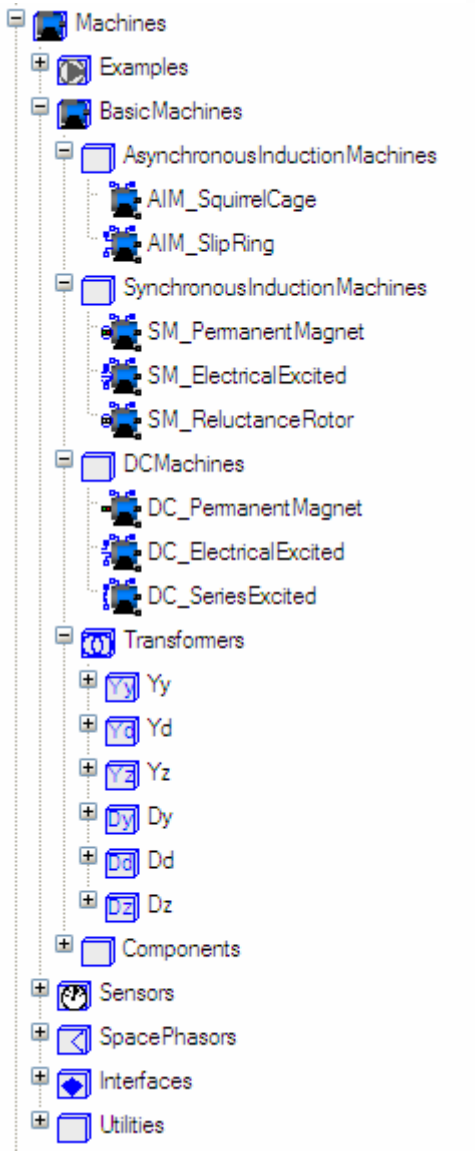
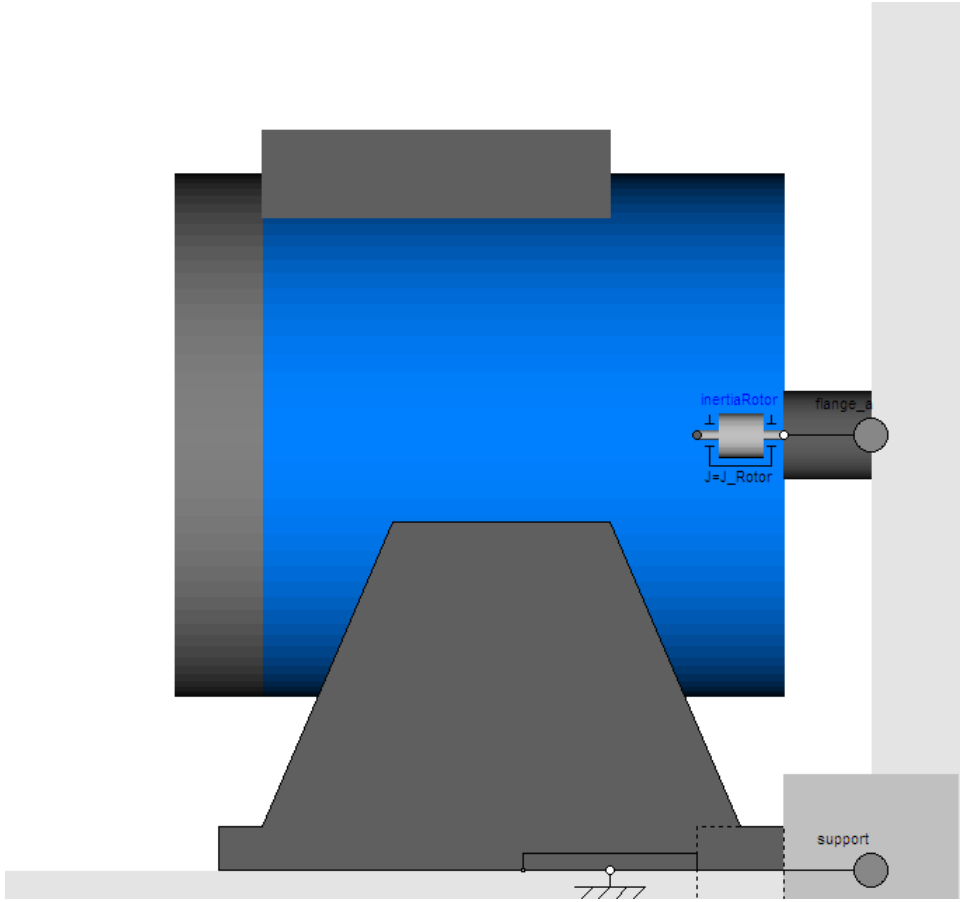


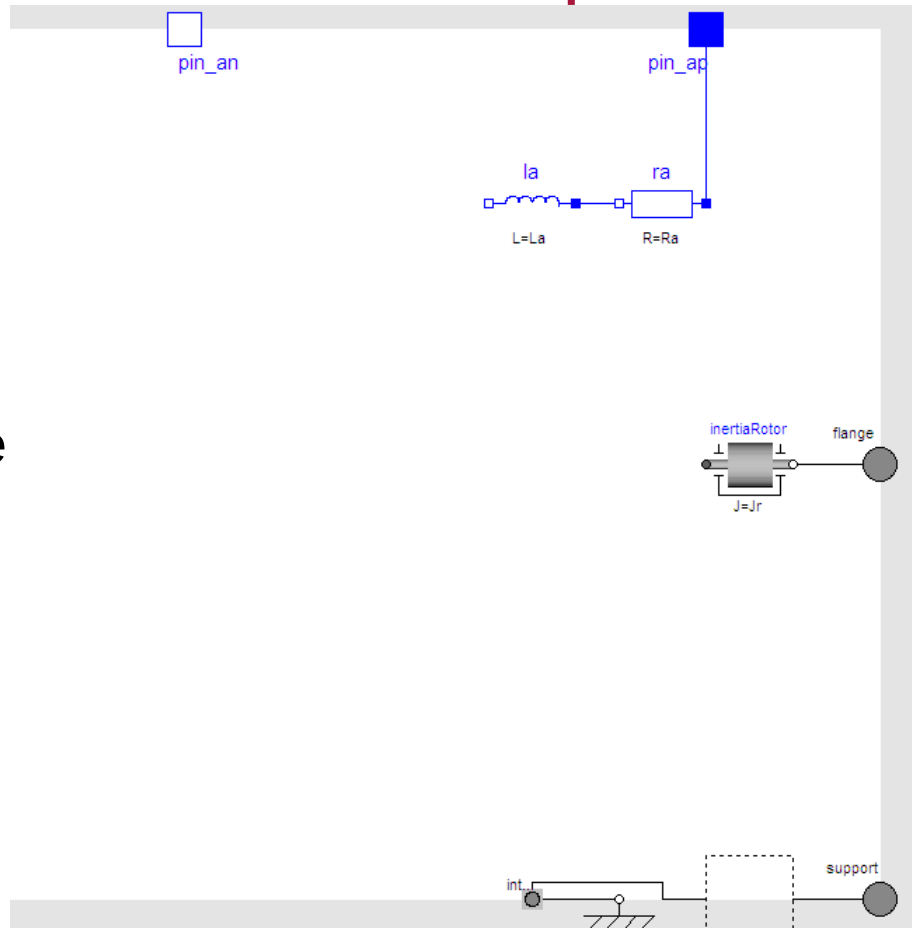
Common Mechanical Components

- Rotor's moment of inertia
- Stator:
  - useSupport = false:
    fixed
  - useSupport = true:
    moment of inertia
    + connect support!
- Common parameters
- Common outputs
  e.g. wMechanical, tauShaft
- Icon



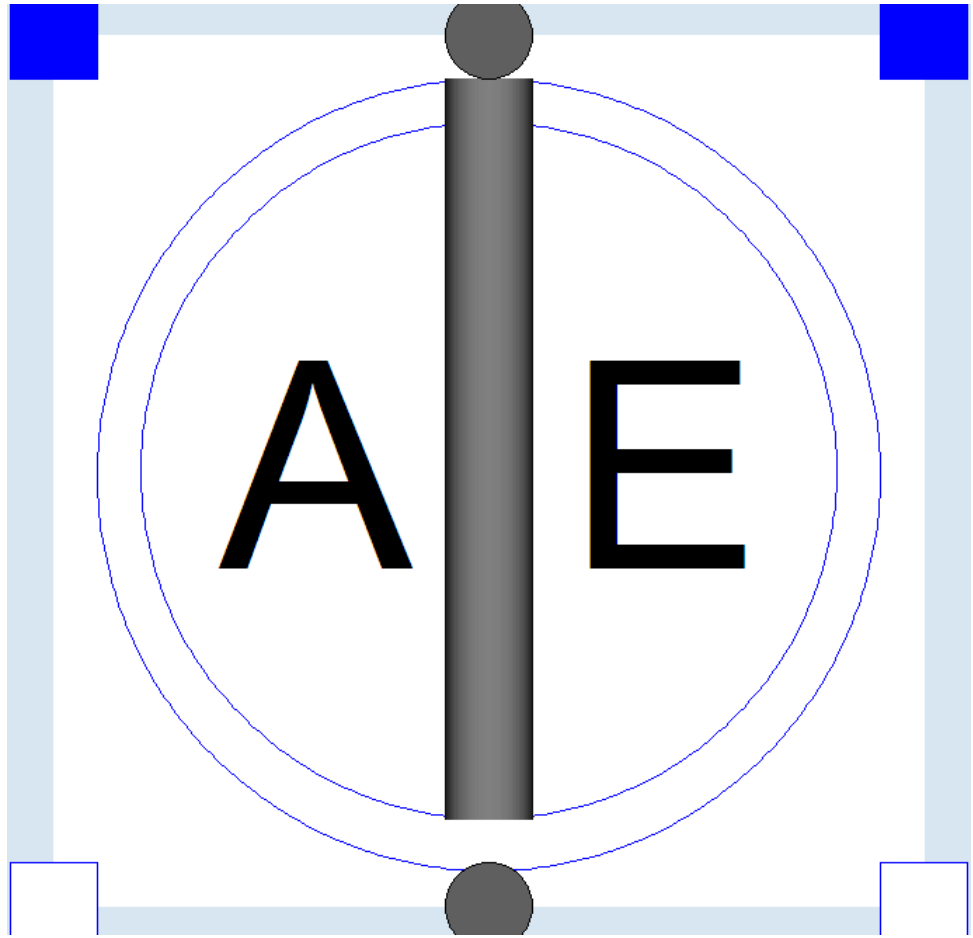
DC Machines: Common Electrical Components

- Armature pins
- Armature resistance + leakage inductance
- Common parameters for:
  - PM DC machine
  - Electrical excited DC machine
  - Series excited DC machine



DC Machines: Airgap

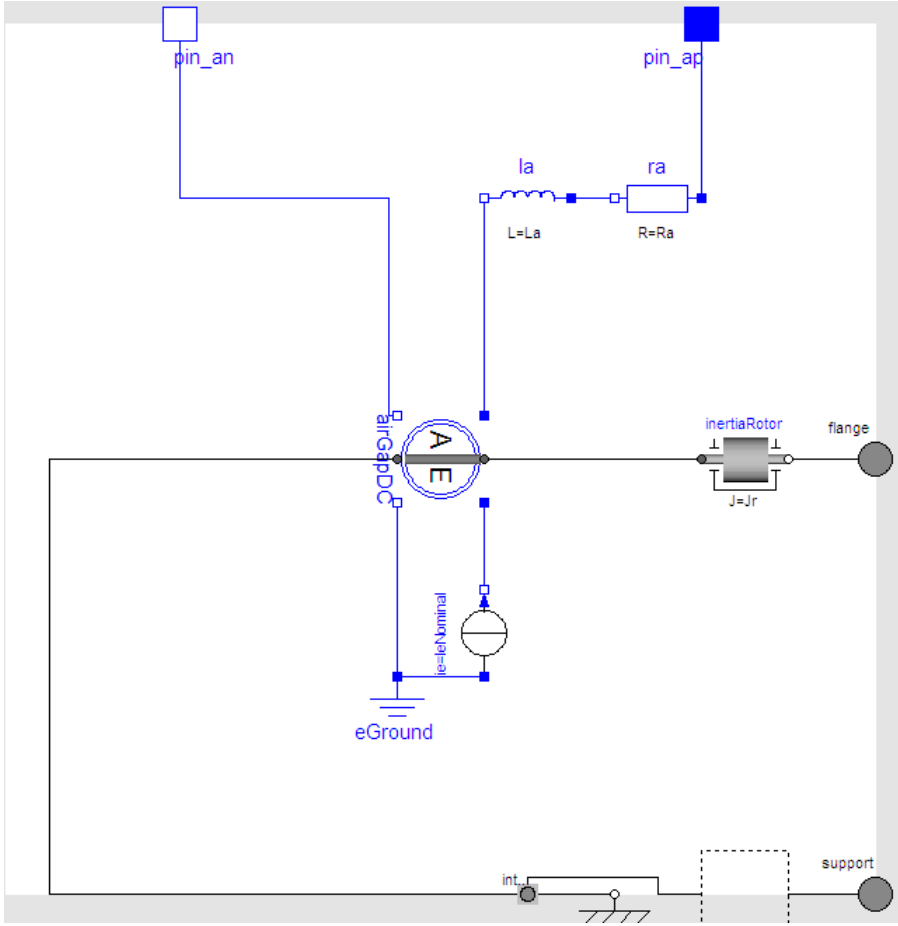
- Calculates flux from excitation current
- Induced armature voltage:
  ~ psi * omega
- Induced excitation voltage:
  ~ der(psi)
- Torque tau:
  ~ psi * armature current
- omega =
  der(shaft.phi – support.phi);
- tau = - shaft.tau;
  tau = support.tau;



Permanent Magnet DC Machine

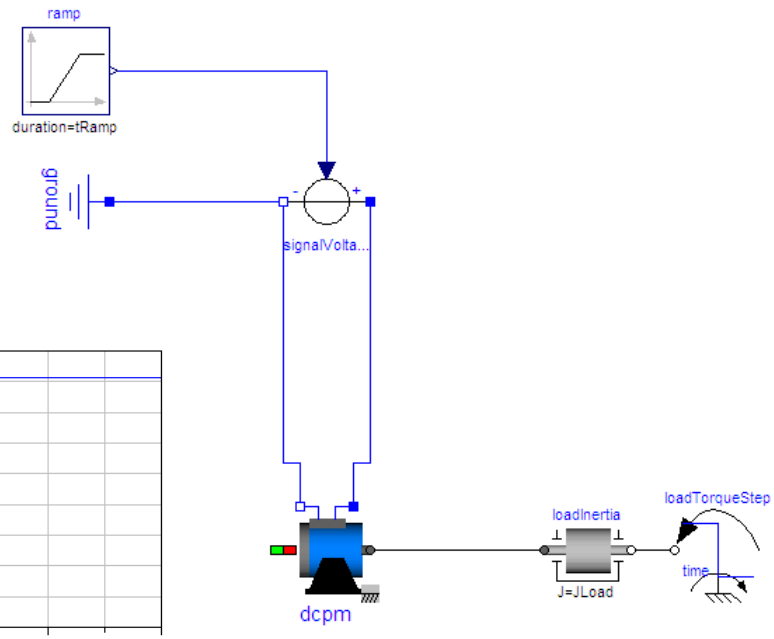
- What's missing:

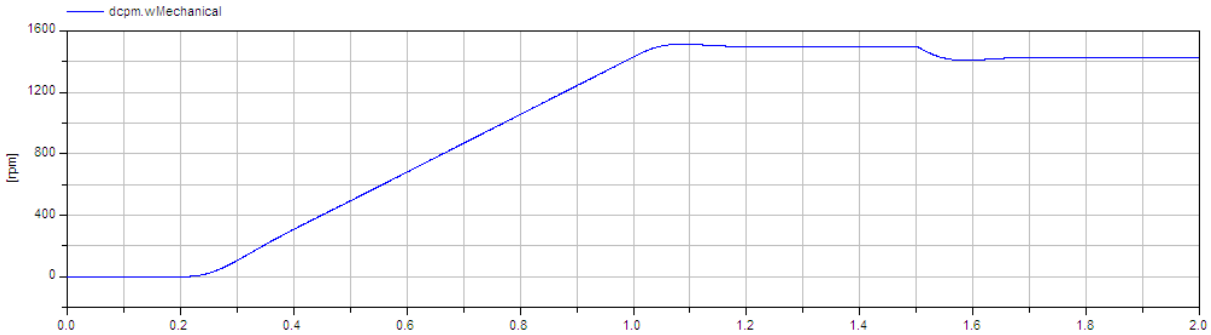
  excitation
- PM acts like
  constant excitation current
- turnsRatio * Ie:
  determined by
  induced armature voltage
  at nominal speed
  and no-load

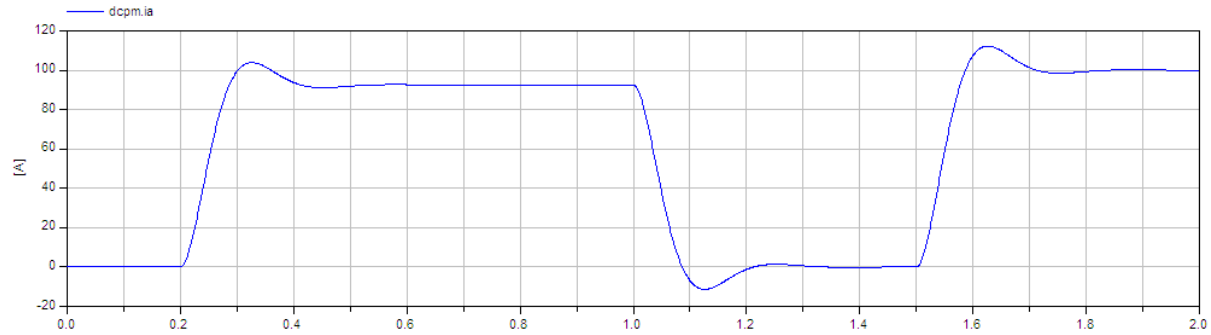


DC Machines: Example 1

- Starting from standstill, applying an armature voltage ramp
- Followed by a torque step

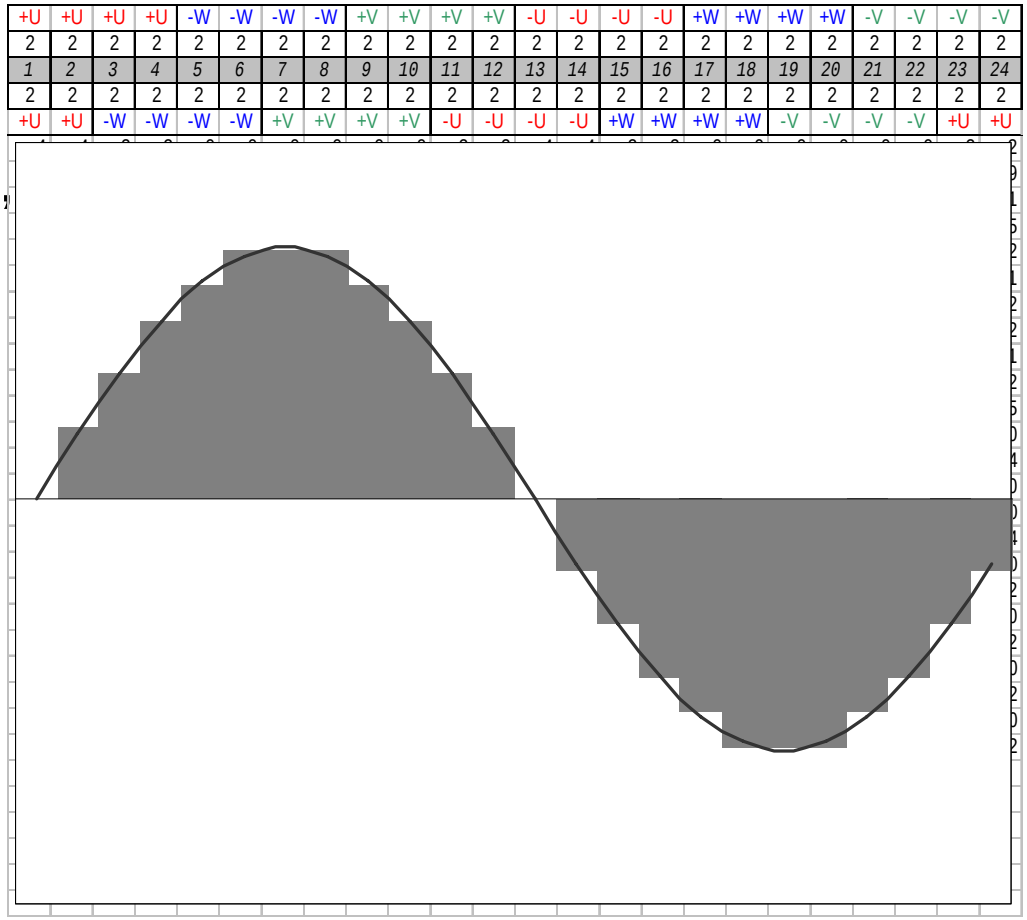






Induction Machines: Three-Phase Winding

- Feeding
  a three-phase winding,
  i.e. shifted spatially by 120°,
  with three-phase current,
  i.e. shifted timely by 120°,
  gives a sinusoidal field,
  rotating with f / p.
- This rotating field
  can be represented by a
  space phasor.



Induction Machines: Space Phasors

- Length ~ field magnitude
- Points to maximum of field
- i.e. rotating with f / p
- Space phasor transformation:

$$\underline{a} = e^{j\frac{2\pi}{3}} = \cos\left(\frac{2\pi}{3}\right) + j \cdot \sin\left(\frac{2\pi}{3}\right)$$

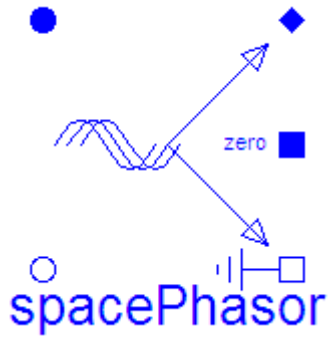
$$V_0 = \frac{1}{3} \cdot (v[1] + v[2] + v[3])$$

$$\vec{V} = \frac{2}{3} \cdot \left(\underline{a}^0 \cdot v[1] + \underline{a}^1 \cdot v[2] + \underline{a}^2 \cdot v[3]\right)$$

$$v[1] = V_0 + \mathrm{Re}\left(\underline{a}^0 \cdot \vec{V}\right)$$

$$v[2] = V_0 + \mathrm{Re}\left(\underline{a}^2 \cdot \vec{V}\right)$$

$$v[3] = V_0 + \mathrm{Re}\left(\underline{a}^1 \cdot \vec{V}\right)$$



- coordinate system (2) rotated by the angle γ against the original coordinate system (1):

$$\vec{V}_{(2)} = \vec{V}_{(1)} \cdot e^{-j\gamma}$$

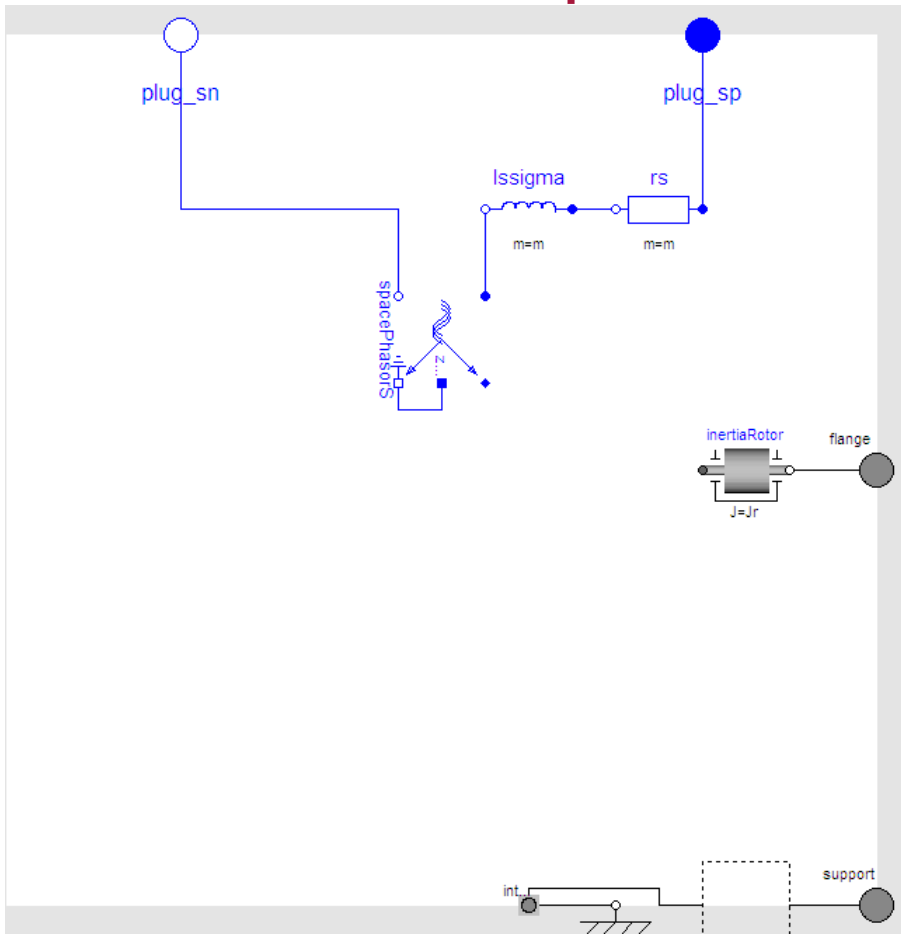
$$\vec{V}_{(1)} = \vec{V}_{(2)} \cdot e^{+j\gamma}$$

Assumptions

- Phase symmetric windings are assumed, as well as symmetry of the whole machine structure.
- Only first harmonics (in space) of current coverage, field excitation curve and flux density distribution are taken into account.
- Waveform of all signals is not restricted.
- Resistances and inductances are considered as constant parameters.
- Eddy currents in solid iron as well as iron losses and friction losses are neglected.
- Skin effects are neglected.
- ➔ http://www.haumer.at/refimg/SpacePhasors.pdf

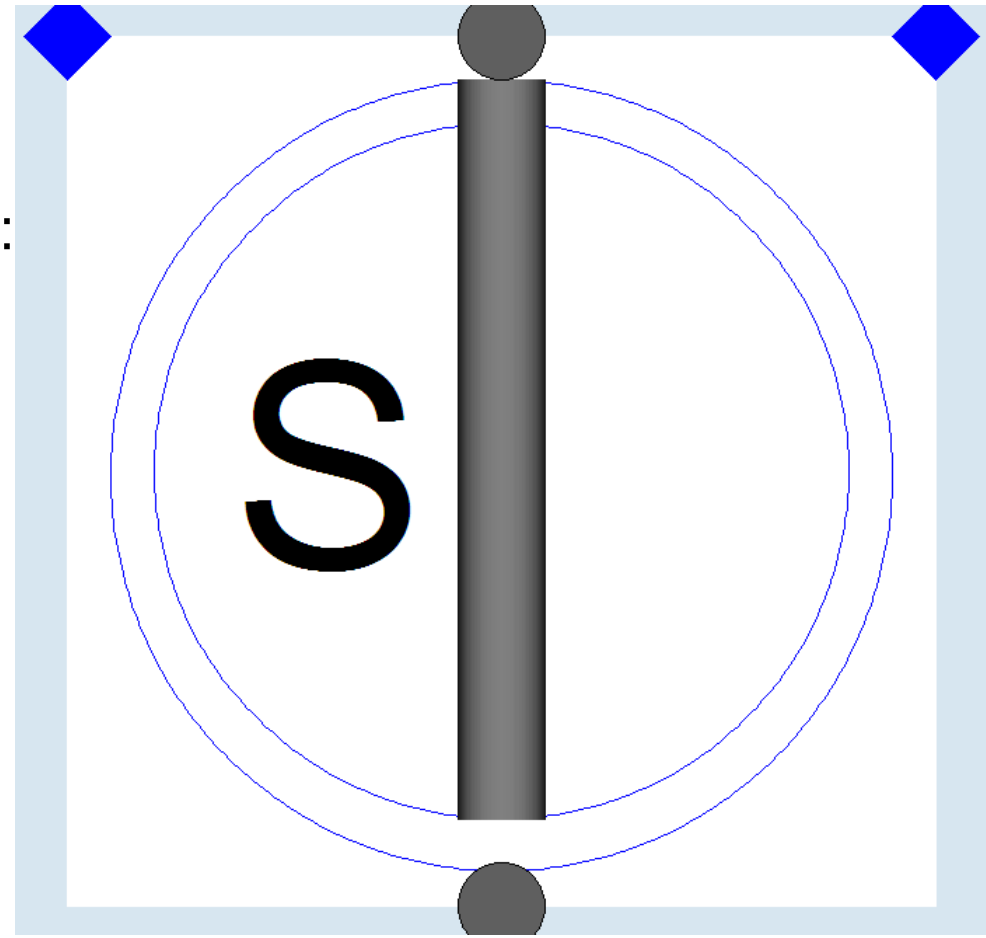
AC Machines: Common Electrical Components

- Stator plugs
- Stator resistances + leakage inductances
- Space phasor transformation
- Common parameters for:
  - AIM squirrel cage
  - AIM slip ring
  - SM permanent magnet
  - SM electrical excited
  - SM reluctance



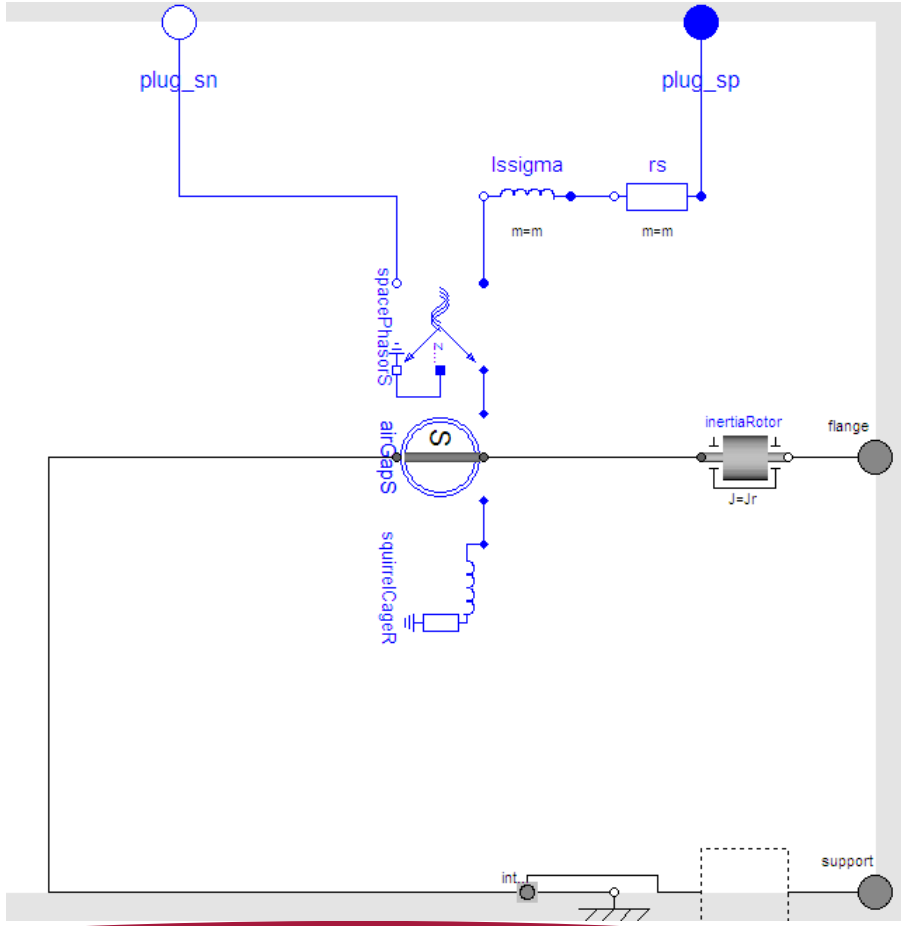
AC Machines: Airgap

- Calculates main flux from stator + rotor current
- Common coordinate system: stator or rotor fixed
- Induced voltage: der(psi)
- Torque tau: $\frac{m}{2} p \cdot \mathrm{Im}\left(\underline{i}_S \cdot \underline{\psi}_S^*\right)$
- omega = der(shaft.phi – support.phi);
- tau = - shaft.tau;
  tau = support.tau;



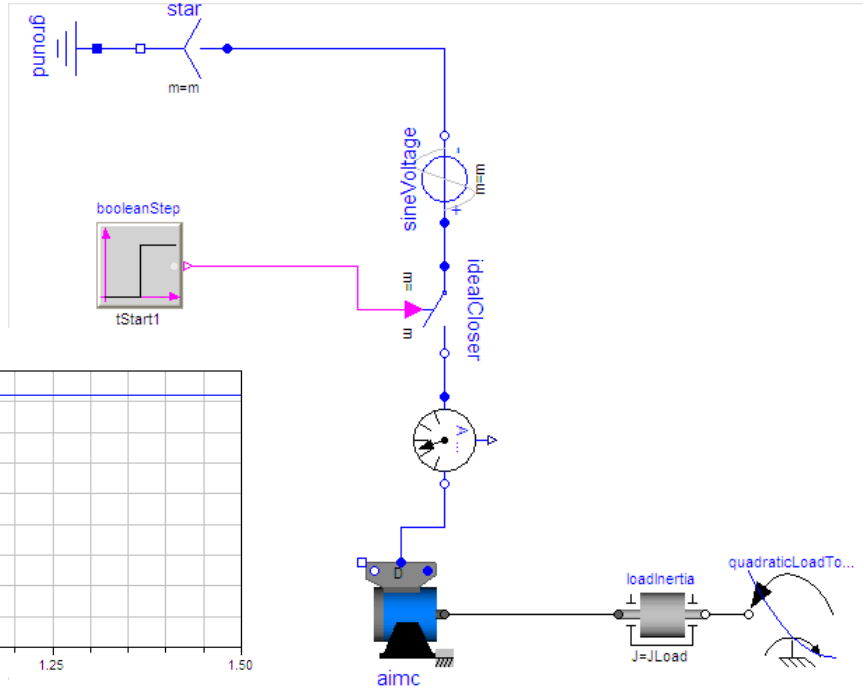
AIM Squirrel Cage

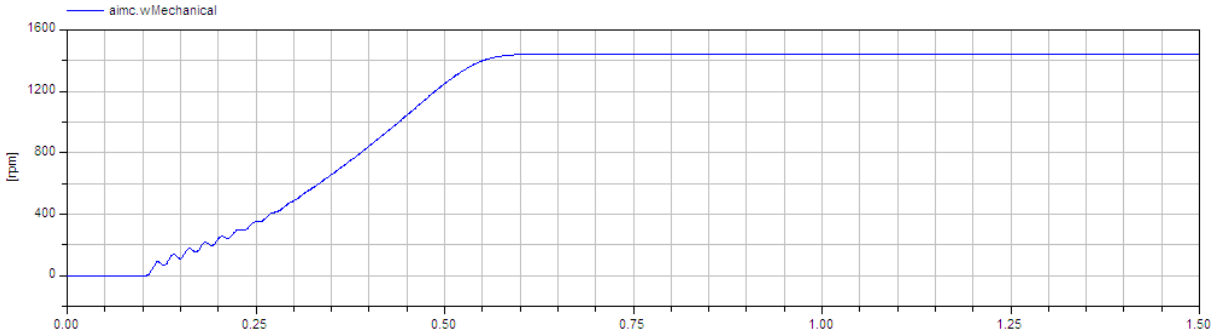
- What's missing:
  squirrel cage
- resistance and inductance of squirrel cage:
  w.r.t. stator

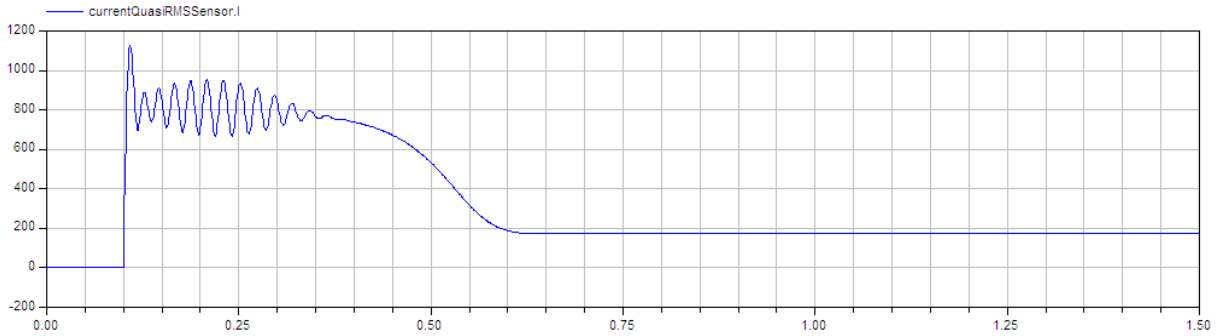


AC Machines: Example 1

- AIM with squirrel cage
- Starting from standstill
- Quadratic load torque

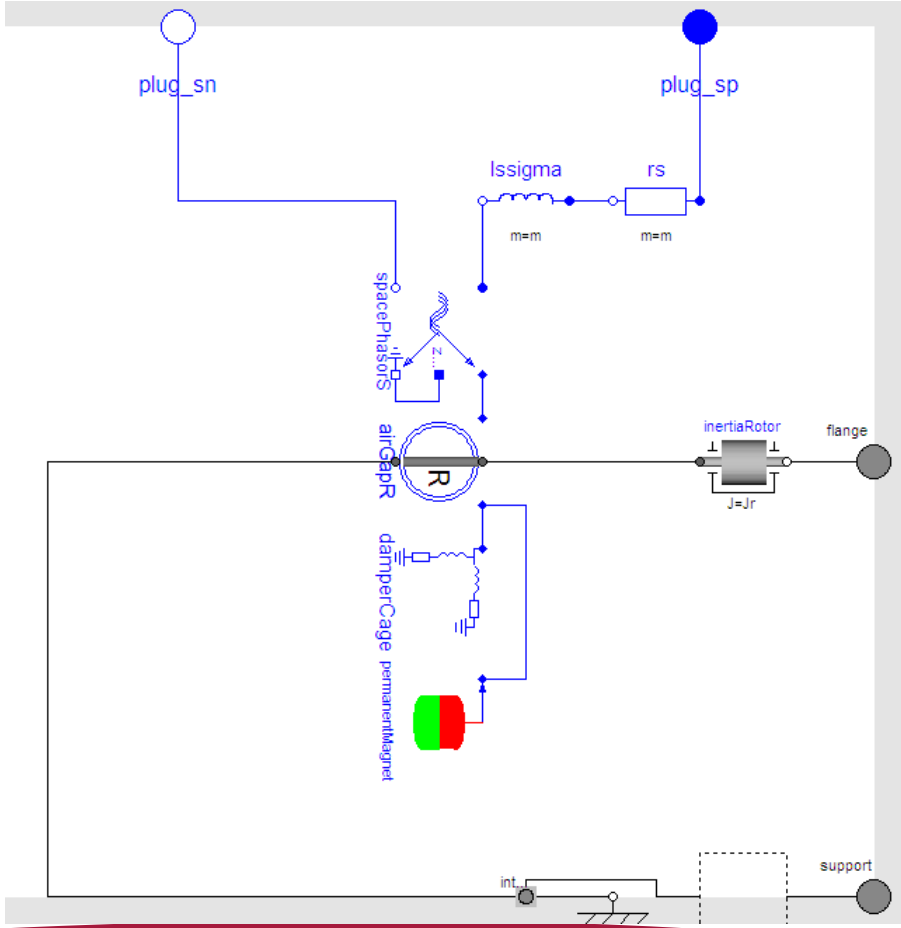






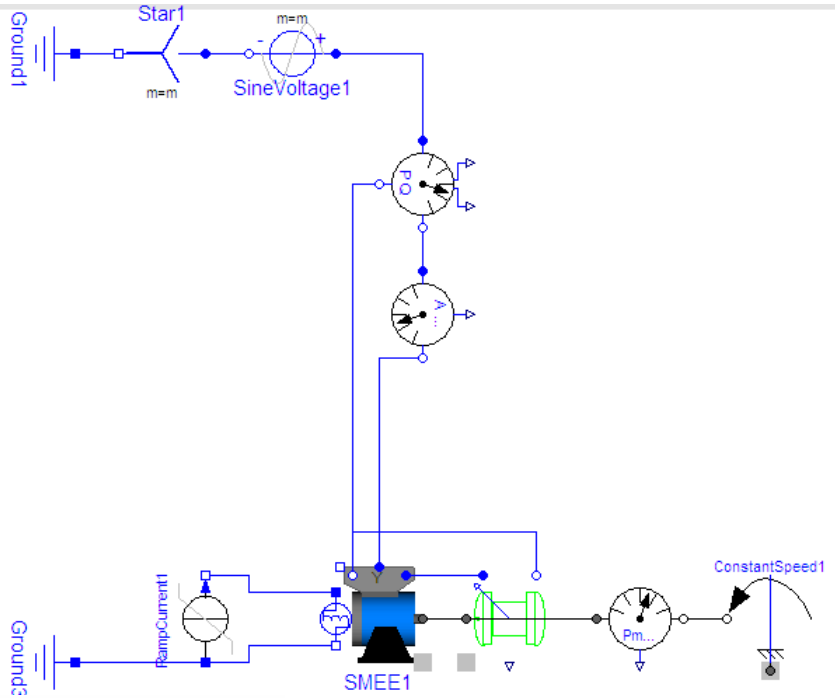
SM Permanent Magnet

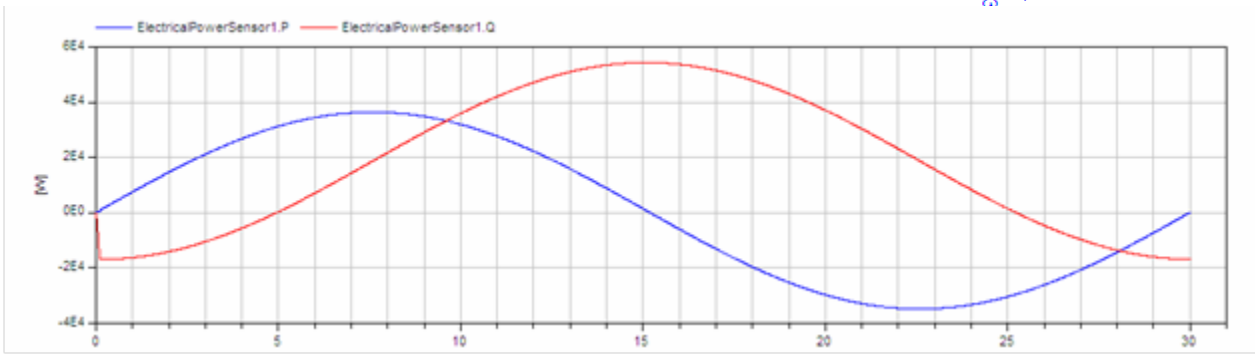
- What's missing:
  excitation
- PM acts like
  constant excitation current
- turnsRatio * Ie:
  determined by
  induced stator voltage
  at nominal speed
  and no-load
- User can choose whether
  damper cage is present or not
- Different inductances
  d-axis and q-axis



AC Machines: Example 2

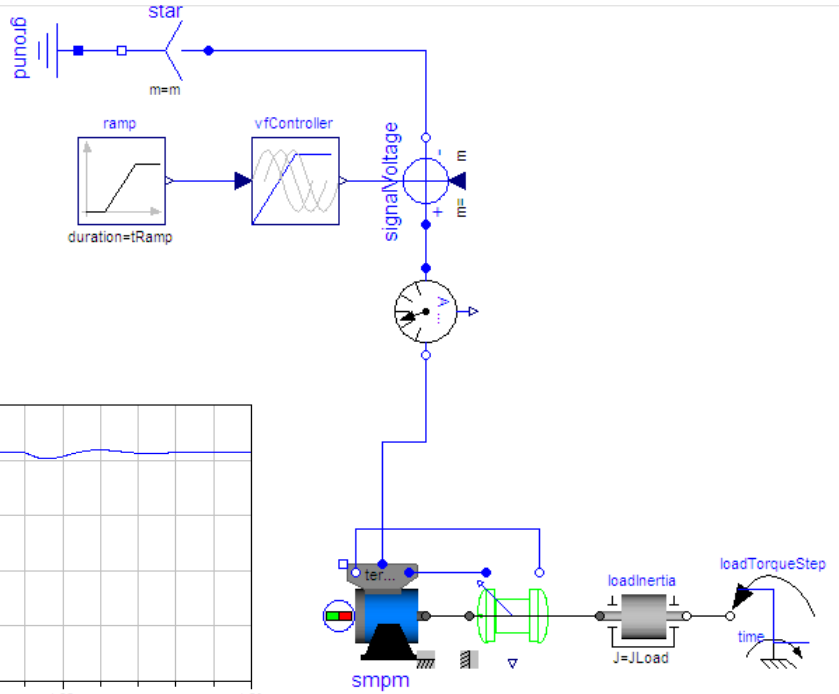
- SM with electrical excitation
- Driven with constant speed
- Constant excitation
- Varying load angle

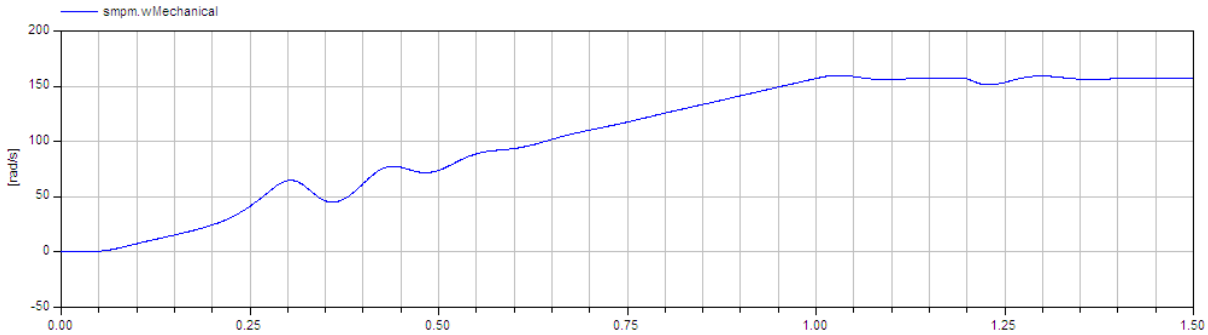


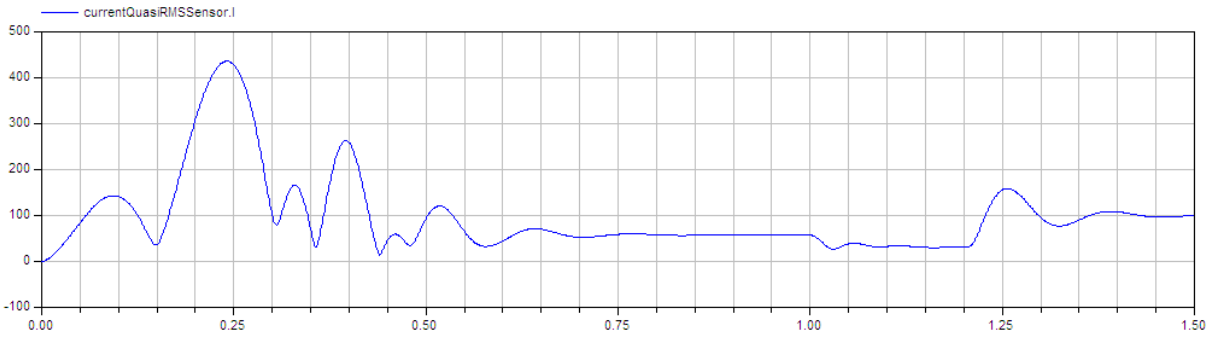


AC Machines: Example 3

- SM with permanent magnet
- Simple open-loop inverter
- Load torque step

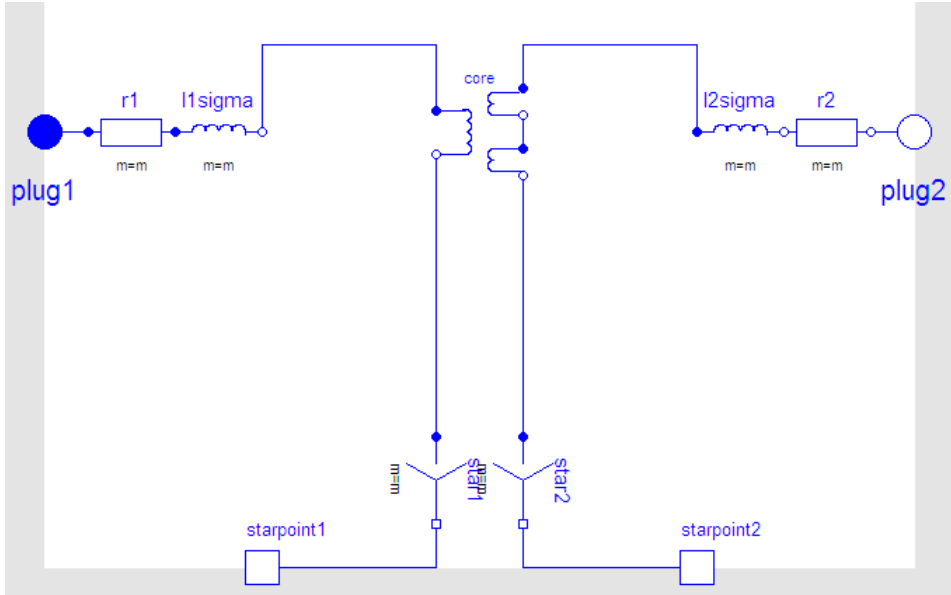






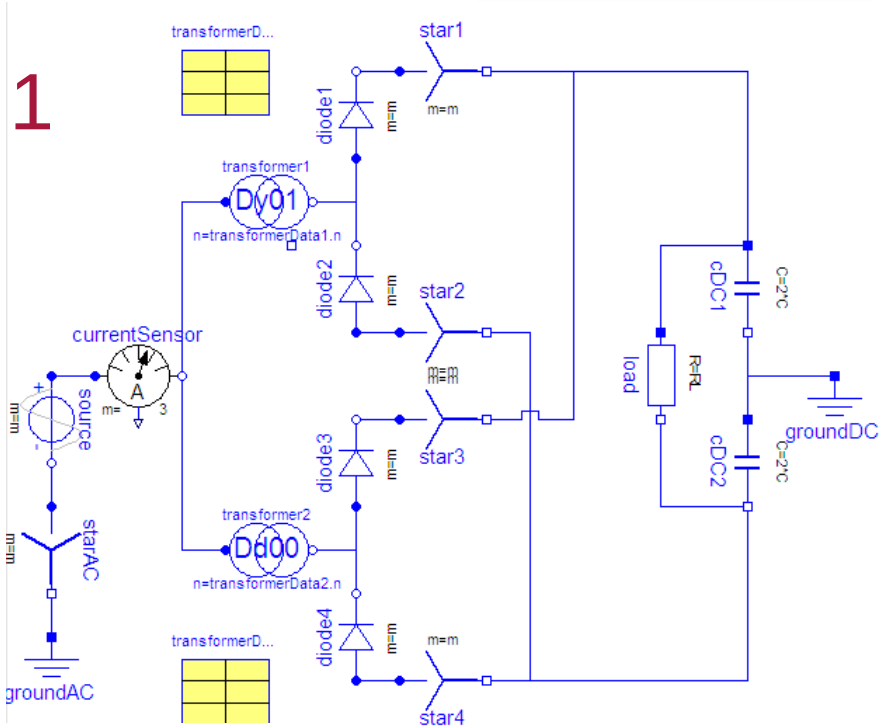
Transformers

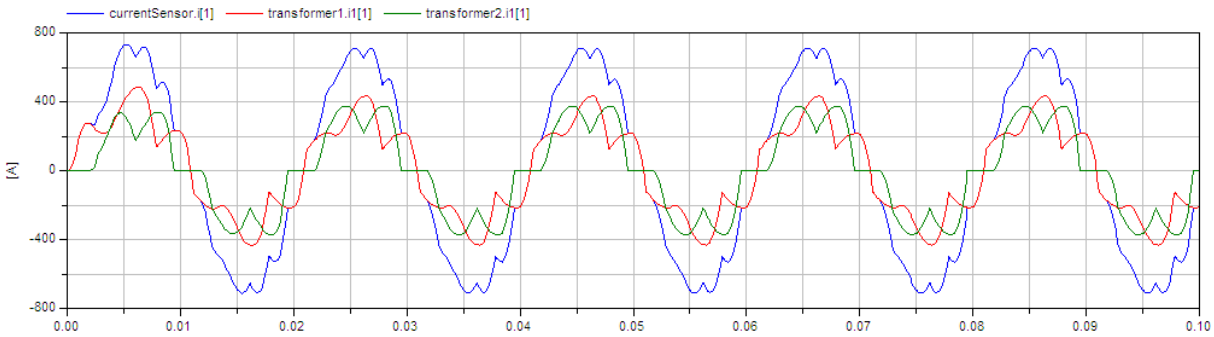
- Primary + secondary resistance + leakage inductance
- No magnetizing current, no magnetizing losses
- Record TransformerData helps to calculate parameters
- All vector groups
  - Yy
  - Yd
  - Yz
  - Dy
  - Dd
  - Dz



Transformers: Example 1

- 12-pulse rectifier
- Transformer Dy1 + Dd0
- Significant reduction of harmonic currents





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