Simulation of Electrical Machines and Drives
Using the Machines and the SmartElectricDrives Library

Tutorial Part 1
Non-controlled Electric Drives

Version 02
2011-03-20

Electric Drive Technologies

Electric Drives are Energy Converters

- Energy Converters
  - rotating electric - machanic
    - DC machines
      - Asynchronous Induction machines
    - AC machines
      - Synchronous Induction machines
  - static electric - electric
    - constant f
      - Transformers
    - variable f
      - Inverter
Electric Drives

- Rotating electric machines = Multi domain energy converters:
  electric ↔ magnetic ↔ mechanic
- By far most important:
  induction machines, esp. asynchronous induction machines with squirrel cage

How does it work?

- Animations: [http://www.georg-andresen.de/el_machinen.html](http://www.georg-andresen.de/el_machinen.html)

- **How does an induction machine work?**
  - 3 phase winding, spaced by 120°
  - 3 currents, shifted by 120°

- **How does an asynchronous induction machine work?**
  - Speed of the rotor <> synchronous speed

- **How does a synchronous induction machine work?**
  - Speed of the rotor = synchronous speed

- Induction Machines Models are based on Space Phasor Theory.
Models of the Modelica Standard Library

- Asynchronous Induction Machines
  - With Squirrel Cage
  - With Slipring (wound rotor)
- Synchronous Induction Machines
  - With Permanent Magnet
  - With Electrical Excitation
  - With Reluctance Rotor
- DC Machines
- Transformers

Parameters of Electric Machines

- Inertia
- Number of poles
- Resistances & Stray Inductances of windings
- The user has to know:
  - Appropriate Voltage & Frequency of the source/grid
Example 1

- Asynchronous induction machine with squirrel cage
- Started direct on line
- Load torque quadratic dependent on speed, like a pump or fan

Example 1: results
Example 2

- Synchronous induction machine
- Driving speed slightly different from synchronous speed \( \Rightarrow \) rotor displacement angle varies slowly
- Characteristics (active & reactive power) vs. rotor displacement angle

Example 2: results
Example 3

- Permanent Magent Synchronous induction machine
- Voltage / Frequency characteristic
- Nearly instable operation ⇒ need for FOC (field oriented control)

Example 3: results
Controlled Electric Drives

- For many applications torque / speed / position control is desired.

- Which devices do we need additionally?
  - Inverter (Power electronics)
    - AC/DC converter feeds an intermediate circuit
    - DC/AC inverter feeds machine
      - from intermediate circuit
      - or from DC source
  - Control structure
    - For induction machines: Field Oriented Control (FOC)

- SmartElectricDrives Library

Outlook: Controlled Electric Drives

- Thanks for your attention!

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- Controlled Electric Drives:
  - Tutorial Part 2
    Anton Haumer
  - Electrical Energy Storage
    - Tutorial Part 3
    Markus Einhorn
Tutorial Part 2
Electric Drive Structure

Version 03
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Electric Drive Application

- Commanded reference
  - torque
  - speed
  - position reference
- Capability of electric drive
  - full torque in constant flux region
  - reduced torque with flux weakening
  - overload
- Electric drive behavior
  - electrical
  - mechanical
  - thermal
Electric Drive Structure

- Power supply, AC or DC
- If AC power supply → AC/DC converter (control ?)
- DC/AC converter (variable voltage and frequency)
- Machine
- Control of machine (torque / speed / position)
  - Measurement equipment (voltages, currents, speed)
  - Flux model
  - Field oriented control
  - Reference values (machine, operation)
- Internal / external bus
- Mechanical load
Components for Simulating an Electric Drive

Modelica Standard Library (MSL)
- Ideal power sources
- Power electronic components
- Controllers
- Bus
- Machine

SmartElectricDrives (SED) library
- Power sources
  - battery models (variable SOC)
  - fuel cell model
- Converter topologies
  - DC / AC converters
  - AC / DC converters
  - DC / DC converters
- Flux / flux weakening / current controller
  - specific for machine type
  - parameter estimation functions
- Internal / external bus
- AdvancedMachines (new in SED 1.4.0)
  - thermal connectors
  - core / friction / stray load losses

Parameters for Operating a Drive

- Machine
  - Modelica.Electrical.Machines (constant parameters)
  - AdvancedMachines / ExtendedMachines
- Flux model
  - machine parameters (constant parameters)
- Field oriented controls
  - machine parameters (constant parameters)
  - controller parameters
  - reference values and limits
  - maximum terminal voltage
  - maximum phase current
  - flux level
Converter Models

- Switching converters
  - conduction losses
  - switching losses
  - electromagnetic transients
  - slow simulations
- Power balance converters
  - conduction losses
  - switching losses
  - no switching effects
  - fast simulations

Drive Models

- Drive models
  - ready to use models
  - DC bus interface
  - external bus interface
  - integrated DC / AC converter
    - ideal converter
    - DC pins
- Transient drive models
- Quasi stationary drive models
  - no electrical transients
  - mechanical inertia effects
  - no controller parameters required
    - Characteristic time constant
    - fast simulation
Library Structure

- QuasiStationaryDrives
  - QuasiStationaryDrives
  - ALMCSupplyDC
  - SMPMSupplyDC
  - DCPMSupplyDC
  - DCEESupplyDC

- TransientDrives
  - TransientDrives
    - AsynchronousInductionMachines
    - PermanentMagnetSynchronousInductionMachines
    - PermanentMagnetDCMachines
    - ElectricalExcitedDCMachines

- SmartElectricDrives
- User's Guide
- Examples
- QuasiStationaryDrives
- TransientDrives
- Converters
- Sources
- ProcessControllers
- Loads
- Sensors
- Interfaces
- AuxiliaryComponents
- Icons
Library Structure

Key Advantages of the SED library

- Comprehensive library for electric drive simulation in automotive applications
- Applicable for hardware in the loop (HIL) and real time simulations
- ‘Ready to use’ models
- Controller parameter estimation functions for easy controller handling
- Models at different layers of abstraction
- SED bus concept for easy coupling with other Dymola libraries
- Many examples, extensive documentation and intelligible SED library structure
SED Tutorial. Example 2:

Permanent Magnet Synchronous Machine
- Application: water pump
- Quasi stationary drive model
- Ideal battery (inner resistance) supply
- Speed control
- Mechanical load (pump)
  - inertia (J)
  - quadratic torque speed characteristic

SED Tutorial. Example 2: Results
SED Tutorial. Example 2: Results

![Graph showing simulation results.]

SED Tutorial. Example 4

![Diagram showing Modelica components.]

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TOMORROW TODAY
Thank you for your attention.

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- Electrical Energy Storage
  Tutorial Part 3
  Markus Einhorn
Objective

A library to simulate electric energy storages like batteries and supercaps for

- Electric and hybrid electric vehicles
- Mobile devices
- Stationary storage applications

Benefits

- Universal models with different level of detail
- Stationary and transient storage applications
- Conditional thermal connectors
Structure of the Library

- ElectricEnergyStorages
  - User's Guide of EES library
  - Examples
  - Batteries
    - BatteryManagement
    - Chargers
    - Loads
    - Sensors
    - Icons
    - Interfaces
    - SIUnits
    - Components

- Batteries
  - Cells
    - Single
    - StaticResistance
    - LinearDynamicImpedance
    - WithMeasurement
    - StaticResistance
    - LinearDynamicImpedance
    - Stacks
      - Single
      - StaticResistance
      - LinearDynamicImpedance
      - WithMeasurement
      - StaticResistance
      - LinearDynamicImpedance
    - Components

General Battery Cell Model

\[ Q = \int_{t_{\text{start}}}^{t_{\text{stop}}} I(t) \, dt \]

\[ SOC = SOC_{\text{ini}} - \frac{Q}{C} \]
Static Single Battery Cell Model
Static resistance

Dynamic Single Battery Cell Model
Variable, linear dynamic impedance and self discharge
Measurement Concept
Both single cell models are available with measurement

Static Battery Stacks
One single cell model is upscaled to a stack with $ns$ cells in series and $np$ cells in parallel
$\Rightarrow$ very fast because only one equivalent cell needs to be simulated
Dynamic Battery Stacks

$ns \times np$ instances of the dynamic single cell model and optional single cell connectors

$=>$ cell variation can be simulated

Sensors

Sensors from MSL are used and consequently extended

charge  abs. charge  energy  combined energy and charge
Bus System
Bus system for cell/stack level with bus connectors for current, voltage and temperature

Example Simulation I – Cycling a Battery Stack
Charging and discharging 3 serially connected cells with different capacity
Example Simulation II – Discharging a Single Cell

A single battery cell and the parameterized dynamic single cell model is being discharged with a current profile gained from the FTP72 real life driving cycle.

Battery cell in the climate chamber

Conclusion and Outlook

- Powerful tool for many aspects of battery simulation
- Applying for possible inclusion in the MSL
  - Modelica.Electrical.EnergyStorages
- Documentation will be completed
- Evaluation version will be provided soon on Modelica SVN