Reduced-Order-Models of electric motors for systems engineering including effects of variable magnet and winding temperatures

EM-motive GmbH, DBEM/EEP4, Marc Brück & Tobias Cors, 22 June 2018

ROMs of electric motors for systems engineering ...

Outline

- EM-motive GmbH
- System E-drive
- Functional Mockup Interface (FMI) – Functional Mockup Unit (FMU)
- State of the art – ROMs at a glance
- Impact of magnet and winding temperature
- FMU incorporating impact of magnet and winding temperature
- Providing the power of optiSLang to full capacity
- Summary

EM-motive GmbH

A joint company of Daimler and Bosch

Mercedes-Benz C350e, C300h

Porsche 918 Spyder

Peugeot 3008 Diesel Hybrid

Citroen DS5 Diesel Hybrid

Streetscooter Work

Volkswagen Touareg E-Hybrid

Volvo V60 Diesel Plug-in Hybrid

Fiat 500e

Smart fortwo electric drive

Mercedes-Benz GLC350e

Porsche Panamera S E-Hybrid

Peugeot 508 Diesel Hybrid

Mercedes-Benz E300e, E350e

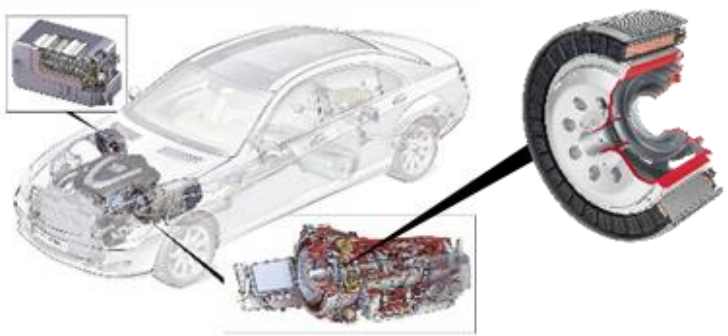
Porsche Cayenne S E-Hybrid

Mercedes-Benz GLE500e

Mercedes-Benz S500e, S300h, S400h

Mercedes-Benz SLS electric drive

- Full-range portfolio for EVs, plugin hybrids and hybrids
- More than 430 000 e-motors manufactured since 2012



System E-drive

Component vs. (or better and?) systems engineering

CONTROL PATH

mechanical interaction | thermal interaction | electrical interaction

Circulation & environment	Vehicle & driver	Powertrain	Electric traction motor	Inverter	Battery
					

IoT
Internet of Things

xECU
other Electronic Control Units

HTCU
Hybrid Transmission Control Unit

MCU
Motor Control Unit

BMS
Battery Management System

Powertrain CAN / Chassis CAN

CONTROL UNIT(S)

Systems engineering necessary to handle the complexity with universal file format for model exchange

Functional Mockup Interface (FMI)

Functional Mockup Unit (FMU)

- Basic thoughts
  - systems engineering needs component submodels
  - tool-independent exchange of component models
  - co-simulation with different tools
  - IP protection and licensing

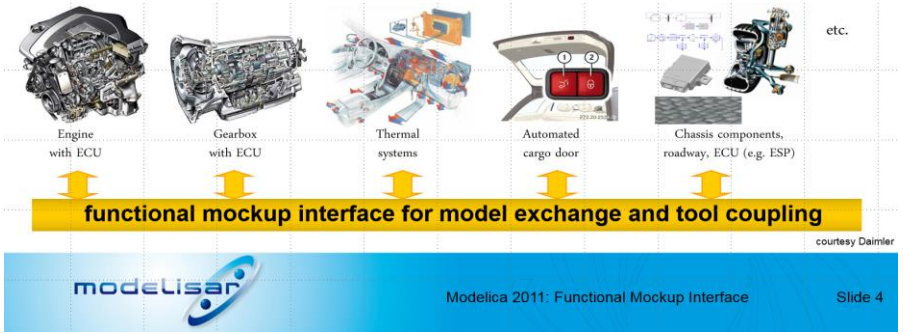
- FMU = component which implements FMI
  - zipped file (*.fmu)
    - description of interface data (XML file)
    - functionality (C-code or binary)
    - optional additional data (e.g. manual.pdf)
  - FMU-**export** by e.g.

    - Amesim
    - ANSYS Simplorer
    - ASim AUTOSAR
    - CATIA
    - MATLAB/Simulink
    - Dymola
    - Easy5 (MSC Software)
    - MapleSim
    - OpenModelica
    - Silver
    - SimulationX
    - ...

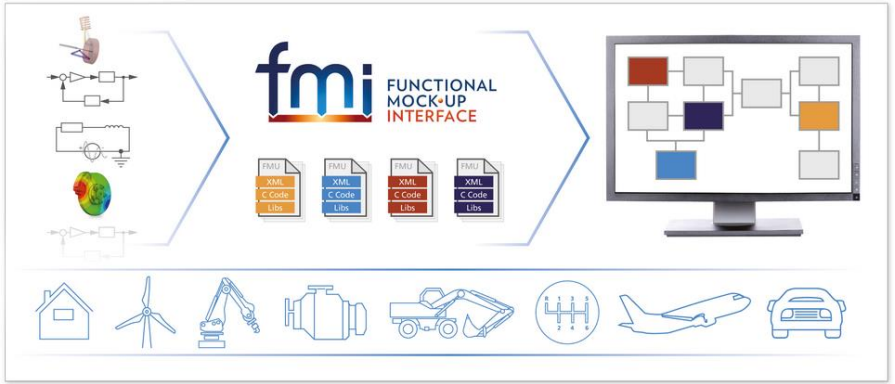
  - FMU-**import** by e.g.

    - tools that support export (see left)
    - Adams
    - AVL CRUISE / CRUISE M / Model.CONNECT
    - GT-SUITE
    - MoBA Lab
    - PyFMI
    - solidThinking Activate
    - TLK FMI Suite (LabView blocks)
    - xMOD
    - ...

for details visit: www.fmi-standard.org/tools



source: www.fmi-standard.org (overview PPT slides)

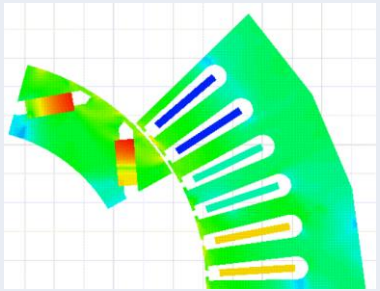
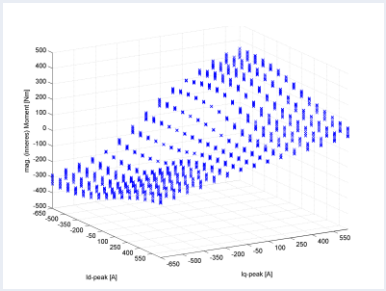
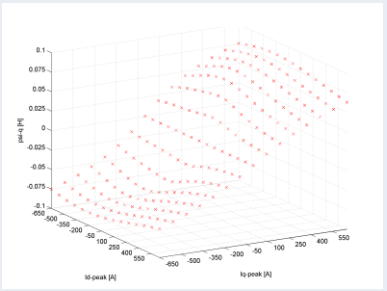
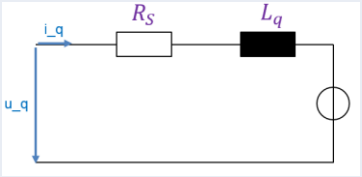


source: www.fmi-standard.org

considerable FMI-support by nearly all standard systems engineering tools

State of the art

ROMs at a glance

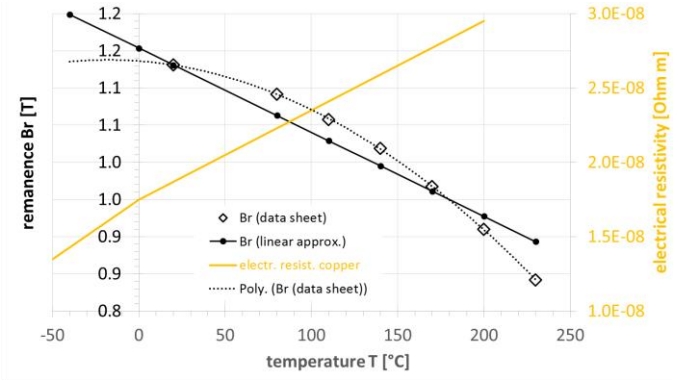
	„Finite-Element-Analysis“	„Instantaneous Flux Model“	„Average Flux Model“	„Constant Inductance Model“
Modeling	Maxwell-equations	ψ_d / ψ_q / M = f(I_d, I_q, α_{mech})	ψ_d / ψ_q / M = f(I_d, I_q)	L_d / L_q = const., M = f(I_q)
Representation				
Characteristics	detailed basis for ROMs, based on physics	nonlinear, no core & eddy losses	nonlinear, no core & eddy losses, no cogging torque & torque ripple, sinusoidal back-EMF	linear, no core & eddy losses, no cogging torque & torque ripple, sinusoidal back-EMF no saturation effects
Effort				

ROMs with different level of detail but for constant temperature are available. → Need to account for temperature effects

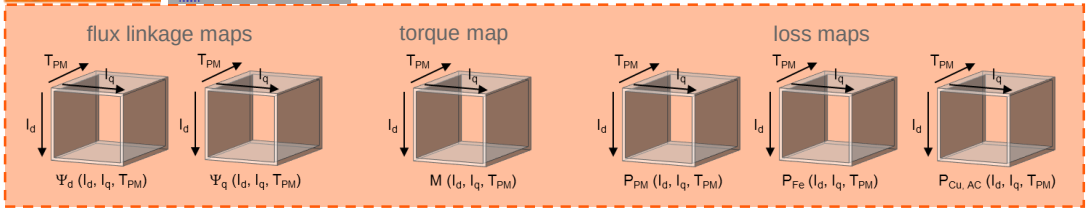
Impact of permanent magnet (PM) and winding (W) temperature

Basic thoughts and consequences for handling

- Basic thoughts
  - T_{magnet}
    - Remanence Br → Flux linkages → Back EMF → Torque
    - B in lamination → Iron losses + Winding AC losses
    - Electr. resistivity magnet → Magnet losses
  - $T_{winding}$
    - Electr. resistivity copper → Phase resistance → Winding DC losses
- Handling impact of
  - $T_{winding}$ analytically $P_{Cu,DC} = I^2 R(T) = I^2 \frac{L}{A} \rho_{el}(T_0)[1 + K(T - T_0)]$
  - T_{magnet} via 3D-lookup-tables
- Generation of 3D-lookup-tables
  - Electromagnetic FEAs with Motor-CAD on I_d/I_q-grid at constant speed
  - Grid generation and workflow management with optiSLang



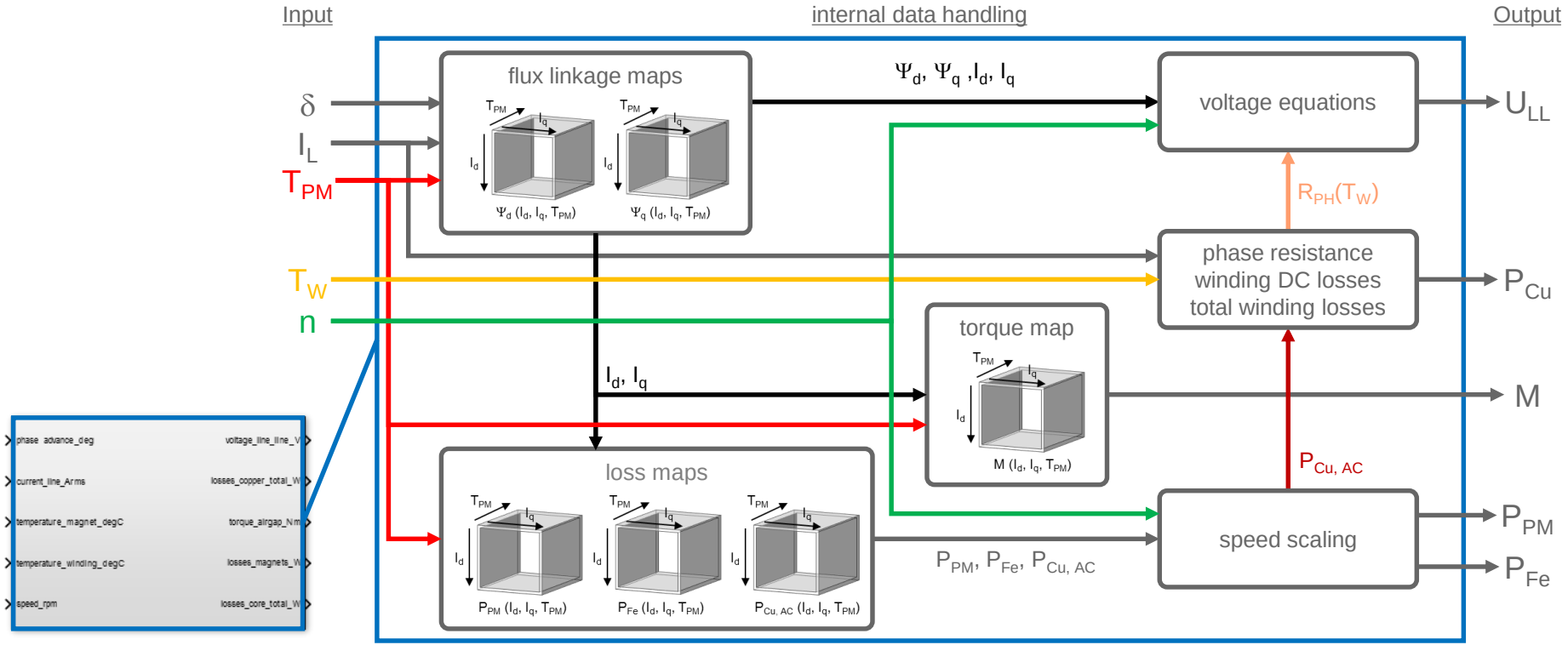
optiSLang® motordesign LIMITED



Impact of magnet and winding temperature can be handled separately

FMU (average flux model) incorporating impact of magnet and winding temperature

Signal processing flow chart

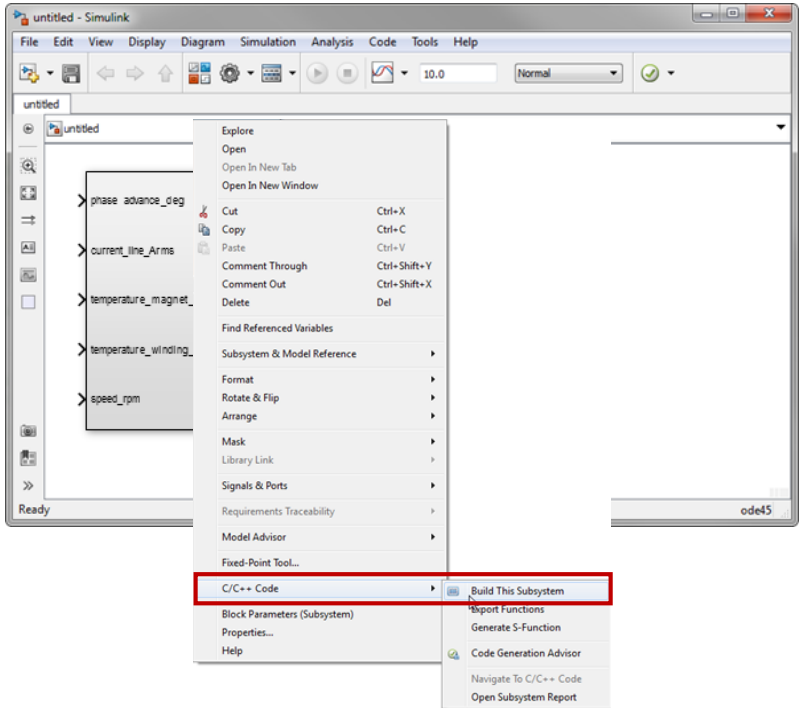


Workflow for generation of FMUs is available

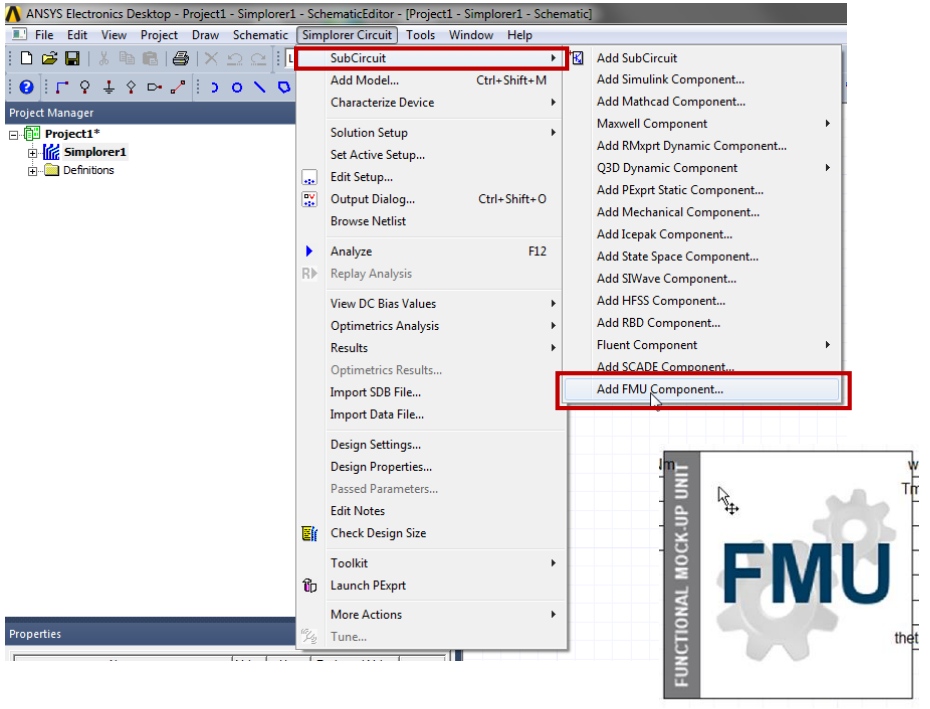
FMU (average flux model) incorporating impact of magnet and winding temperature

Workflow example: Export FMU from MATLAB/Simulink and import FMU in ANSYS Simplorer

export



import

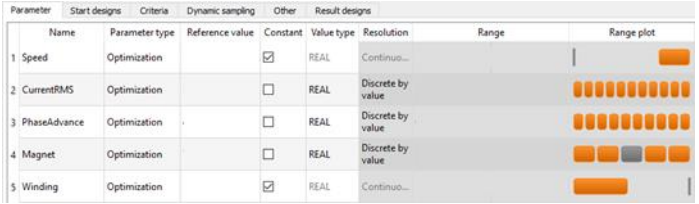


2-click-solutions for FMU export and import are available

Providing the power of optiSLang to full capacity

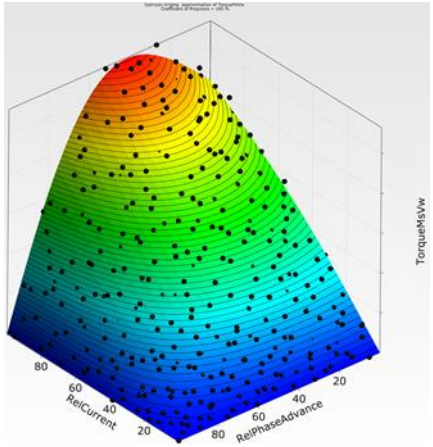
3D-lookup-table vs. Metamodel of Optimal Prognosis (MOP)

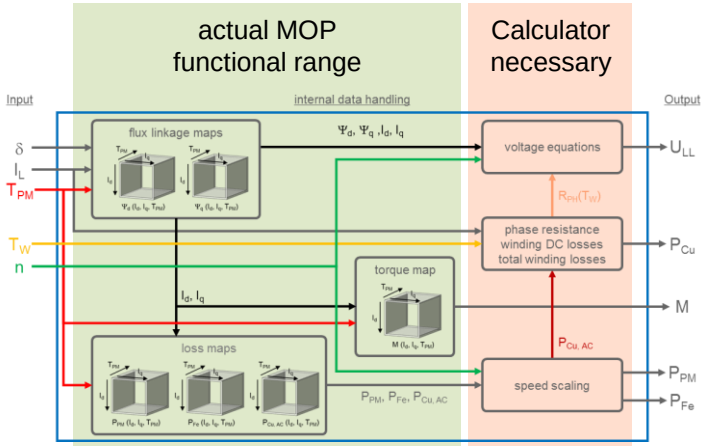
- Actual implementation: 3D-lookup-tables in MATLAB/Simulink
  - # design points ~ discretization^3
  - computational effort ~ # design points
  - easy interpolation
  - interpolation and FMU-export in 3rd party software



- Future implementation: MOP with scattered design points in optiSLang
  - flexible positioning of design points
  - less design points necessary
  - refinement via Adaptive MOP (AMOP)
  - AMOP instead of interpolation
  - FMU-export in optiSLang

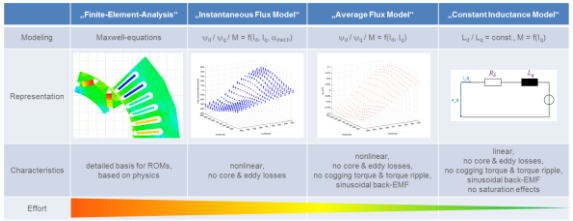
- Request for feature: Calculator to be included in FMU-export functionality

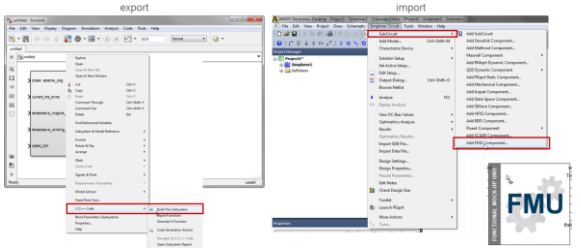


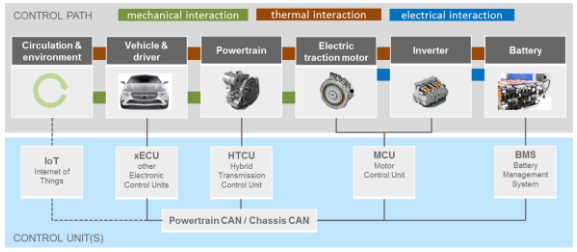


FMU-export from coupled module „MOP + Calculator“

Summary







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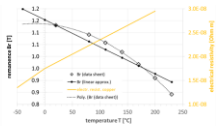

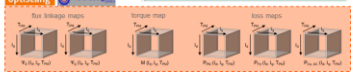

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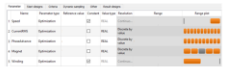

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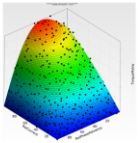

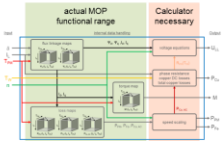

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    ▪ Amesim
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    ▪ CATIA
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    ▪ Dymola
    ▪ EasyEV_BISC Software
    ▪ MapleSim
    ▪ OpenModelica
    ▪ Silver
    ▪ SimulationX
  ▪ FMU-**import** by e.g.
    ▪ tools that support export (see left)
    ▪ Adams
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    ▪ GT-SUITE
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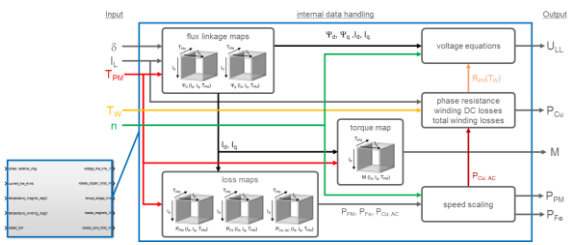
    ▪ PSIM
    ▪ rapid Training Activate
    ▪ TLK FMI Suite (LabView blocks)
    ▪ xMOD

for details visit: www.fmi-standard.org/tools



Special THANKS to
Tobias Cors

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Wir sind der Antrieb der E-Mobilität.

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