Initiatives for Acausal Model Connection Using FMI

The Society of Automotive Engineers of Japan.
Investigating Committee on Model Development and Distribution by International Standard Description.
The Model Connection Technology Study WG.

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- Adaptors between causal and acausal terminals
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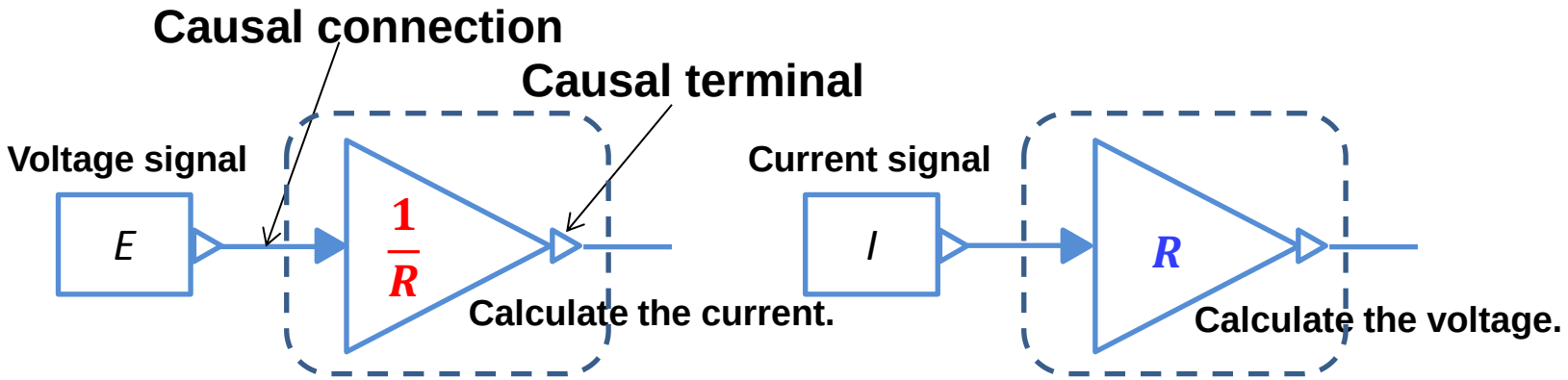
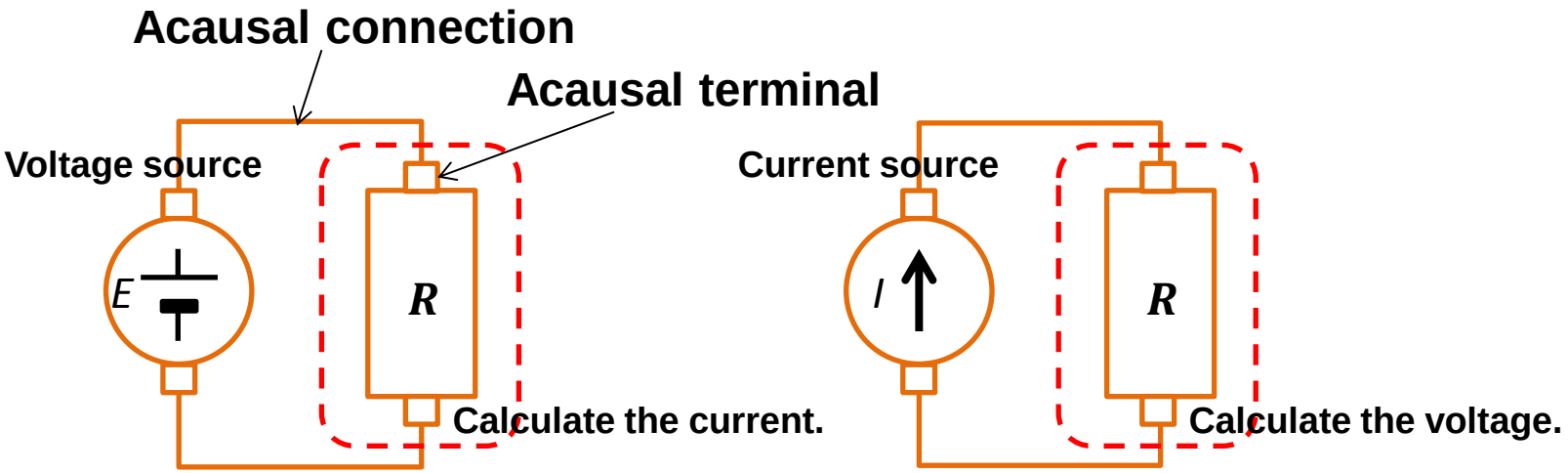
Causal model and acausal model

Causal model



Different resistor model is required for voltage signal or current signal.

Acausal model



Same resistor model can be reused for voltage source and current source.

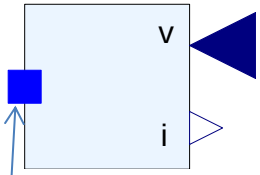
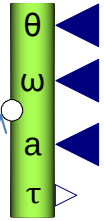
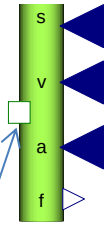
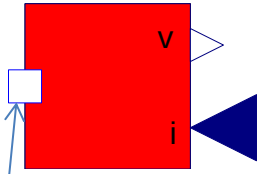
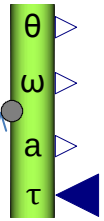
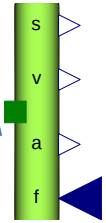
FMU export is restricted to the model of causal terminal.
Many difficulties of connecting models by FMI are occurred.

Basic Idea

- **Connect causal FMUs in acausal modeling environment to make use of following merits of acausal modeling.**
  - **Automatic regulation of causality.**
  - **Symbolic manipulation of equations when solving the total system of the model.**

How?

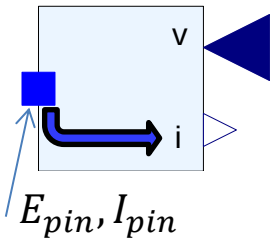
Adaptors between causal and acausal terminal

Electronics	Rotational mechanics	Translational mechanics
Current signal output  $E_{pin} = v$ $I_{pin} = i$ E_{pin}, I_{pin}	**Torque signal output**  $\Theta_{flange} = \theta$ $\Omega_{flange} = \omega$ $A_{flange} = a$ $T_{flange} = \tau$ $\Theta_{flange}, \Omega_{flange}, A_{flange}, T_{flange}$	**Force signal output**  $S_{trfln} = s$ $V_{trfln} = v$ $A_{trfln} = a$ $F_{trfln} = f$ $S_{trfln}, V_{trfln}, A_{trfln}, F_{trfln}$
Voltage signal output  $E_{pin} = v$ $I_{pin} = -i$ E_{pin}, I_{pin}	**Angle signals output**  $\Theta_{flange} = \theta$ $\Omega_{flange} = \omega$ $A_{flange} = a$ $T_{flange} = -\tau$ $\Theta_{flange}, \Omega_{flange}, A_{flange}, T_{flange}$	**Position signals output**  $S_{trfln} = s$ $V_{trfln} = v$ $A_{trfln} = a$ $F_{trfln} = -f$ $S_{trfln}, V_{trfln}, A_{trfln}, F_{trfln}$

Sign of flow variables of the model is important!

Rule of defining sign of flow variables

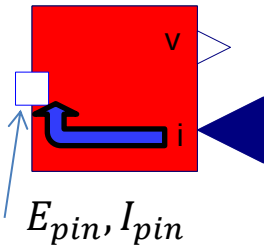
- For flow variable(s) coming into the component at acausal connector, the sign should be plus.



$E_{pin} = v$

$I_{pin} = i$

- For flow variable(s) going out of the component at acausal connector, the sign should be minus.

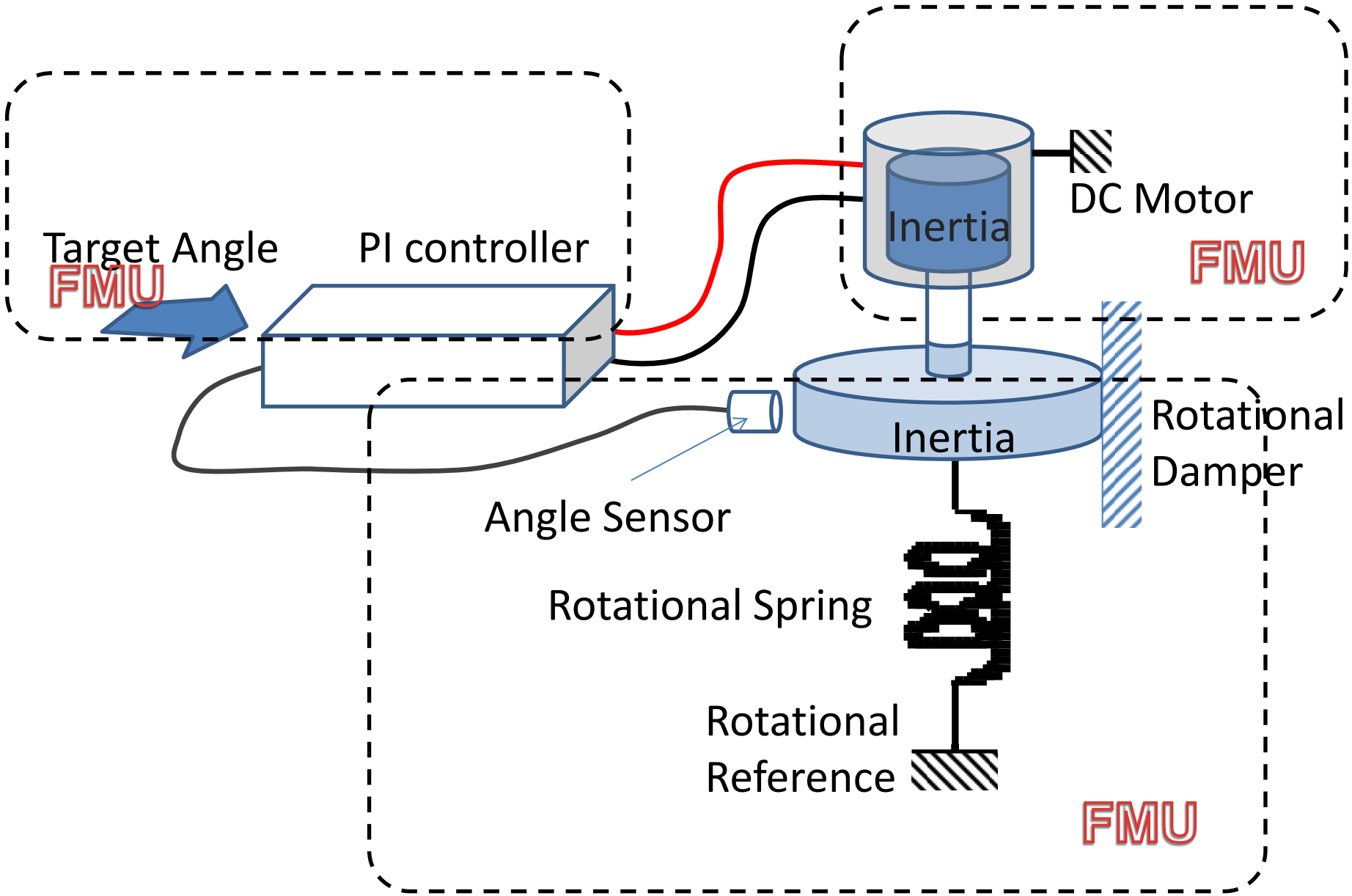


$E_{pin} = v$

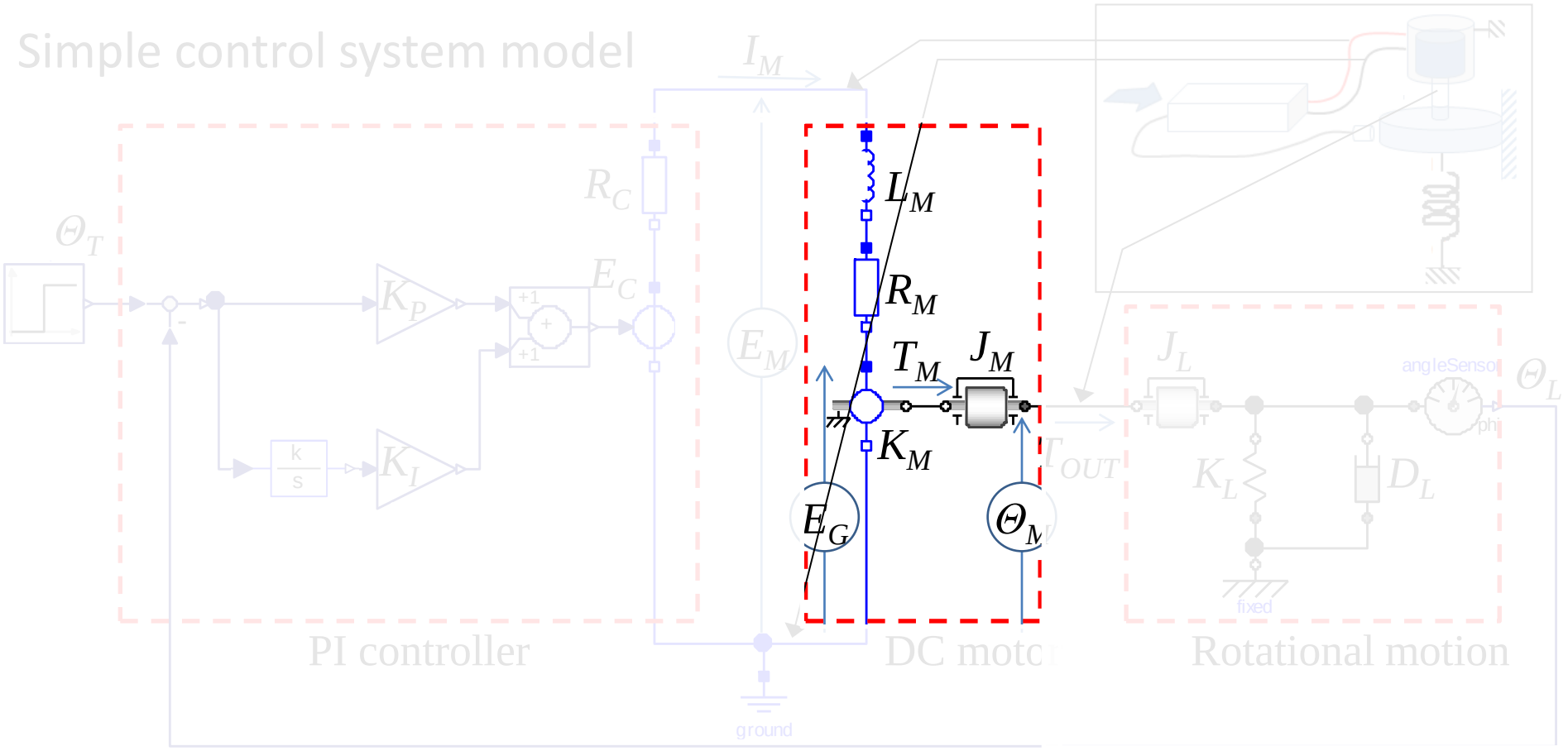
$I_{pin} = \ominus i$

Definition of Modelica Standard Libraries:
Sign of flow variables is plus when they come into the component.

Image of benchmark system



Acausal model of benchmark system



PI controller parameter

K_P=1;	Proportional gain
K_I=100;	Integral gain
R_C=0.1;	Internal resistance of PI controller [Ω]

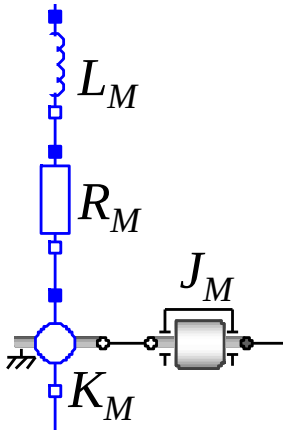
DC motor parameter

L_M=1e-6;	Motor inductance [H]
R_M=0.9;	Motor resistance [Ω]
K_M=0.1;	Torque const. [N・m/A] Back-emf const.[V/(rad/sec)]
J_M=0.001;	Motor inertia [kg・m^2]

Rotational motion parameter

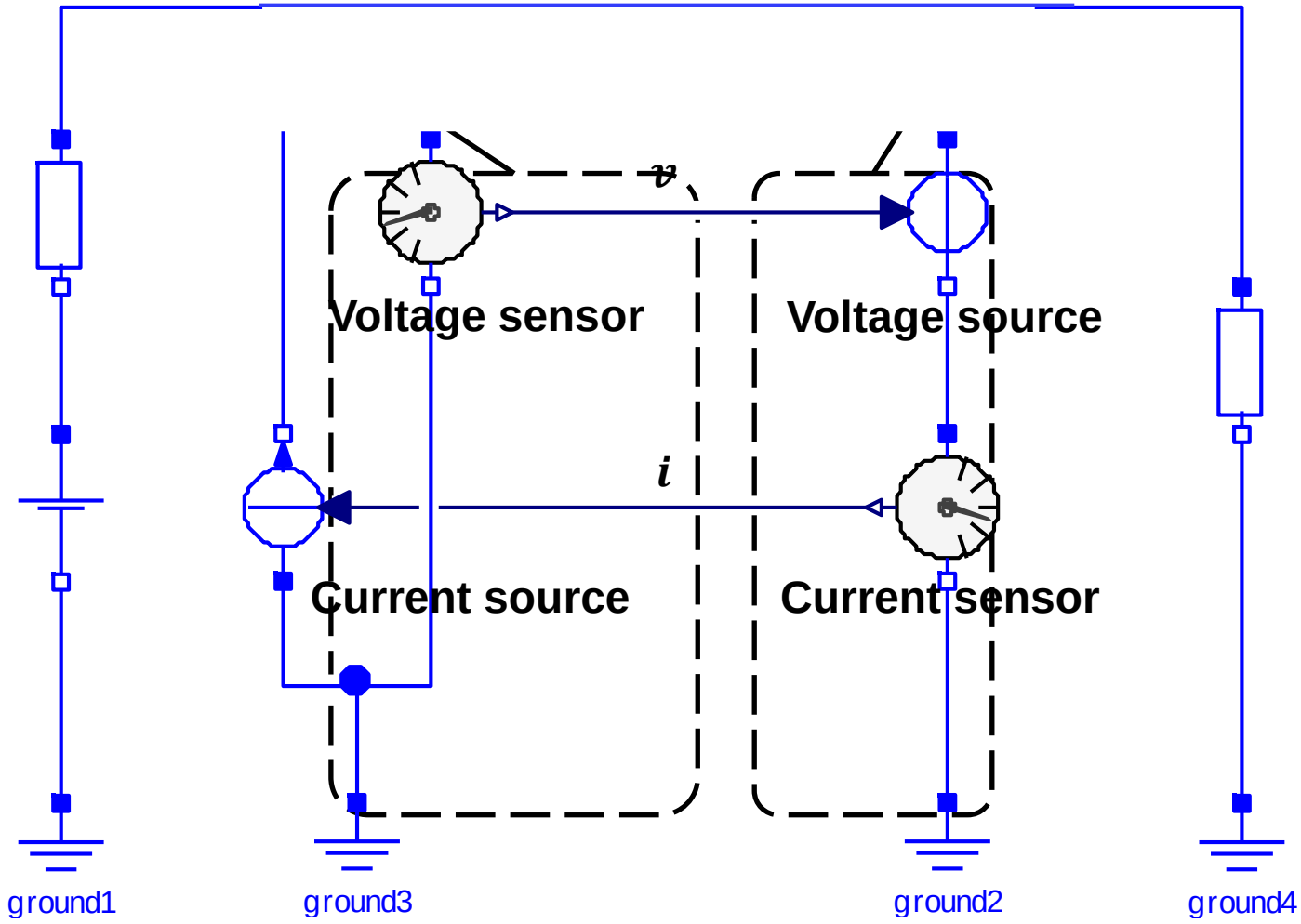
J_L=0.009;	Load inertia [kg・m^2]
D_L=0.001;	Load damper [N・m/(rad/sec)]
K_L=10;	Load spring [N・m/rad]

Motor model

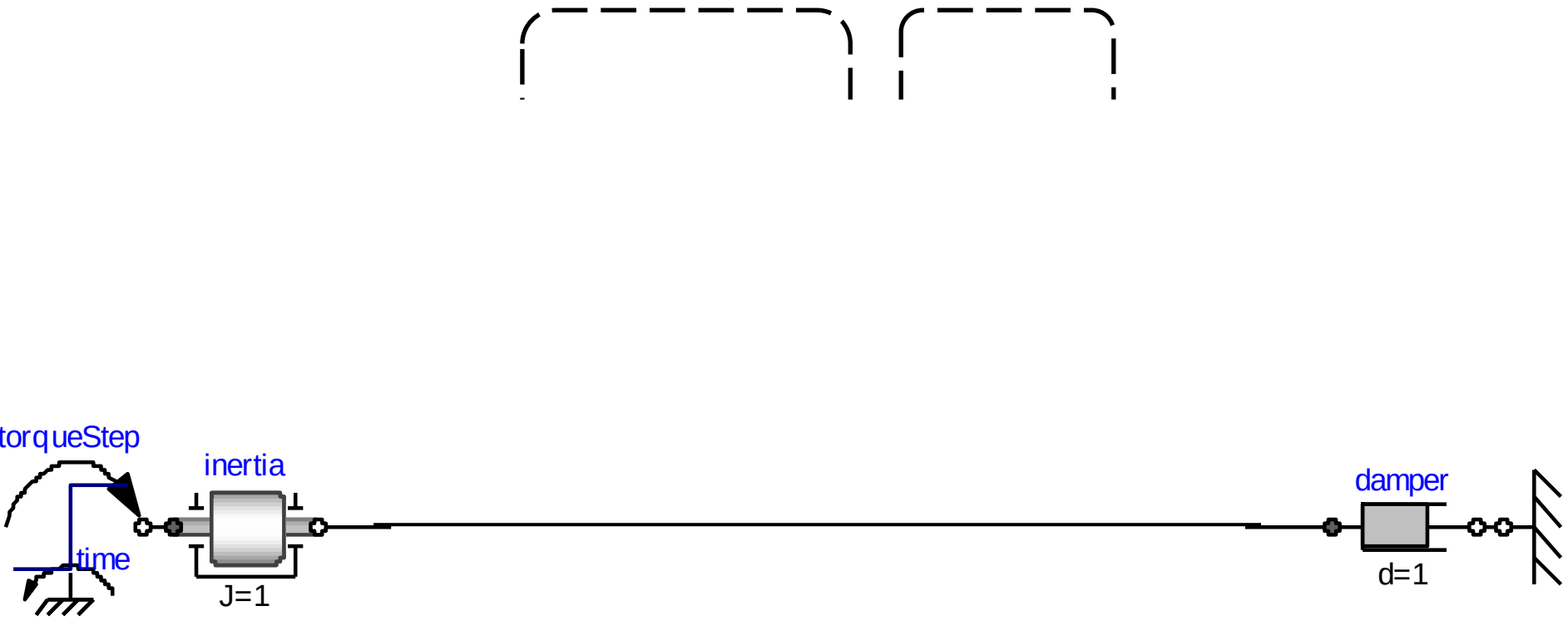


It is impossible to export FMU from acausal terminal model.

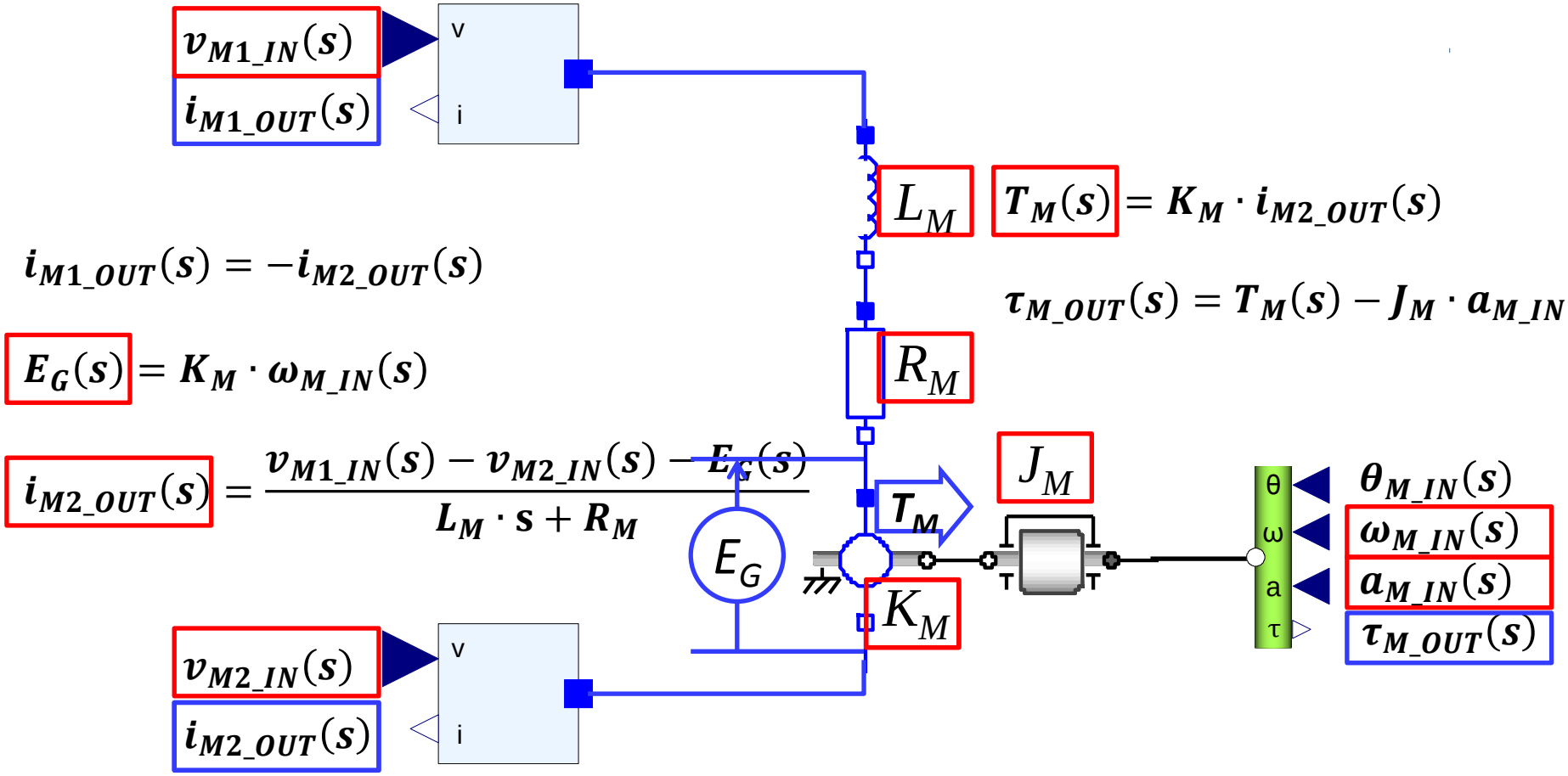
Adaptors for electronic system



Adaptors for rotational mechanical system

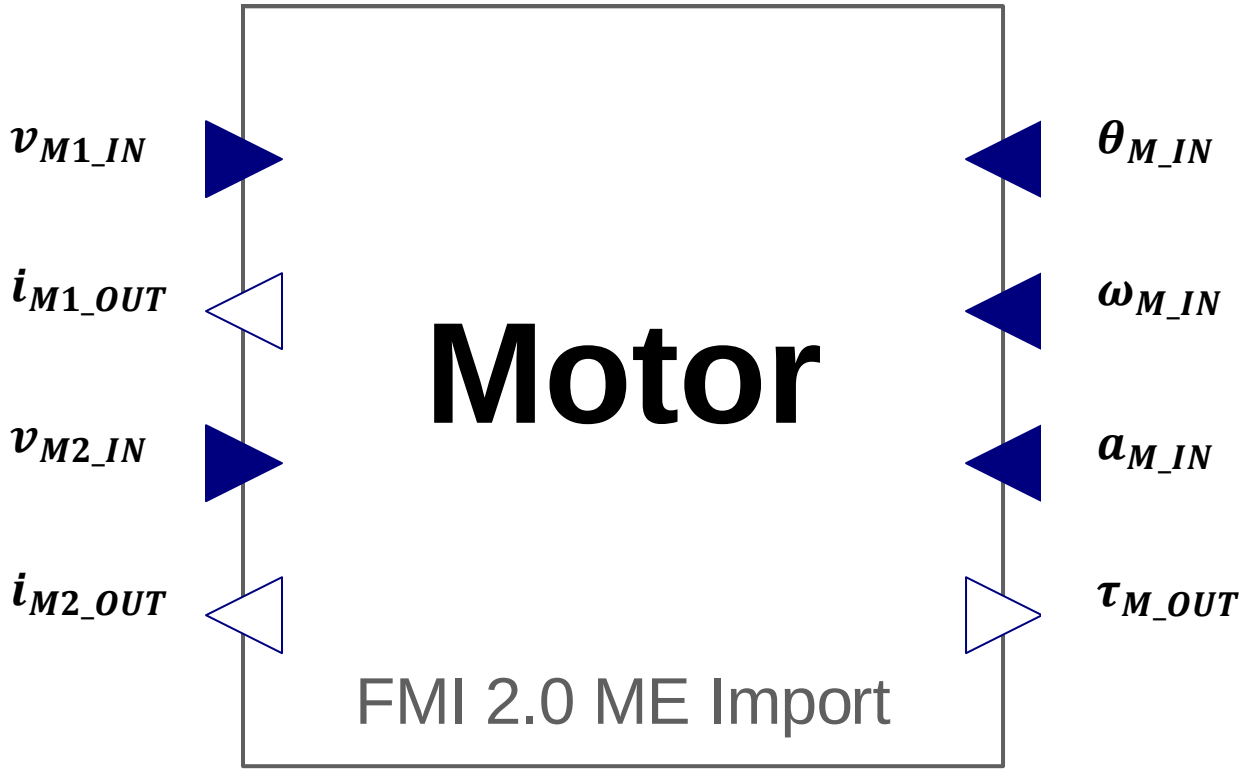


Motor model for FMU



Electrical and rotational adaptor convert to the causal terminal.

FMU Import

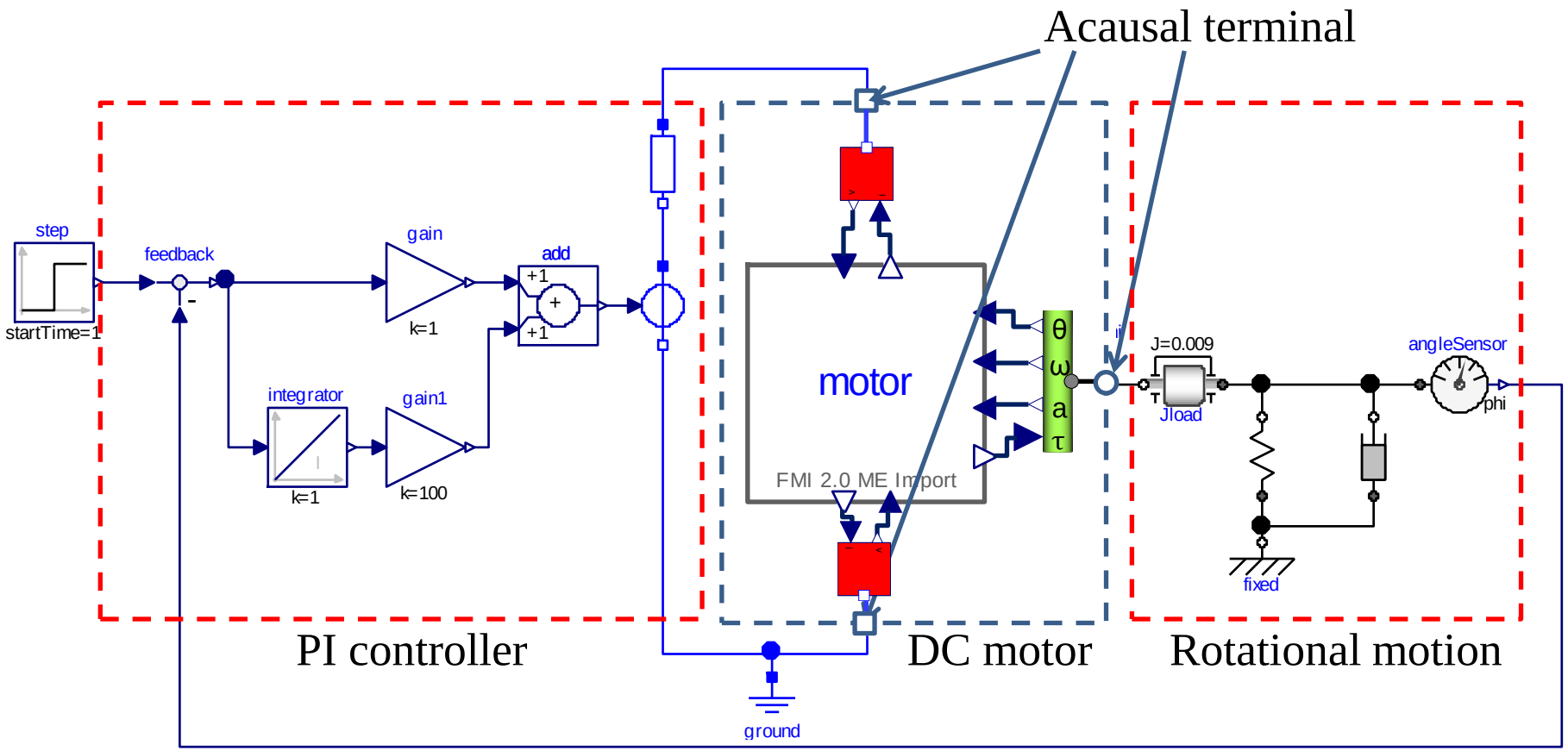


$$i_{M2\_OUT} = f_1(v_{M1\_IN}, v_{M2\_IN}, \theta_{M\_IN}, \omega_{M\_IN}, a_{M\_IN})$$

$$i_{M1\_OUT} = -i_{M2\_OUT}$$

$$\tau_{M\_OUT} = f_2(v_{M1\_IN}, v_{M2\_IN}, \theta_{M\_IN}, \omega_{M\_IN}, a_{M\_IN})$$

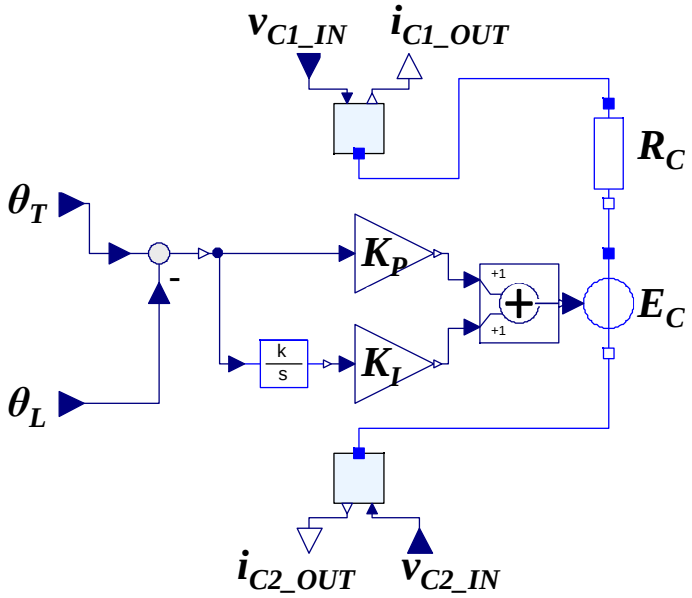
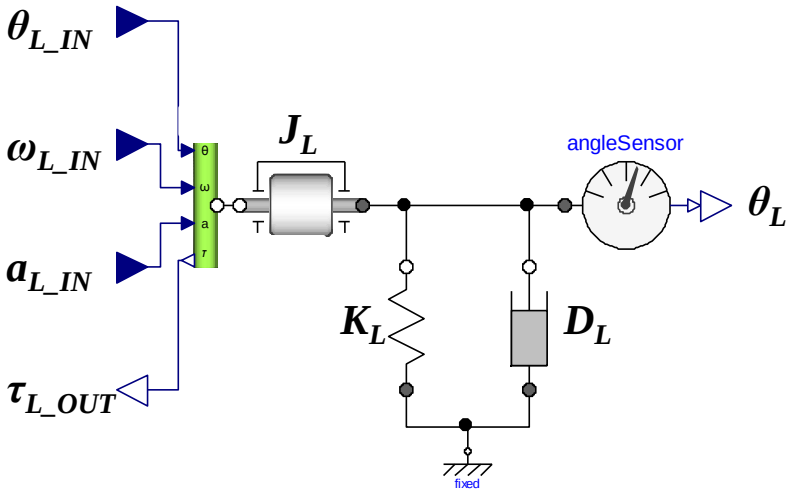
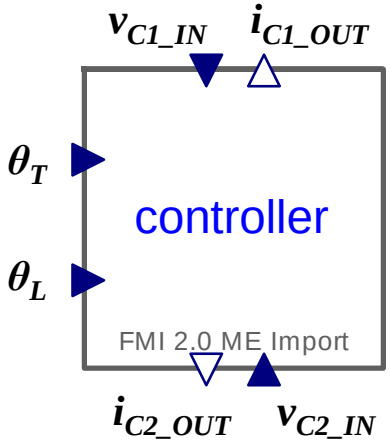
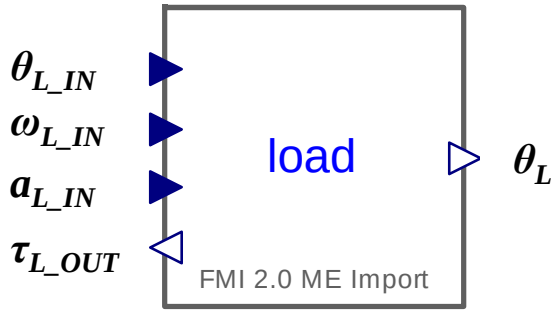
Model of benchmark system



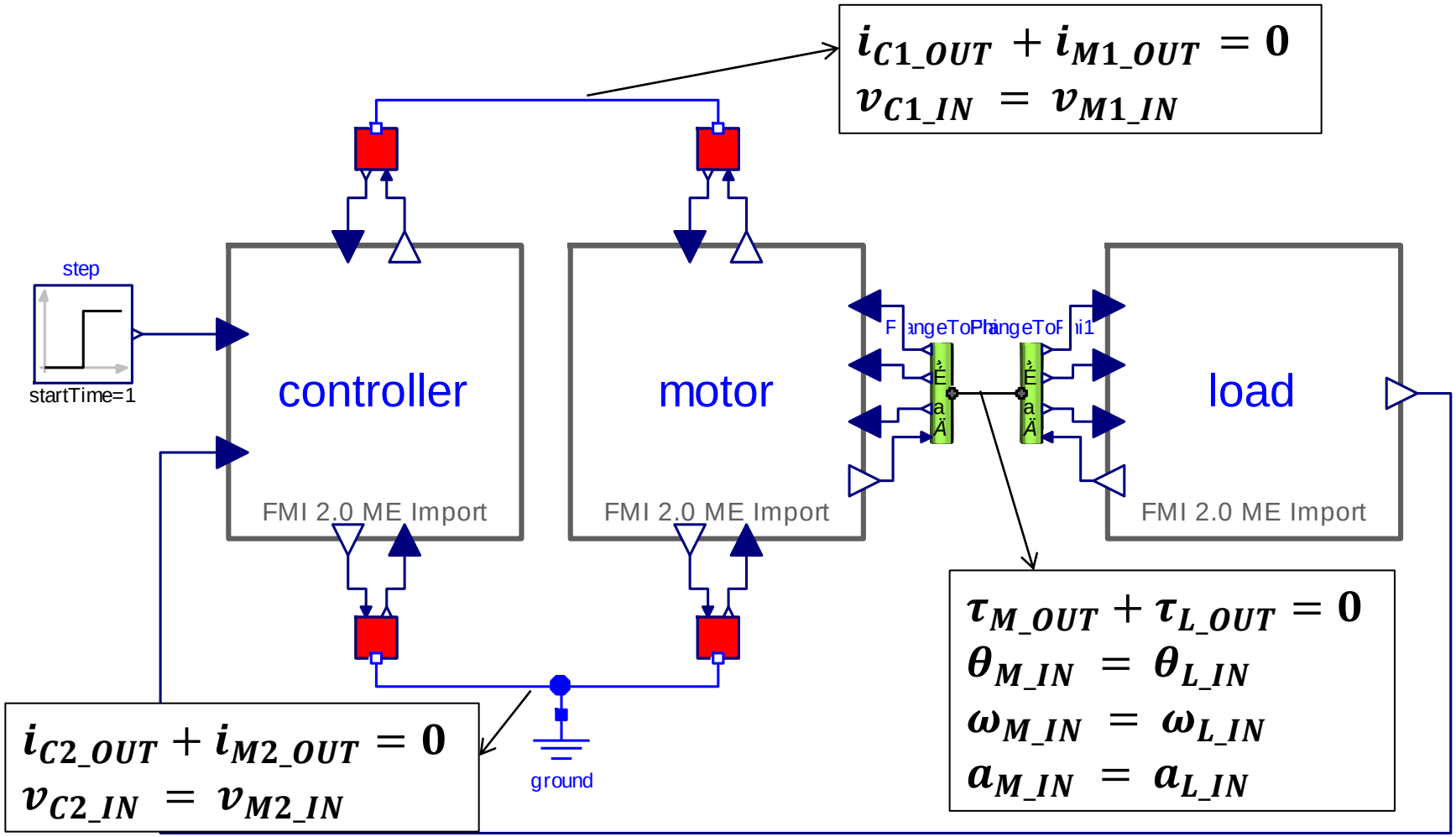
Electrical and rotational adaptor convert to the acausal terminal.

It is impossible to connect FMU that have causal terminals.

Separated models

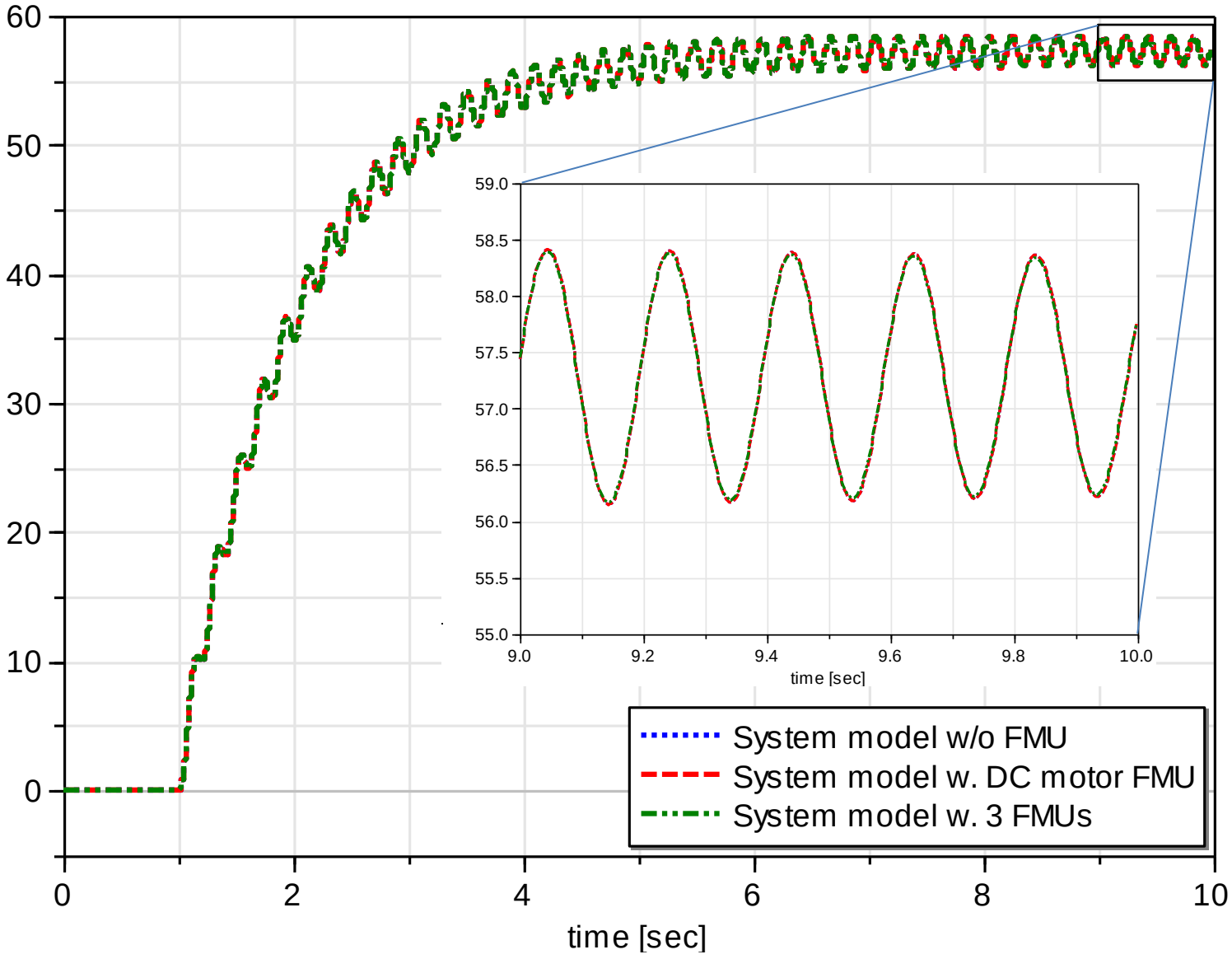
	PI controller	Rotational motion
Model for FMU		
FMU		

System model using 3 FMUs



Simulator solves the simultaneous equations that is depending on the connections.

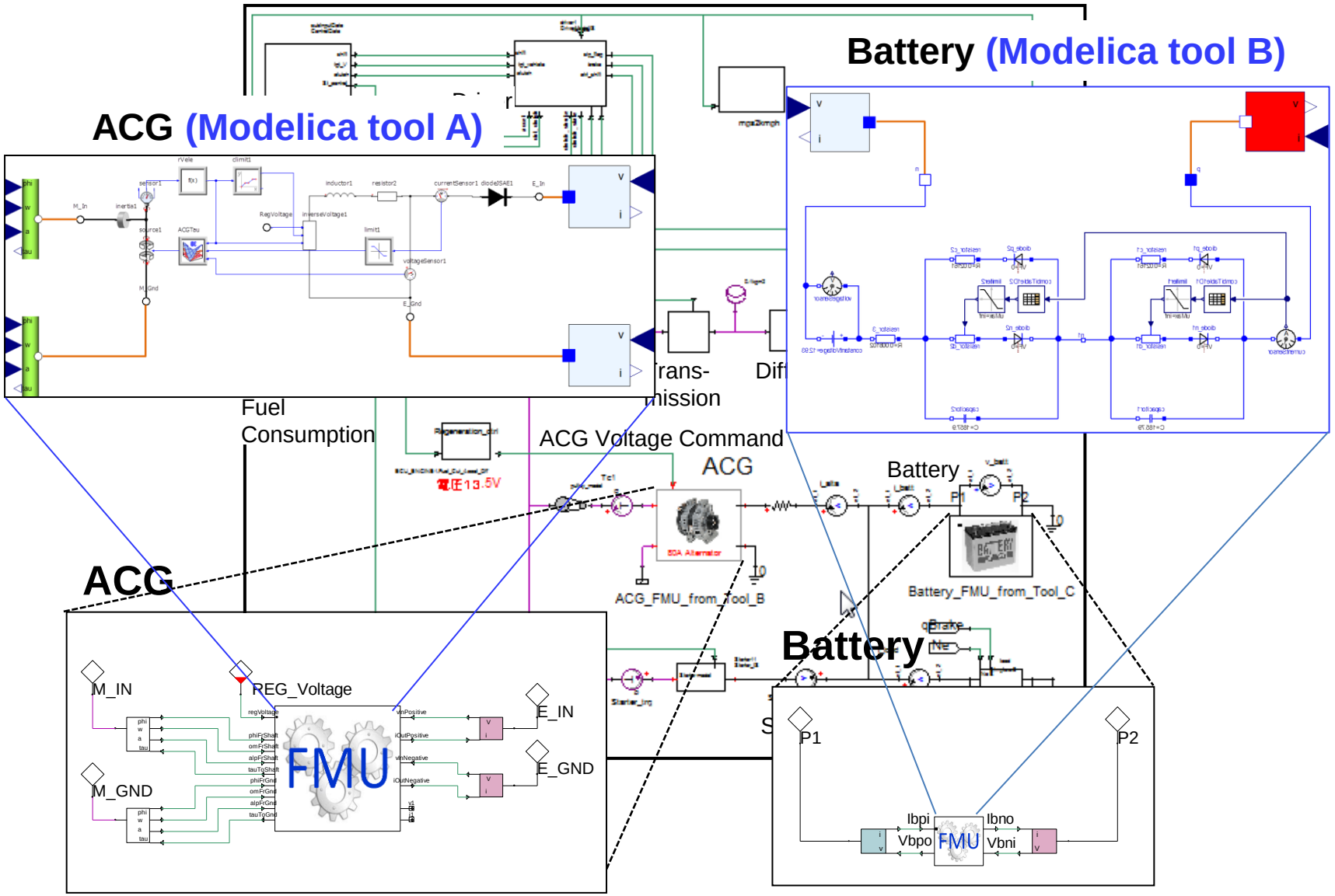
Simulation results



Another example

(AC Generator & Battery with Electric Load)

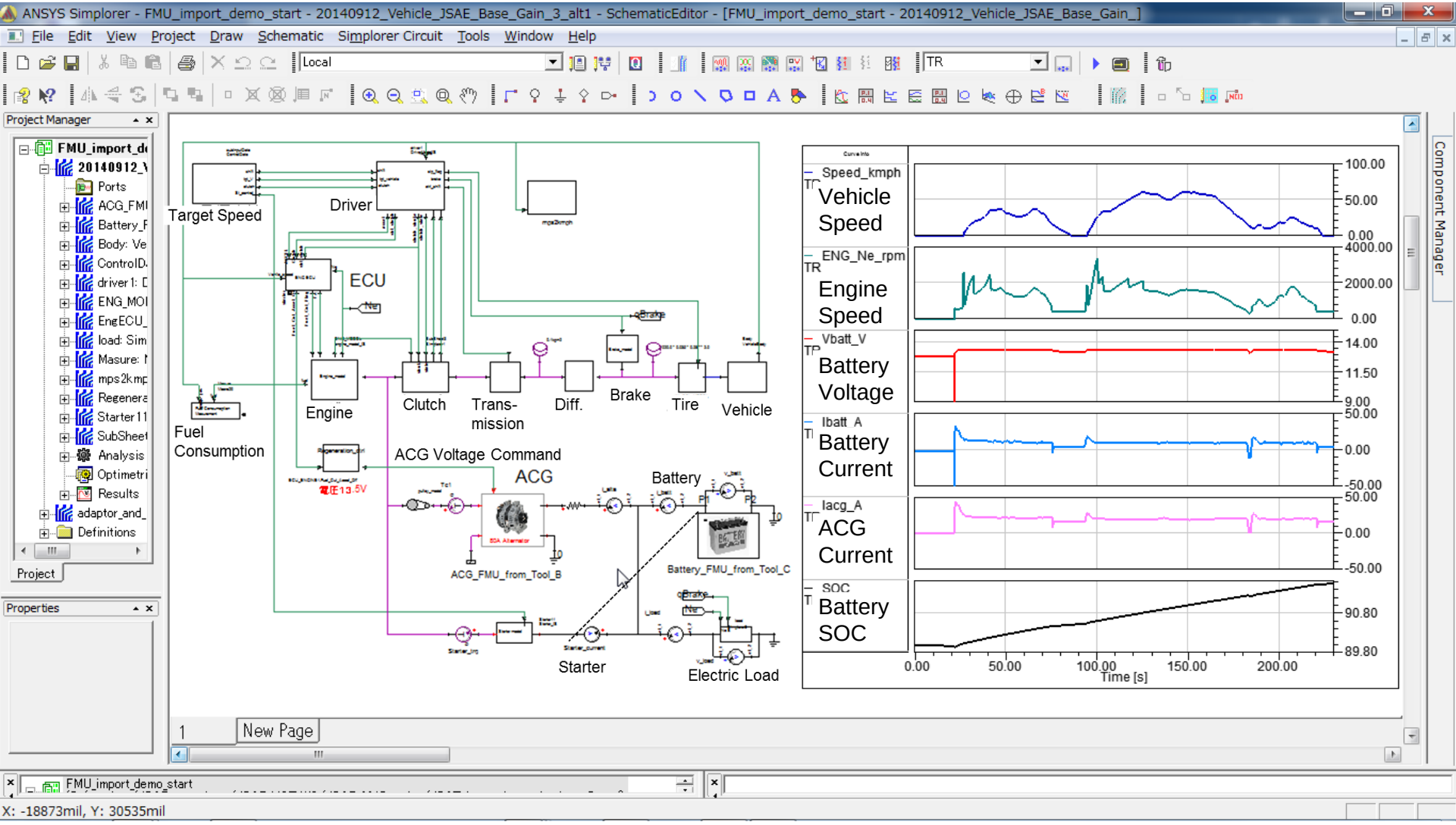
Full Vehicle Model (VHDL-AMS tool)



Another example

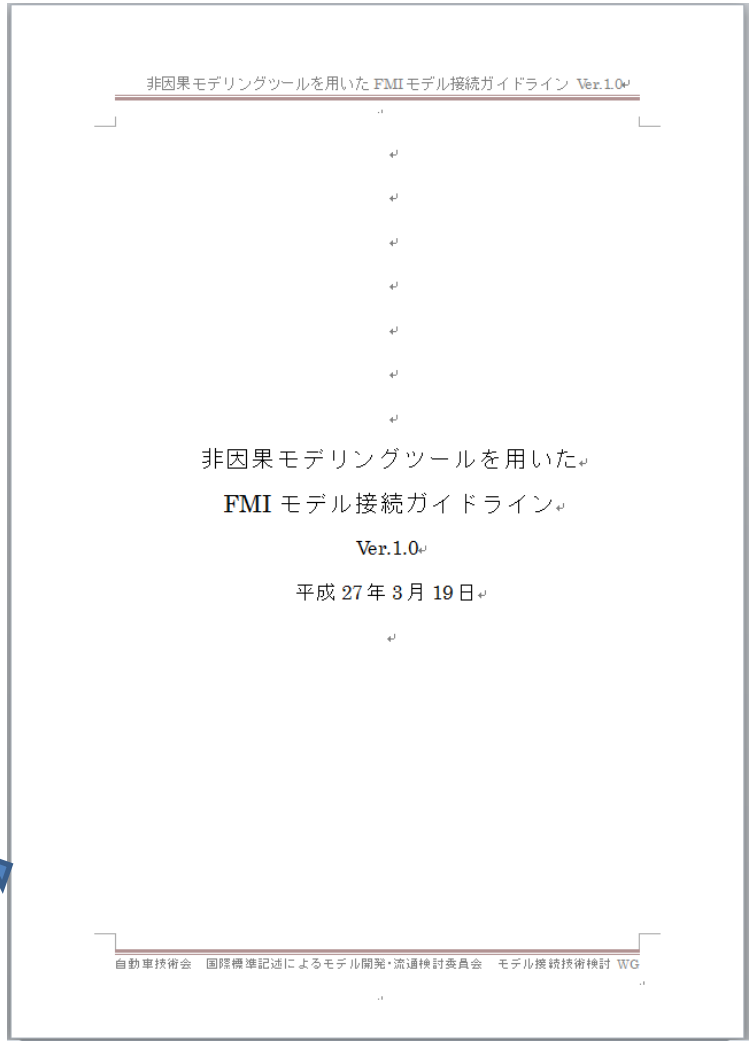
(AC Generator & Battery with Electric Load)

Simulation Result



FMI model connection guideline for acausal modeling tools

(95 pages. Available only in Japanese.)



Access from here! ⇒ http://www.jsae.or.jp/tops/topic.php?code=1241

Future Expectations

- **As much as possible tools will support the following functions based on coming FMI 2.x.**
  - **Automatic handling of algebraic loops.**
  - **Automatic allocation of input and output signals for causal connectors.**

Conclusion

- **Acausal models can be connected using FMI by proposed method.**
  - **Generating FMUs which have adapters of terminals of causal signals from acausal model.**
  - **Converting causal FMUs to acausal sub-models and connecting them by acausal modeling way.**
- **Simulation using multiple FMUs showed good results.**
- **A guideline for this method was released from JSAE on the web.**

Thank you for your attention.