Tallinn University of Technology, May 2025

Estonian Doctoral School

“Energy Management Strategy”

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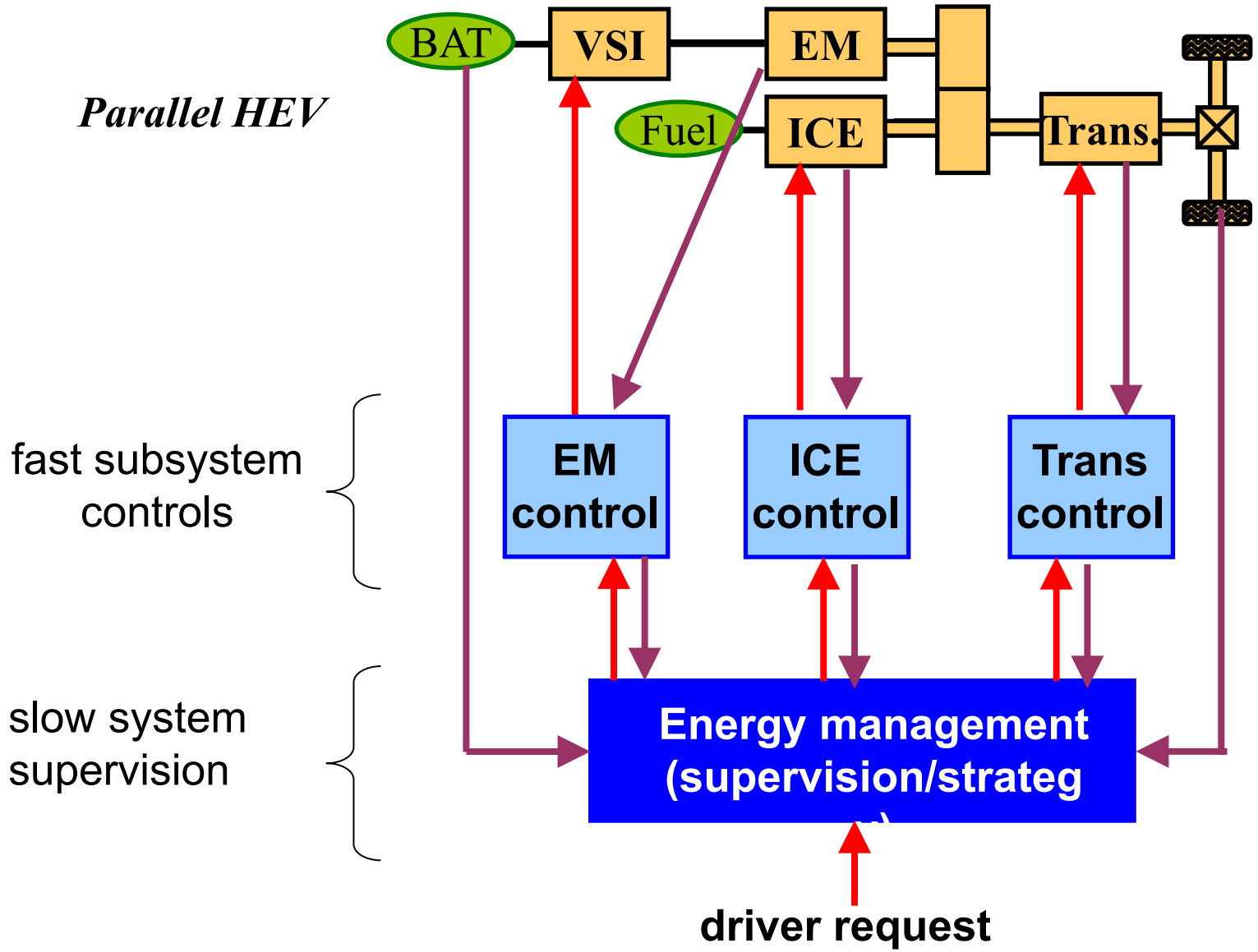
Based on the EMR summer school
and Master “Electrical Engineering for
sustainable development” course at Univ. Lille

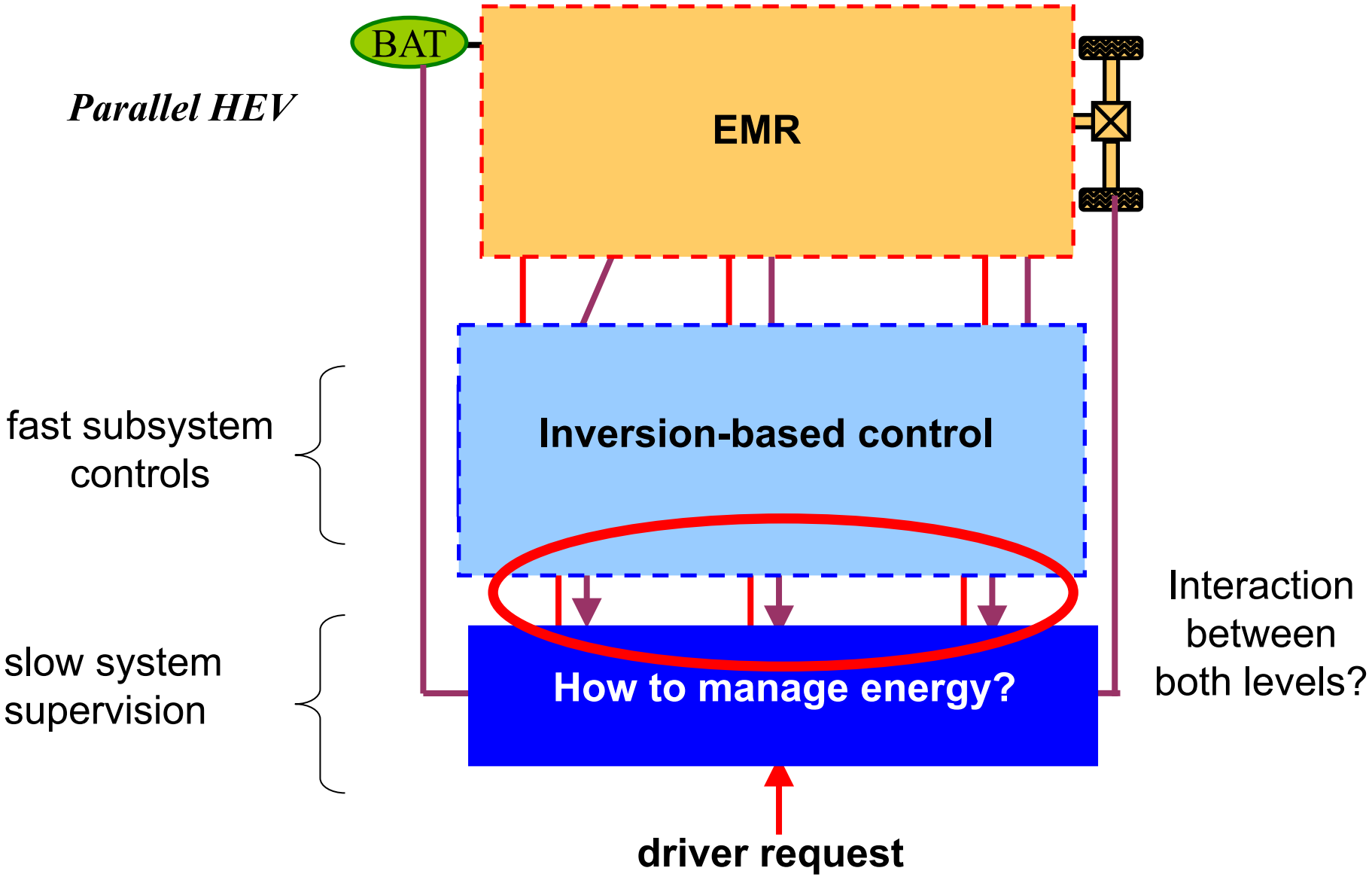
L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille

Université de Lille — Arts et Métiers Sciences et Technologies — centralelille — JUNIA Grande école d'ingénieurs

Example of HEV control



Different control level



1. **Control decomposition**
   - Local control structure
   - Strategy level for energy management

2. **Various inversions of distribution elements**
   - Different kinds of energy management
   - Inversion of the different cases

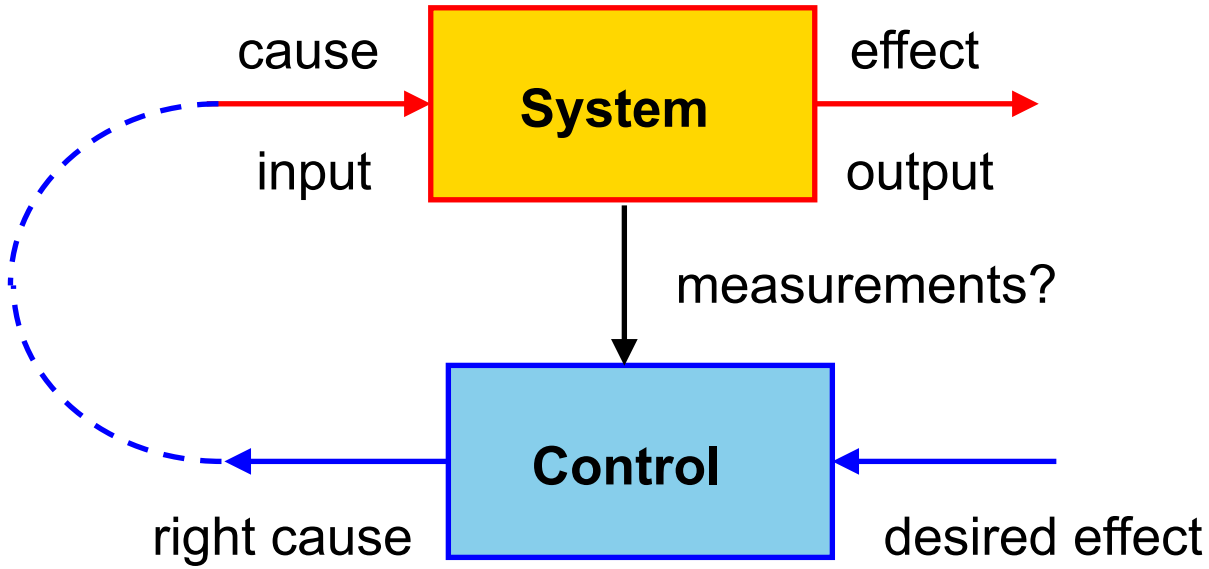
3. **Analysis and strategy**
   - Analysis of the system possibilities
   - Strategy level

4. **Application to the automatic subway VAL 206**

1. « Local control and energy management »

Principle of inversion based methodology

[Hautier 96]



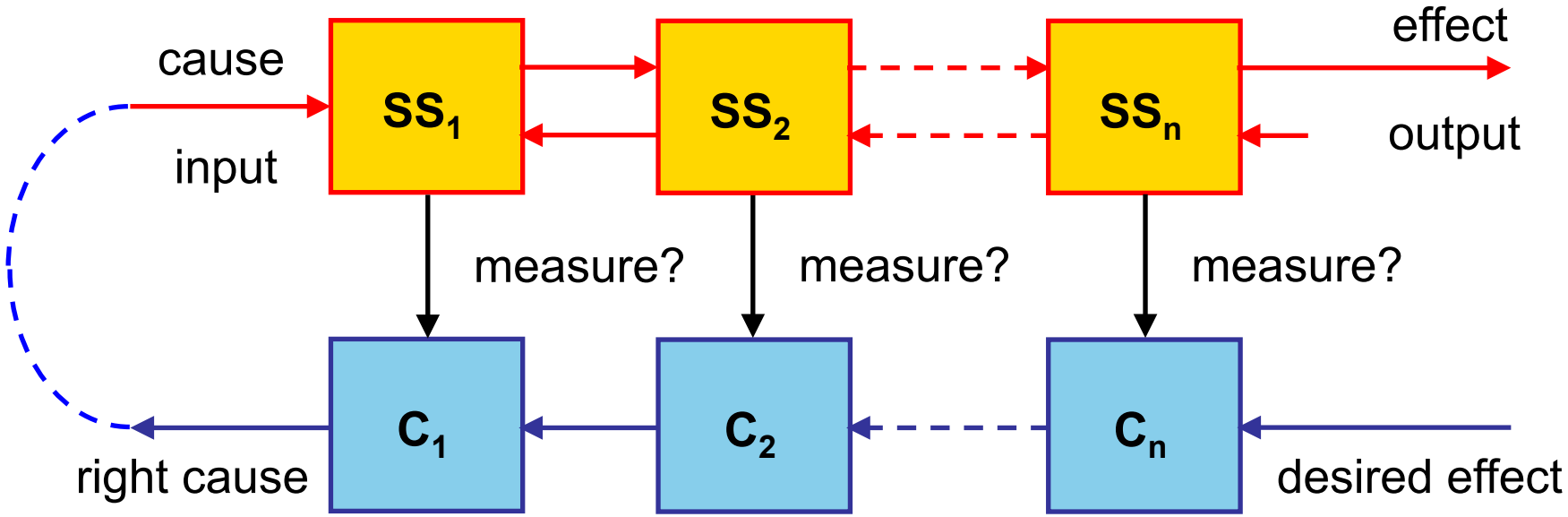
control = inversion of the causal path

1. Which algorithm? (how many controllers)
2. Which variables to measure?

→ **Inversion-based methodology**

3. How to tune controllers? → automatic control
4. How to implement the control? → industrial electronics

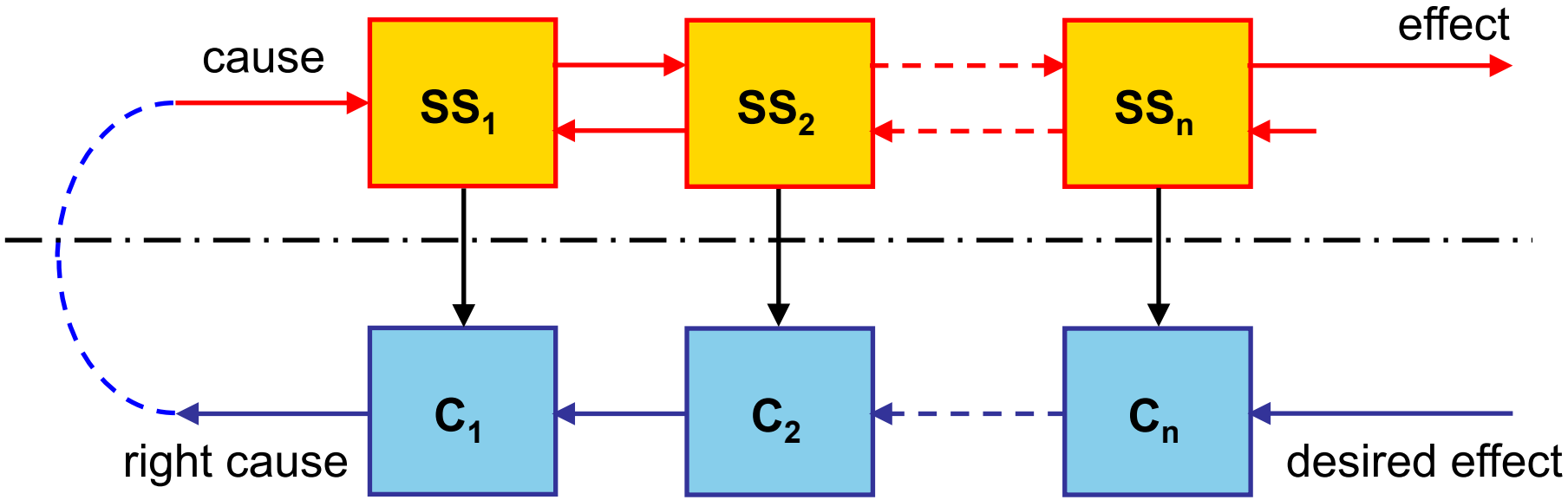
Principle of inversion based methodology



EMR = system decomposition in basic energetic subsystems (SSs)

Remember,
divide and conquer!

Inversion-based control: systematic inversion
of each subsystems using
open-loop or closed-loop control



The control scheme is developed as a mirror of the model

[Hautier 96] [Bouscayrol 03]

Legend

Control = light blue Parallelograms with dark blue contour

direct inversion

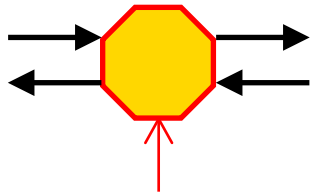
indirect inversion

sensor

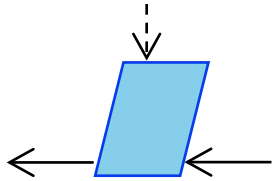
mandatory link

facultative link

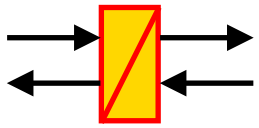
conversion element



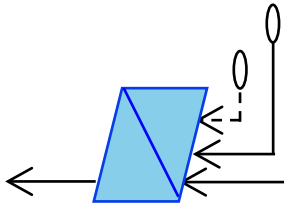
direct inversion + disturbance rejection



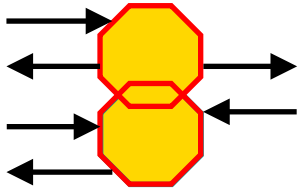
accumulation element



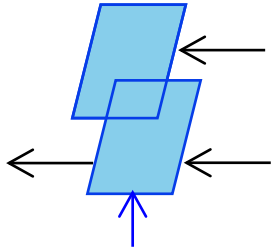
controller + disturbance rejection



coupling element



distribution criteria

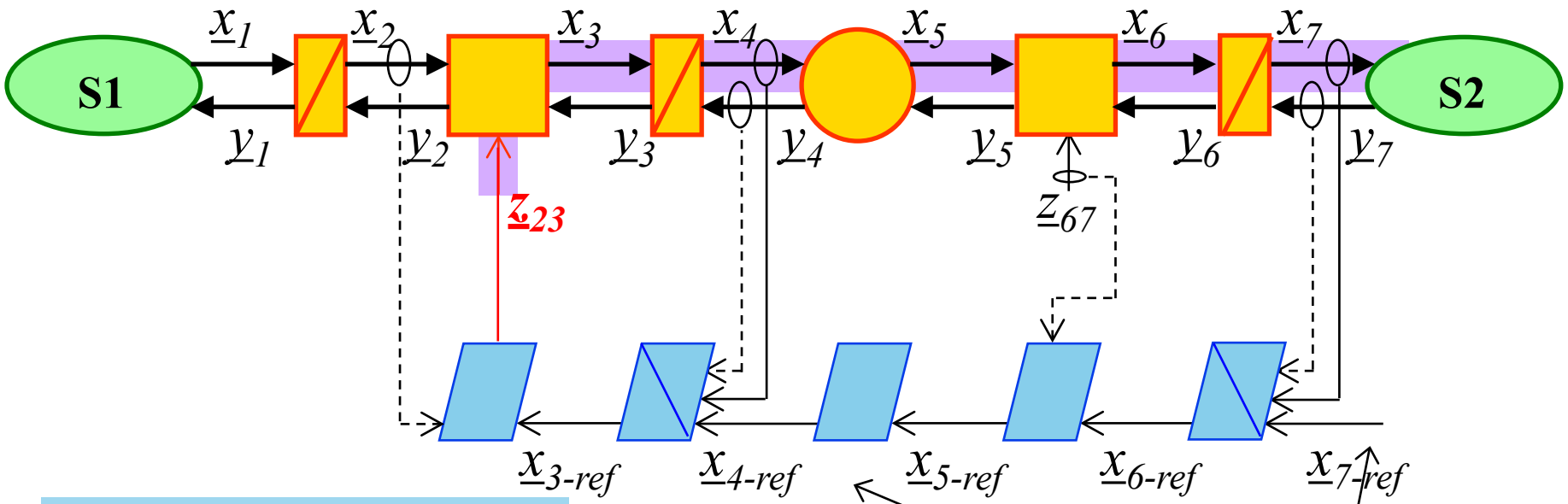


1. EMR of the system

2. Tuning path

3. Inversion step-by-step

Strong assumption: all variables can be measured!



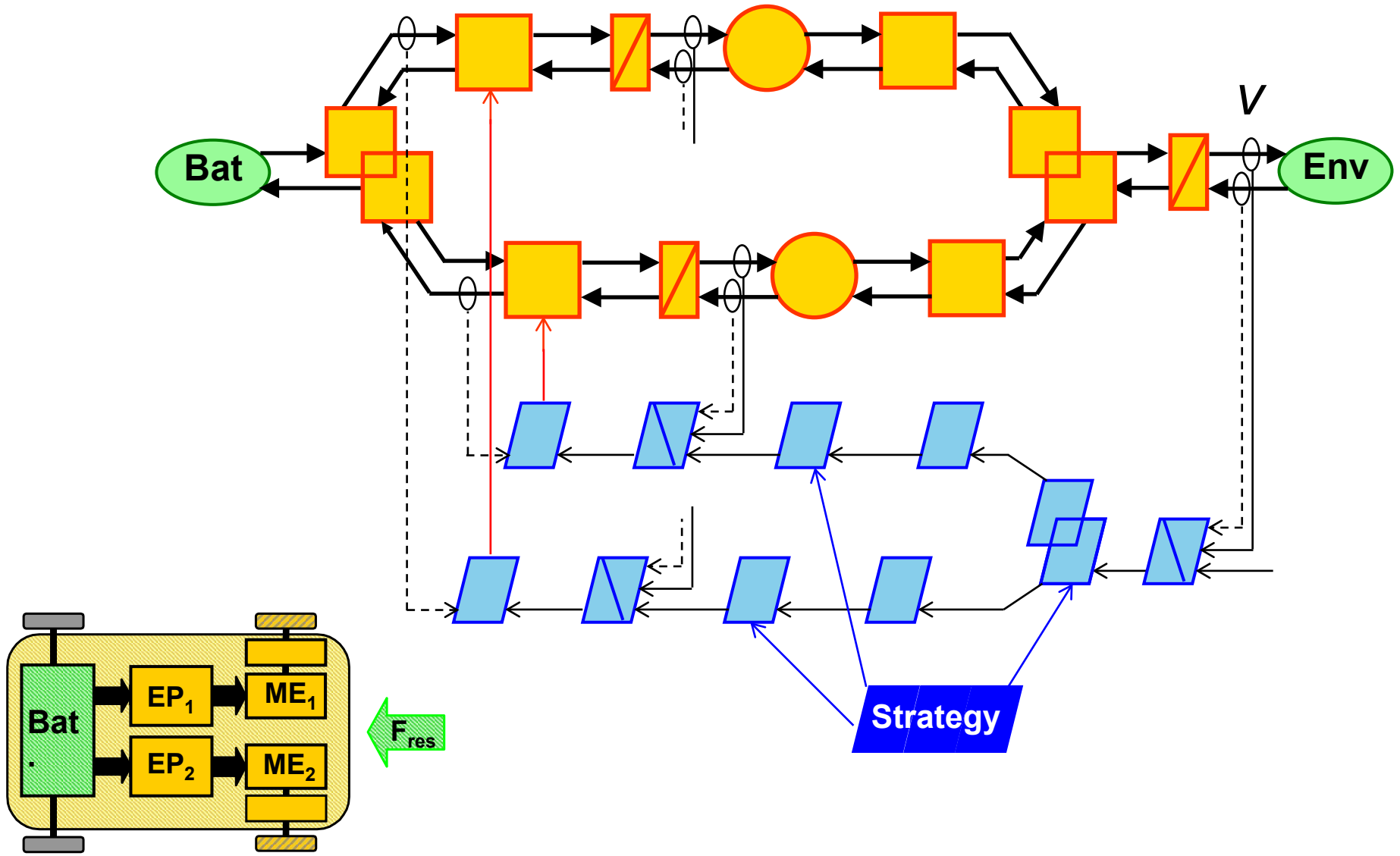
4. Simplification of control

5. Estimation of non-measured variables

6. Tuning of controllers

7. Strategy

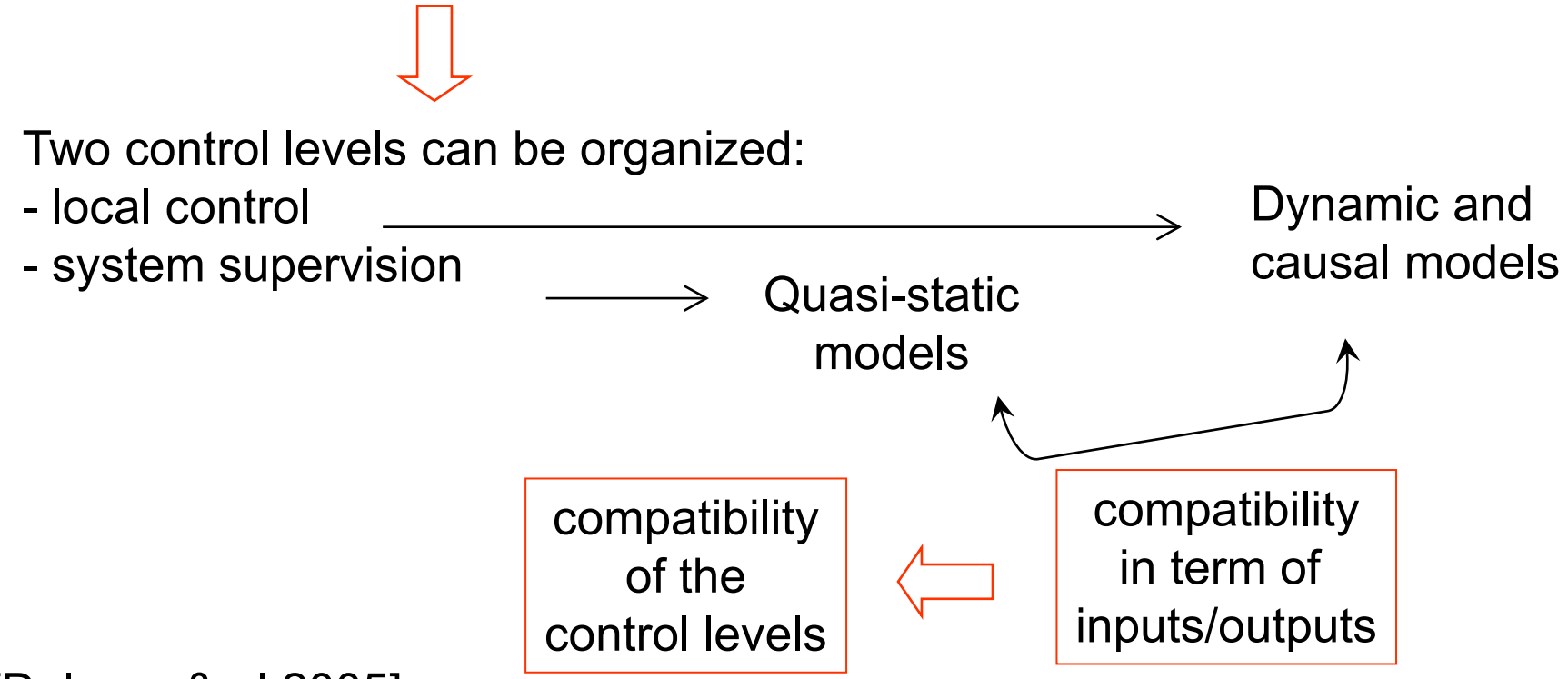
Management of energy distribution



Energy management of HEVs:

Energy management of local subsystems

Energy management of the whole system (co-ordination of subsystems)



[Delarue & al 2005]

Local control:

Fast energy management in each subsystem

Objective: ensure the best efficiency of each component in function of the request

Inversion of each element, step-step-step, using dynamic causal models

Global control or Strategy:

1.Translation of user's reference to system reference (Cf. Wind Energy)

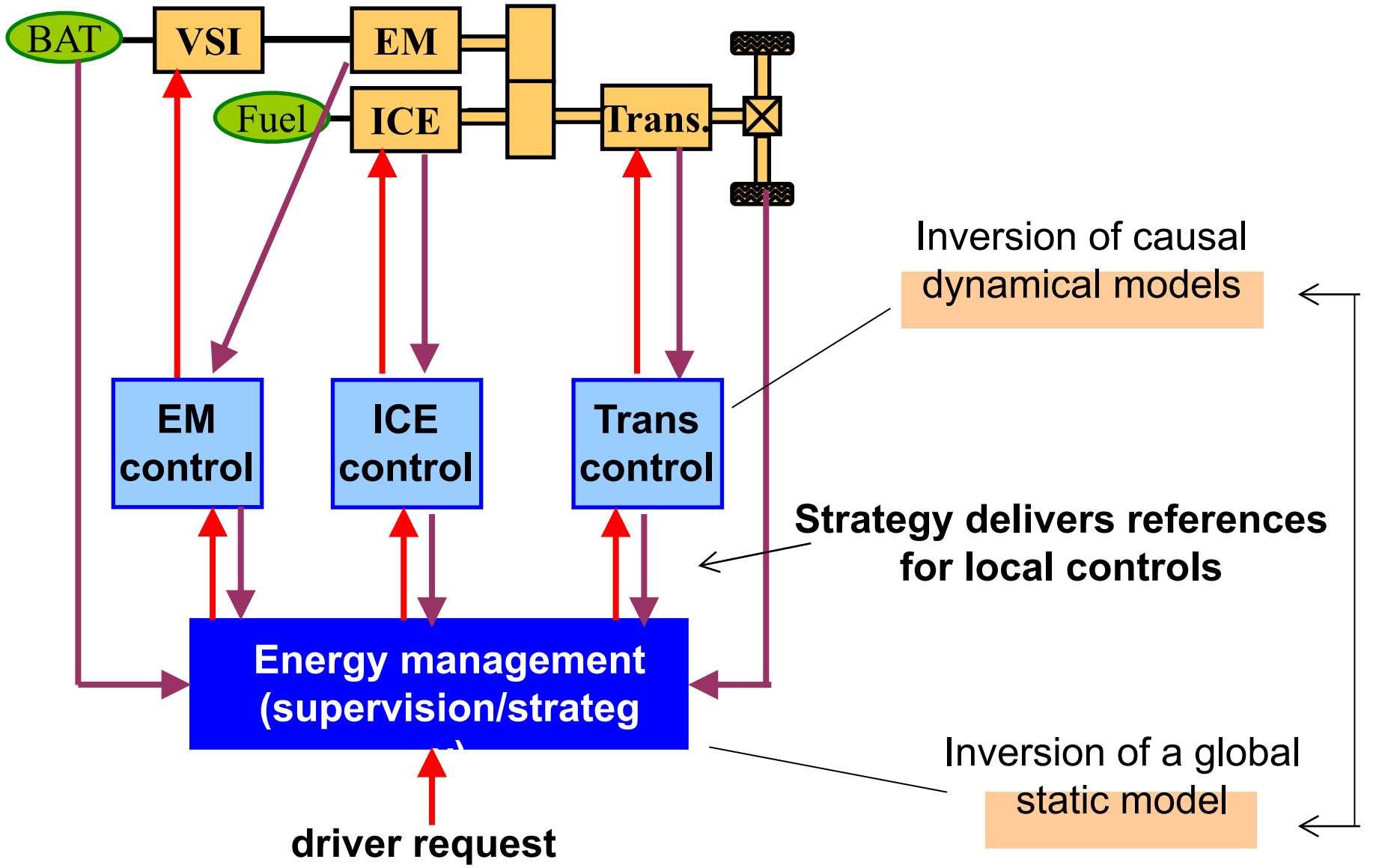
2. Coordination of energy between all subsystems

Objective: ensure the best energy distribution in function of the global demand

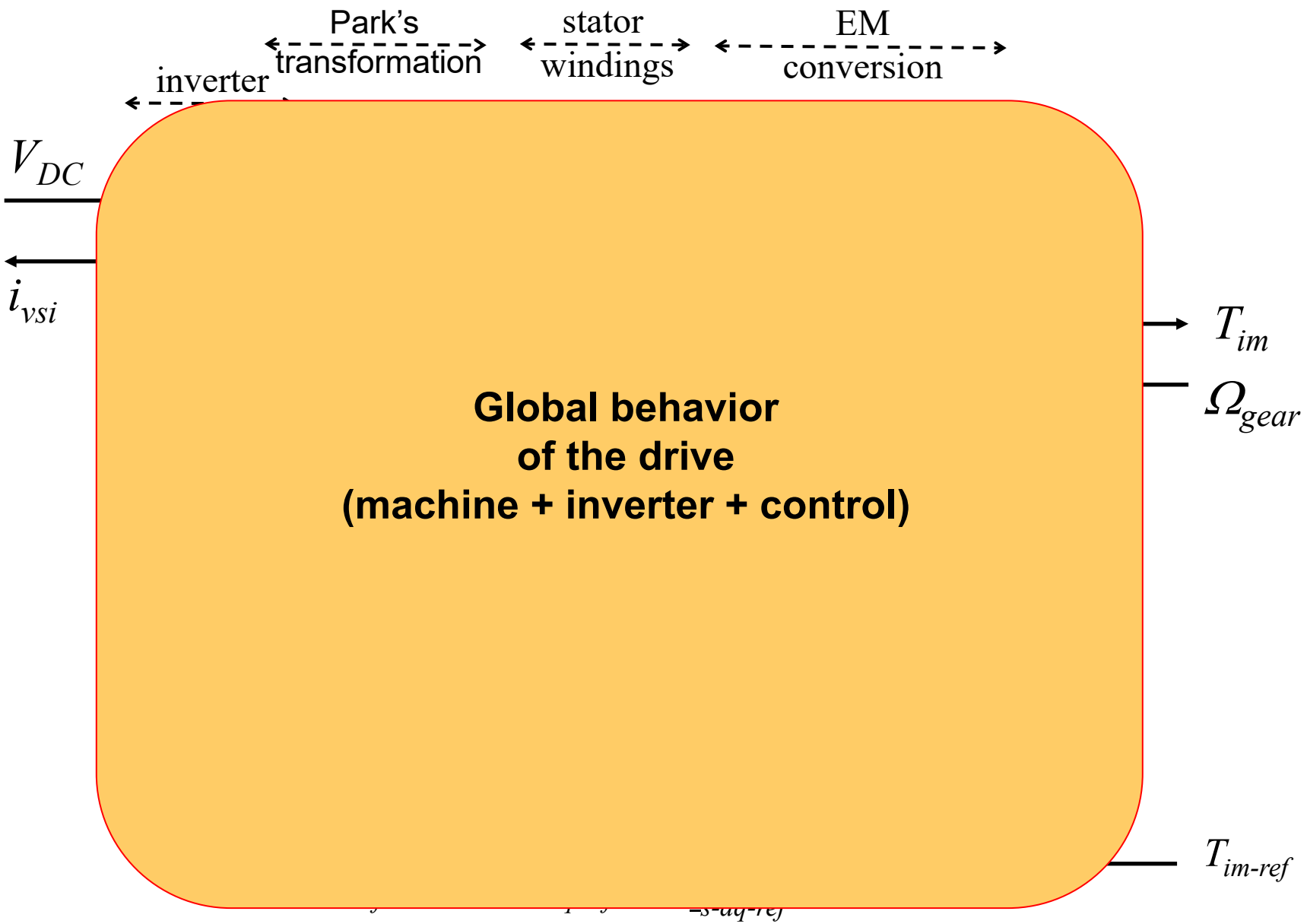
Global view for decision using quasi-static or static models

Could be considered as an inversion of a global model of the system

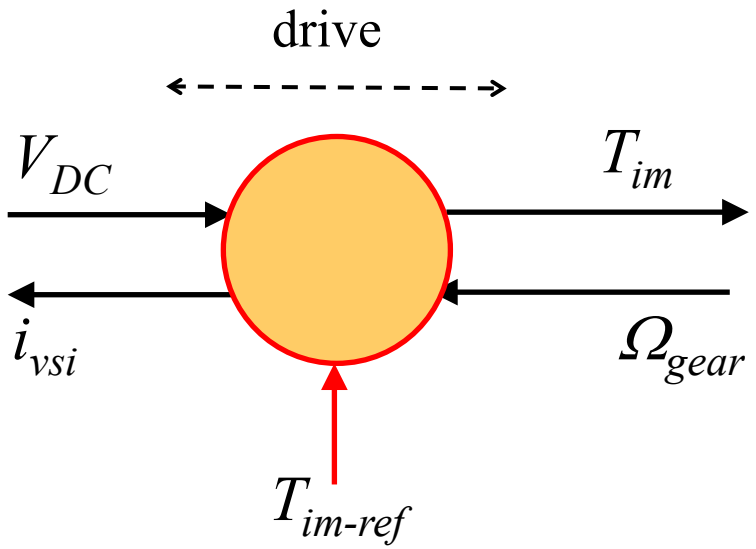
Articulation of control & models

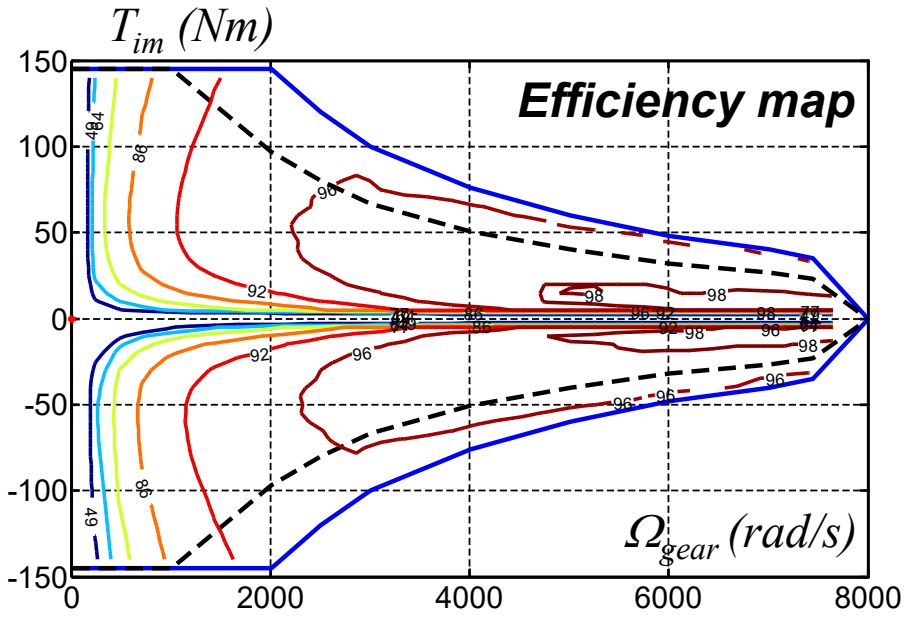


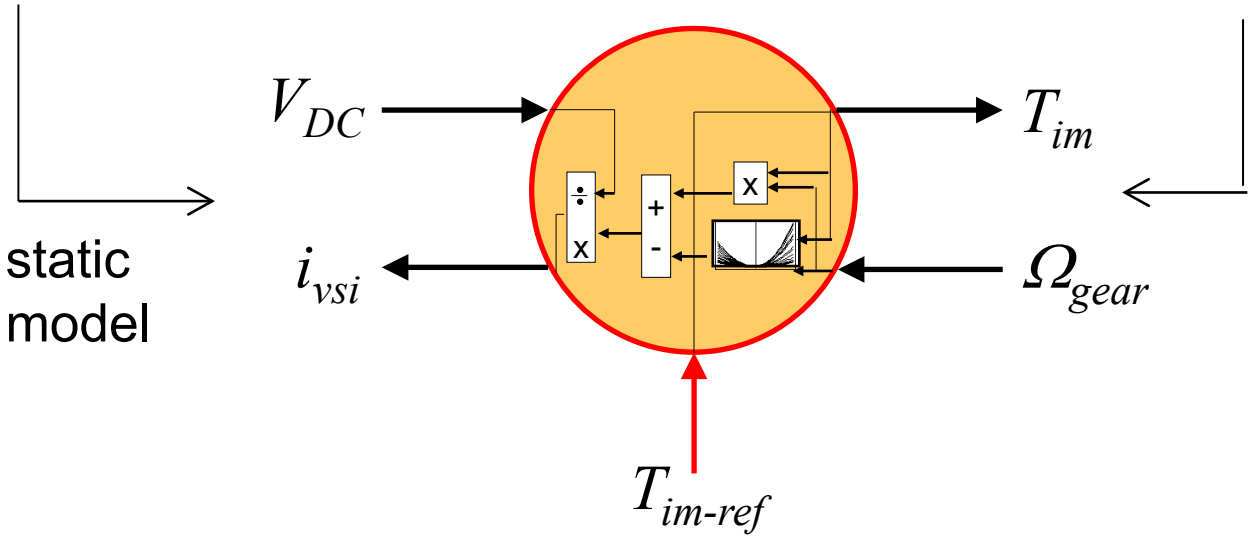
From dynamical model to static model



Static model

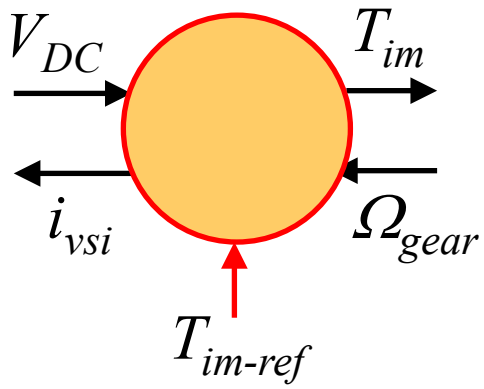


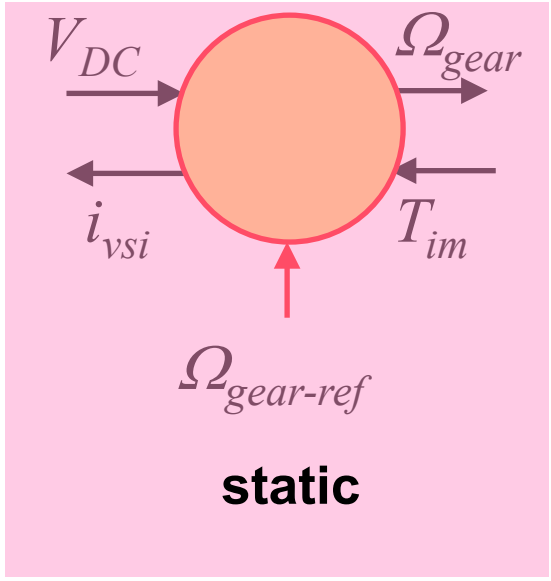


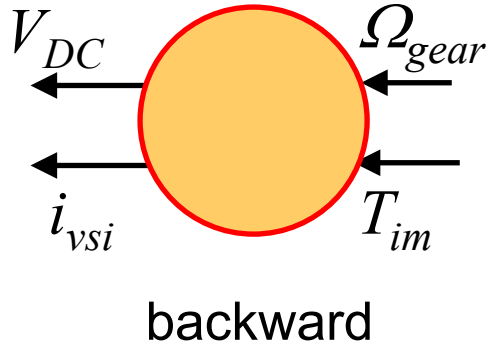


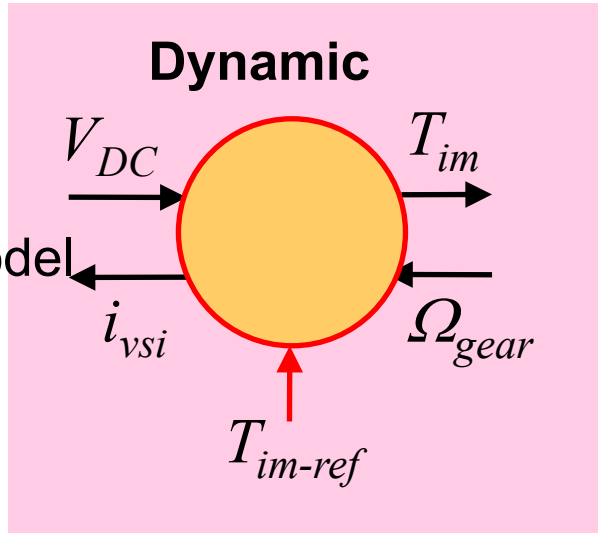
Coherence of dynamical and static models

Static model: no dynamical effect, I/O could be changed



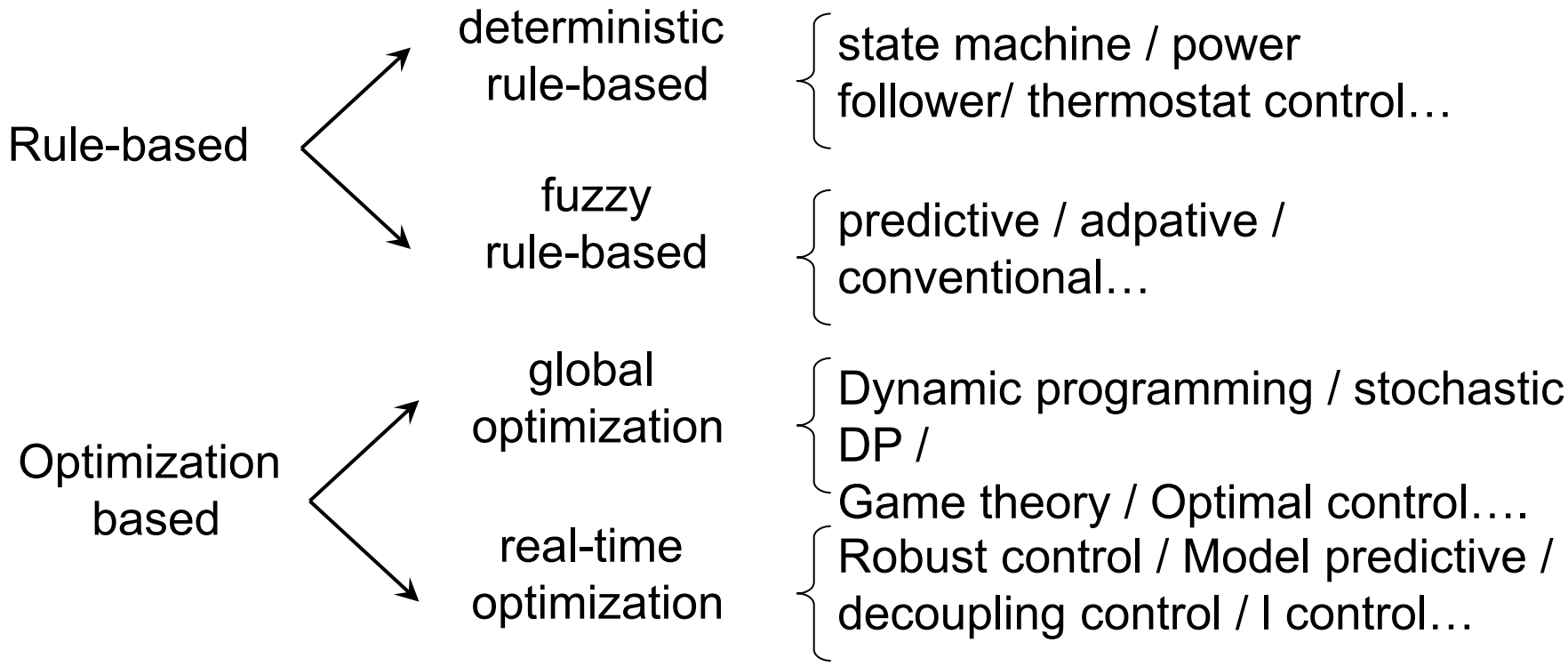




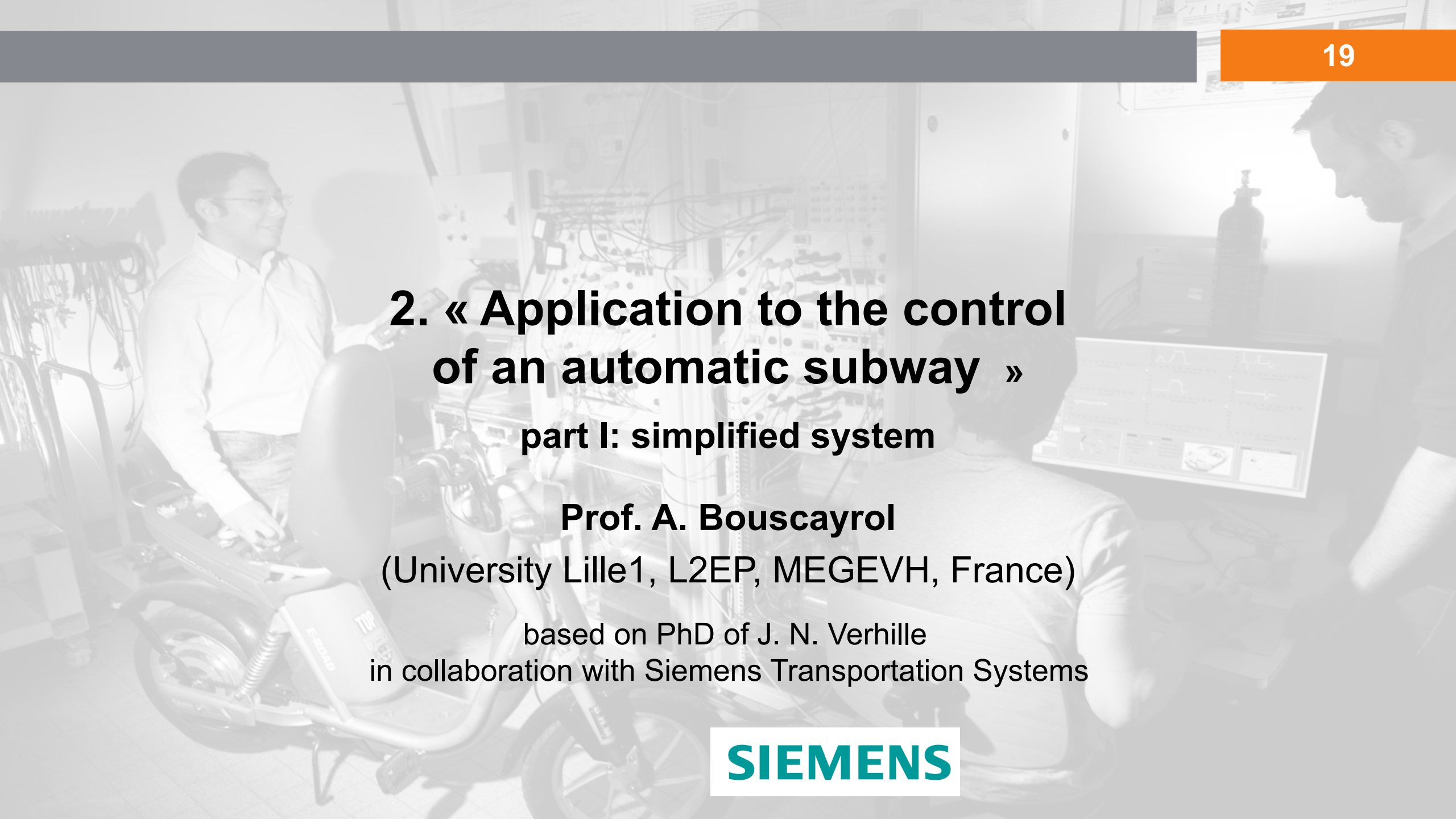


What happens if EM = inversion of a static model
and IBC = inversion of dynamical models
with differents I/O?

Bad articulation between control levels



[Salmasi 2007]



2. « Application to the control of an automatic subway »

part I: simplified system

Prof. A. Bouscayrol

(University Lille1, L2EP, MEGEVH, France)

based on PhD of J. N. Verhille
in collaboration with Siemens Transportation Systems

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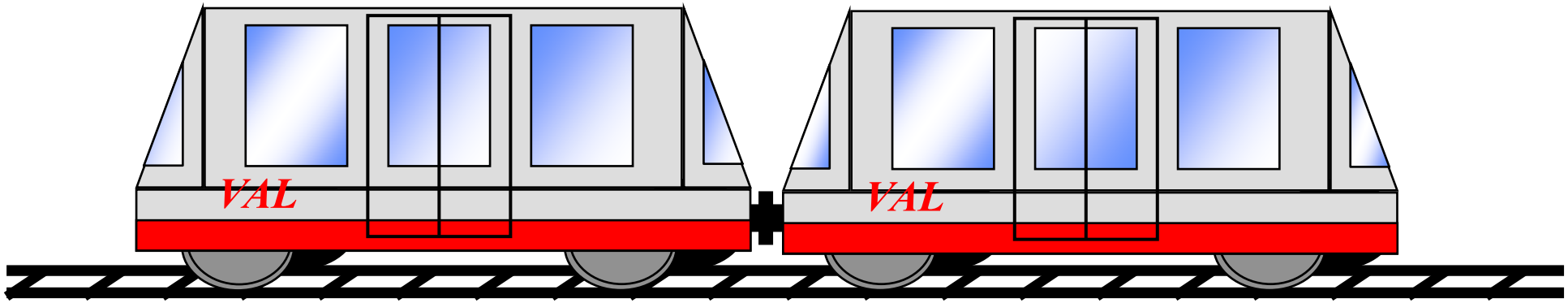
Example of VAL automatic subway

Traction systems of the subway VAL 206



Actual system (4 DC machines + 6 choppers)

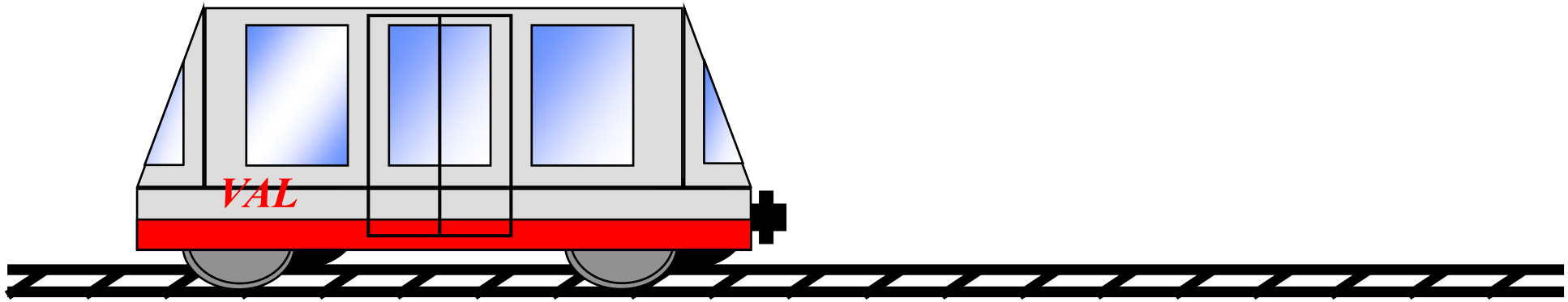
1 vehicle = 2 car, 1 car = 2 bogies

1 bogie = 1 DC machine with field winding

1 chopper for each field winding

1 chopper for the armature wining in series

Traction systems of the subway VAL 206



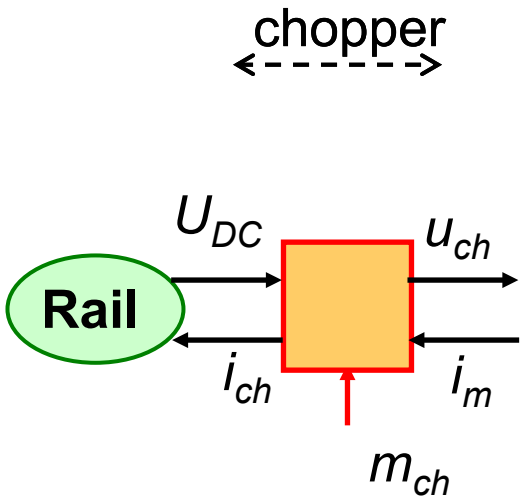
Studied system (2 DC machines + 1 chopper)

1 vehicle = 1 car avec 2 bogies

1 bogie = 1 DC machine with permanent magnets

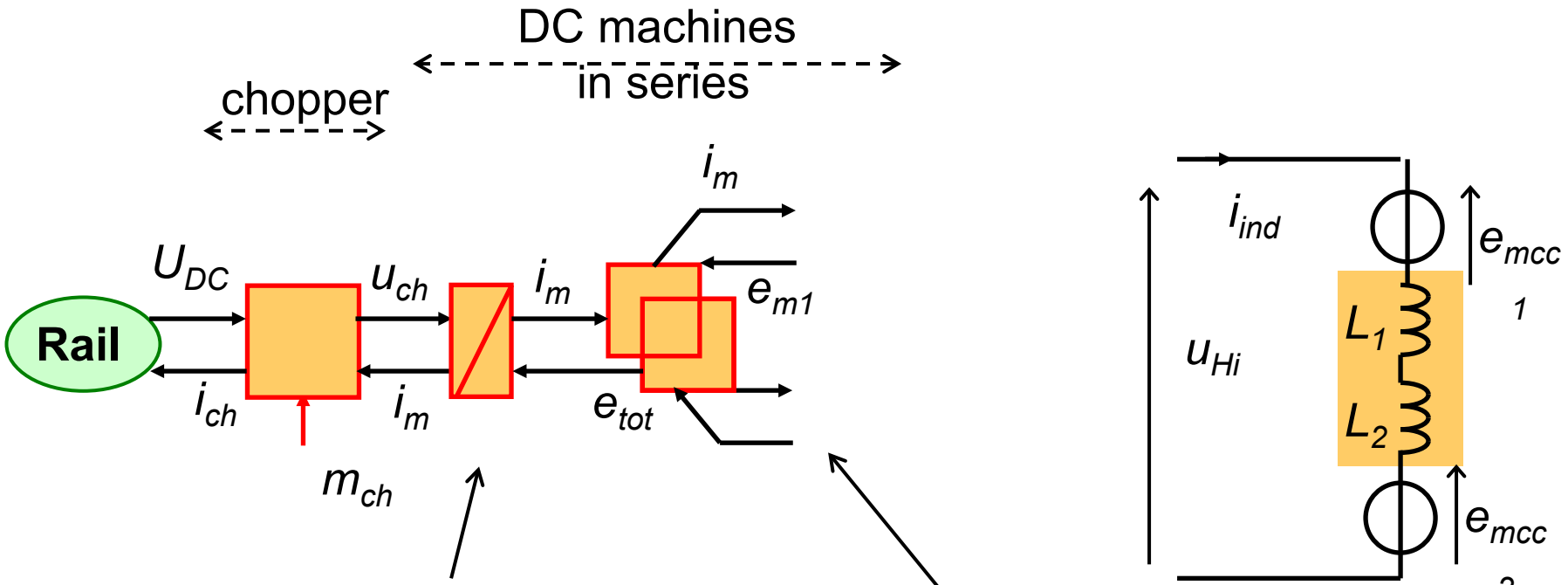
1 4 quadrants chopper for the DC machines in series

1. EMR of the System



$$\begin{cases} u_{ch} = m_{ch}\, U_{DC} \\ i_{ch} = m_{ch}\, i_m \end{cases}$$

1. EMR of the System



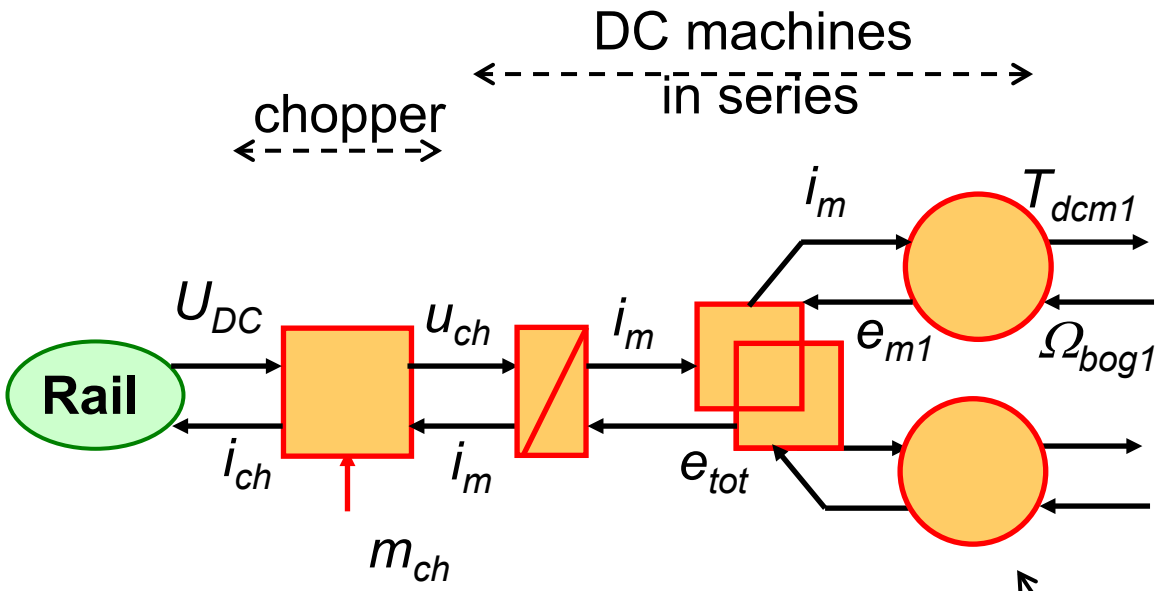
$$u_{Hi} = (L_1 + L_2)\frac{d}{dt} i_{ind} + e_{tot}$$

L_1+L_2 equivalent inductance

$$\begin{cases} i_1 = i_1 = i_{ind} \\ e_{tot} = e_{mcc1} + e_{mcc2} \end{cases}$$

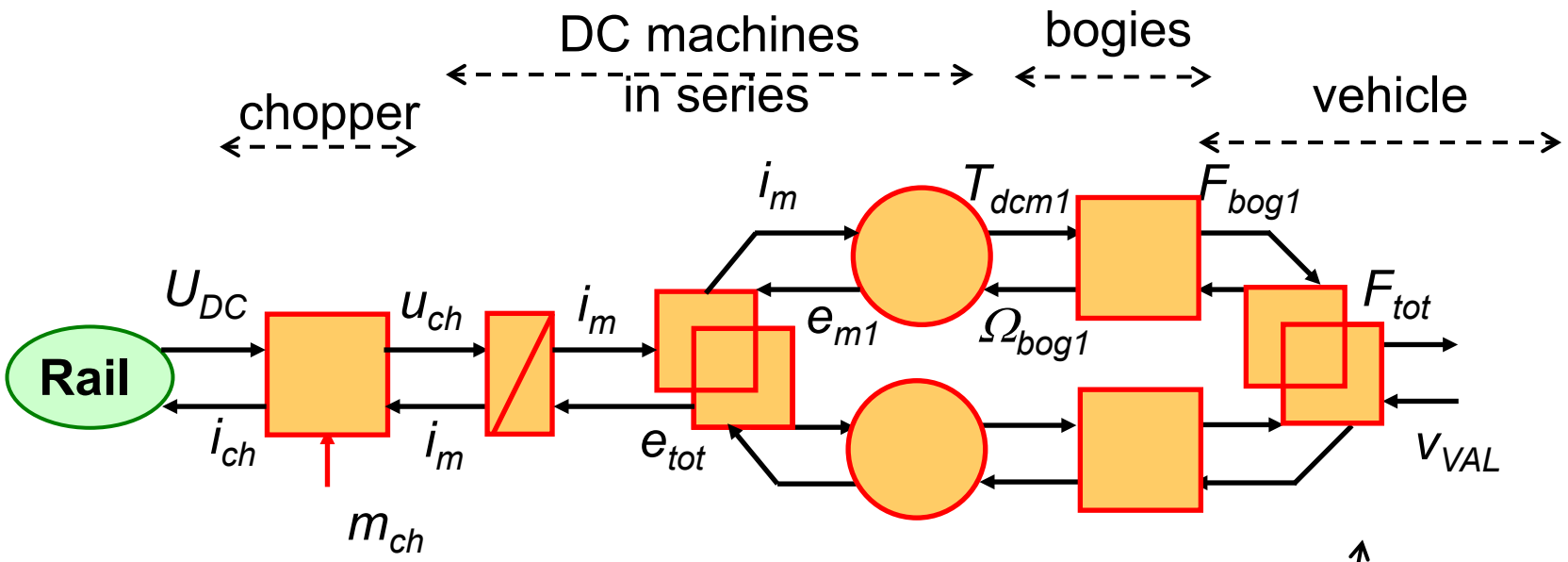
series connection

1. EMR of the System



$$\begin{cases} C_{mcc1} = k_\phi \, i_{ind} \\ e_{mcc1} = k_\phi \, \Omega_{bog1} \end{cases}$$

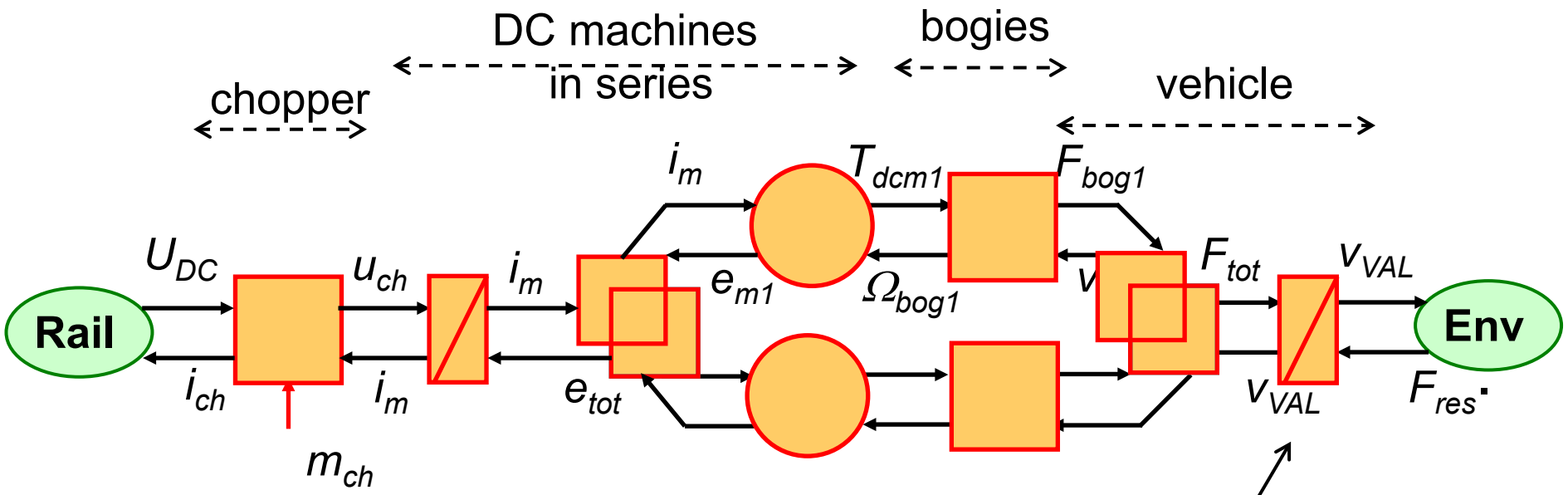
Example of VAL automatic subway



$$\begin{cases} F_{bog1} = k_{bog}\ T_{m1} \\ \Omega_{bog1} = k_{bog}\ v_{rame} \end{cases}$$

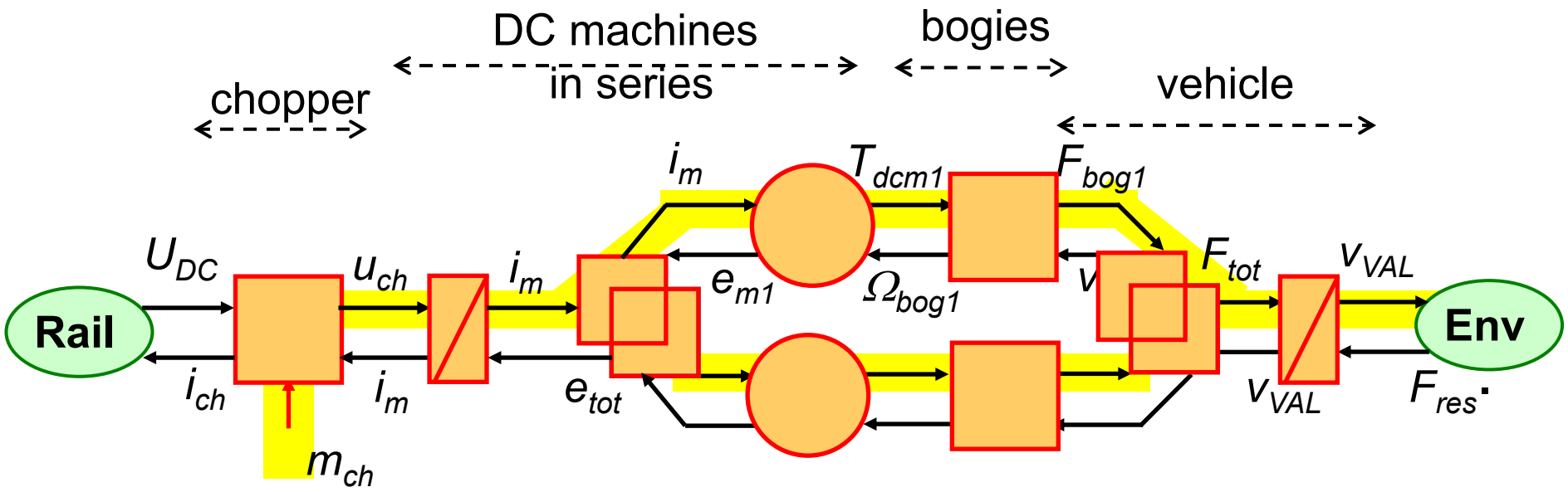
$$\begin{cases} F_{tot} = F_{bog1} + F_{bog2} \\ v_1 = v_2 = v_{rame} \end{cases}$$

Example of VAL automatic subway

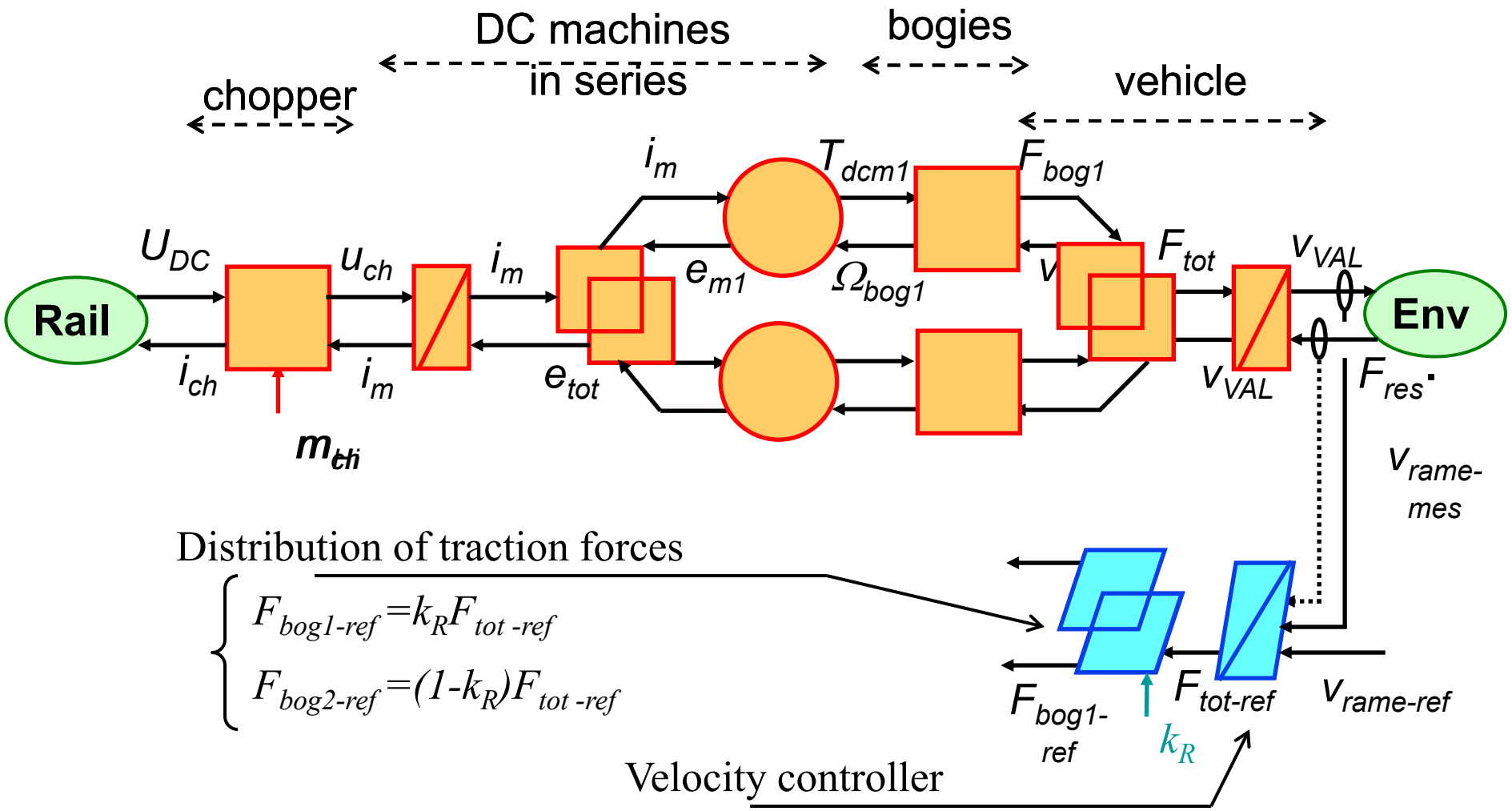


$$M\frac{d}{dt}v_{rame} = F_{tot} - F_{res}$$

2. Tuning path of the System



3. MCS of the System



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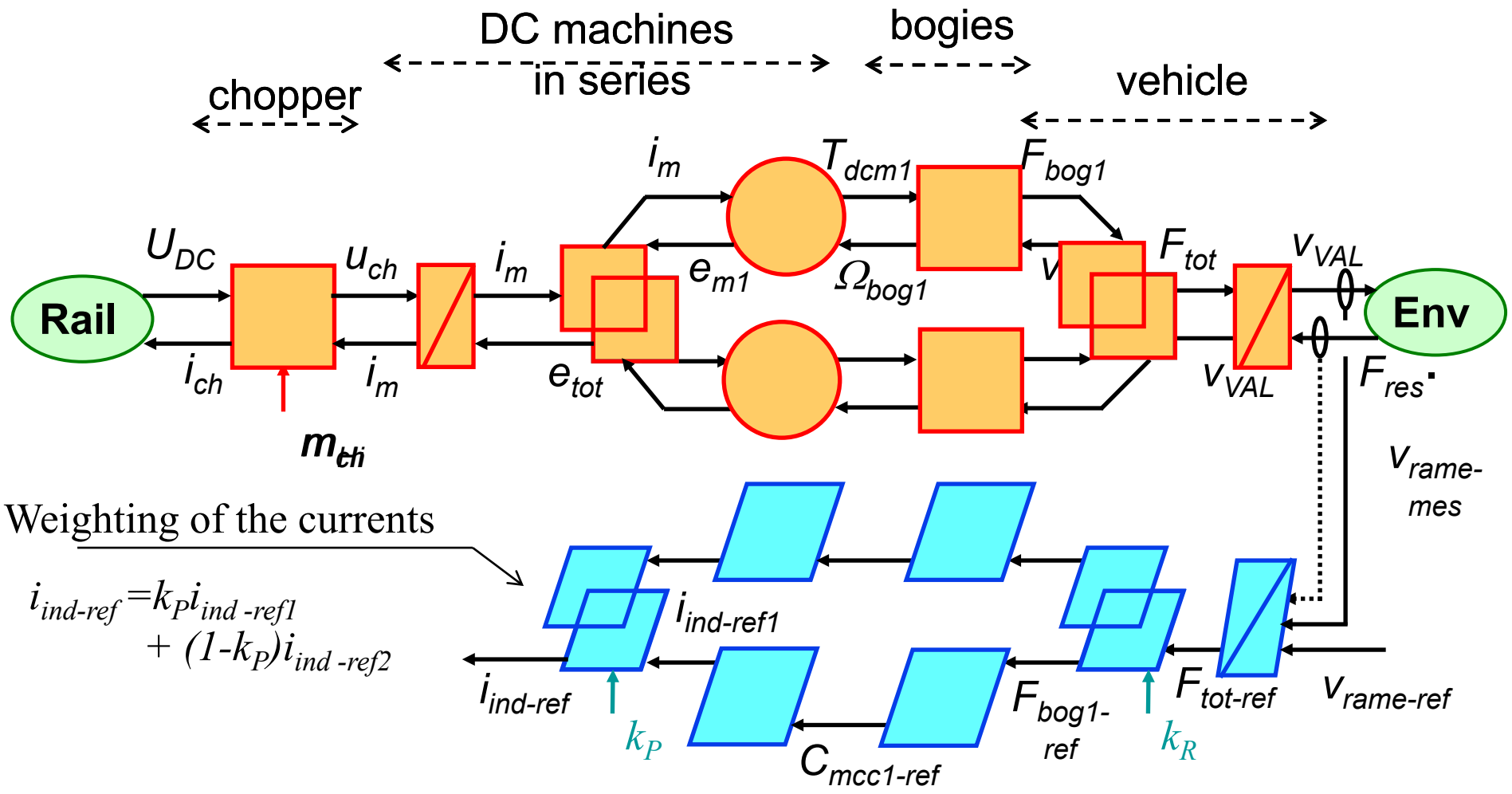

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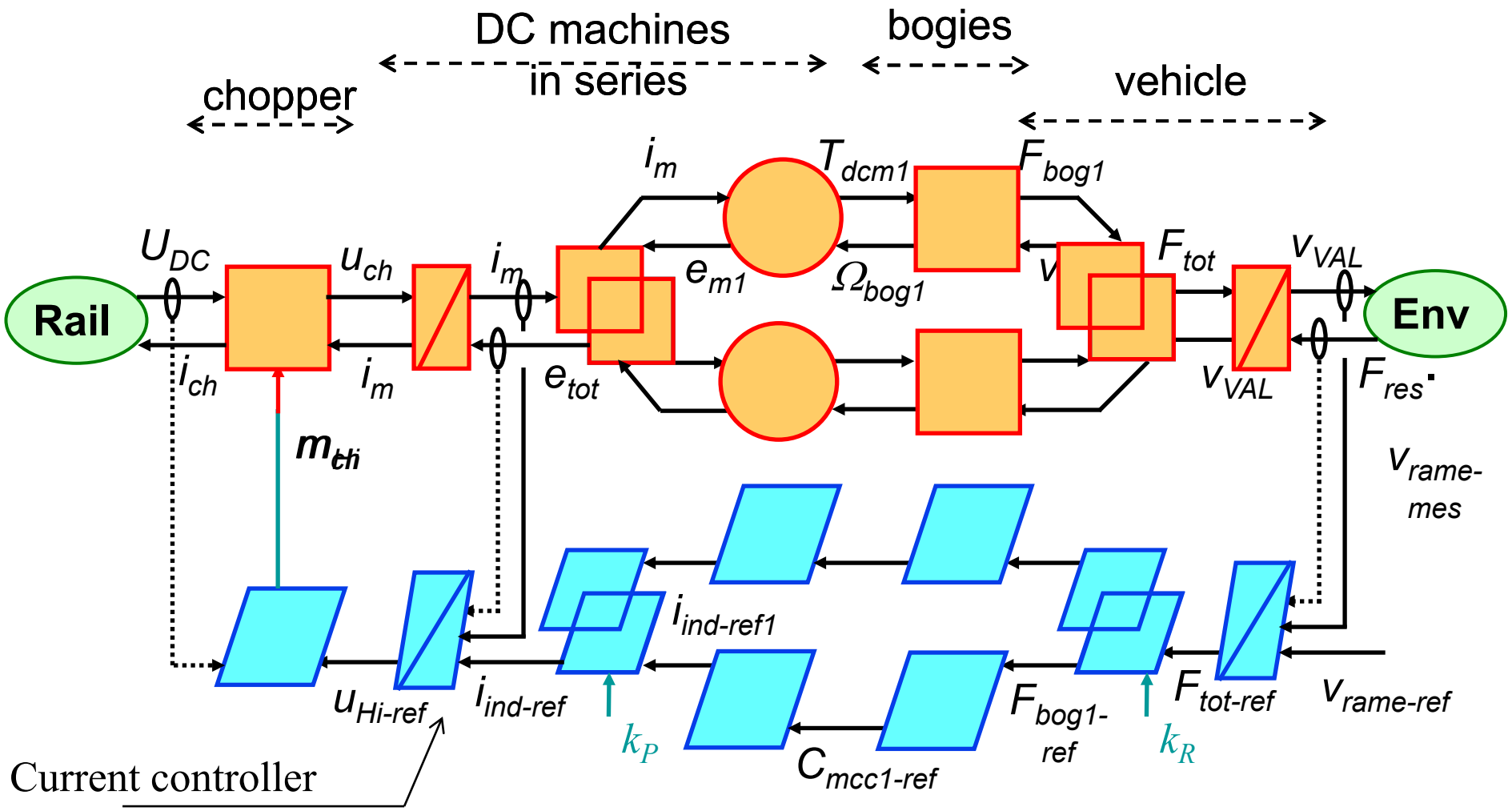
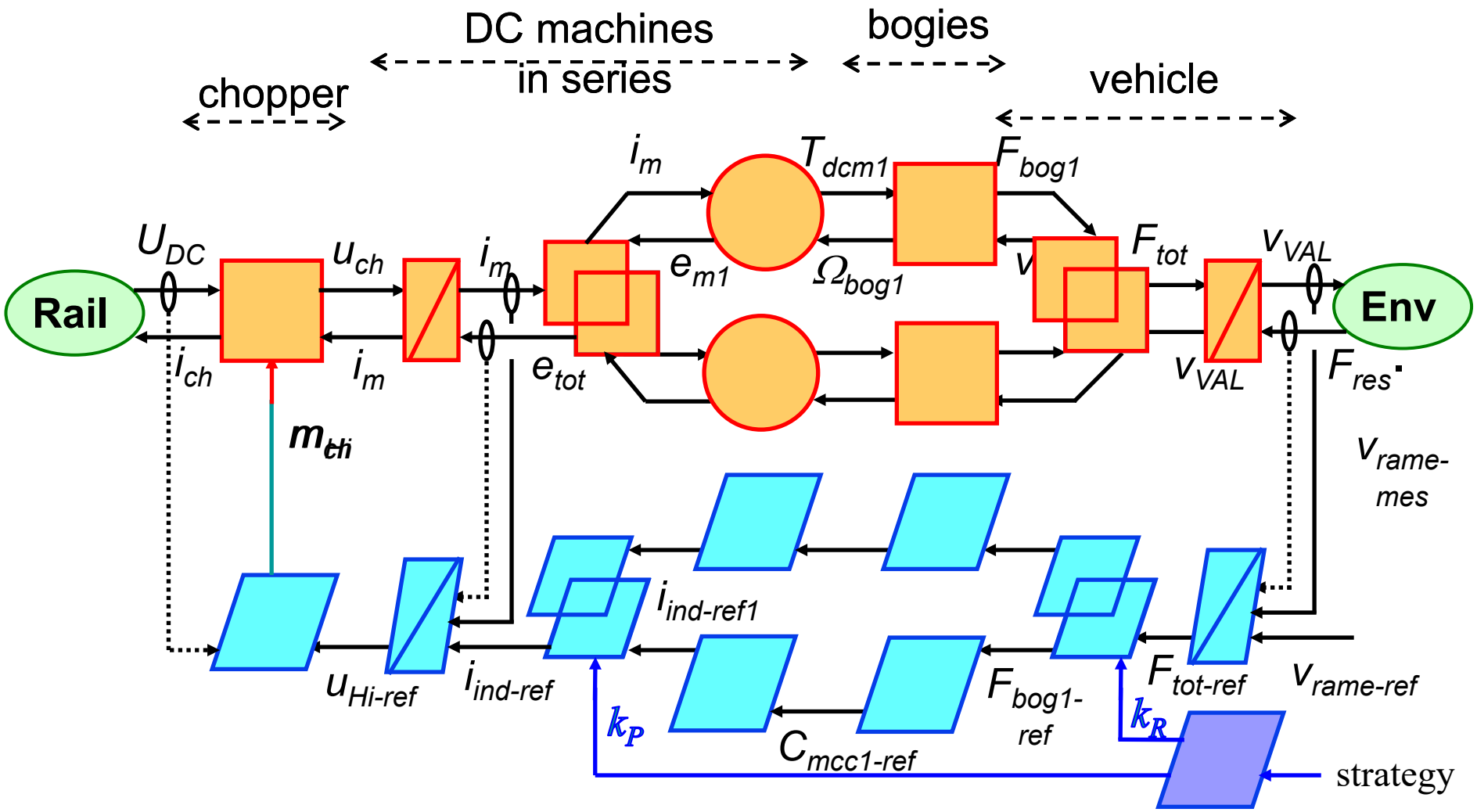
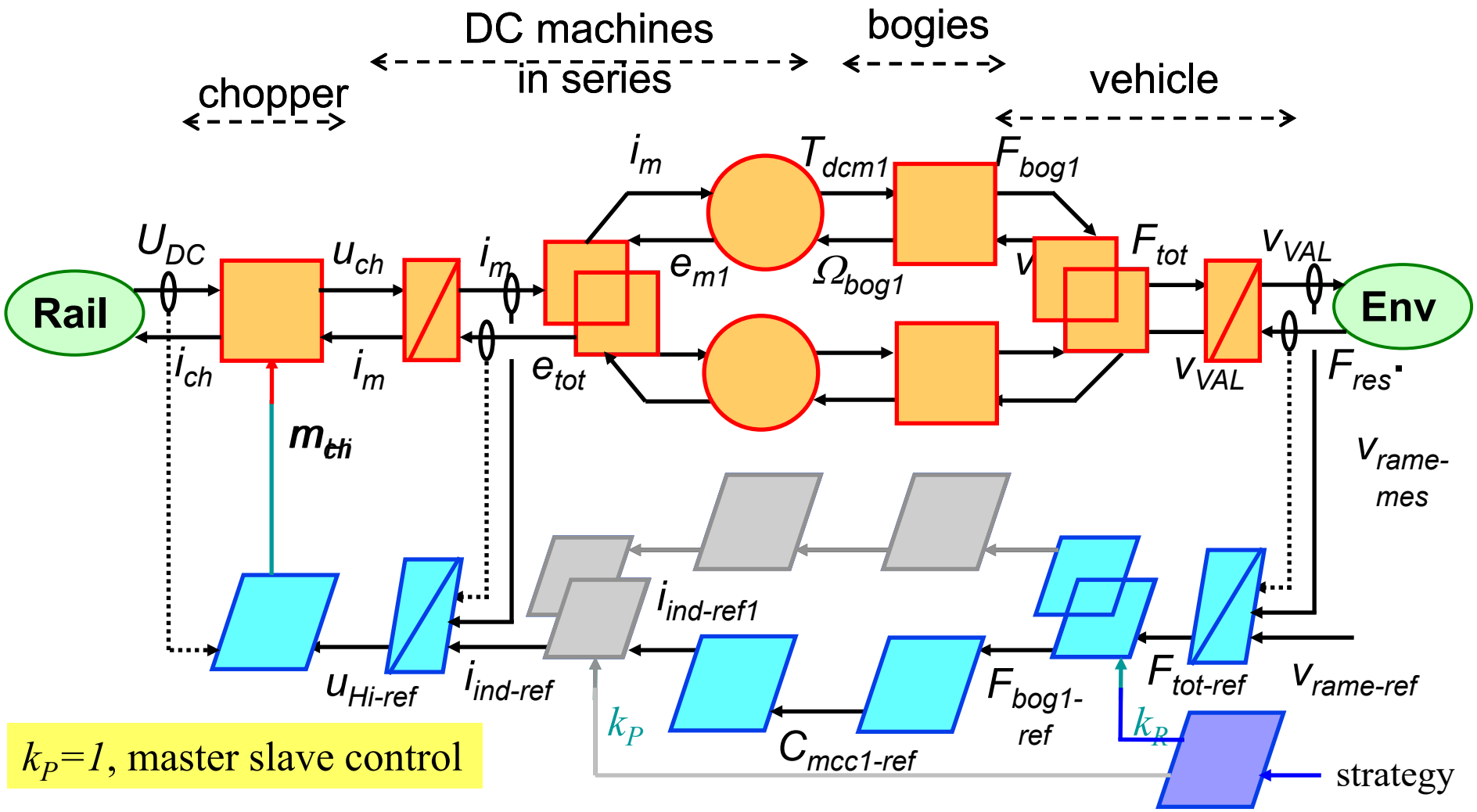


3b. Strategy of the System



4. Simplification of the control



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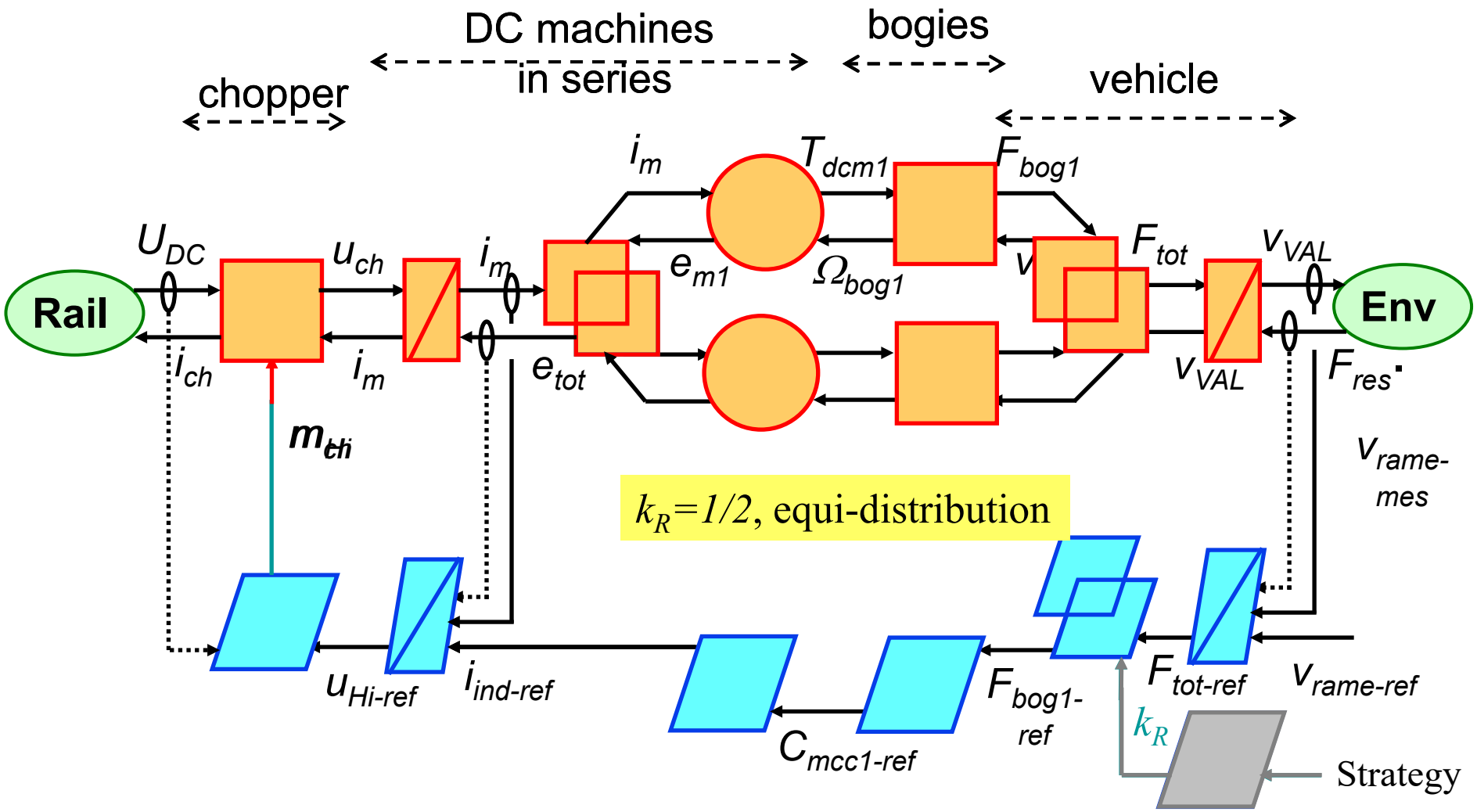

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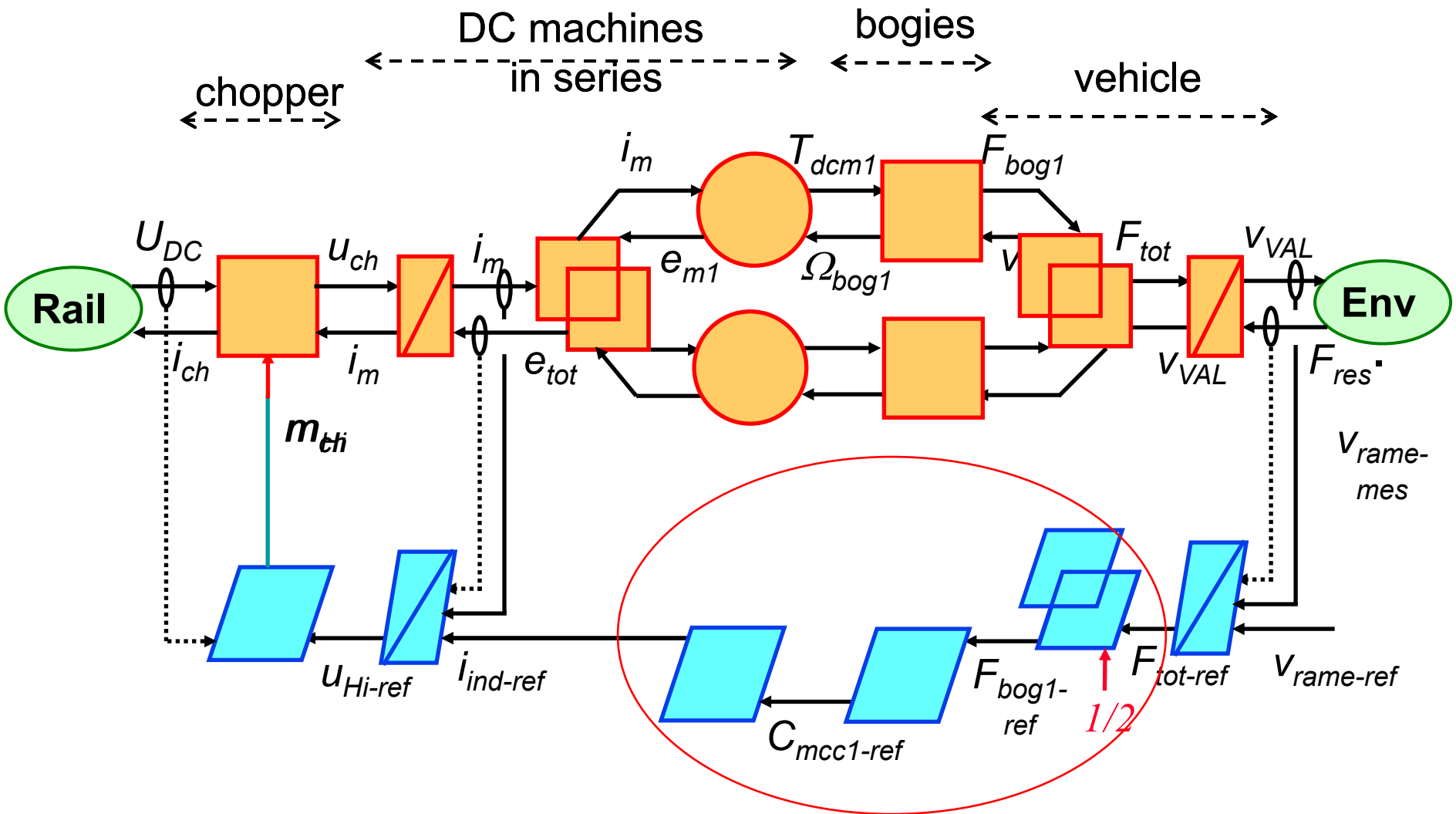

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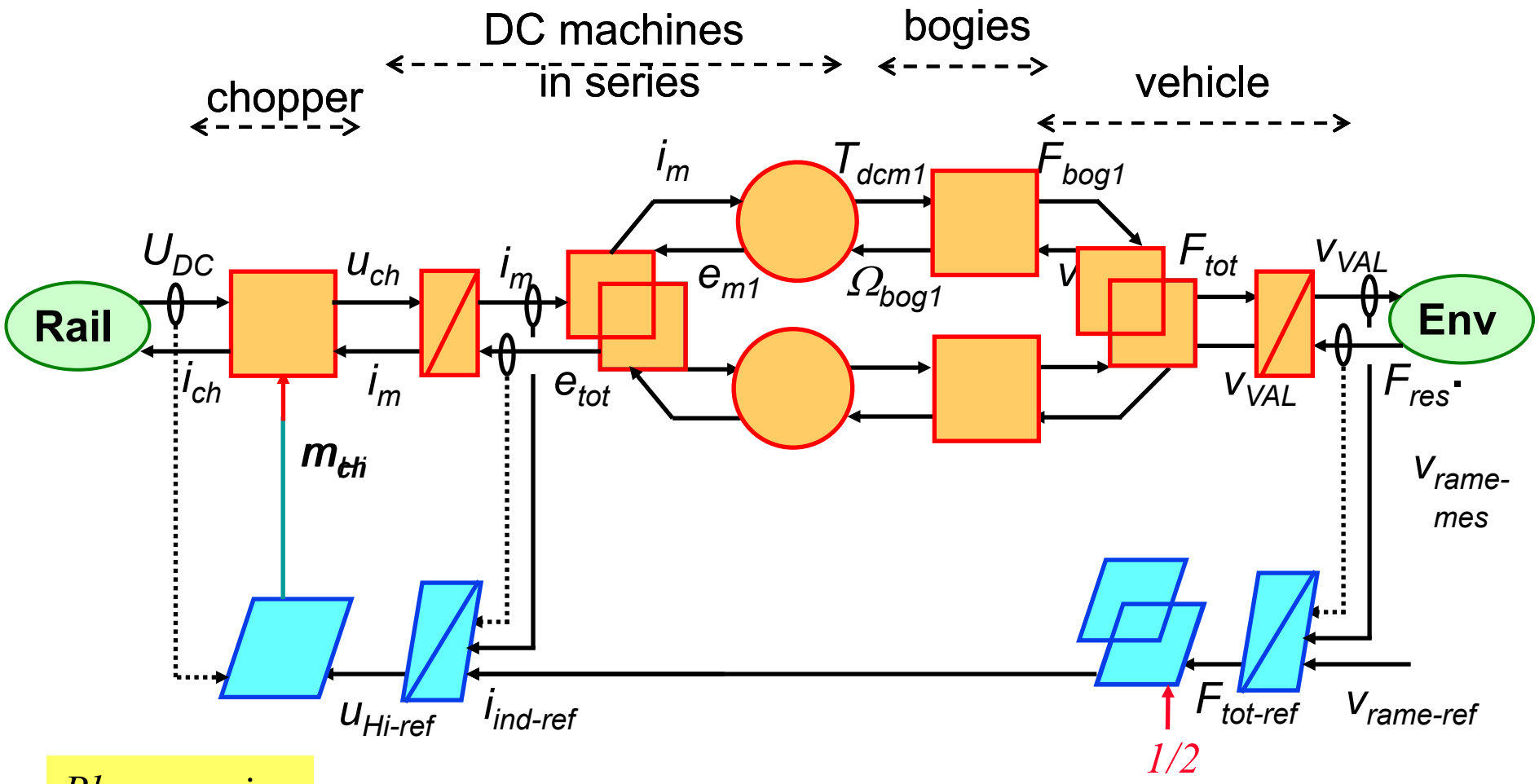
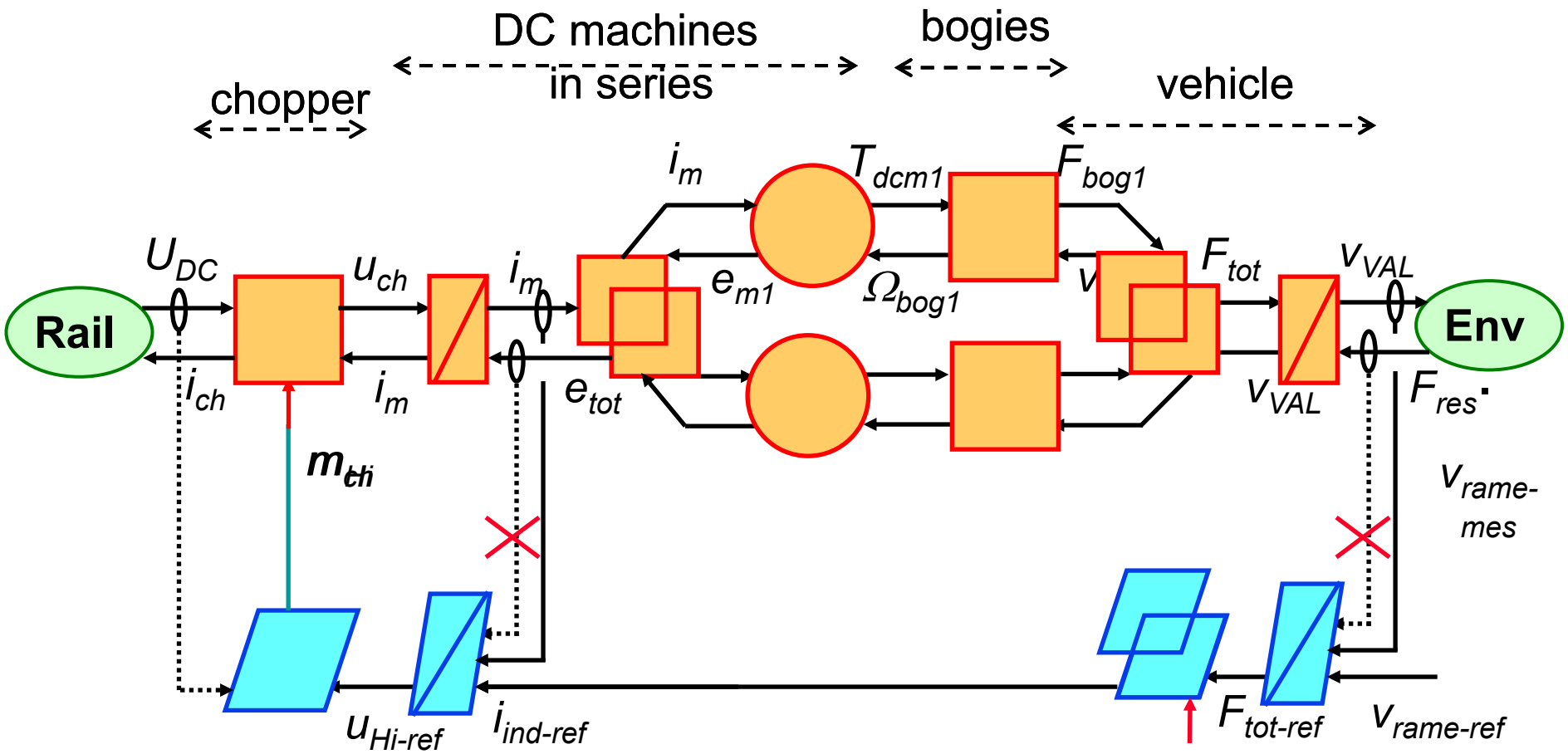


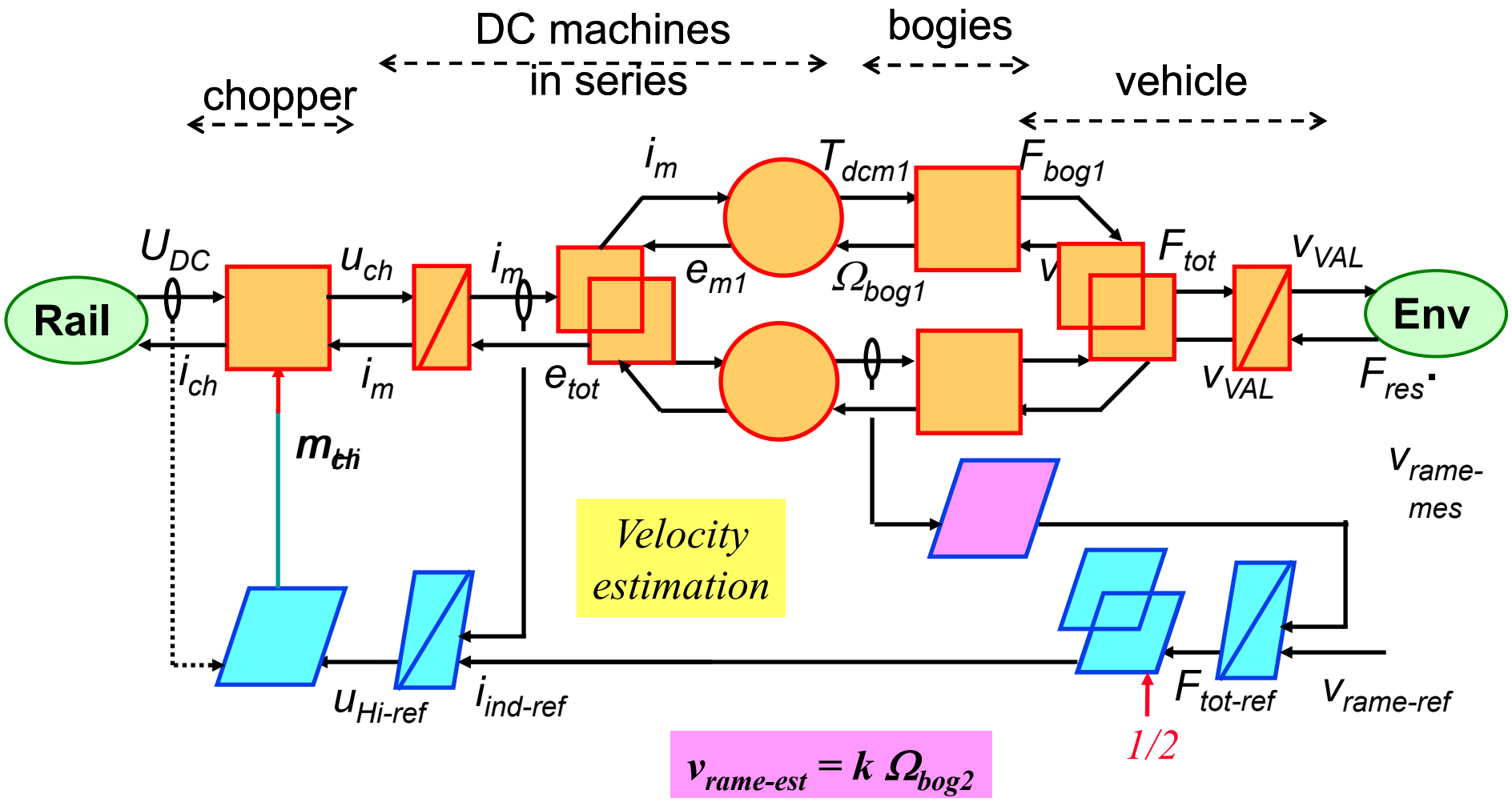
Bloc merging

4. Simplification of the control

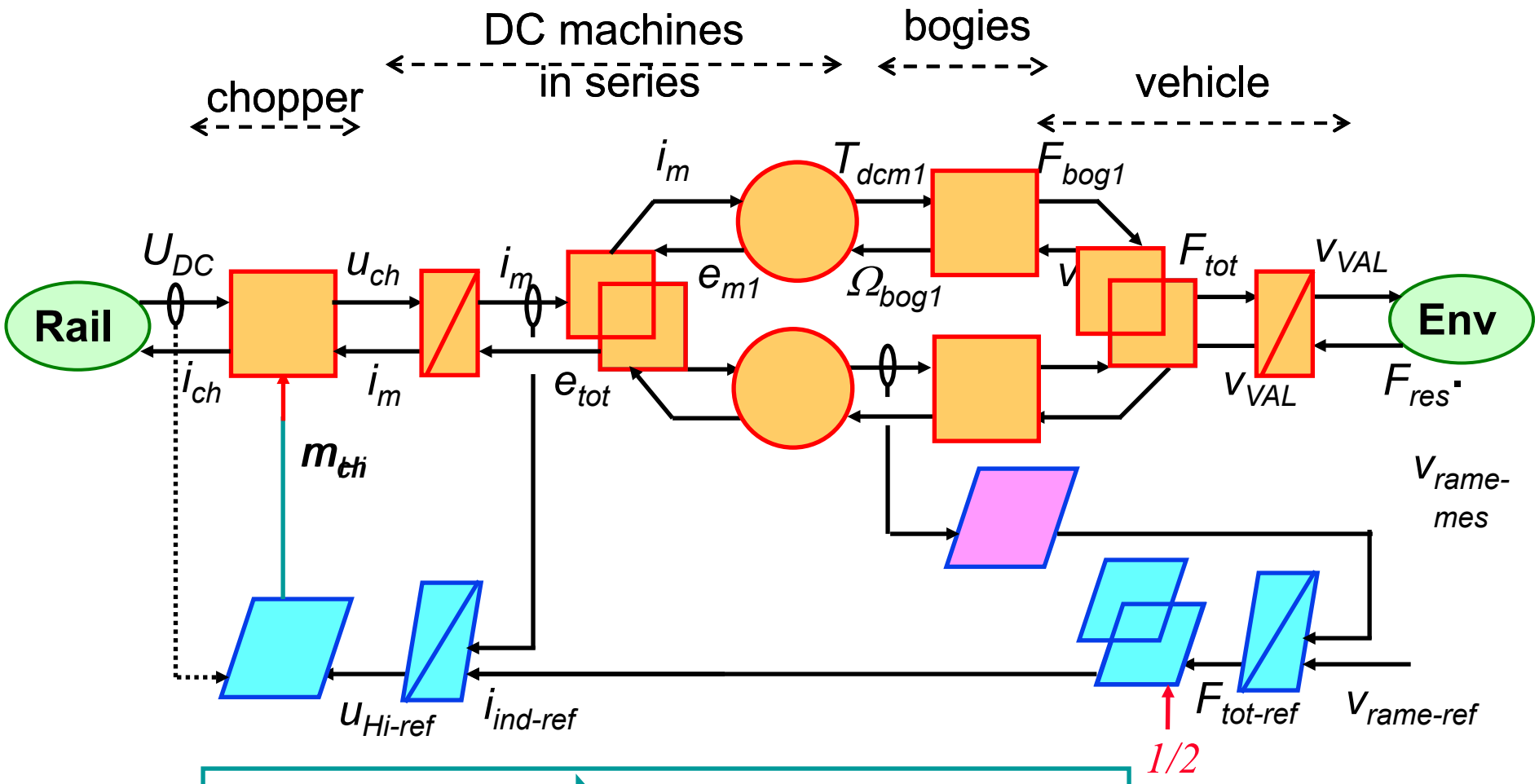


Simplification of compensations

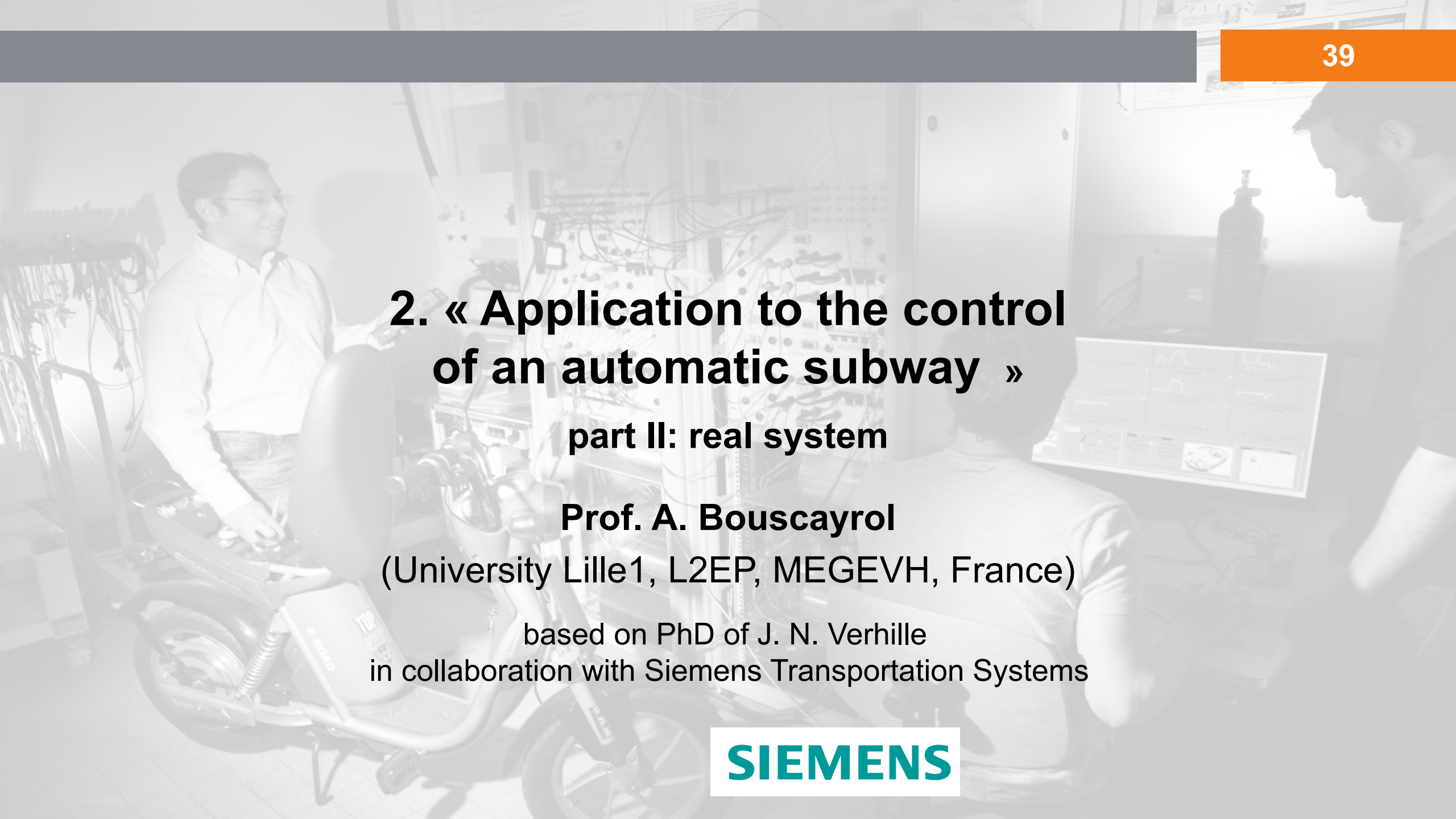
5. Estimation of non-measured variables



Example of VAL automatic subway



simplifications ⇨ limitations de prformances



2. « Application to the control of an automatic subway »

part II: real system

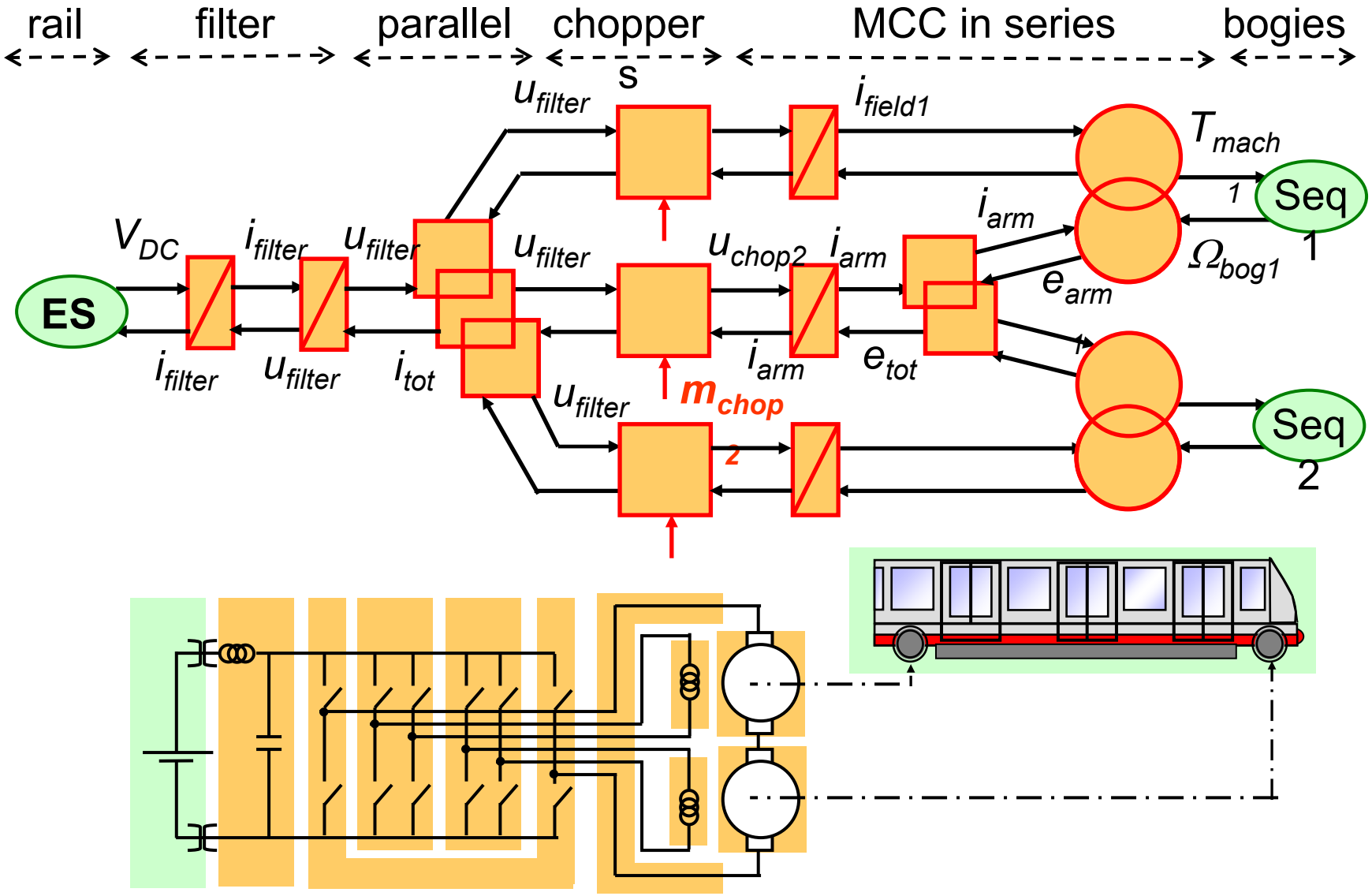
Prof. A. Bouscayrol

(University Lille1, L2EP, MEGEVH, France)

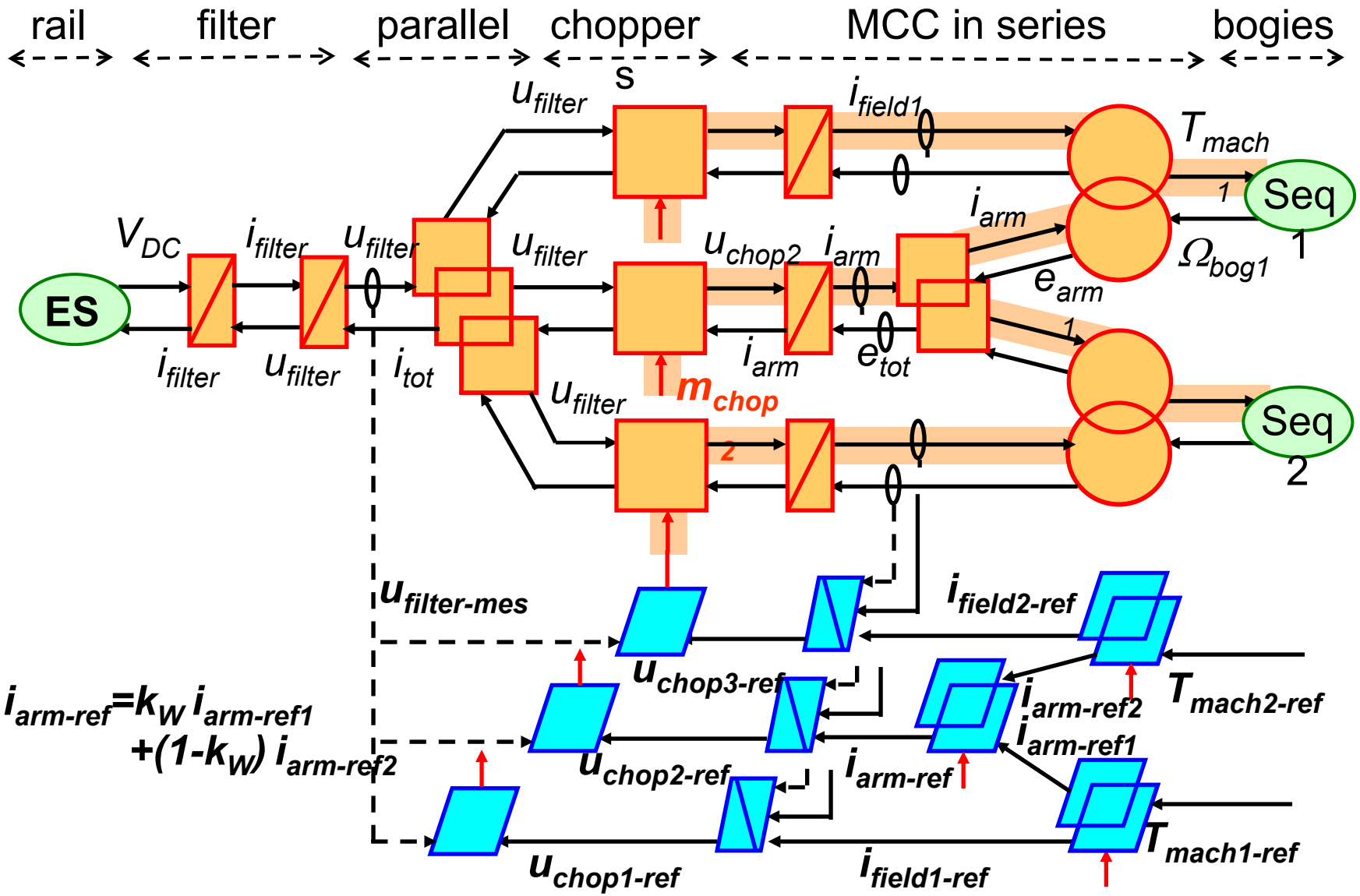
based on PhD of J. N. Verhille
in collaboration with Siemens Transportation Systems

SIEMENS

- EMR of electrical part -



- Control of electrical part -



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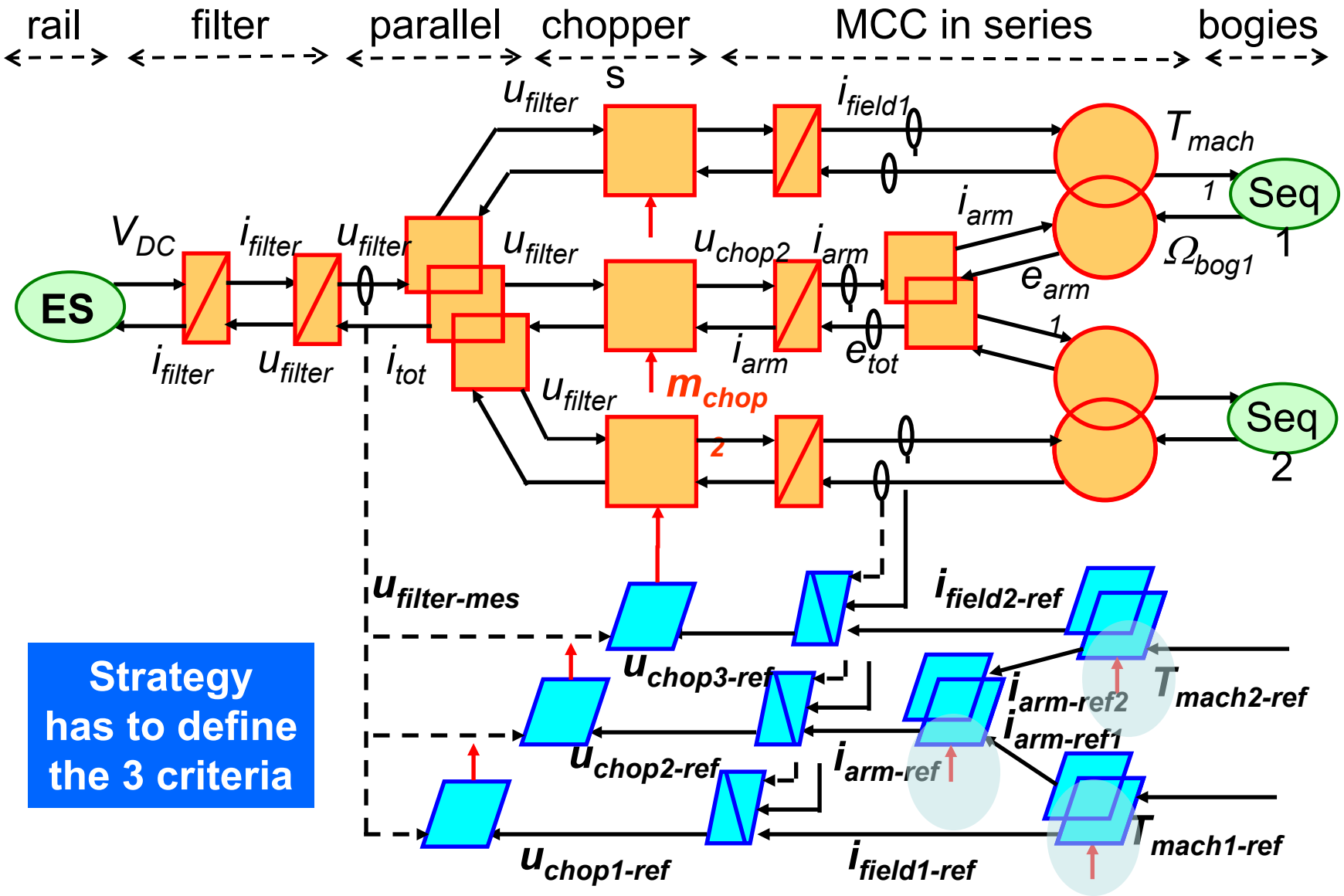

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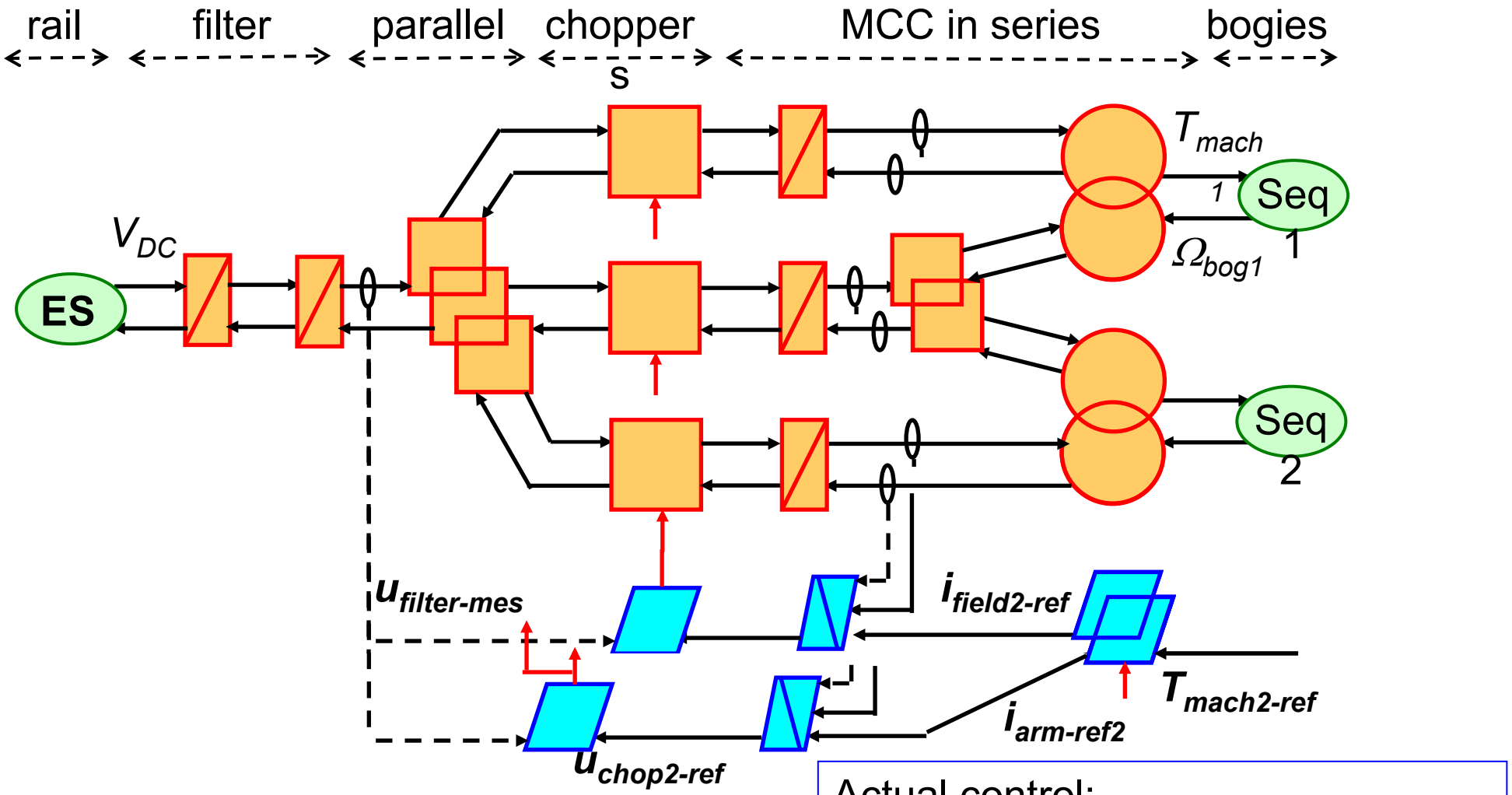
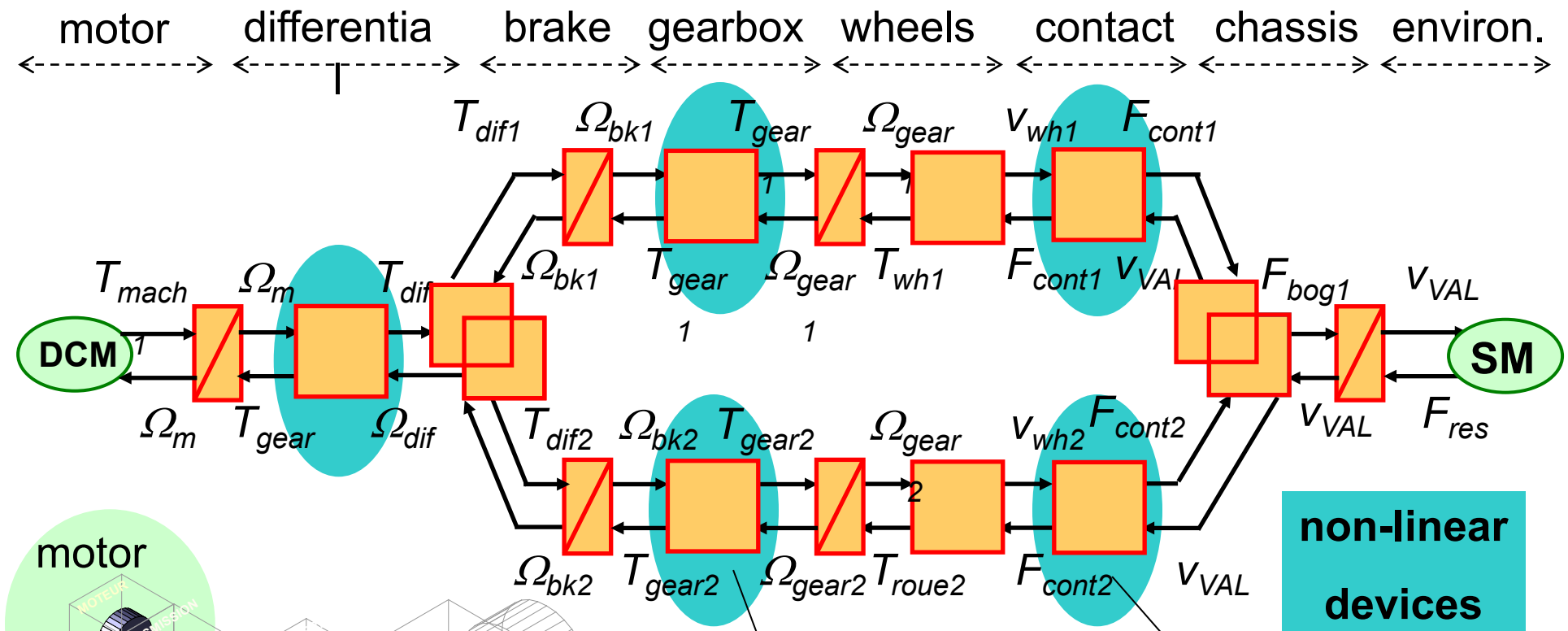
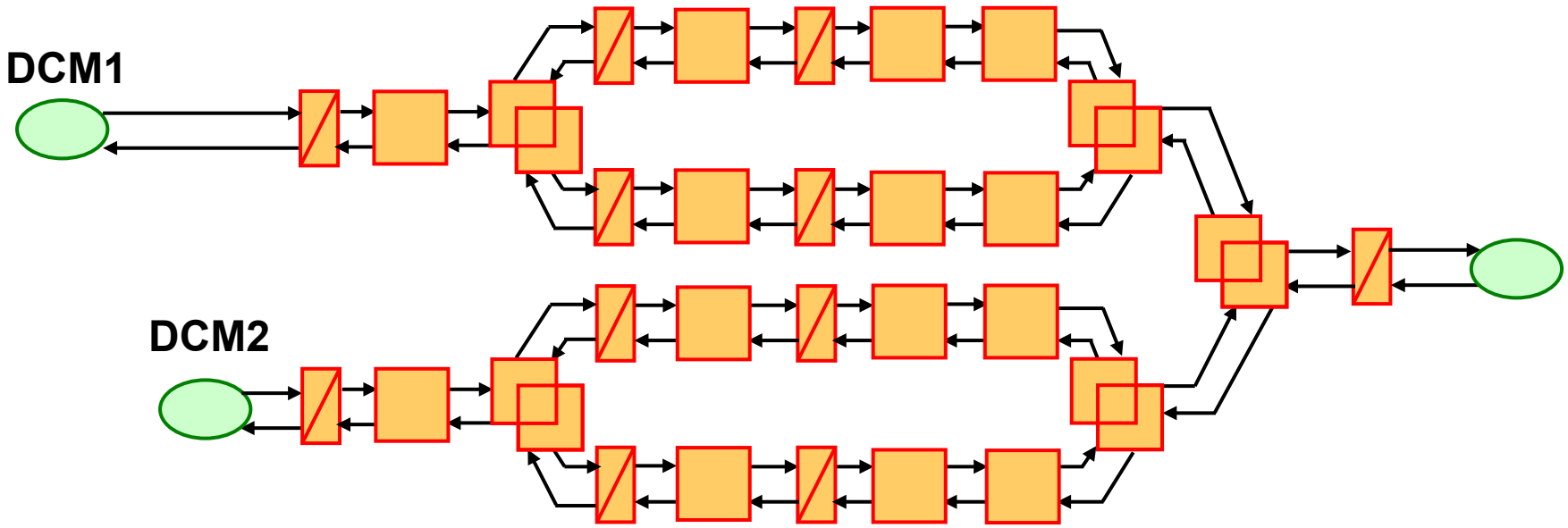


Actual control:
no possibility of independent torque

- EMR of mechanical part -

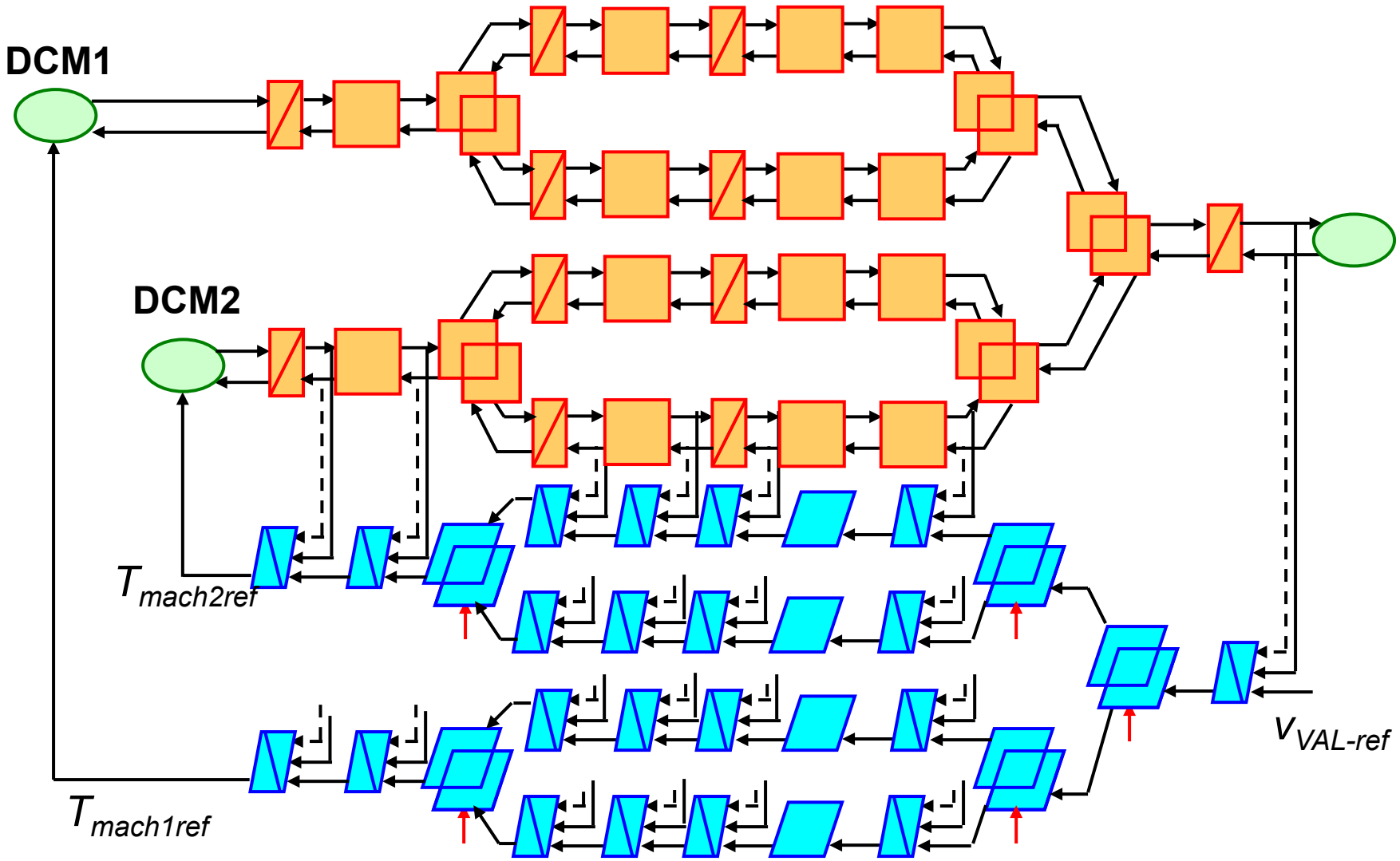


- Control of mechanical part -

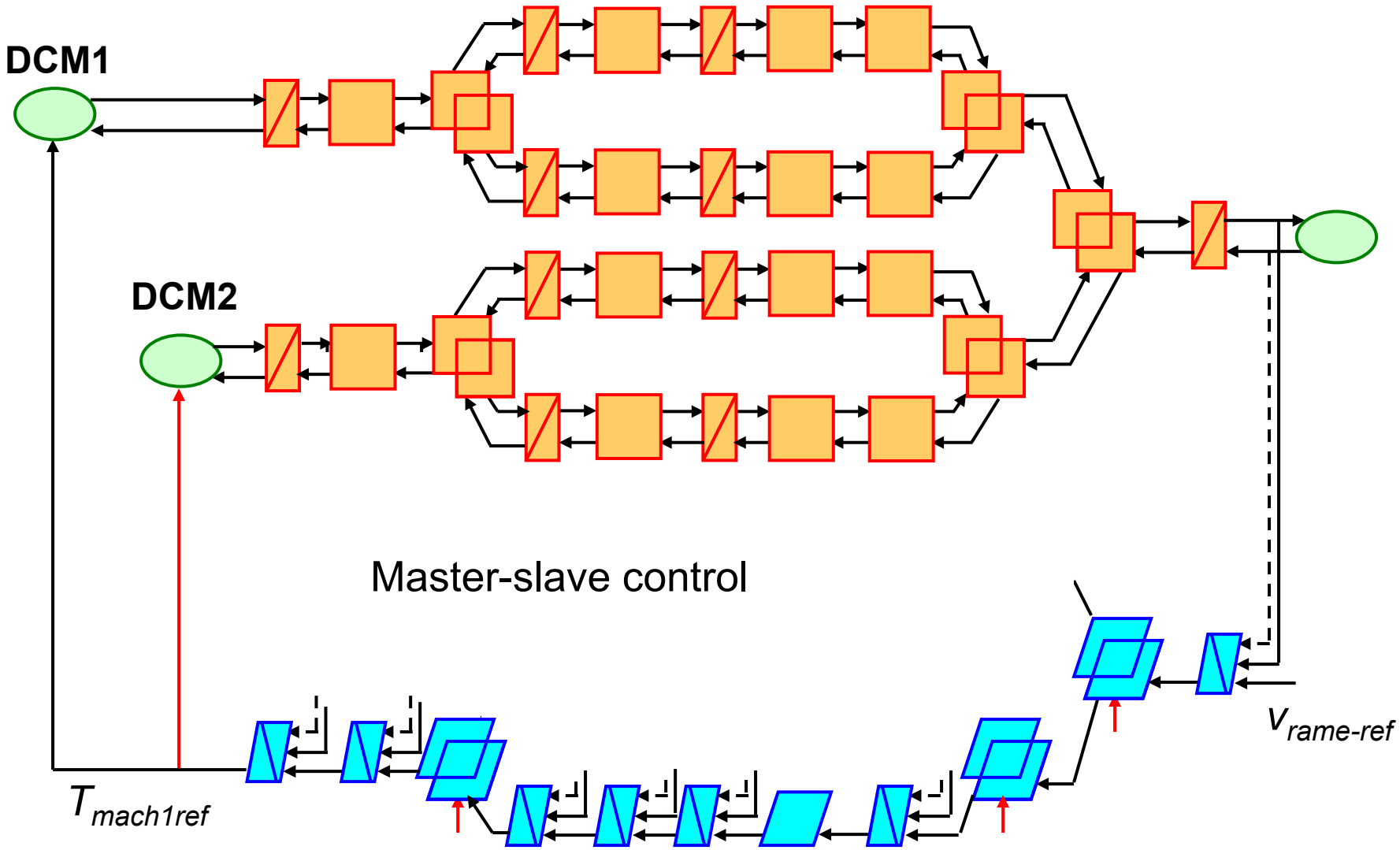


Complete VAL automatic subway

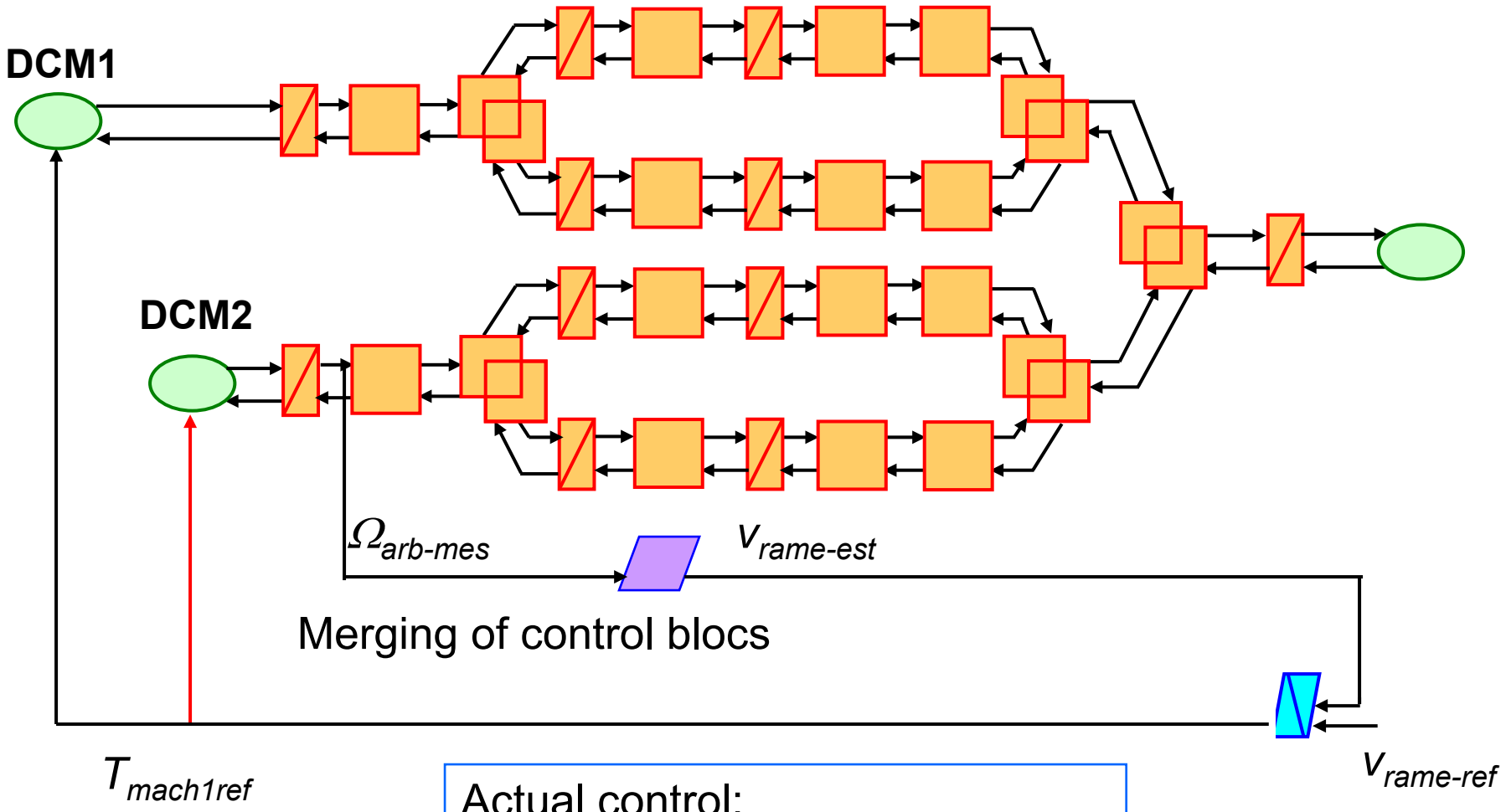
- Control of mechanical part -



- Control of mechanical part -



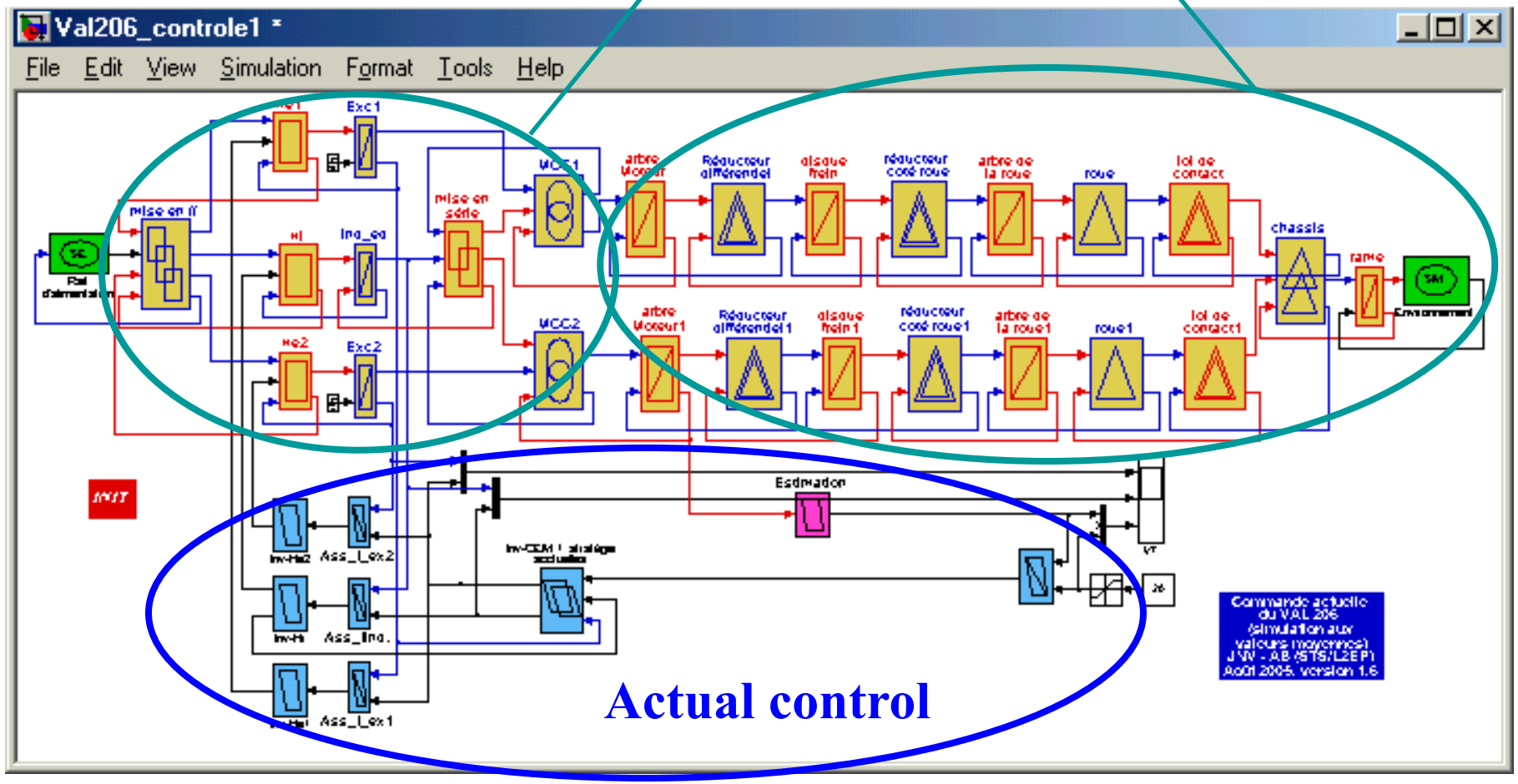
- Actual control of mechanical part -



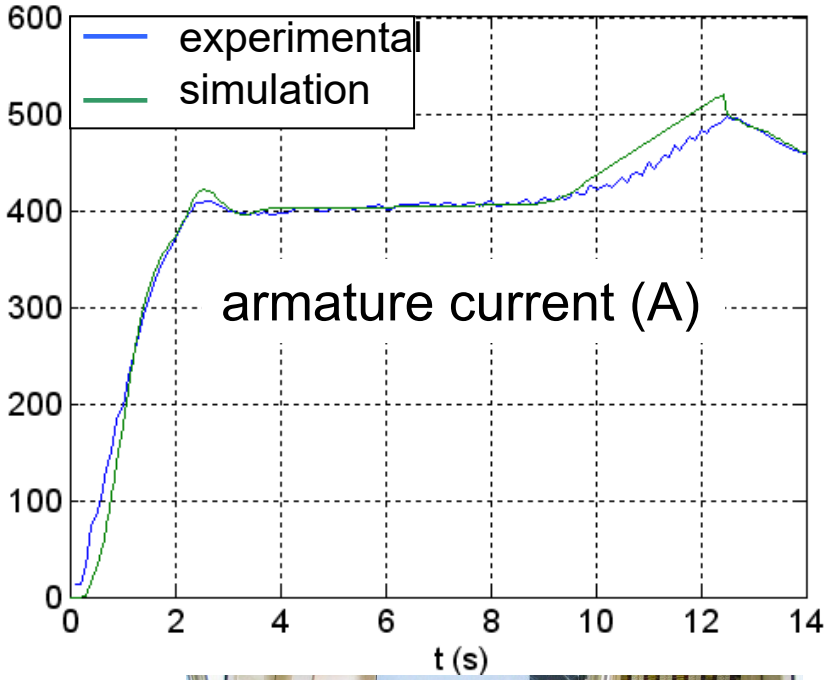
Actual control:
no local management of anti-slip

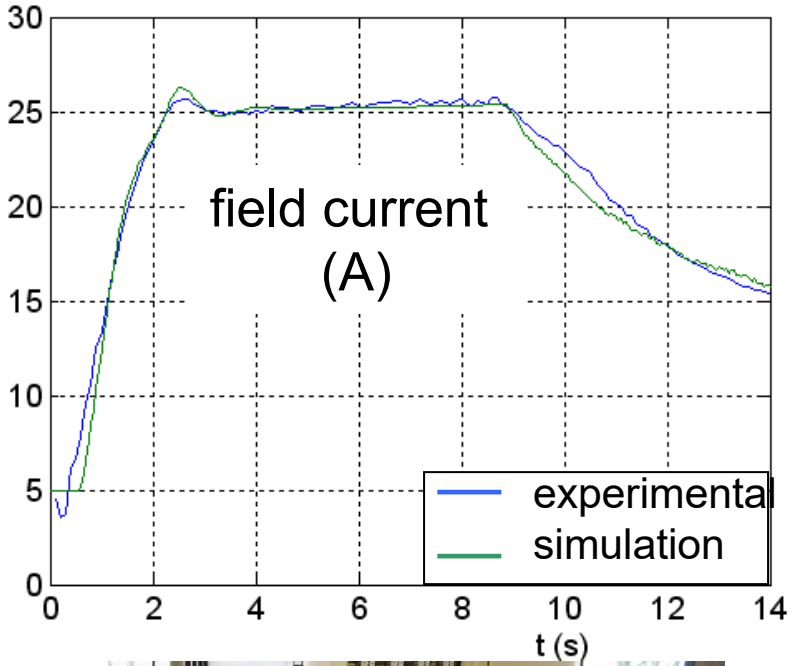
- Simulation model -

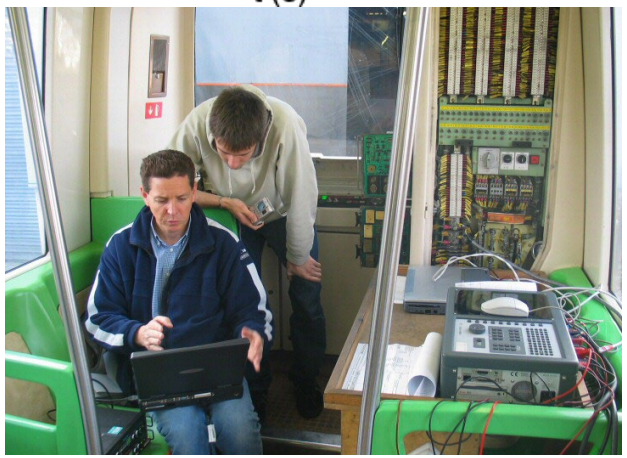
Matlab/Simulink™



- Validation model (1) -

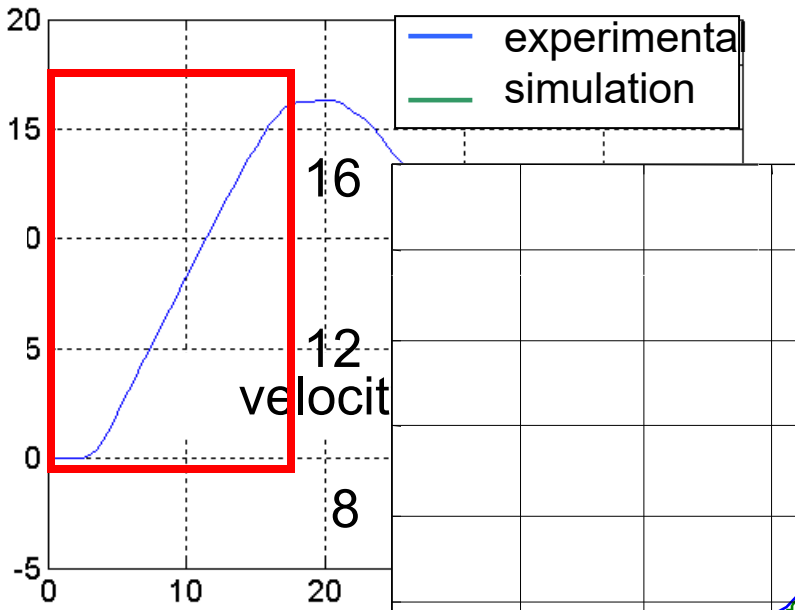


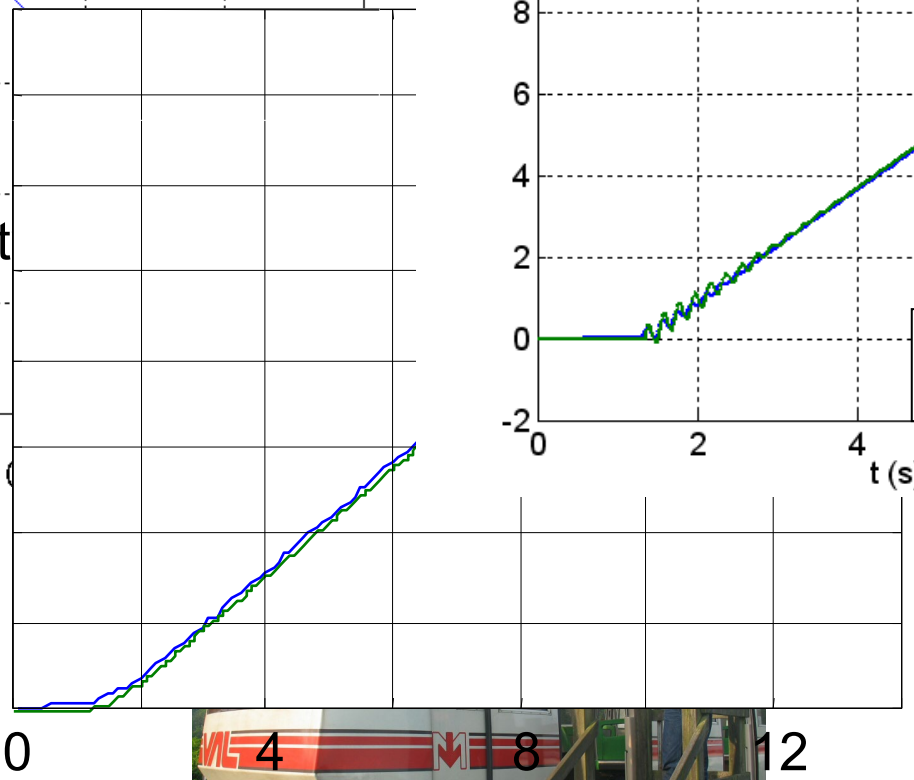




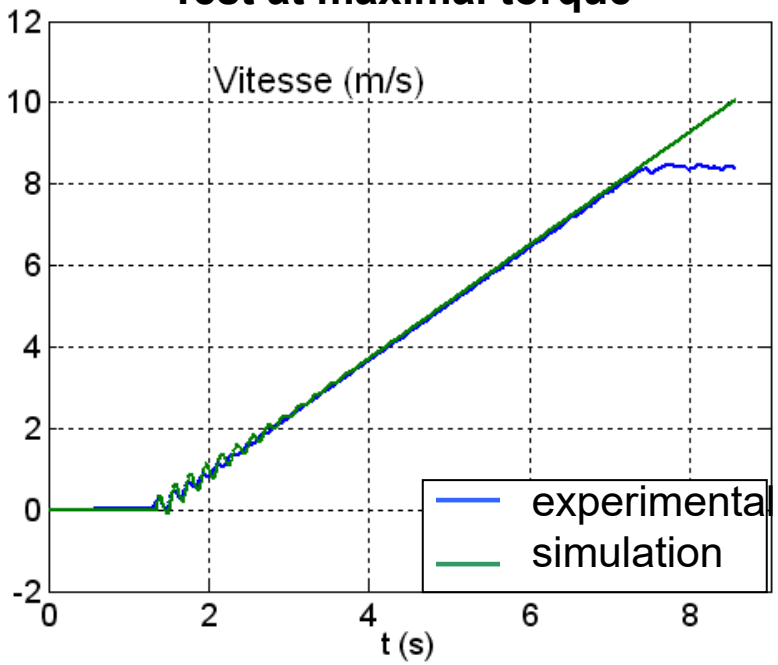
- Validation model (2) -

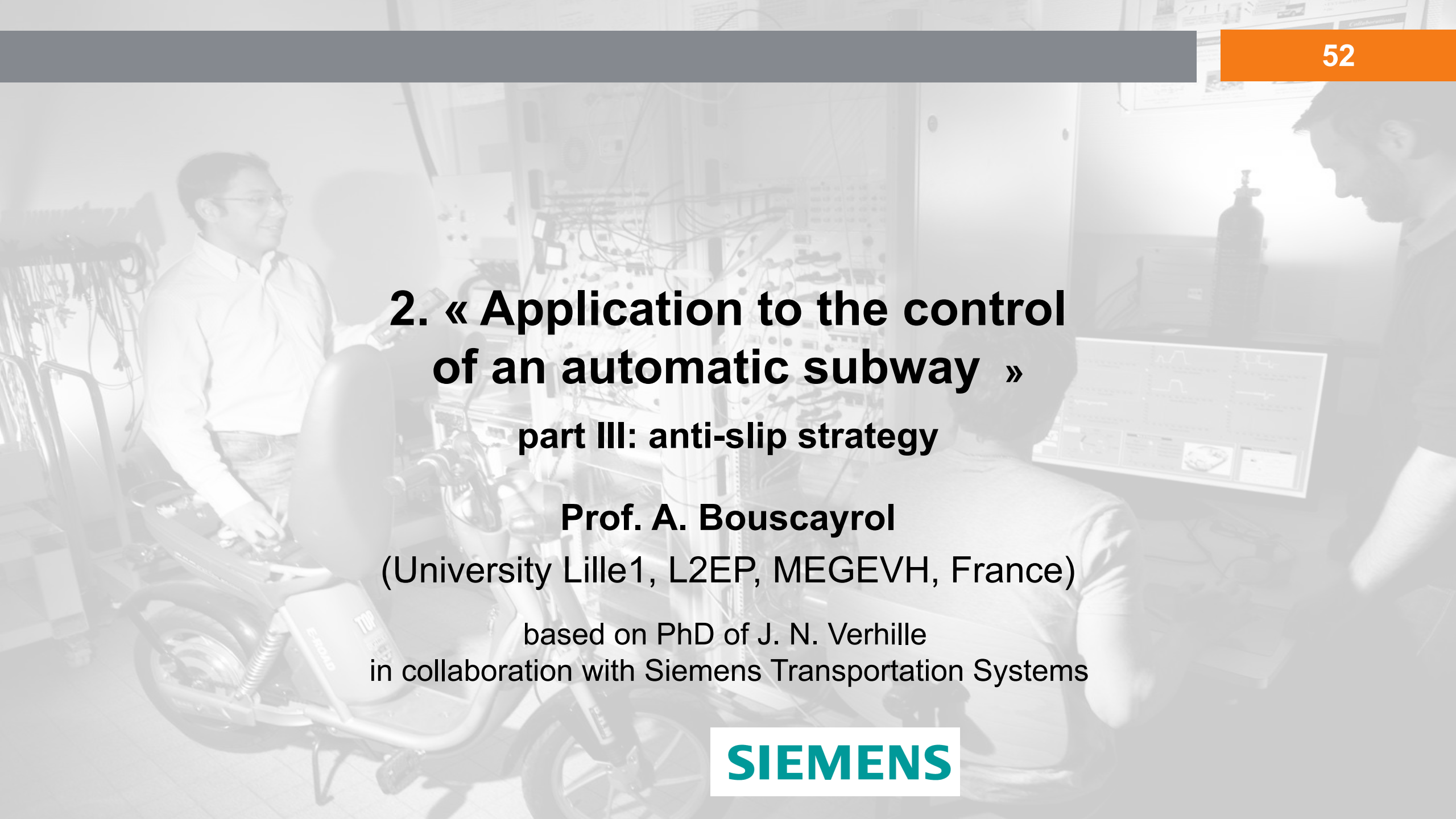
Test at normal operating





Test at maximal torque





2. « Application to the control of an automatic subway »

part III: anti-slip strategy

Prof. A. Bouscayrol

(University Lille1, L2EP, MEGEVH, France)

based on PhD of J. N. Verhille
in collaboration with Siemens Transportation Systems

SIEMENS

- VAL 206 and control -

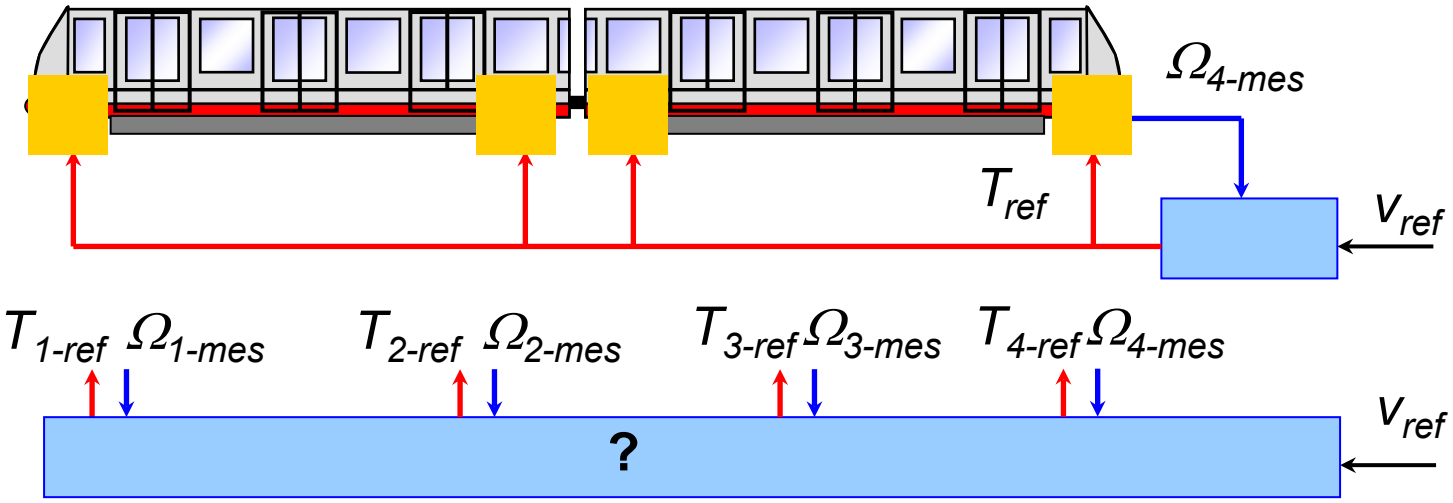
SIEMENS

VAL Automatic Subway:
Lille, Paris airport, Chicago, Taïpeh...

Actual control
VAL 206

⇨

- identical torque for **4 motors**
- global anti-slip (cancellation of torque)

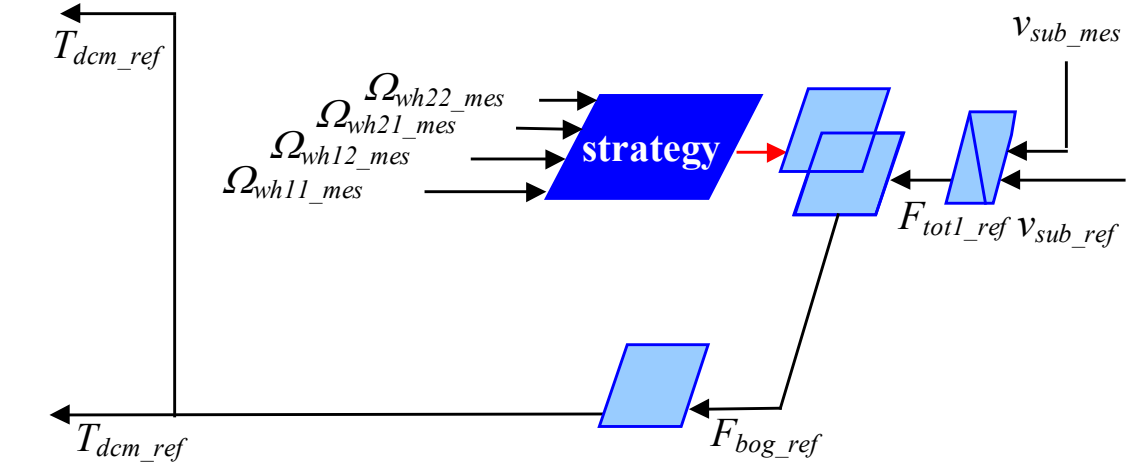


STS

Independent controls with same power structure
Performances with local anti-slip?

L2EP LILLE

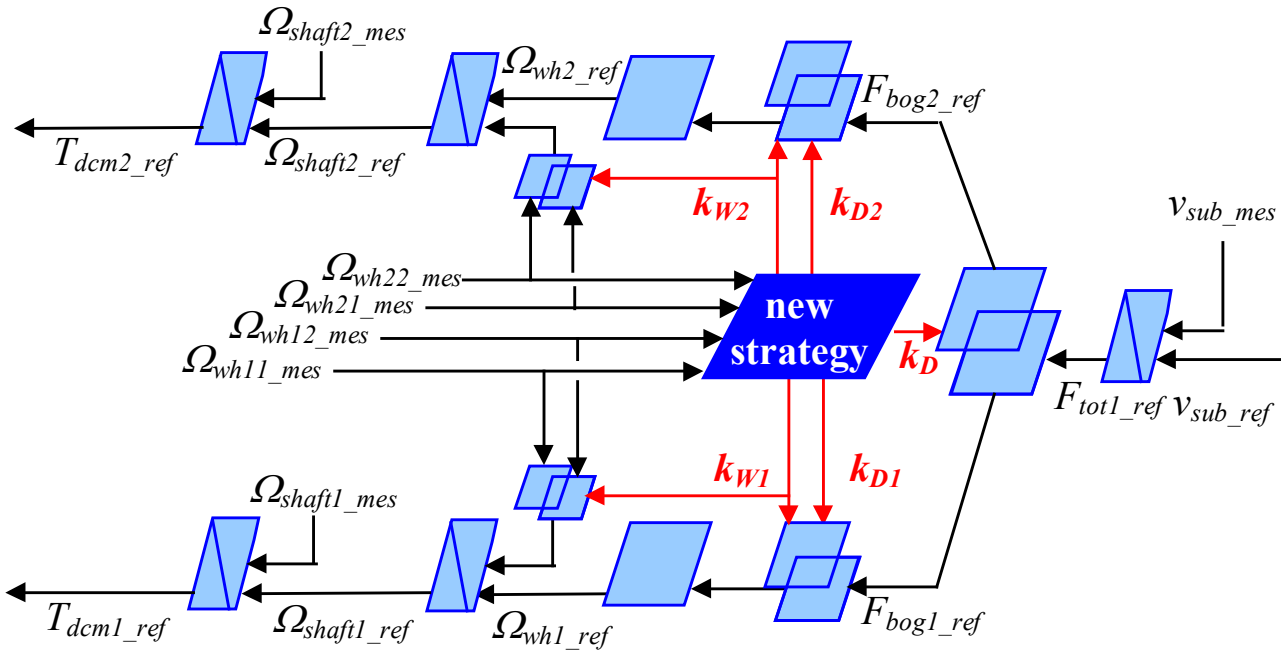
- Anti-slip control -



Actual control:
slip detection

⇩

Torque set to zero



New strategy:
slip detection

⇩

Reduction of torque of the slipping wheel

Increase of other torques

- Philosophy of the strategy -

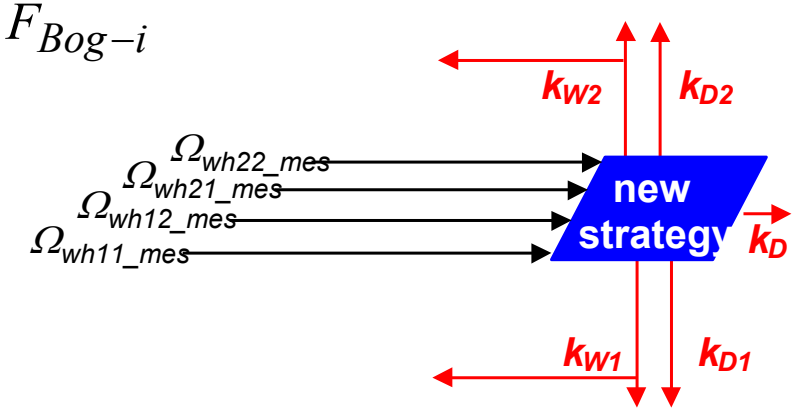
Normal operation:
equal distribution of traction forces

$$k_D = k_{D1} = k_{D2} = k_{W1} = k_{W2} = \frac{1}{2}$$

$$\Downarrow$$

$$F_{Bog1} = F_{Bog2} = F_{Bog3} = F_{Bog4} = \frac{1}{4} F_{tot}$$

$$F_{tot} = \sum F_{Bog-i}$$



Slipping on bogie 1:
cancelation of F_{bog1} and new distribution of other forces

$$\begin{cases} k_D = \frac{1}{2} \\ k_{D2} = k_{W2} = 1 \\ k_{D1} = k_{W1} = 0 \end{cases}$$

$$\Downarrow$$

$$\begin{cases} F_{Bog1} = 0 \\ F_{Bog2} = F_{Bog3} = F_{Bog4} = \frac{1}{3} F_{tot} \end{cases}$$

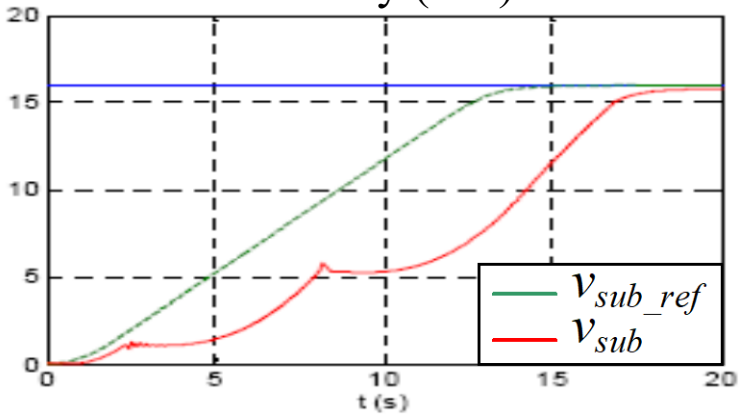
$$F_{tot} = \sum F_{Bog-i}$$

- Simulation results -

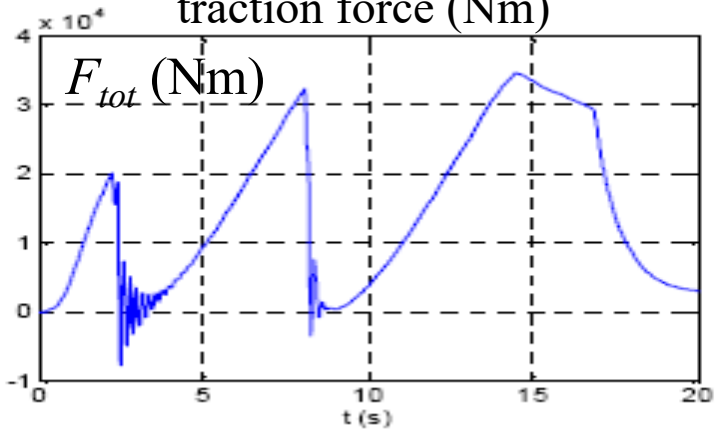
Loss of adhesion of wheel no. 1

actual control

velocity (m/s)

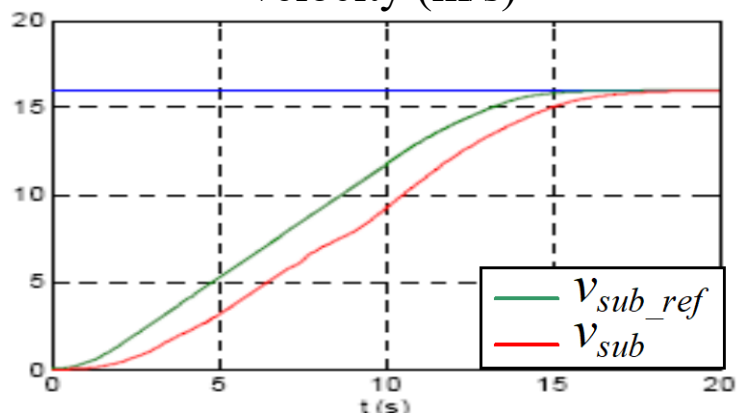


traction force (Nm)

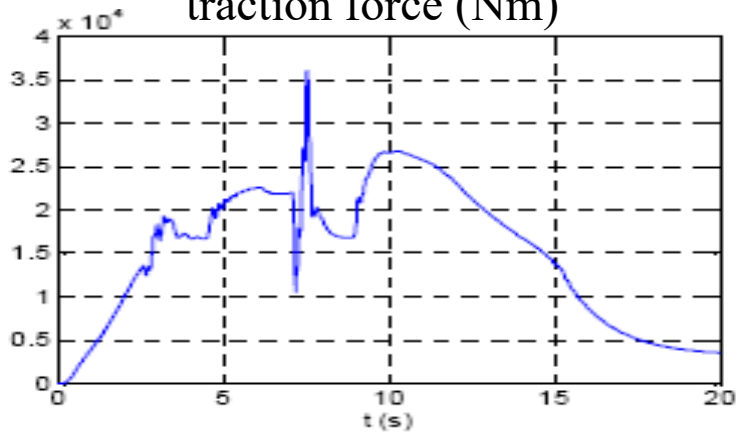


New anti-slip strategy

velocity (m/s)



traction force (Nm)



Conclusion

Inversion based control = inversion of EMR

inversion of dynamic causal models

a unique Maximum Control Schemes

Strategy Level = inversion of a global static model

global model and local dynamic models must have same I/O

different strategies are possible

Efficient energy management of EVs and HEVs

Well-defined local controls of subsystems

coherent articulation between control levels

efficient strategy level

Selected references

J. N. Verhille, A. Bouscayrol, P. J. Barre, J. P. Hautier, “Validation of anti-slip control for a subway traction system using Hardware-In-the-Loop simulation”, **IEEE-VPPC’07**, Arlington (USA), September 2007 (common paper L2EP Lille and Siemens Transportation System)

L. Horrein, V. Derache, A. Bouscayrol, J. N.Verhille, P. Delarue, “Different models of the traction system of an automatic subway”, **ElectrIMAC’11**, Cergy Pointoise (France), June 2011 (common paper of L2EP and Siemens Transportation Systems).

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Thanks for your attention!

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Arts et Métiers Sciences et Technologies

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