« EMR AND INVERSION-BASED CONTROL OF AN ELECTRIC VEHICLE »

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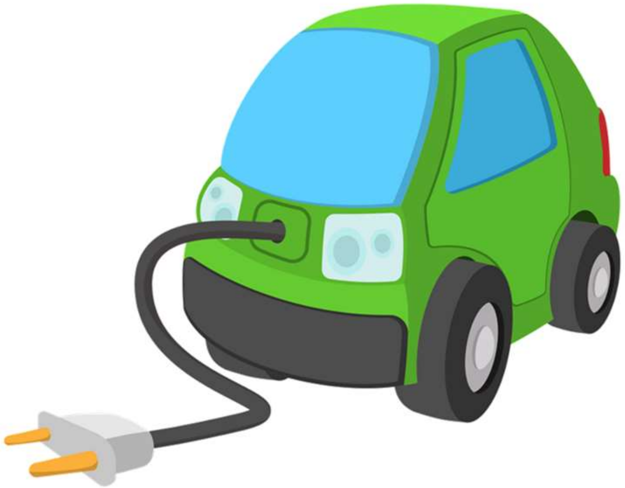
UdS Université de Sherbrooke
Instituto Superior de Engenharia Politécnico de Coimbra
inesc 30 anos · coimbra
L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille
Université de Lille

1 **Studied EV**

2 **EMR of the studied EV**

3 **Inversion-based control of the EV**



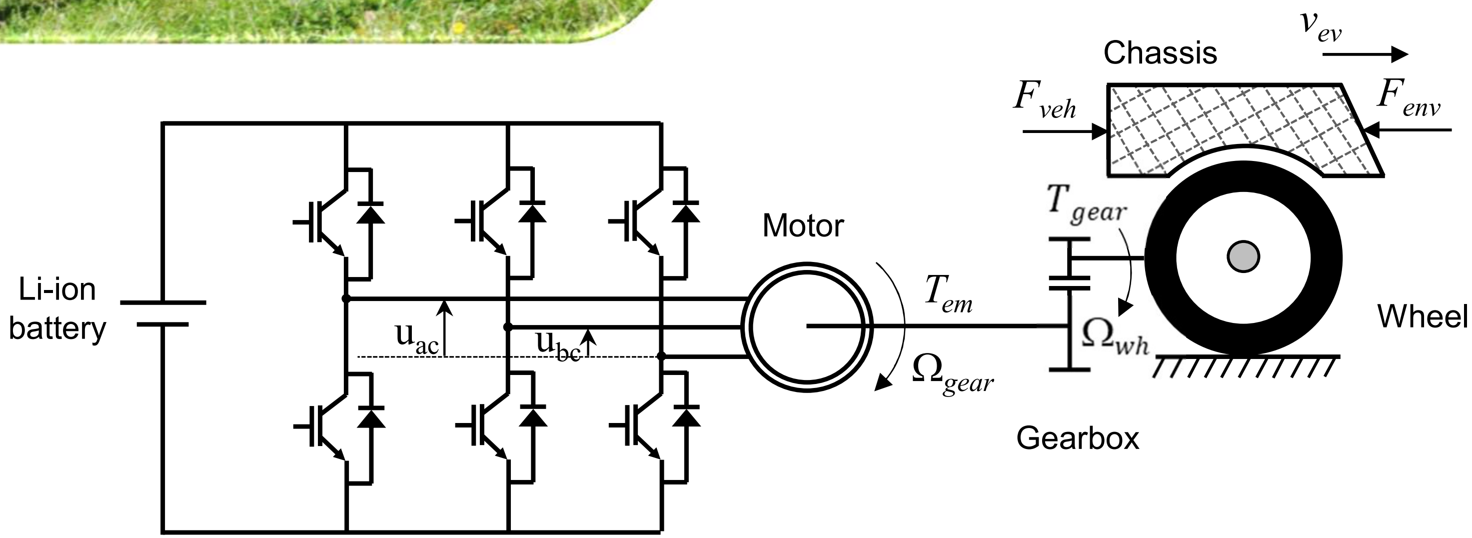
« 1. STUDIED EV »

UNIVERSITÉ DE SHERBROOKE | Voir au futur

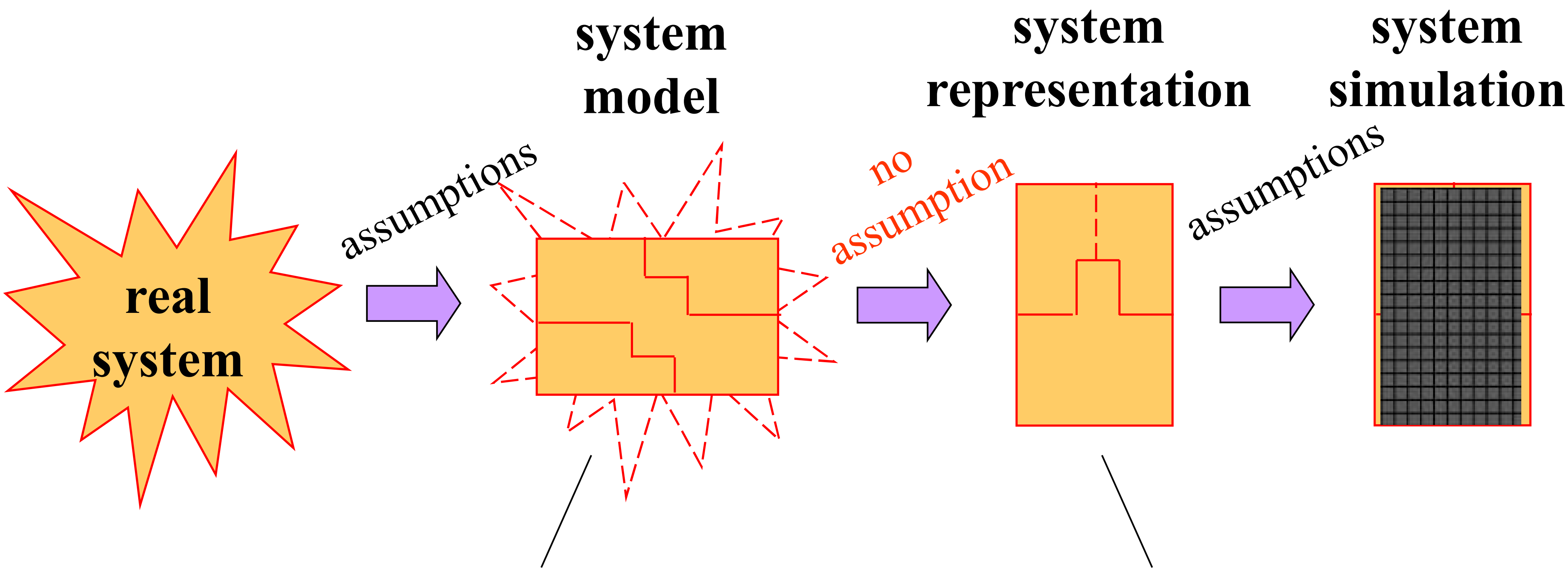
e-TESC Lab

electric - Transport, Energy Storage and Conversion

e-Commander specifications (off-road vehicle)
• 8,5 kW induction motor • 48V 110Ah Lead-acid battery • 871 kg (curb weight) • Maximum speed: 45 km/h



« 2. EMR OF THE STUDIED EV »



Limitation to main phenomena in function of the objective

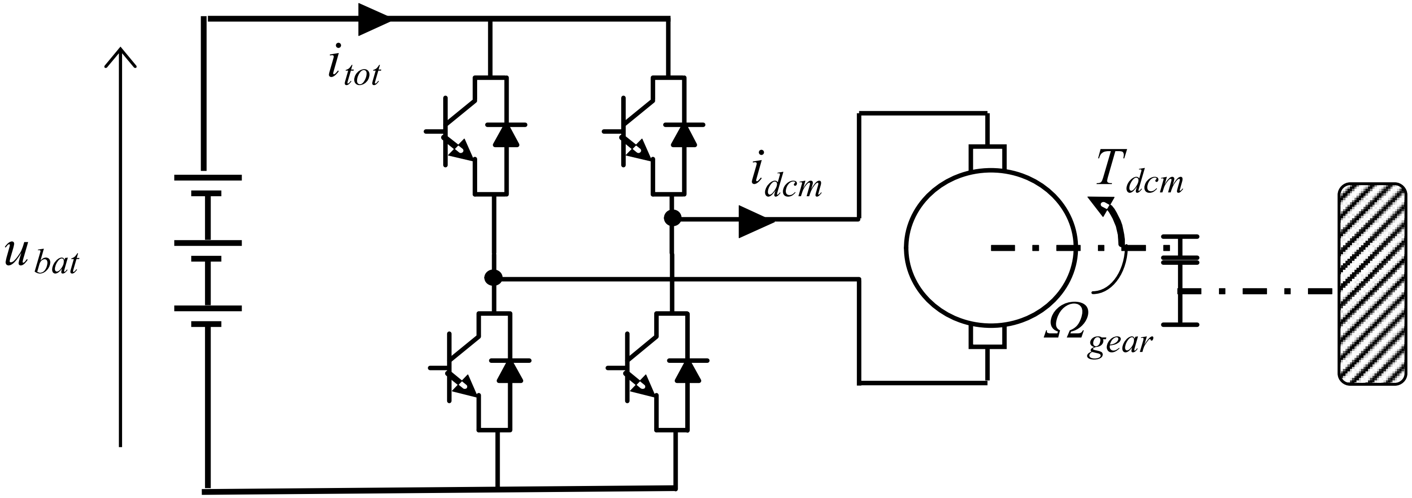
Organization of the model to highlight some properties

- Simplified EV-

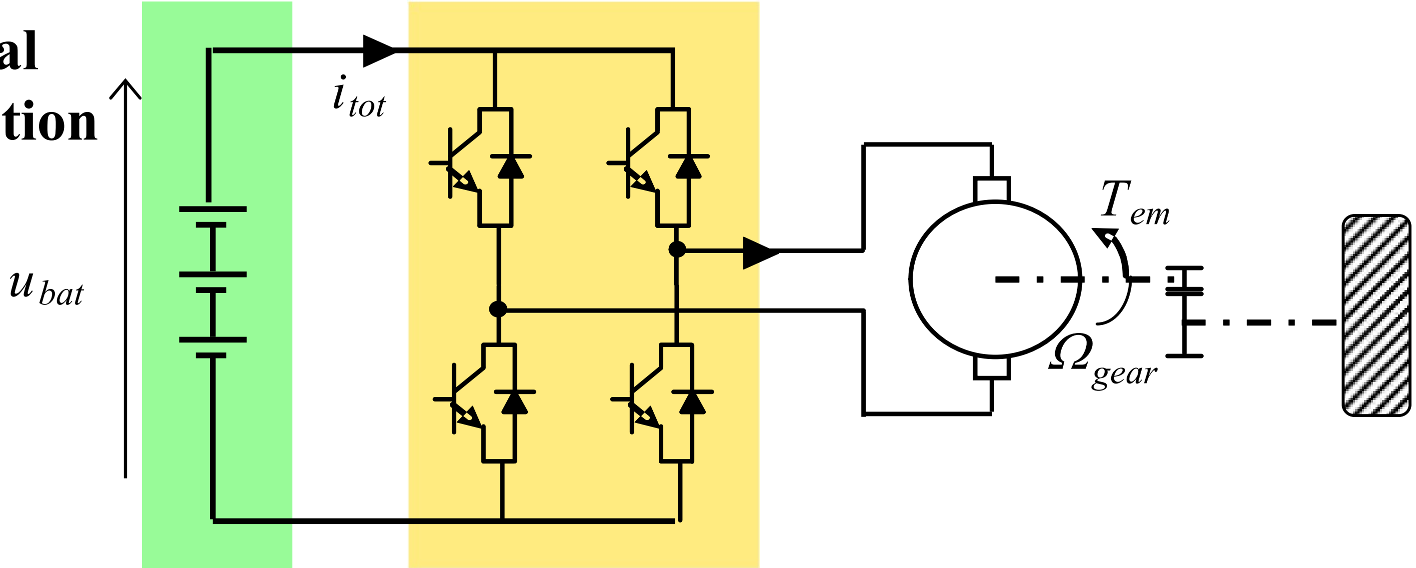
Objective:
control of the traction system in straight road

Simplifications:

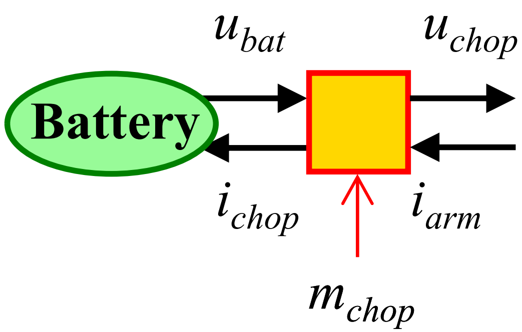
- a permanent magnet DC machine is considered in the first step
- the PE converter is a H-bridge (chopper)
- an equivalent wheel is considered



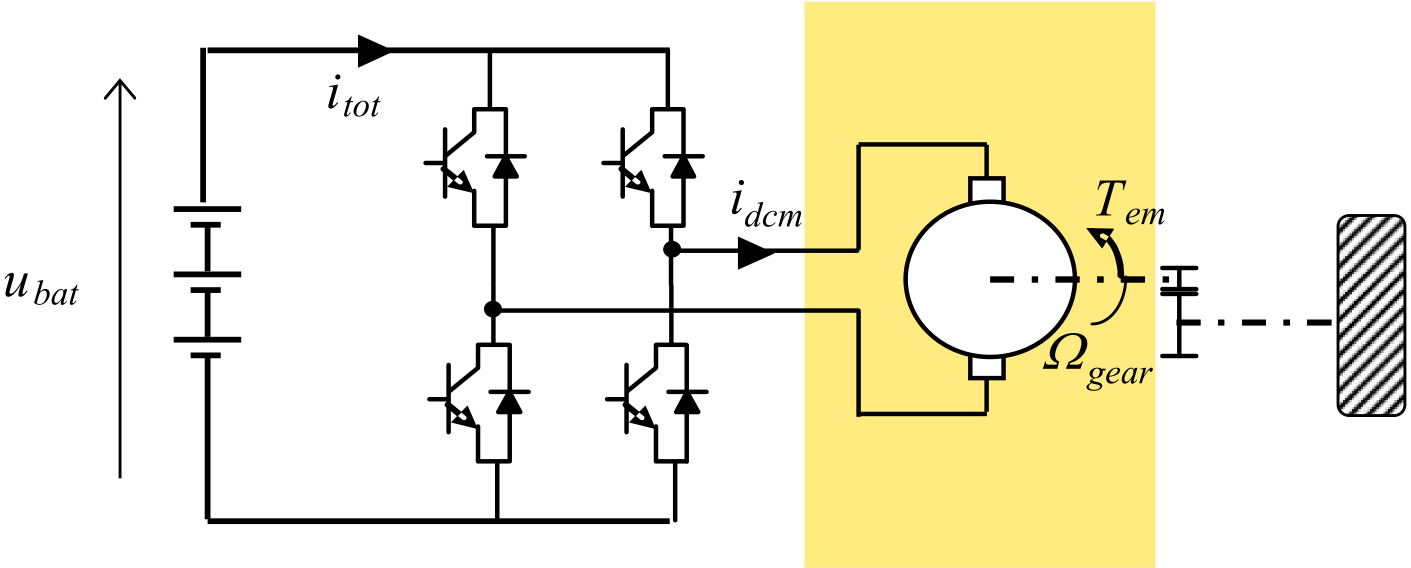
Structural Representation

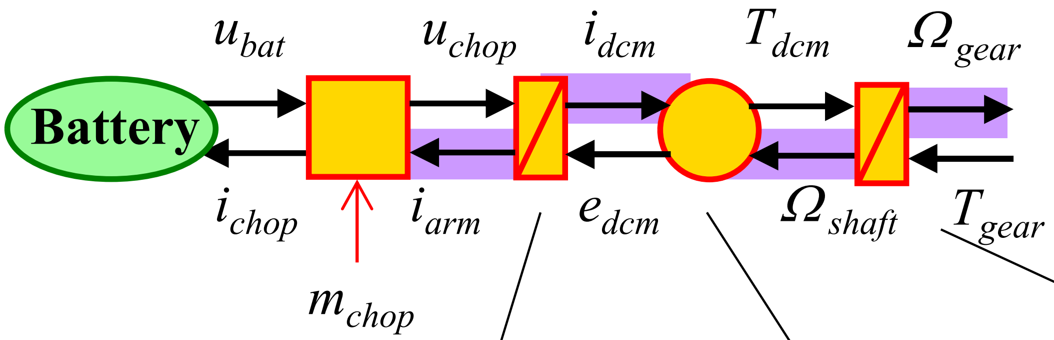


Functional Description



$$\begin{cases} \mathrm{u}_{\mathrm{chop}} = m_{\mathrm{chop}} V_{bat} \\ \mathrm{i}_{\mathrm{chop}} = m_{\mathrm{chop}}\, i_{arm} \end{cases}$$

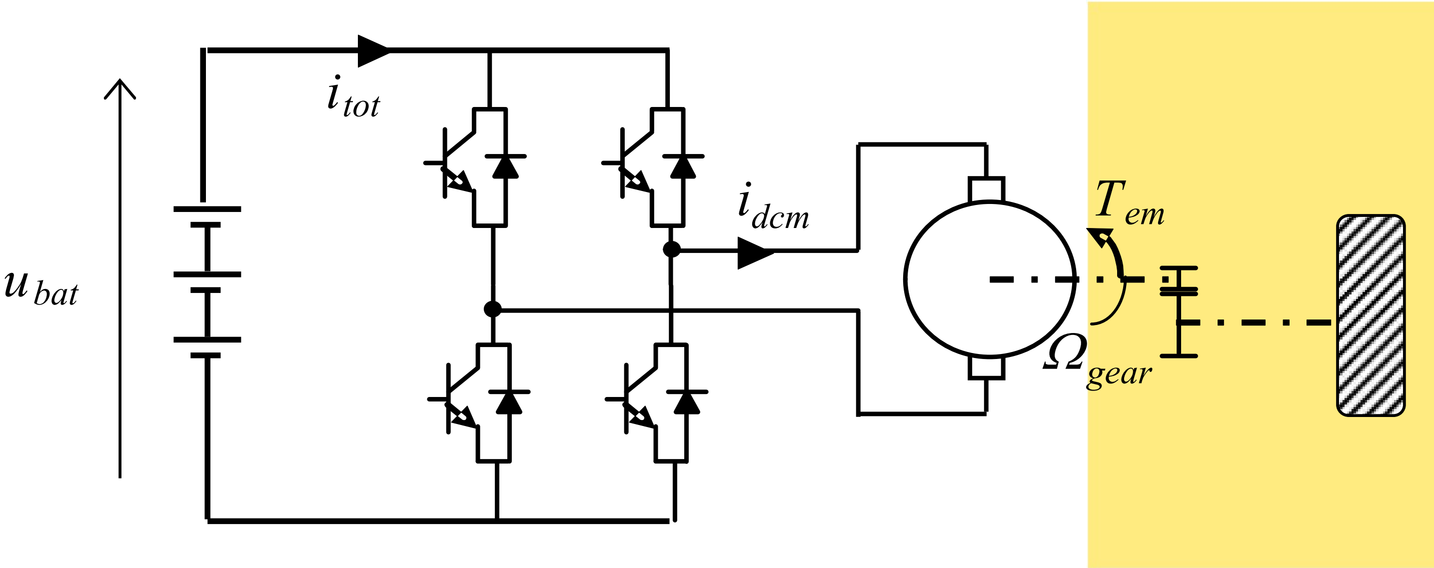


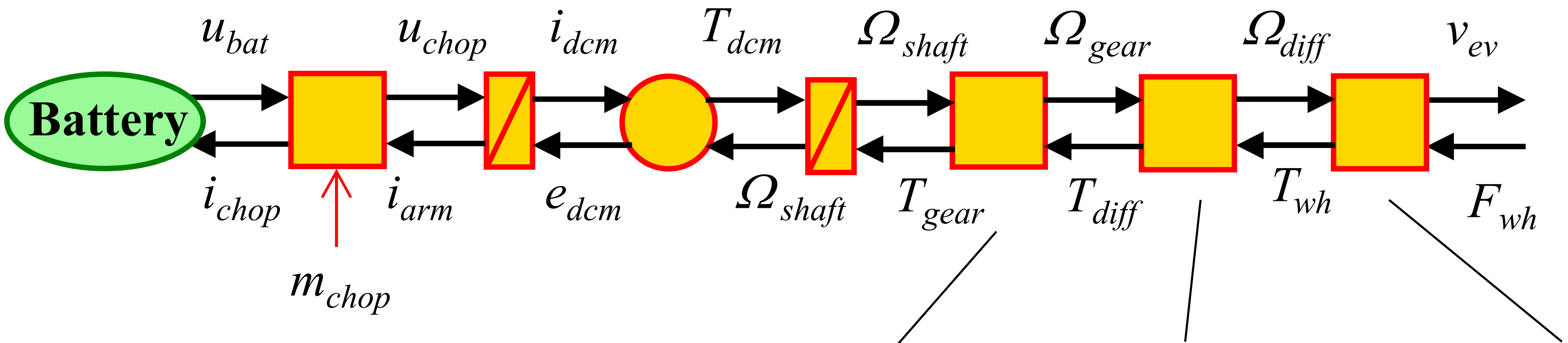


$$L_{arm}\frac{d}{dt}i_{dcm} = u_{chop} - e_{dcm} - R_{arm}i_{dcm}$$

$$\begin{cases} T_{dcm} = k_{dcm}i_{dcm} \\ e_{dcm} = k_{dcm}\Omega_{shaft} \end{cases}$$

$$J\frac{d}{dt}\Omega_{gear} = T_{dcm} - T_{gear} - f\Omega_{gear}$$

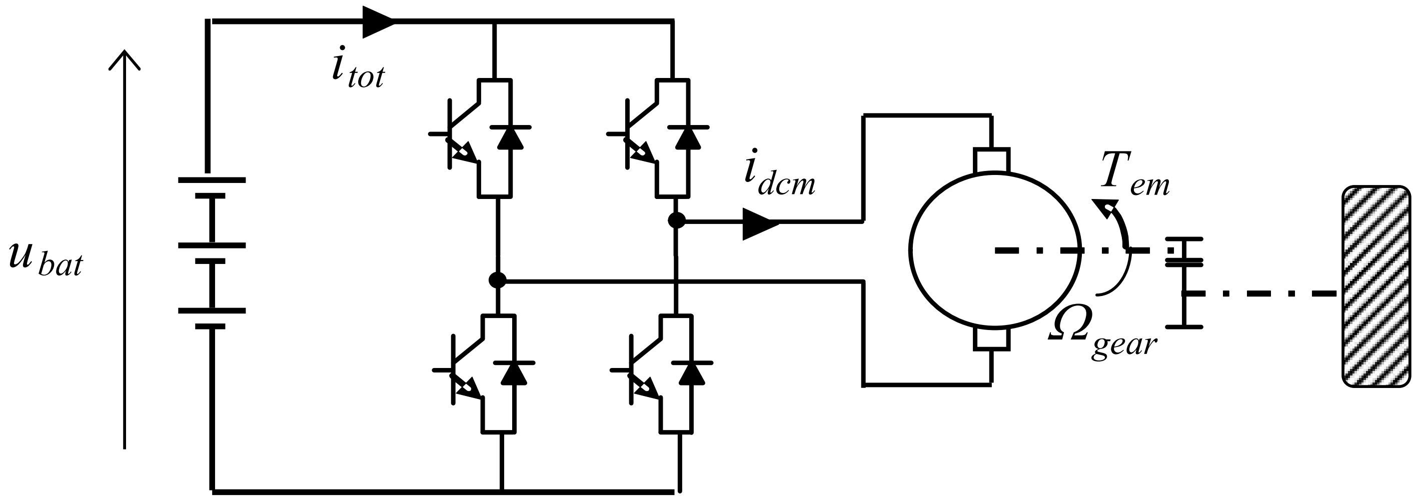


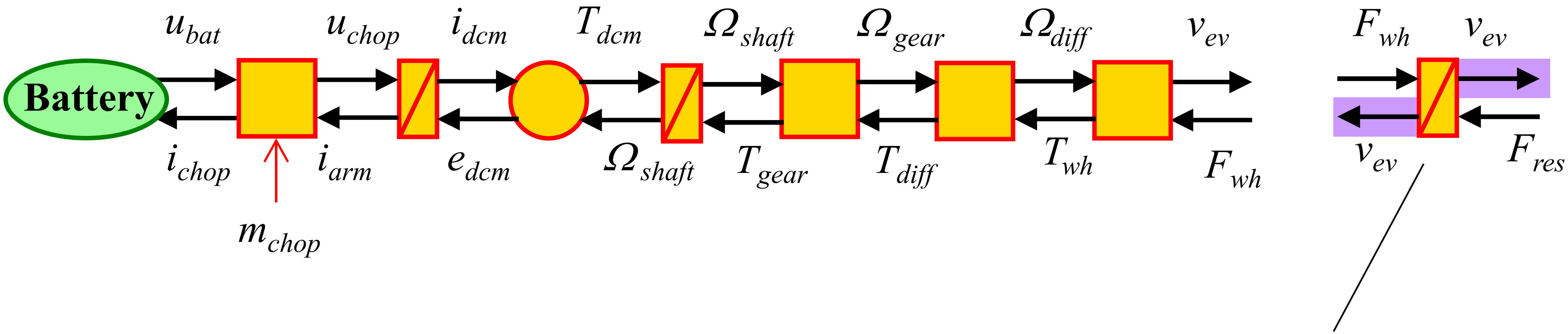


$$\begin{cases} T_{gear} = k_{gear}\, T_{diff} \\ \Omega_{gear} = k_{gear}\, \Omega_{shaft} \end{cases}$$

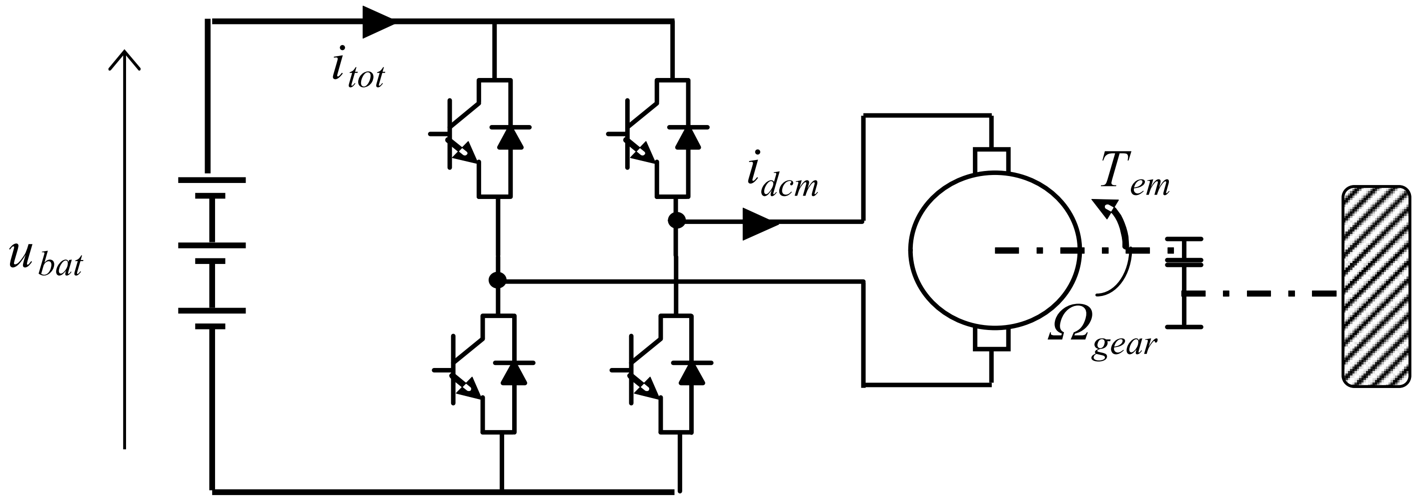
$$\begin{cases} T_{diff} = k_{diff}\, T_{wh} \\ \Omega_{diff} = k_{diff}\, \Omega_{gear} \end{cases}$$

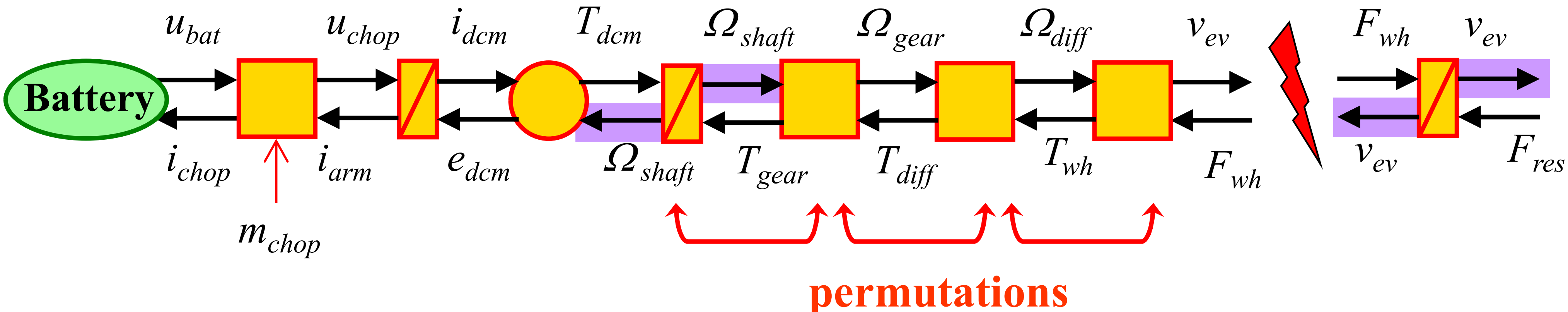
$$\begin{cases} T_{wh} = R_{wh} F_{wh} \\ v_{ev} = R_{wh} \Omega_{diff} \end{cases}$$





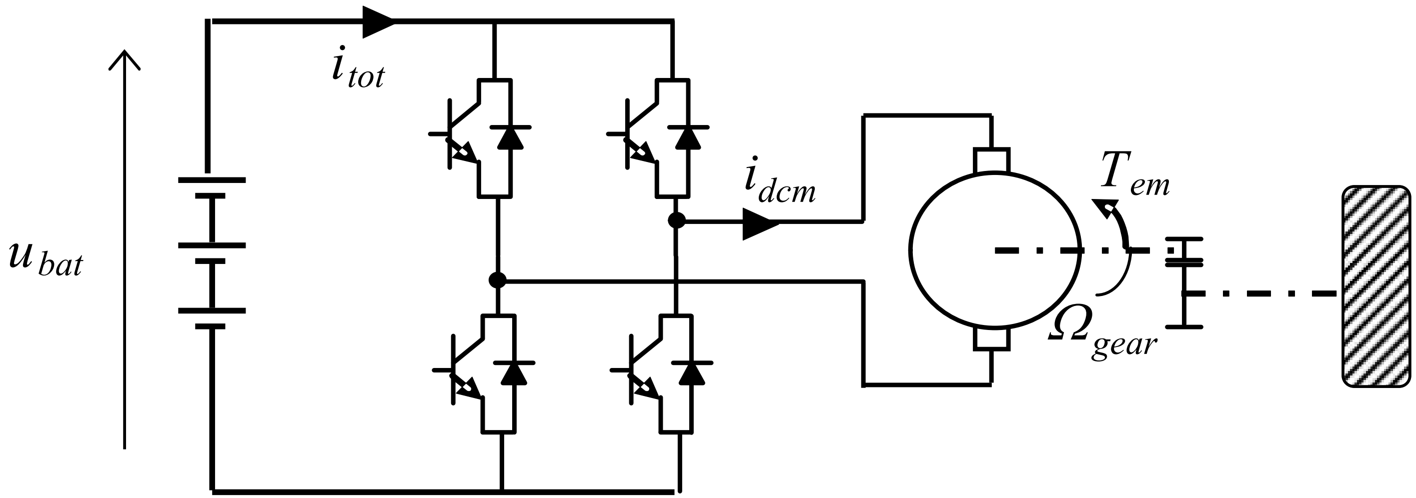
$$M \frac{d}{dt} v_{ev} = F_{tot} - F_{res}$$

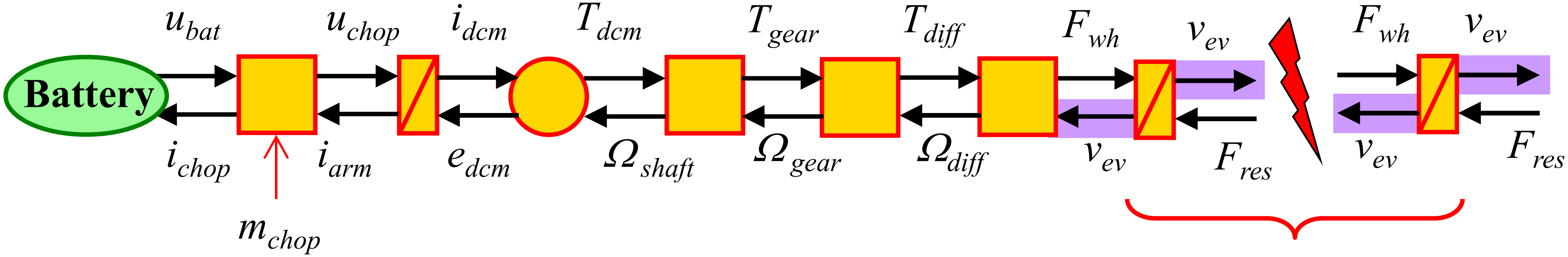




Conflict of association:

Ω_{shaft} and v_{ev} state variables, but $v_{ev} = R_{wh} k_{diff} k_{gear} \Omega_{shaft}$



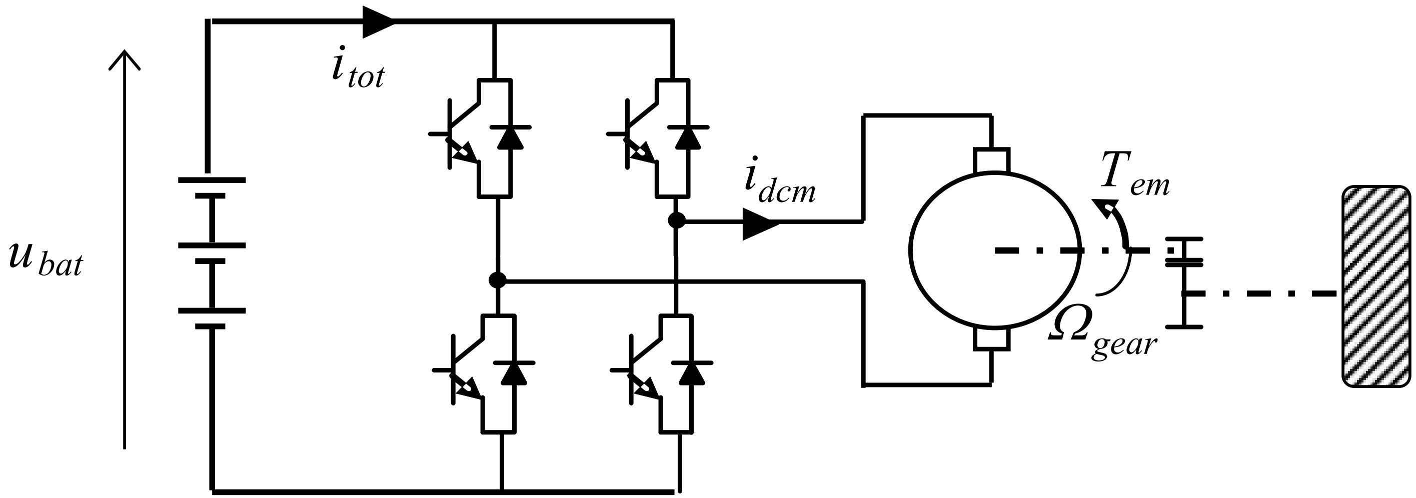


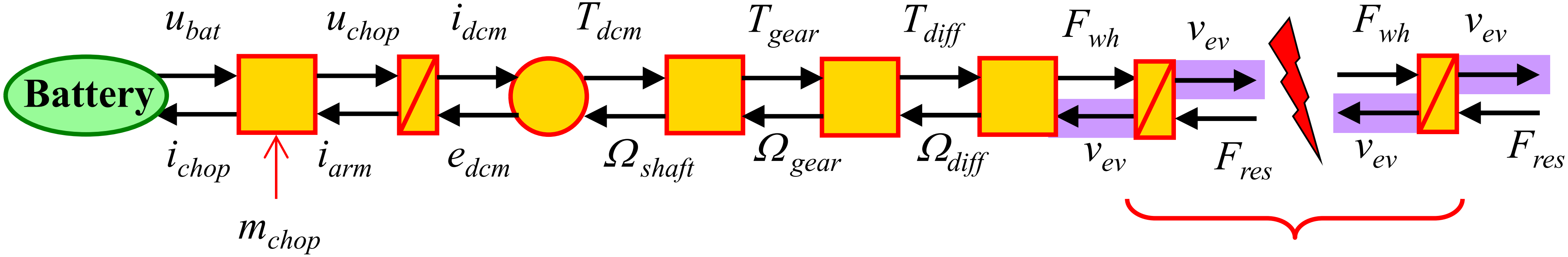
merging

$$M_{eq} \frac{d}{dt} v_{ev} = F_{tot} - F_{res}$$

Conflict of association:

a unique state variable is required!





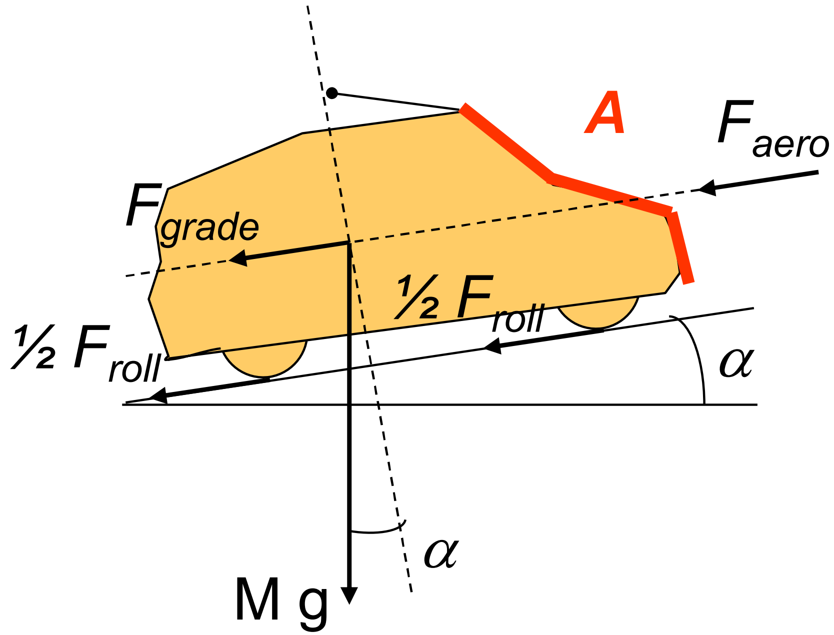
merging

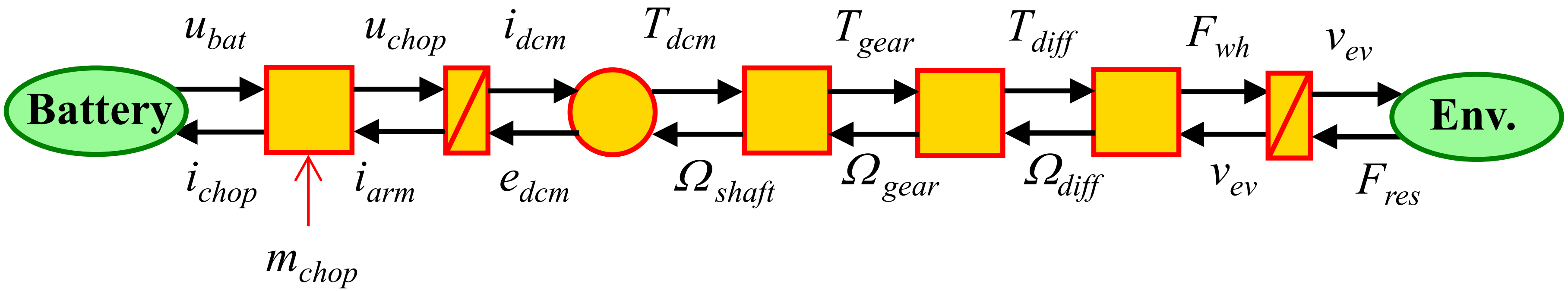
$$M_{eq}\frac{d}{dt}v_{ev} = F_{tot} - F_{res}$$

Conflict of association:

a unique state variable is required!

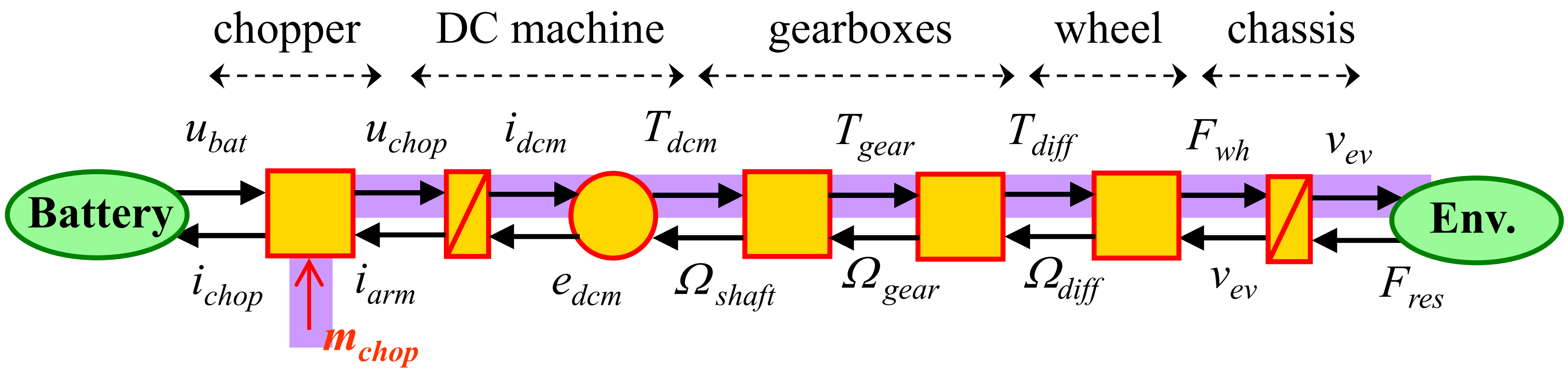
$$M_{eq} = M + \frac{J_{shaft}}{\left(k_{gear}^2 k_{diff}^2 R_{wh}^2\right)}$$





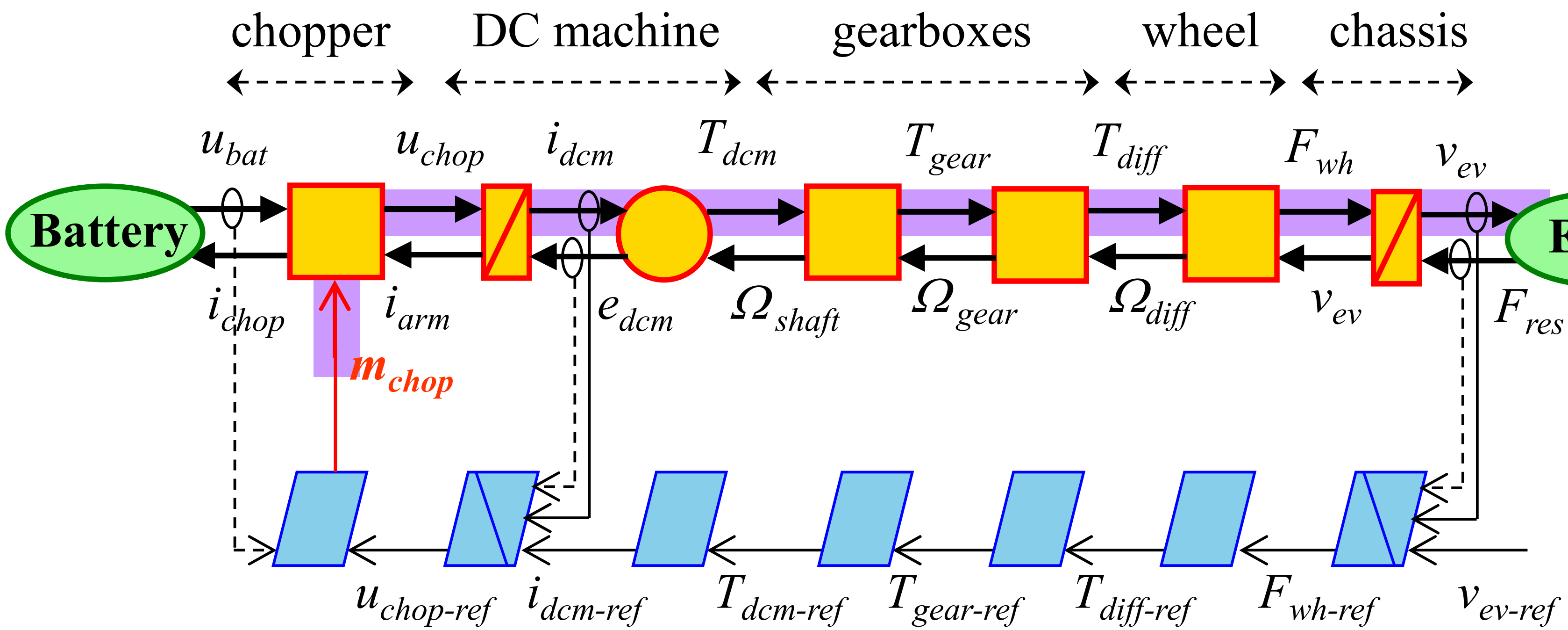
$$F_{res} = k_{roll} M g \cos\alpha + \frac{1}{2}\rho_{air} A C_x v_{ev}^2 + M g \sin\alpha$$

«3. INVERSION-BASED CONTROL OF THE STUDIED ELECTRIC VEHICLE »



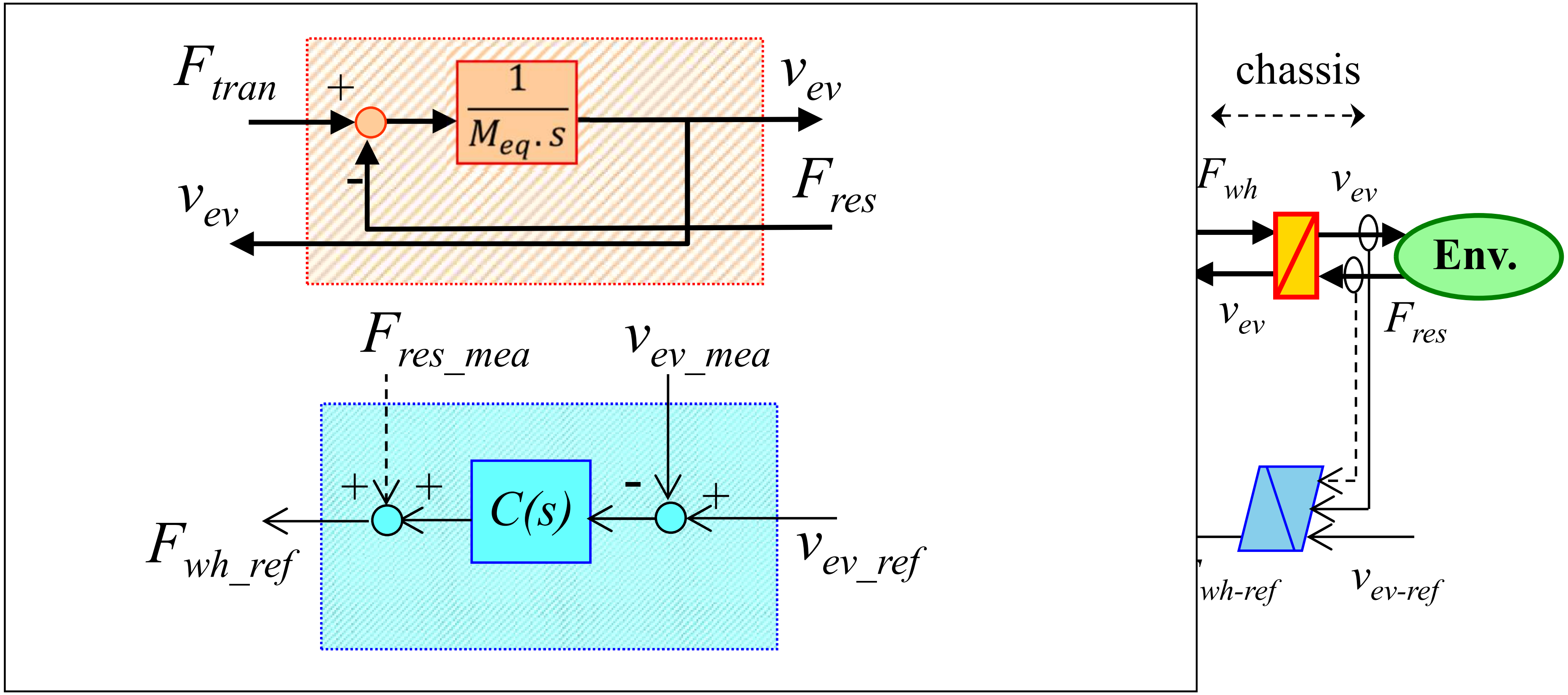
Objective: control the EV velocity

Tuning variable: modulation ratio of the DC-DC converter



Maximum Control Structure:

- inversion of each element step-by-step
- all variables are assumed measurable



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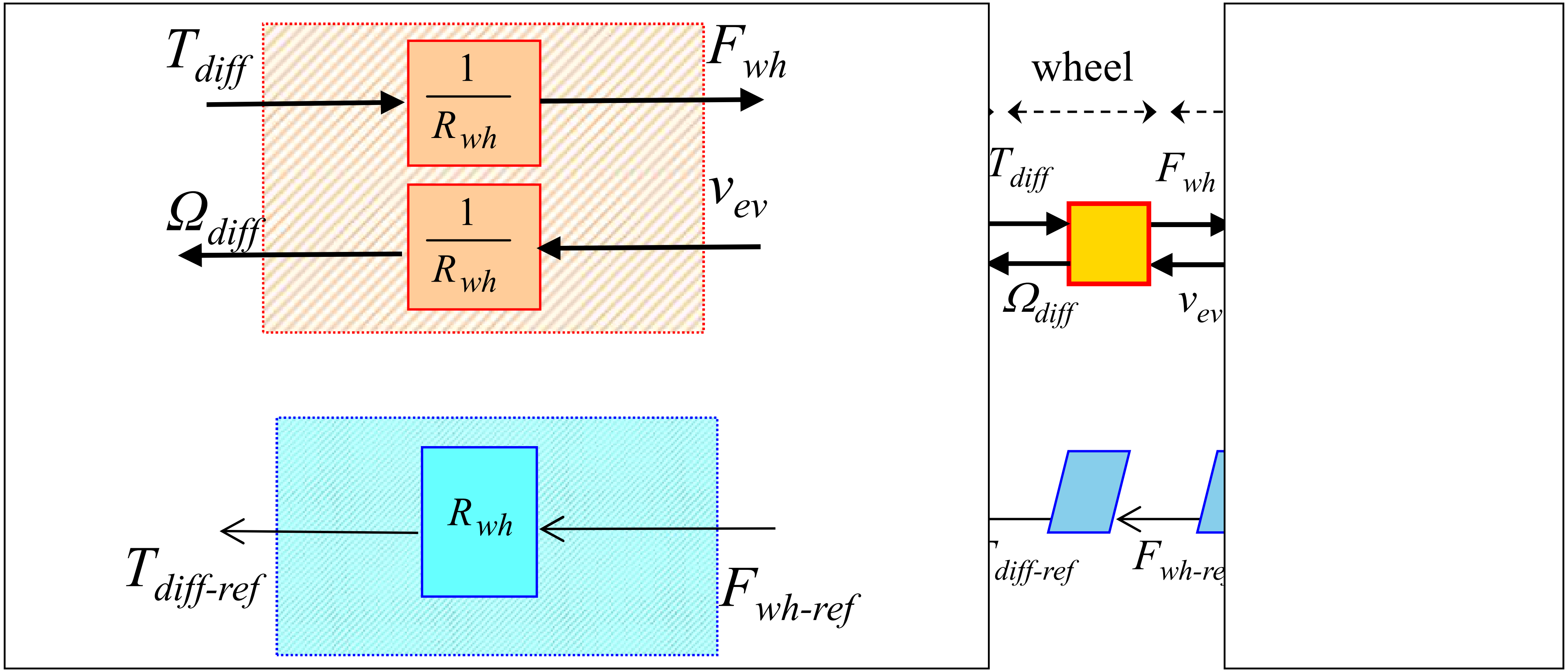

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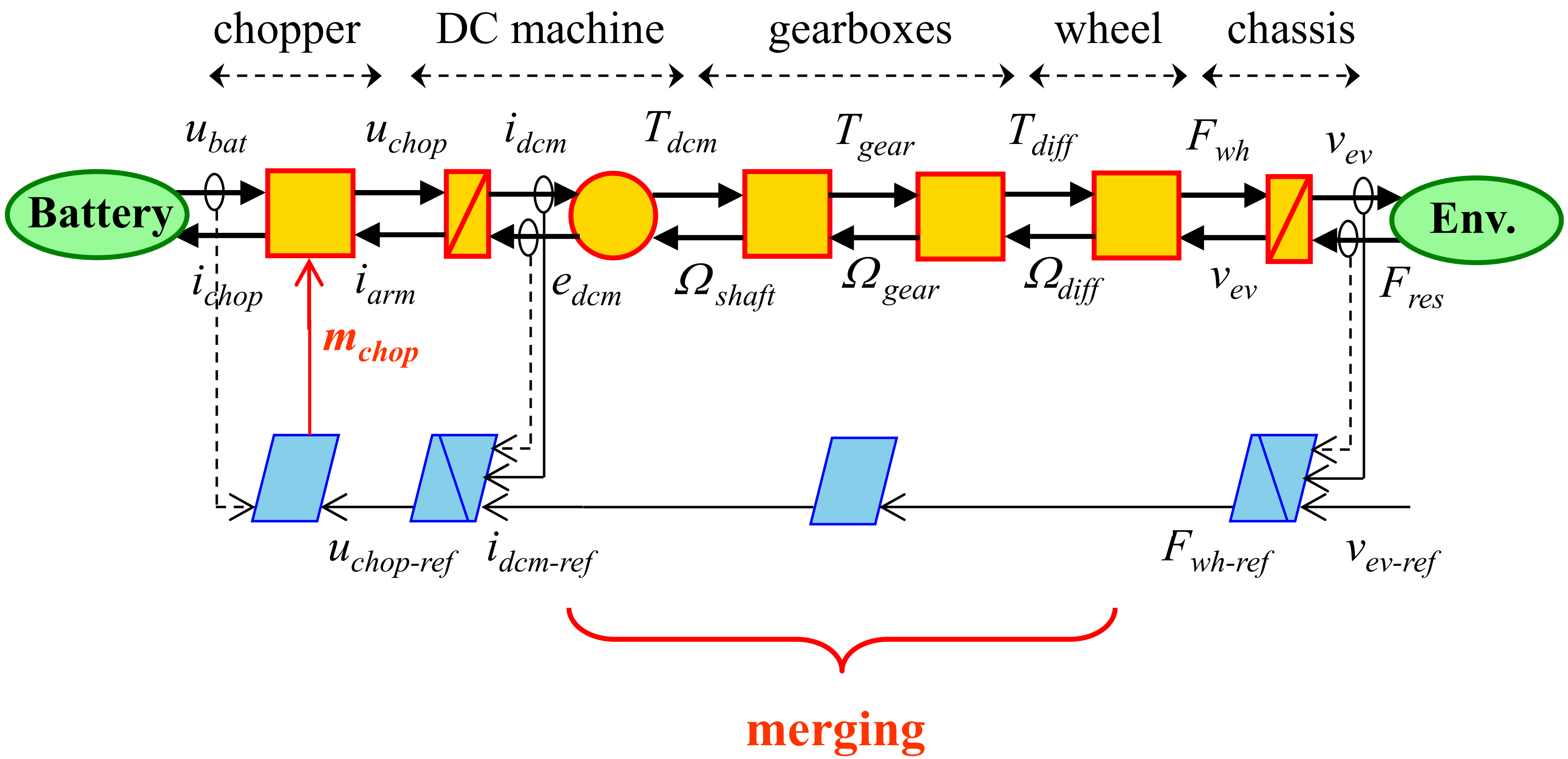
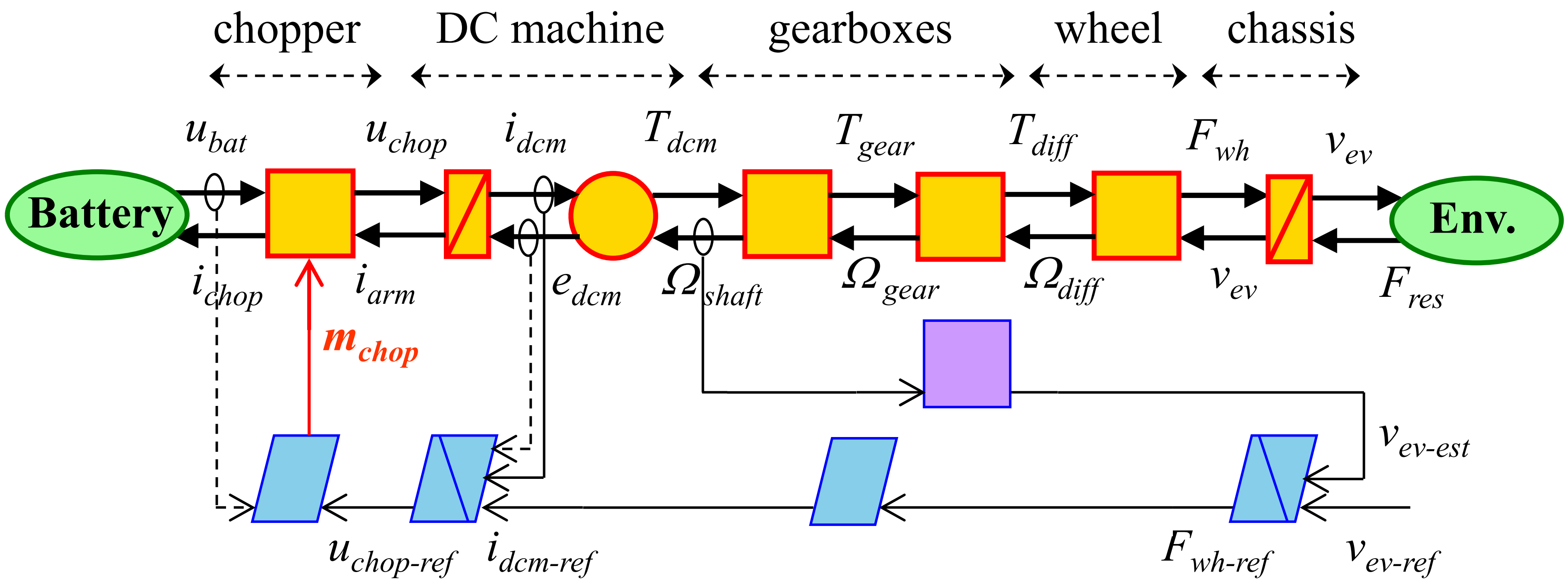


Example of simplification:

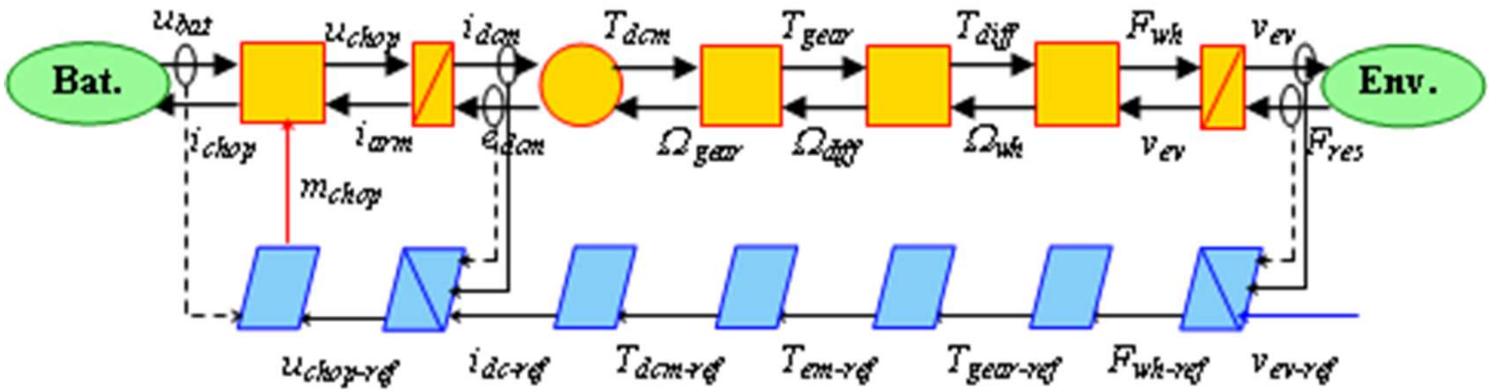
- merging of gains

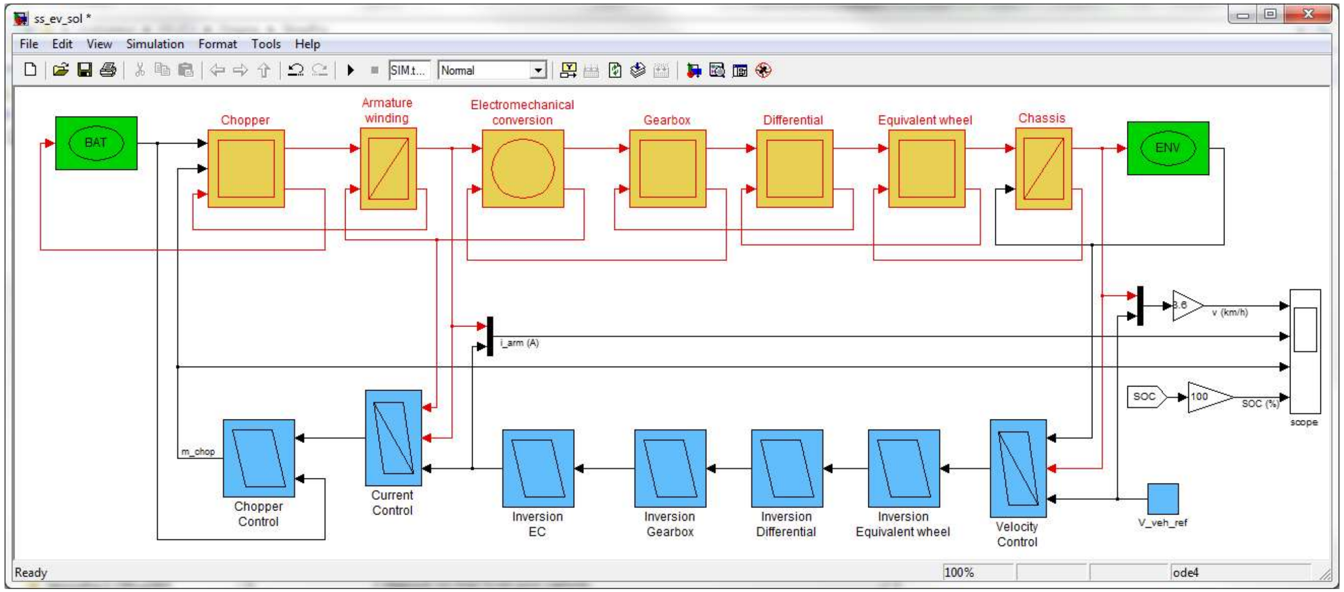
$$k_{tot} = R_{wh} \cdot {}^{1}/_{k_{diff}} \cdot {}^{1}/_{k_{gear}} \cdot {}^{1}/_{k_{dcm}}$$



Example of estimation:

- estimation of velocity





Matlab-Simulink ©, using the EMR library

EMR and Inversion-based Control of an Electric vehicle

- Implementation on the real vehicle -

Blondin, M. J.; Trovão, J. P.: "Soft-computing techniques for cruise controller tuning for an off-road electric vehicle", IET Elect. Syst. Transp., (9)4, p. 196 –205, 2019, doi: 10.1049/iet-est.2019.0008.

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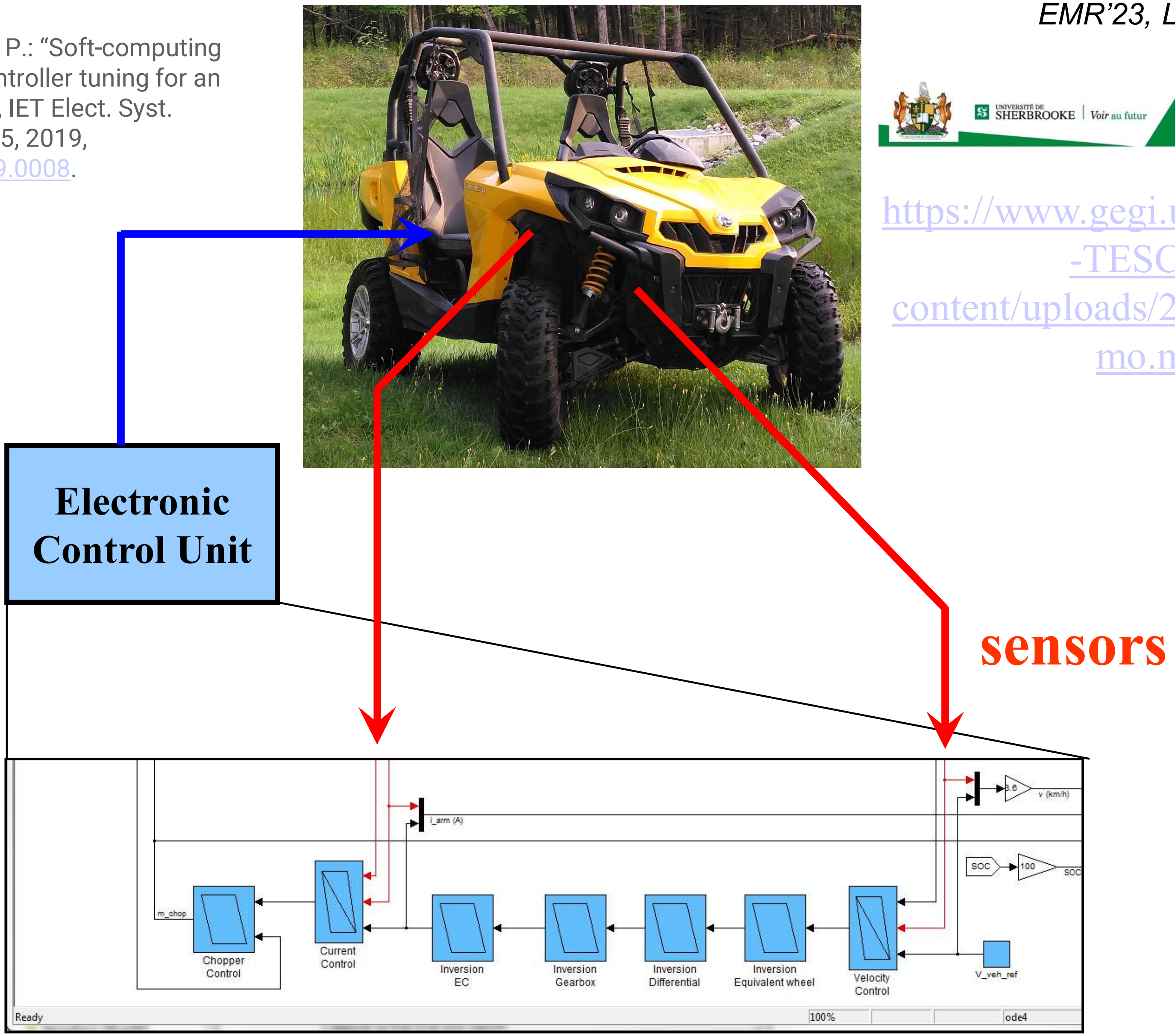

R. Gonzalez-Rubio, A. Khoumsi and J. P. Trovao, "Project-Based Learning in Engineering: Illustration by a Capstone Project of an Electric Vehicle," *2019 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Hanoi, Vietnam, 2019, pp. 1-7. doi: 10.1109/VPPC46532.2019.8952566

« Summary »

- Summary-

❖ EMR: powerful approach for modeling and control of different systems

❖ Electric Vehicles (EVs), driven by:

- DC motor(s)
- Induction motor(s)
- PM sychronous motor(s)
- etc.

❖ EMR for EVs:

- In the 1st step: Simplified model using DC motor with chopper (*for IM, PMSM: the same principles are applied*)
- EMR: construction of elements step-by-step …
- Inversion-based control
- Simulation: in Matlab/Simulink using EMR library

« Biographies and References »

- Authors -

Prof. João TROVÃO, University of Sherbrooke, e-TESC Lab.
IPC-ISEC and INESC Coimbra. Chair of the IEEE-VPPC 2018
Ph.D. in Electrical Engineering at University of Coimbra (2013)
Research topics: electric vehicles, hybridized energy storage systems, energy management and rotating electrical machines.

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Head of the Master "Automatic control & Electrical Systems"
Coordinator of the CUMIN interdisciplinary programme
Chair of the steering committee of IEEE-VPP Ccnference
PhD in Electrical Engineering at University of Toulouse (1995)
Research topics: EMR formalism, HIL testing, control & EV-HEVs

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- References -

[Bouscayrol 2012] A. Bouscayrol, J. P. Hautier, B. Lemaire-Semail, "Graphic Formalisms for the Control of Multi-Physical Energetic Systems", Systemic Design Methodologies for Electrical Energy, tome 1, Analysis, Synthesis and Management, Chapter 3, ISTE Willey editions, October 2012, ISBN: 9781848213883

[Bouscayrol 2023] A. Bouscayrol, B. Lemaire-Semail, "Energetic Macroscopic Representation and Inversion-Based Control ", Encyclopedia of electrical and electronic power engineering, Vol. 3, pp 365-375, Elesevier, DOI : 10.1016/B978-0-12-821204-2.00117-3, ISBN : 978-0-12-823211-8, 2023

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[Nguyen 2020] C. T. P. Nguyen, J. P. F. Trovao, B. -H. Nguyen and M. C. Ta, "Powertrain Analysis of an All-Wheel-Drive Off-Road Electric Vehicle," 2019 IEEE Vehicle Power and Propulsion Conference (VPPC), Hanoi, Vietnam, 2019, pp. 1-6, doi: 10.1109/VPPC46532.2019.8952550.

[Nguyen 2019] B. -H. Nguyen, R. German, J. P. F. Trovão and A. Bouscayrol, "Real-Time Energy Management of Battery/Supercapacitor Electric Vehicles Based on an Adaptation of Pontryagin's Minimum Principle," in IEEE Transactions on Vehicular Technology, vol. 68, no. 1, pp. 203-212, Jan. 2019, doi: 10.1109/TVT.2018.2881057.

« Appendix: EMR graphical rules »

Power source	Power system	System model	System control	Control strategy
pale green	**gold**	**violet**	**sky blue**	**blue**

Power source — pale green
- light green background RGB = (152,251,152) « pale green »
- dark green border RGB = (0,128,0) « greeen »

Power system — gold
- orange background RGB = (255,215,0) « gold »
- red border RGB = (255,0,0) « red »

System model — violet
- purple background RGB = (238,130,238) « violet »
- dark blue border RGB = (0,0,255) « blue »

System control — sky blue
- light blue background RGB = (135,206,235) « sky blue »
- dark blue border RGB = (0,0,255) « blue »

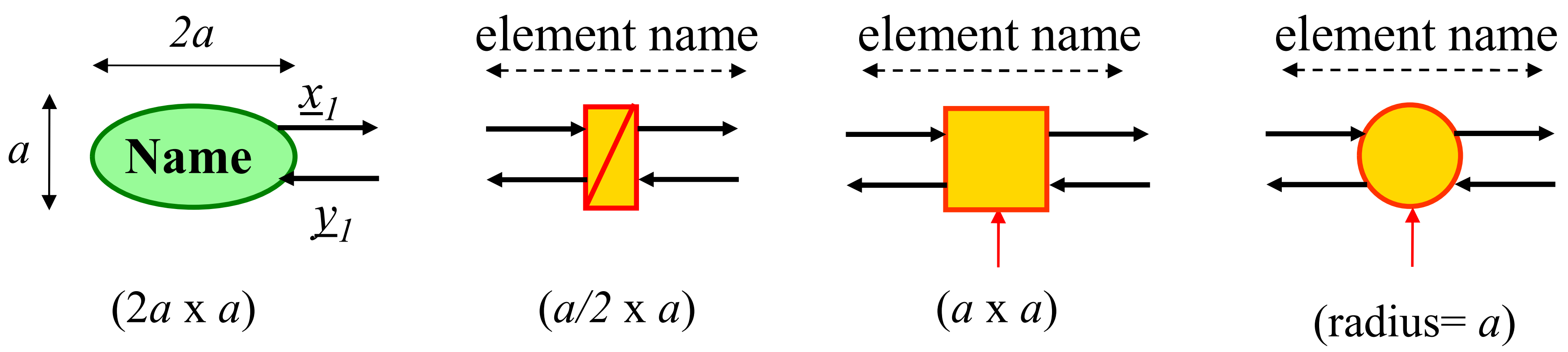
Control strategy — blue
- dark blue background RGB = (0,0,255) « blue »
- dark blue border RGB = (0,0,255) « blue »

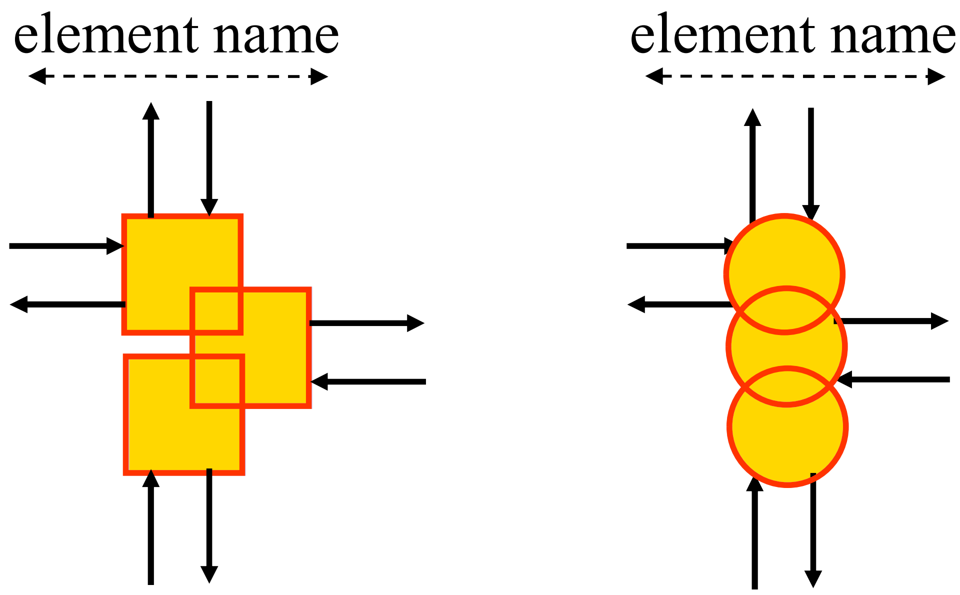
Web X11 colour, standard colours on web pages

http://en.wikipedia.org/wiki/Web_colors

- EMR pictograms -

No equation number in slides

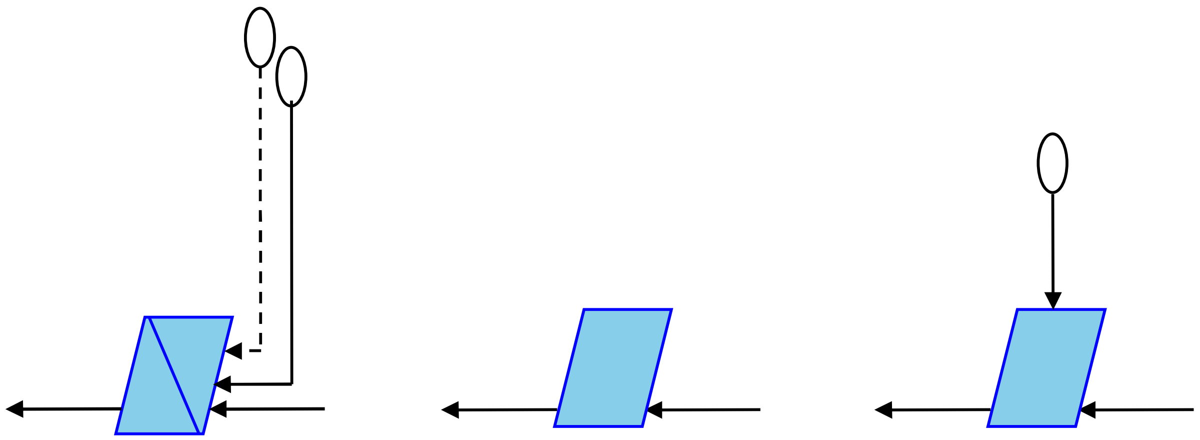




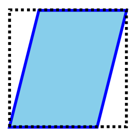
borders of power elements = *b* pt

power vectors (size *b*, full arrows)

signal vectors (size *b/2*, empty arrows)



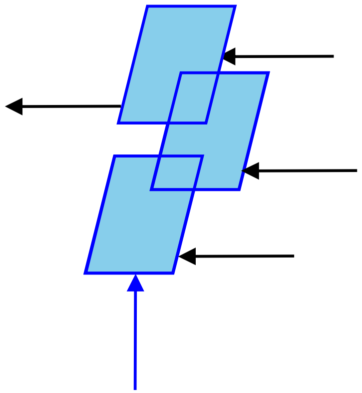
(same pictograms – same size - with or without oblique bar)

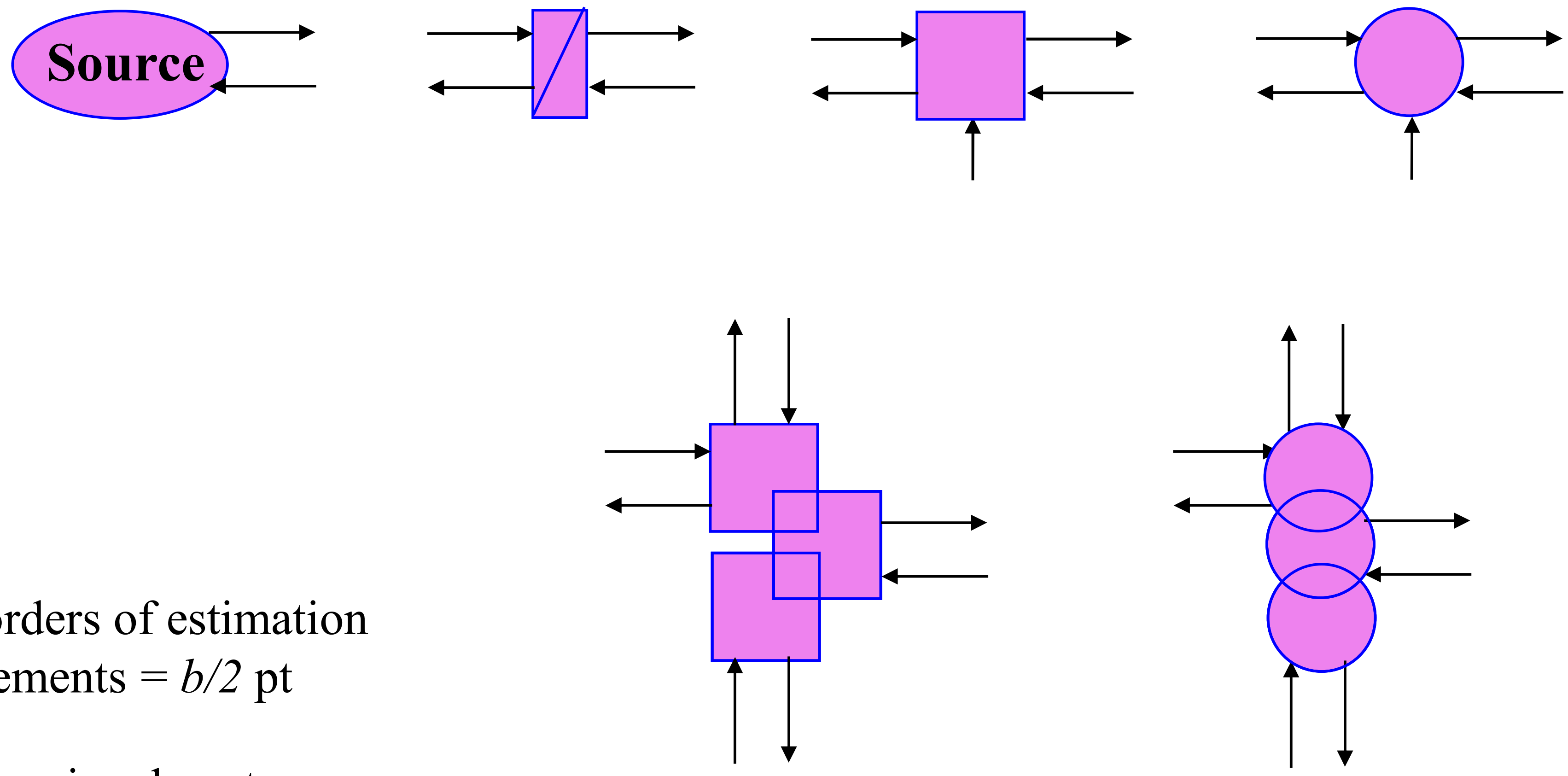


(support square a x a)

borders of control elements = *b/2* pt

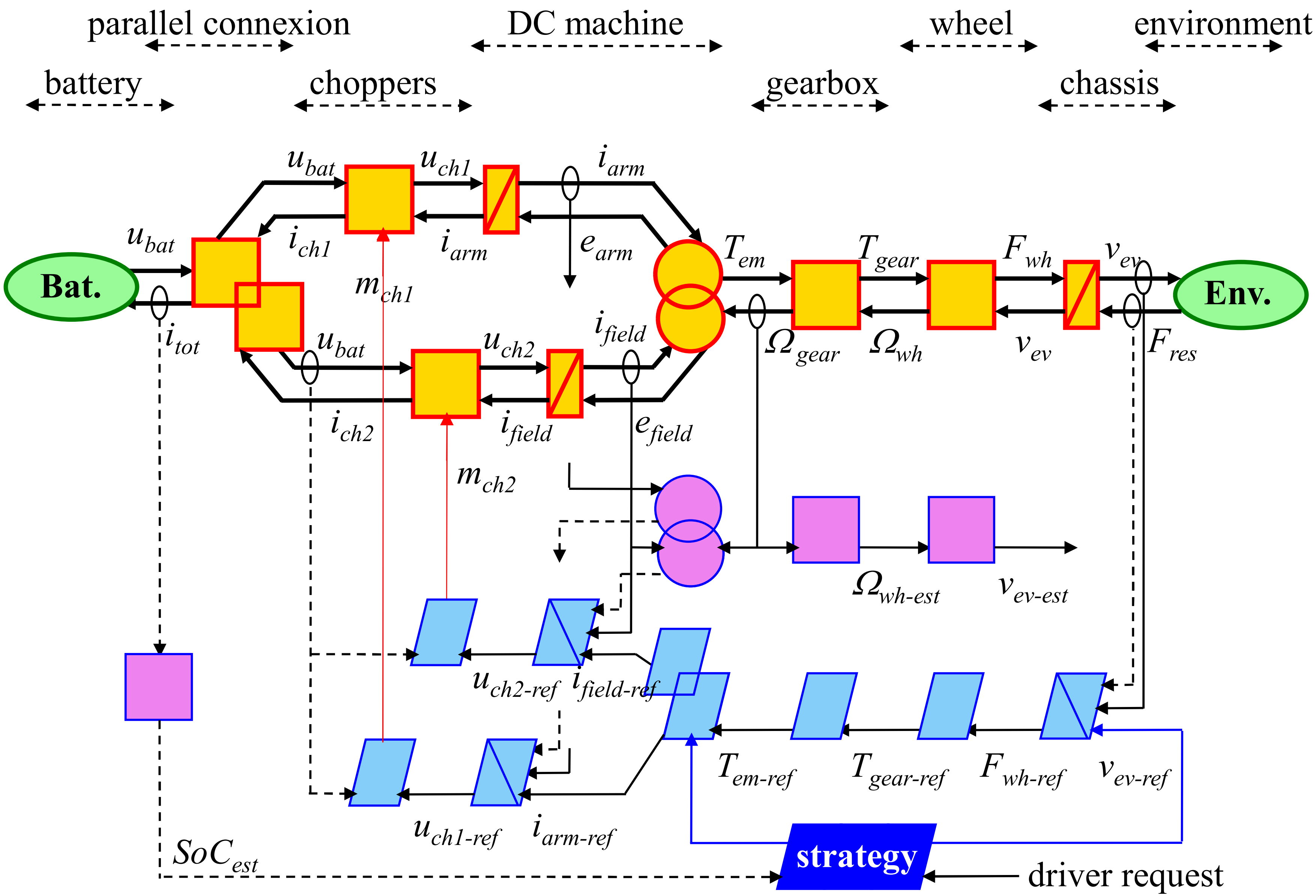
signal vectors (size *b/2*, empty arrows)





borders of estimation elements = *b/2* pt

signal vectors (size *b/2*, empty arrows)


parallel connexion
DC machine
wheel
environment
battery
choppers
gearbox
chassis
Bat.
Env.
strategy
driver request
SoCest