EMR'22
HES-SO Sion
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EMR'21 Summer School
"Energetic Macroscopic Representation"

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

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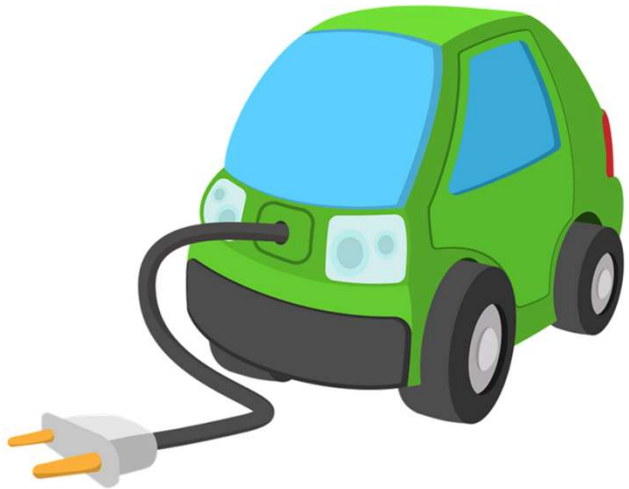
- Outline -

1. Studied EV
2. EMR of the studied EV
3. Inversion-based control of the EV



« 1. STUDIED EV »

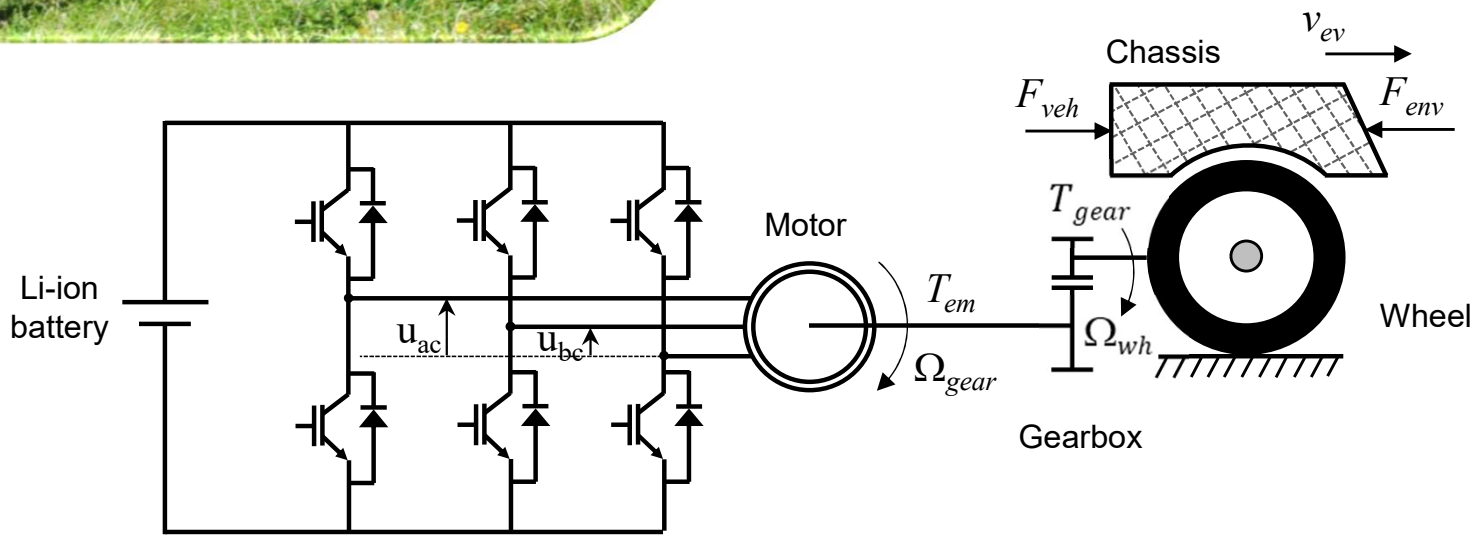
- e-Commander at University of Sherbrooke -

UNIVERSITÉ DE SHERBROOKE | *Voir au futur*

e-TESC Lab
electric - Transport,
Energy Storage and Conversion

e-Commander specifications
(off-road vehicle)

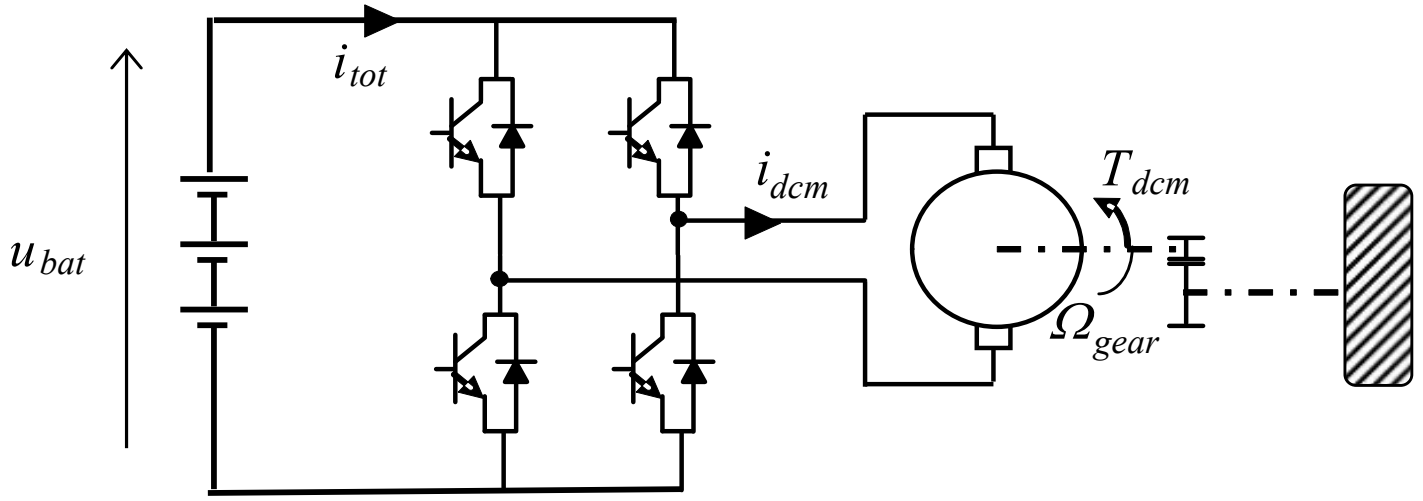
- 8,5 kW induction motor
- 48V 110Ah Lead-acid battery
- 871 kg (curb weight)
- Maximum speed: 45 km/h



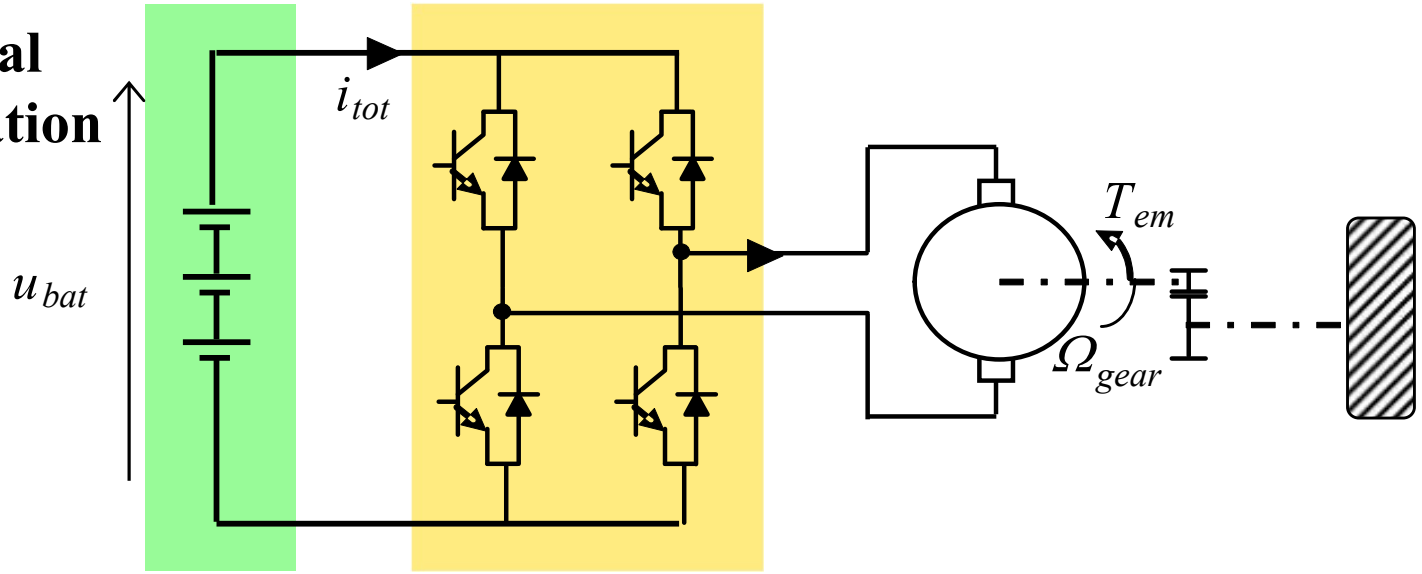
« 2. EMR OF THE STUDIED EV »

Objective:
control of the traction system in straight road

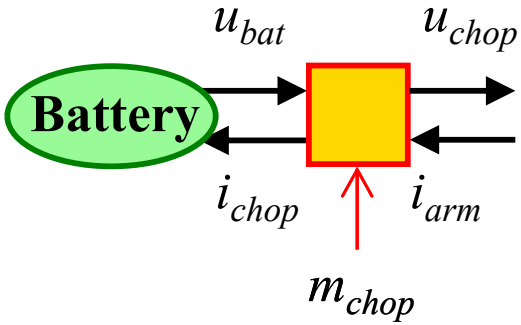
Simplifications:
- a permanent magnet DC machine is considered in the first step
- the PE converter is a H-bridge (chopper)
- an equivalent wheel is considered



Structural Representation

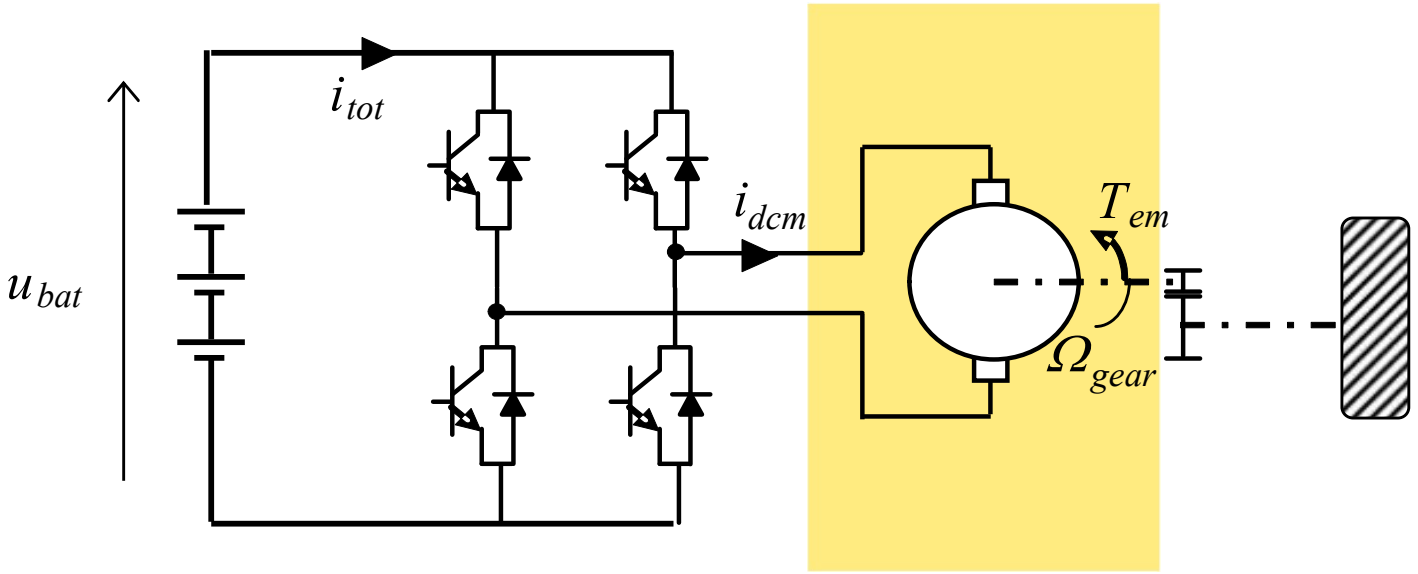


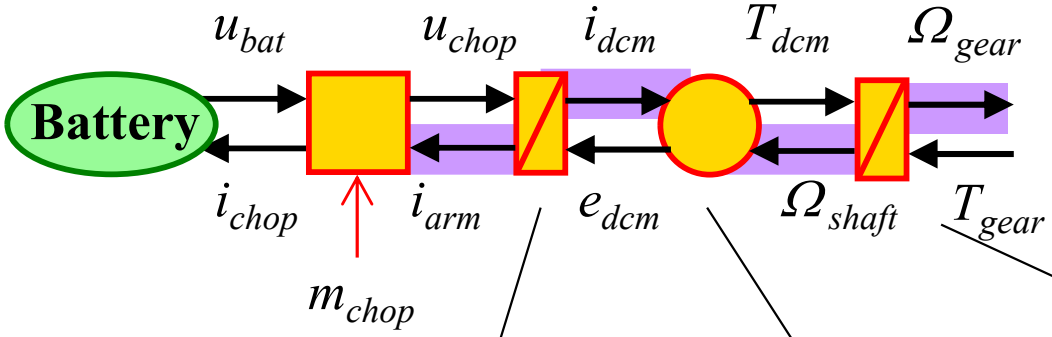
Functional Description



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

- EMR of the EV -



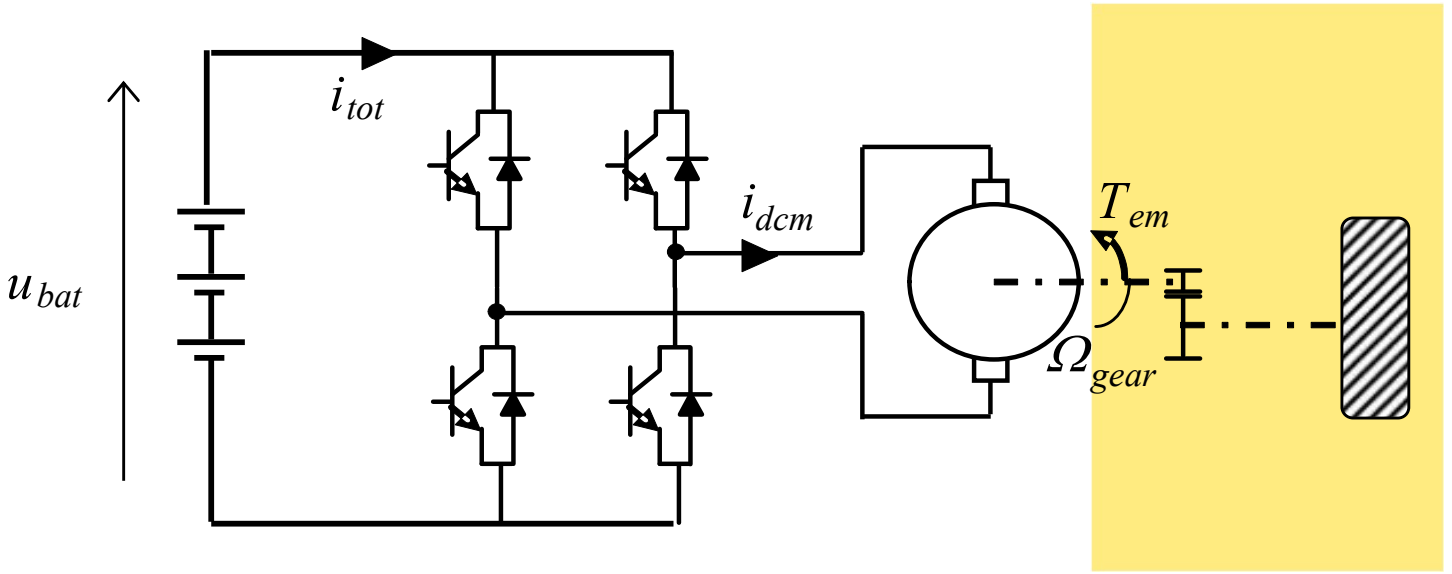


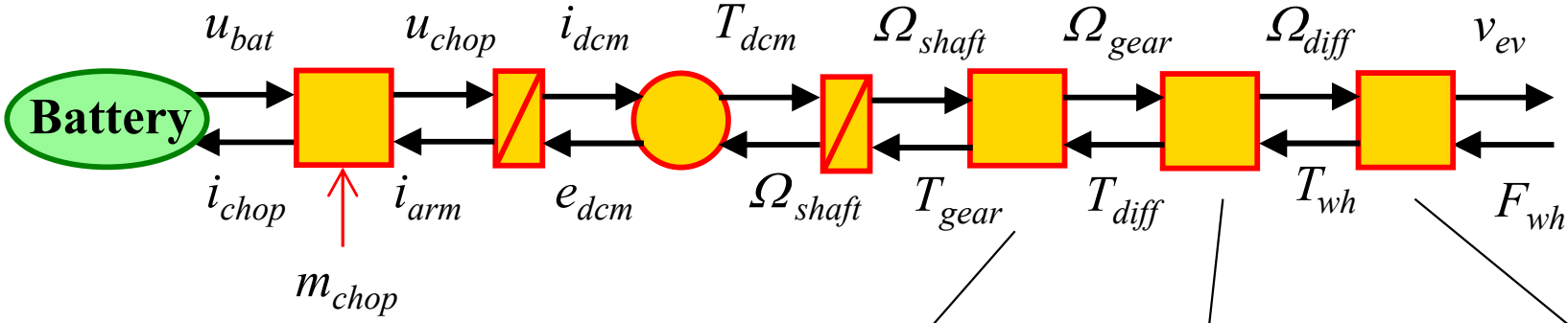
$$L_{arm}\frac{d}{dt}i_{dcm} = u_{chop} - e_{dcm} - R_{arm}i_{dcm}$$

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

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

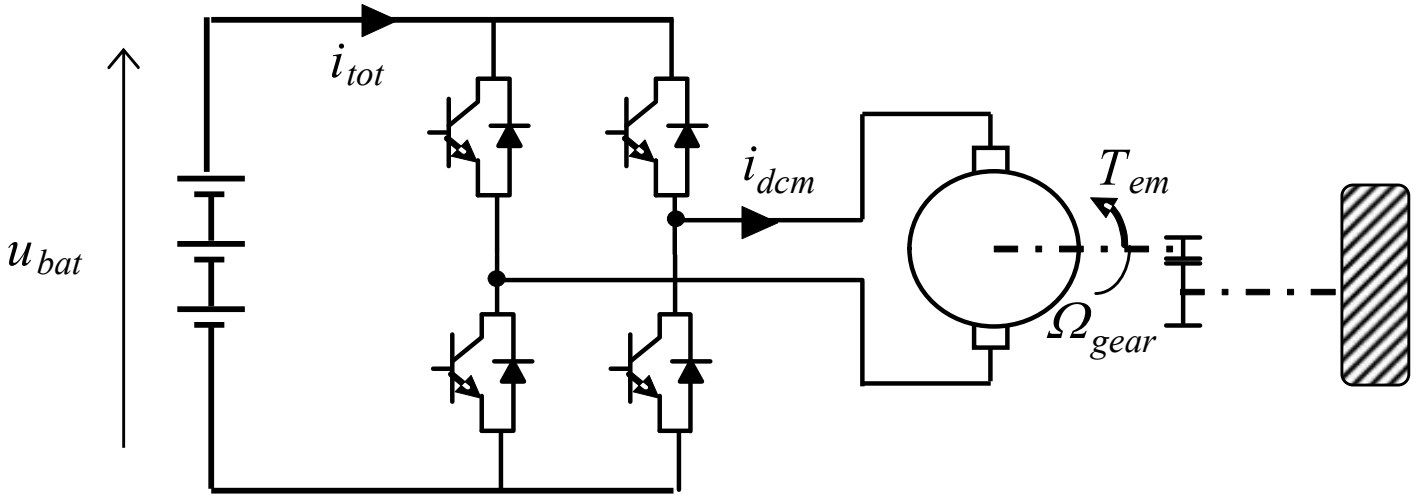
- EMR of the EV -

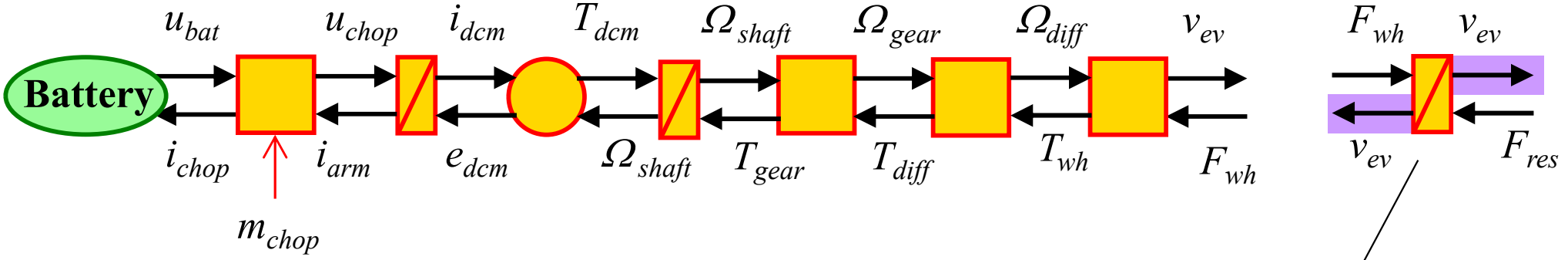




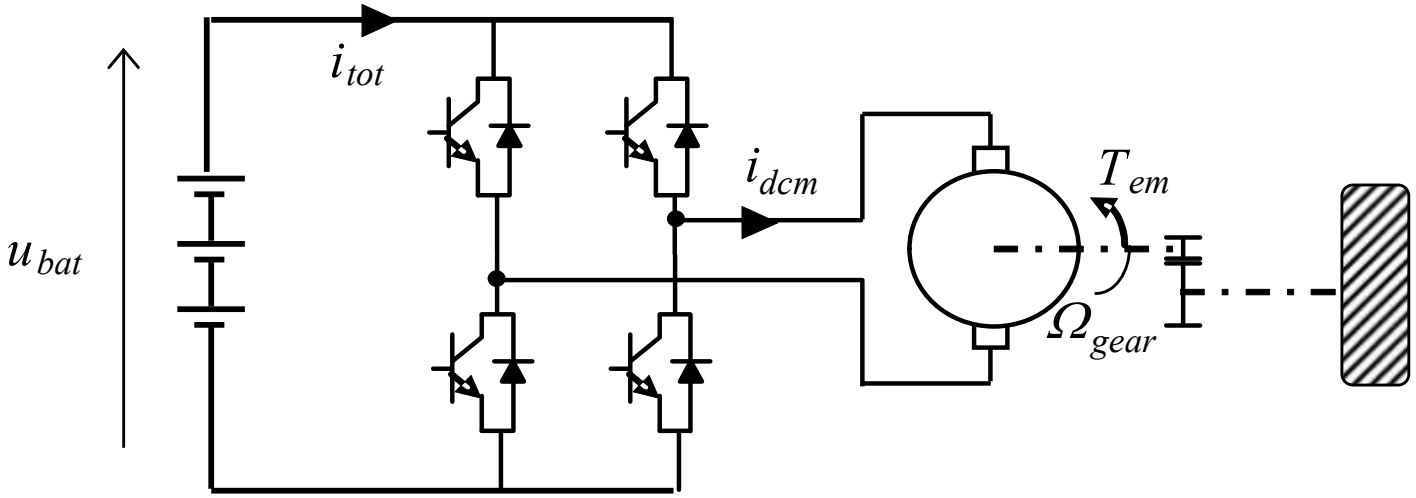
$$\begin{cases} T_{gear} = k_{gear}\, T_{diff} \\ \Omega_{gear} = k_{gear}\, \Omega_{shaft} \end{cases} \qquad \begin{cases} T_{diff} = k_{diff}\, T_{wh} \\ \Omega_{diff} = k_{diff}\, \Omega_{gear} \end{cases} \qquad \begin{cases} T_{wh} = R_{wh} F_{wh} \\ v_{ev} = R_{wh}\, \Omega_{diff} \end{cases}$$

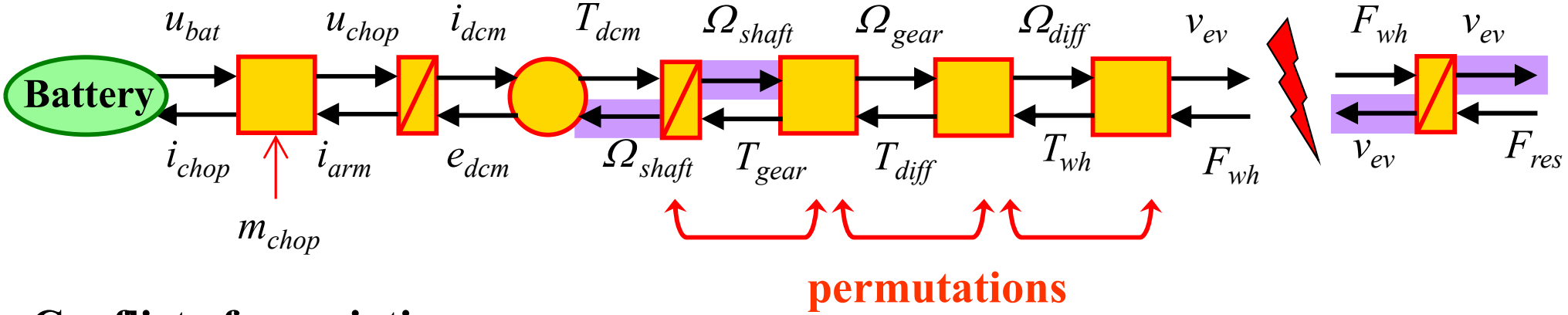
- EMR of the EV -





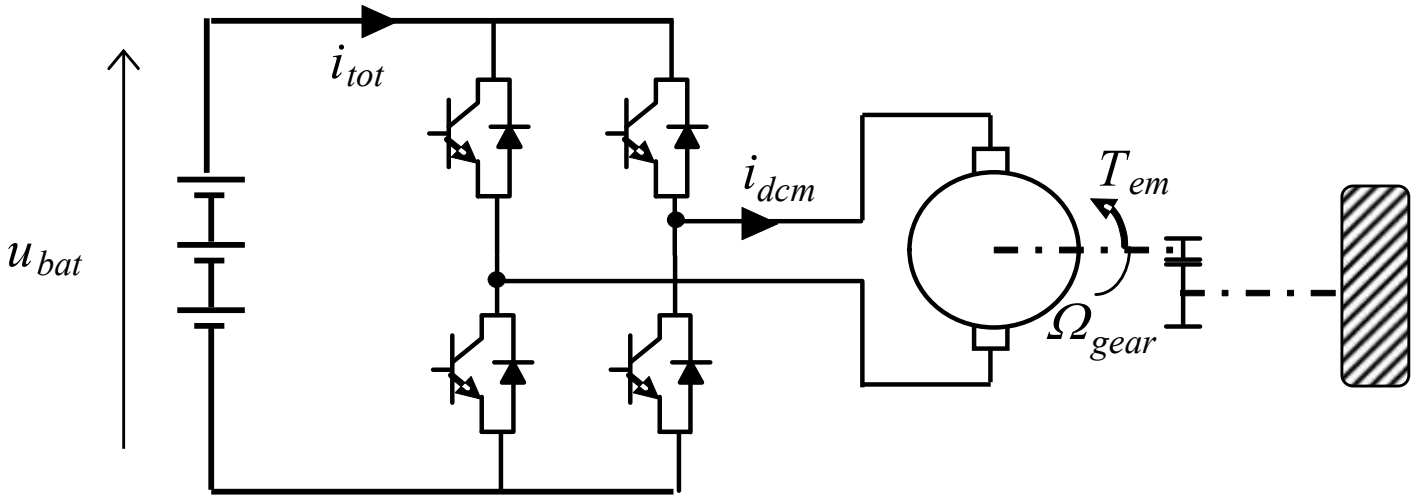
$$M \frac{d}{dt} v_{ev} = F_{tot} - F_{res}$$

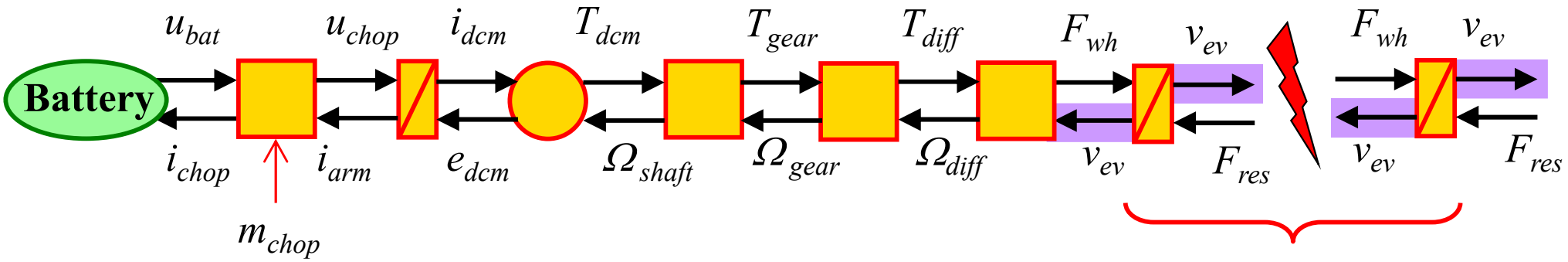




Conflict of association:

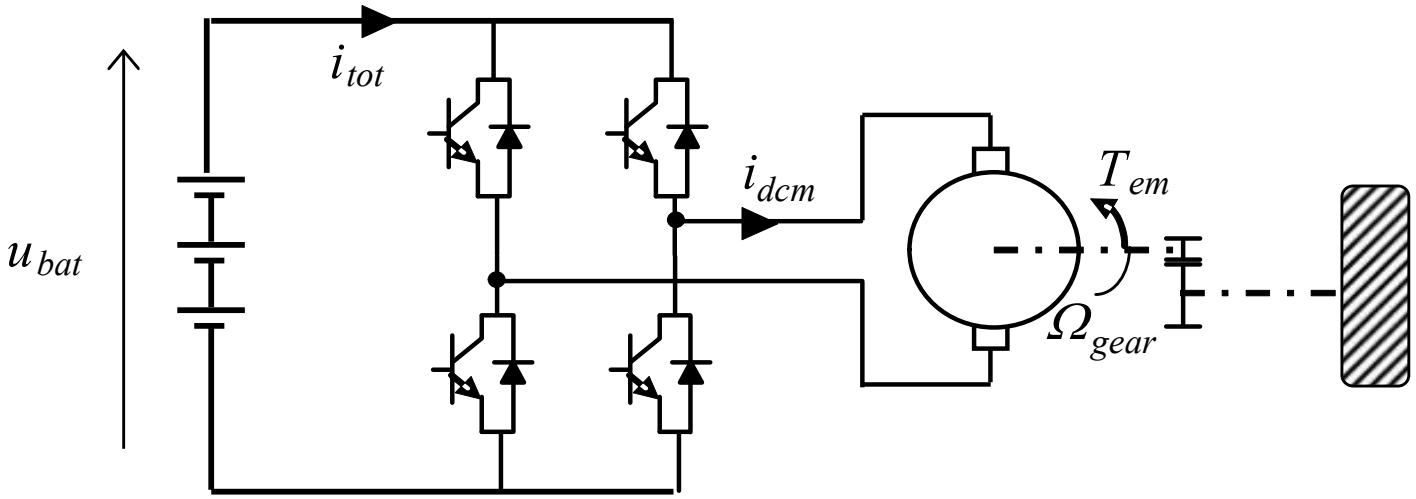
Ω_{shaft} and v_{ev} state variables, but $v_{ev} = R_{wh} k_{diff} k_{gear} \Omega_{shaft}$

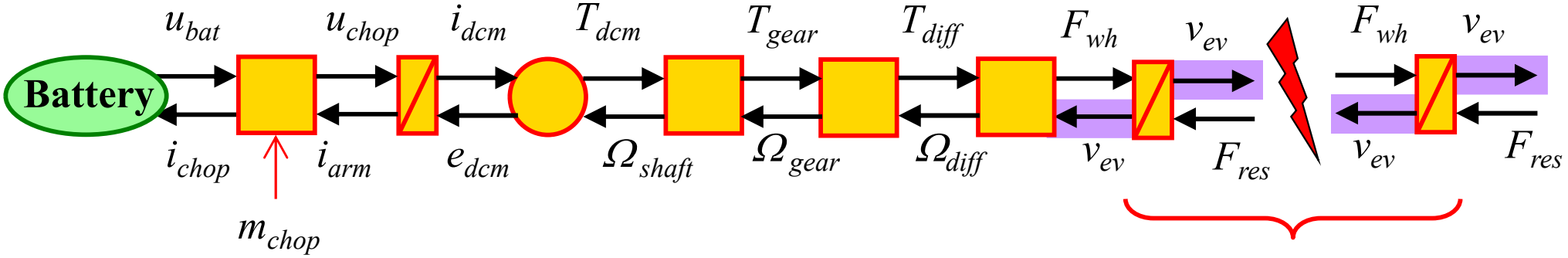




Conflict of association:
a unique state variable is required!

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





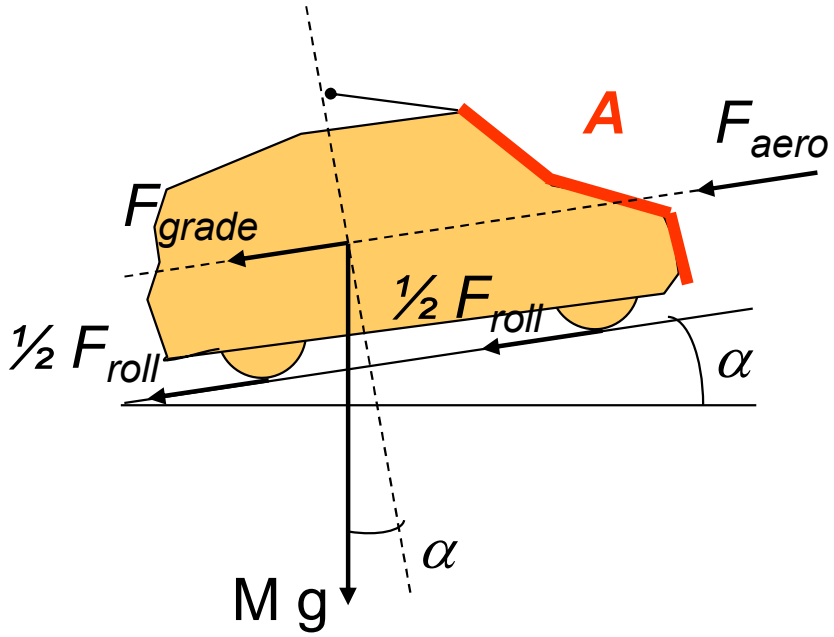
merging

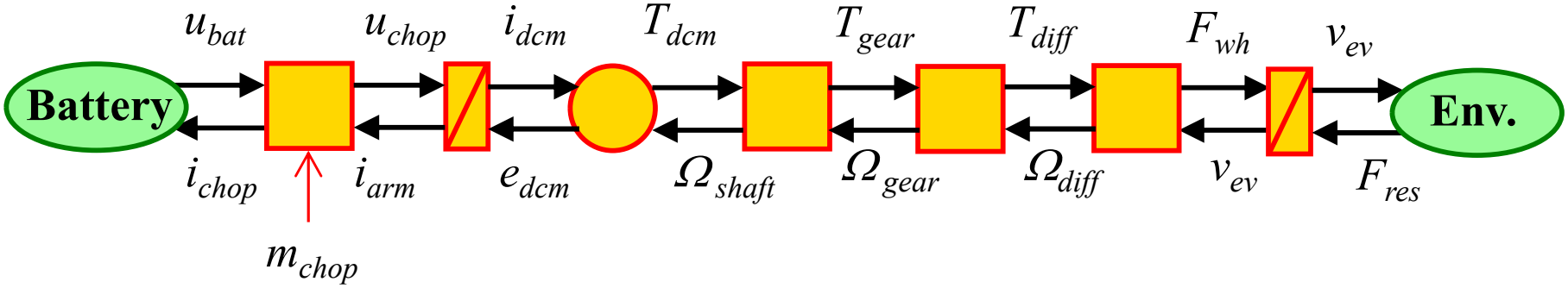
Conflict of association:
a unique state variable is required!

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

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

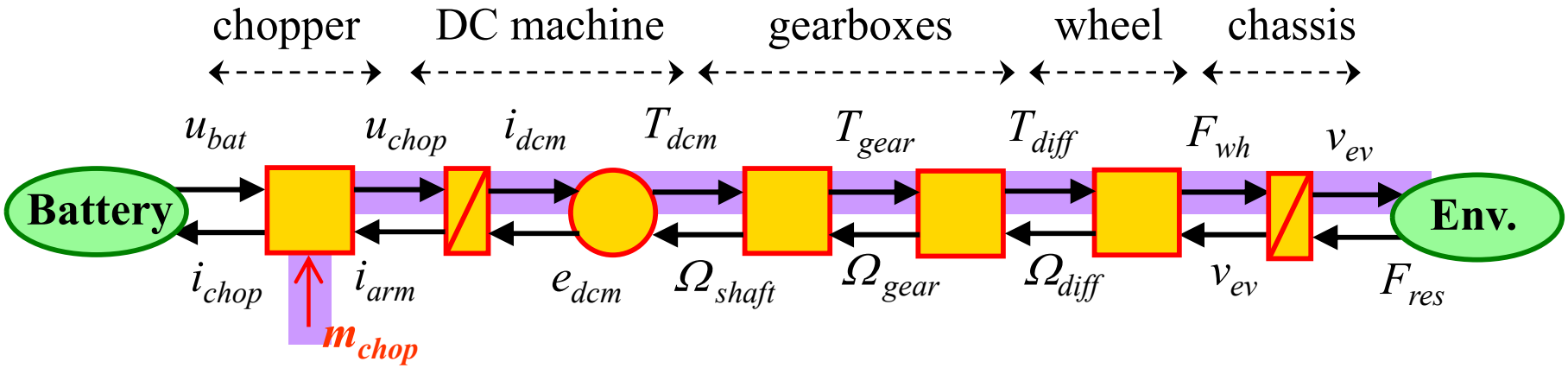
- EMR of the EV -





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

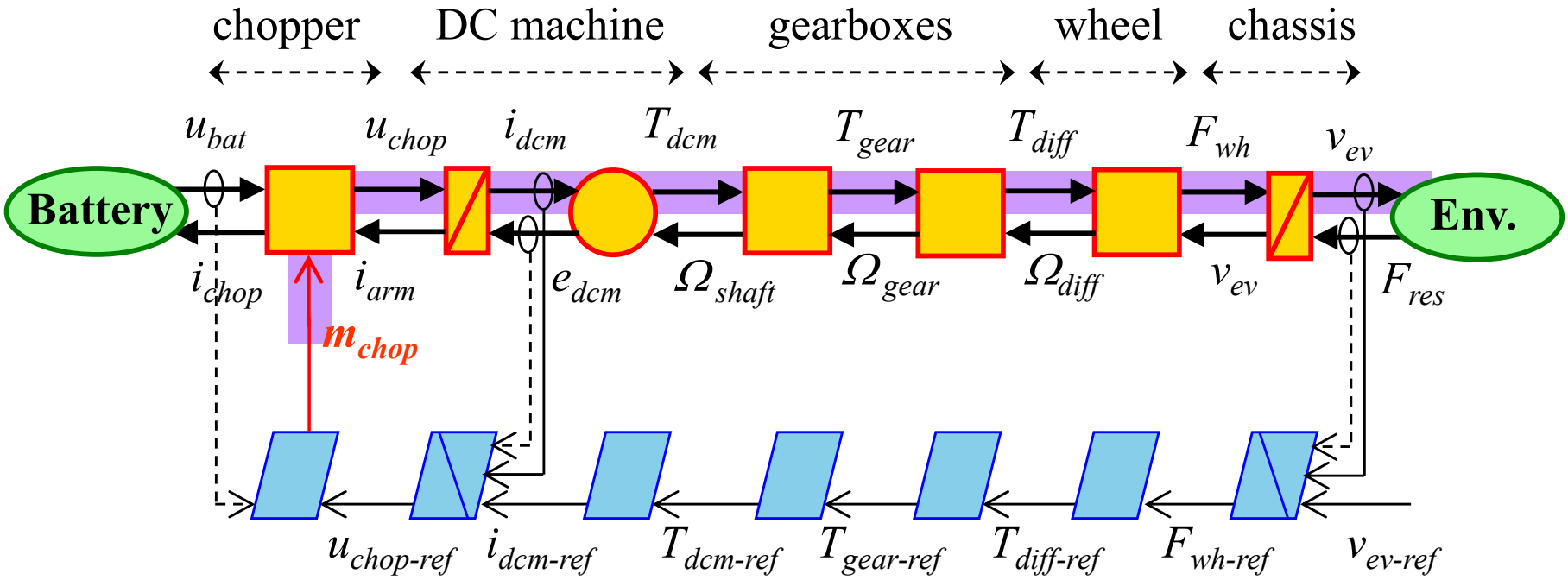
« 3. INVERSION-BASED CONTROL OF THE STUDIED ELECTRIC VEHICLE »



Objective: control the EV velocity

Tuning variable: modulation ratio of the DC-DC converter

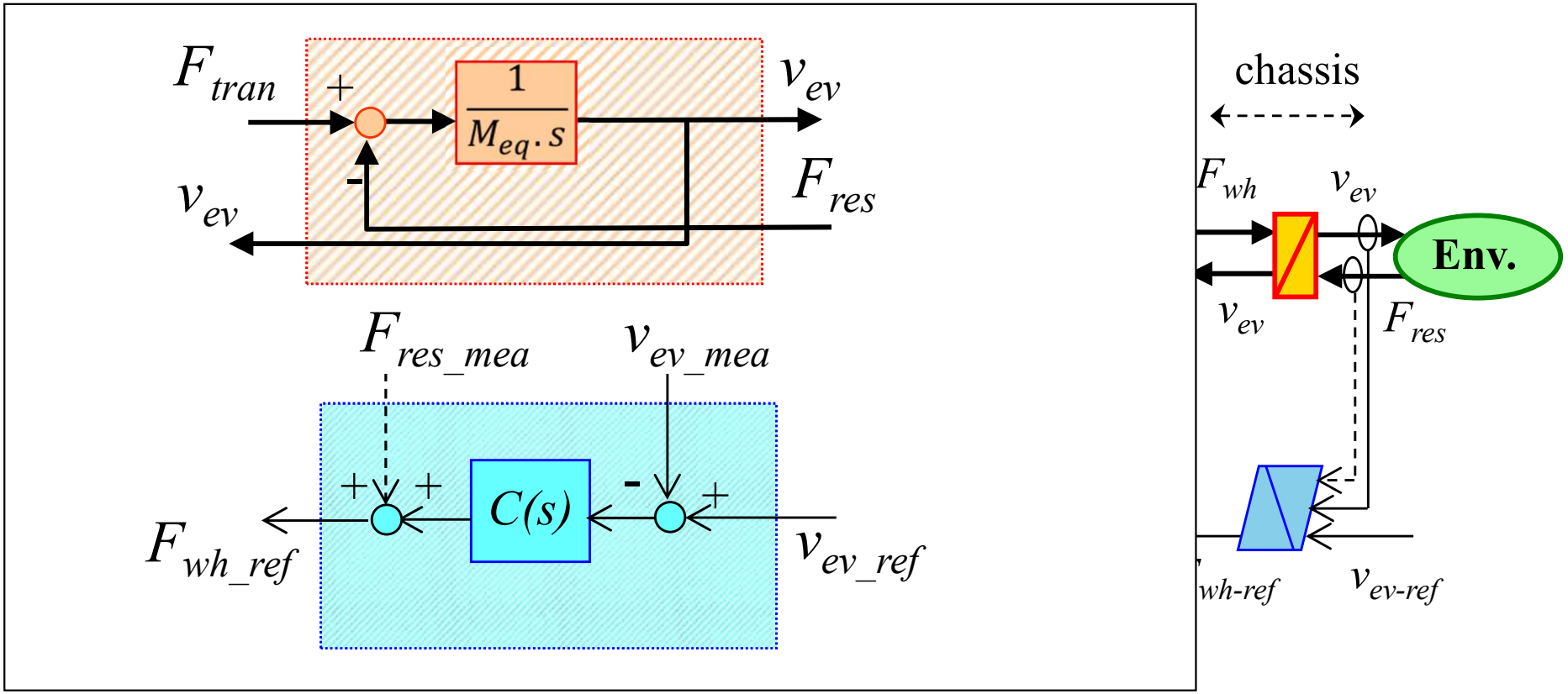
- Maximum Control Structure -



Maximum Control Structure:

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

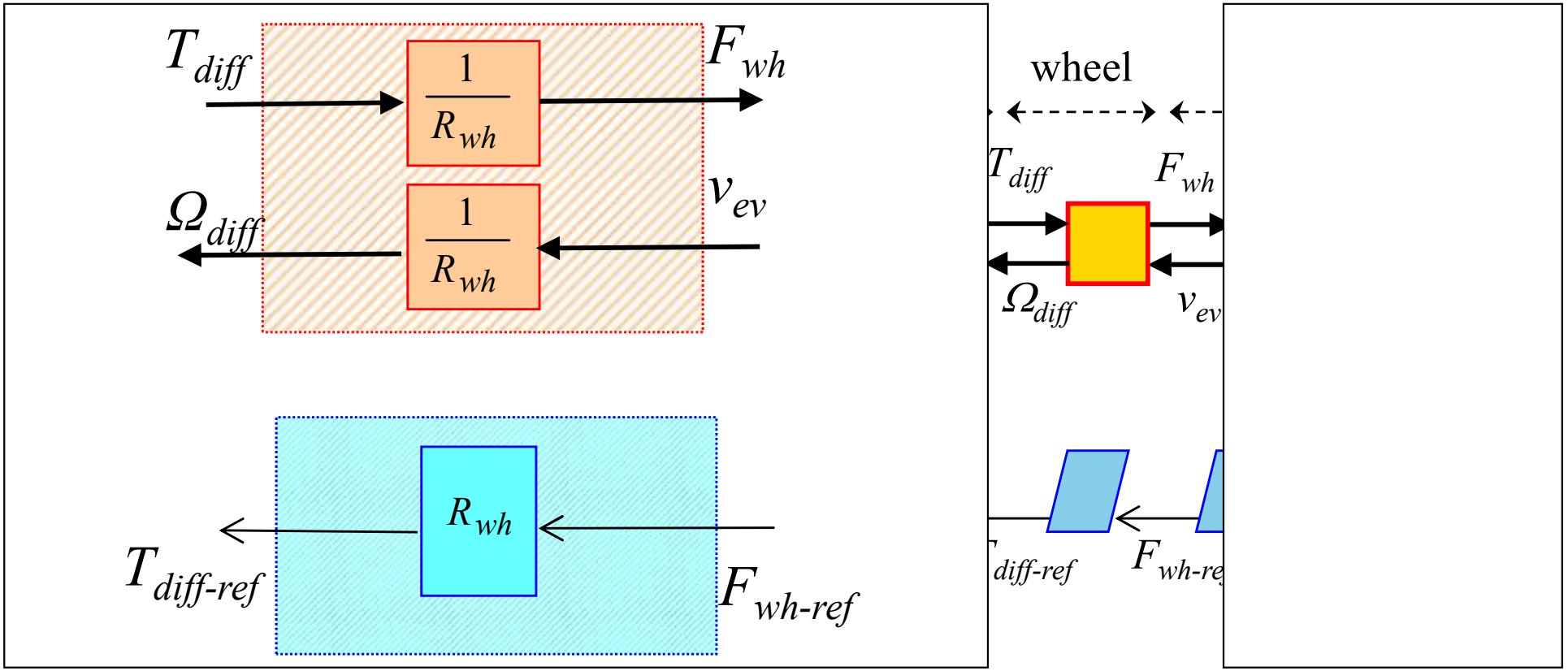
- Inversion of chassis -



Maximum Control Structure:

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

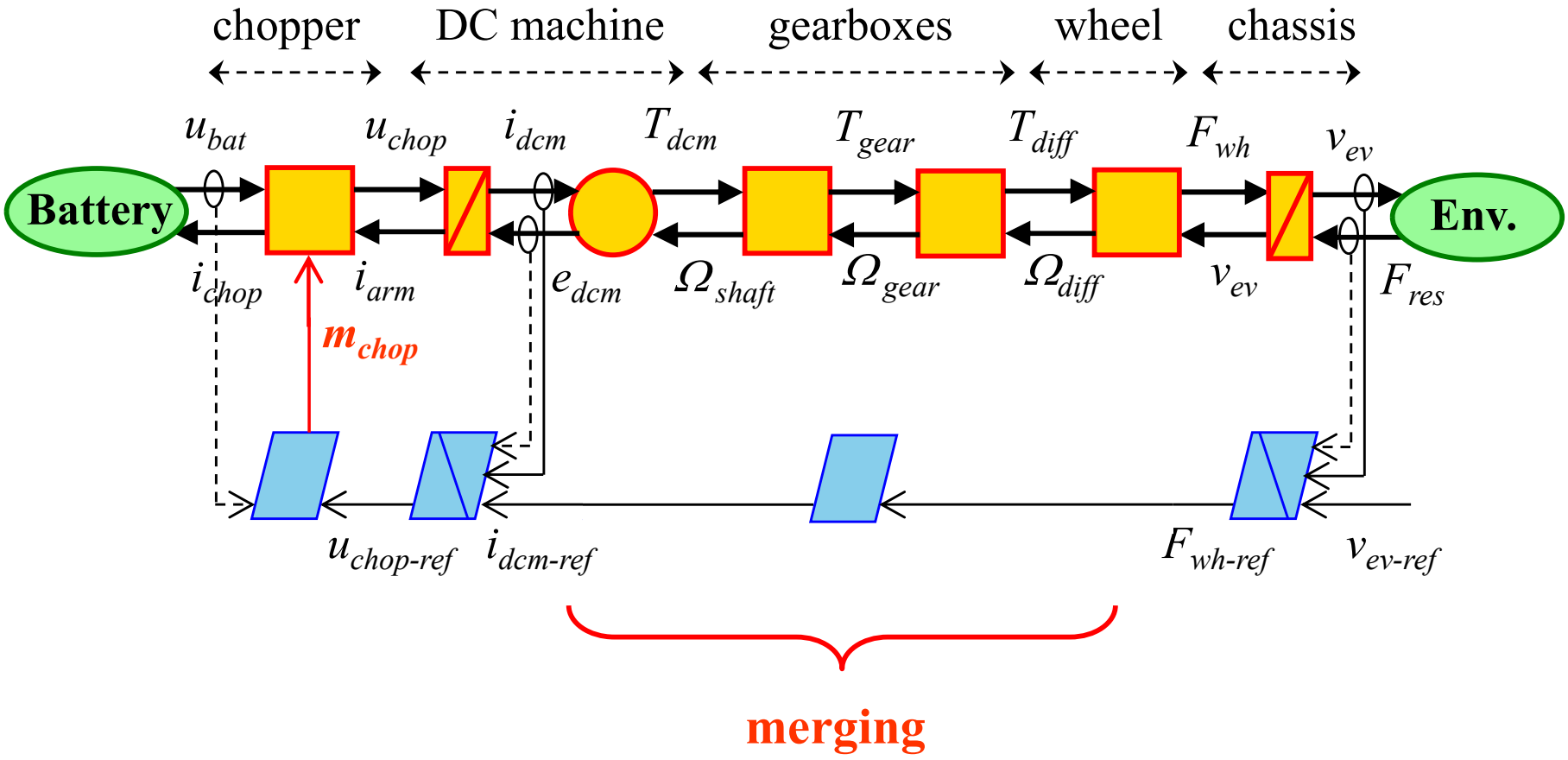
- Inversion of wheel -



Maximum Control Structure:

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

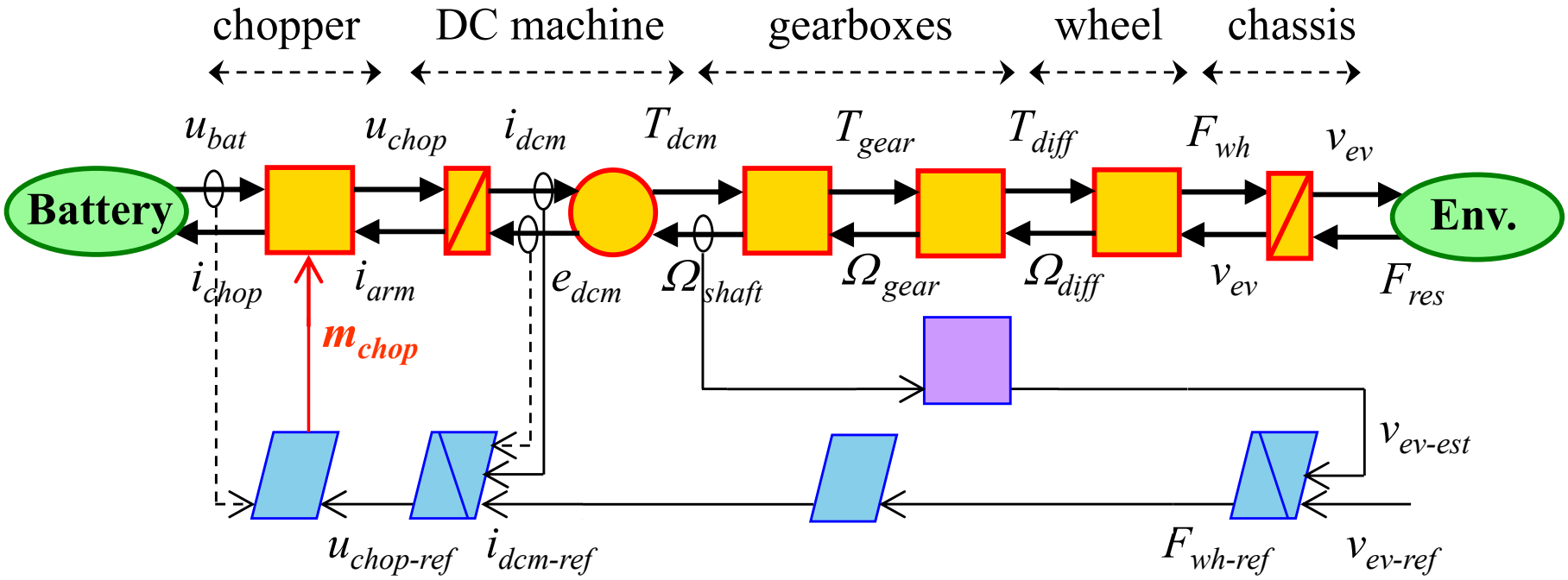
- Practical Control Structure -



Example of simplification:

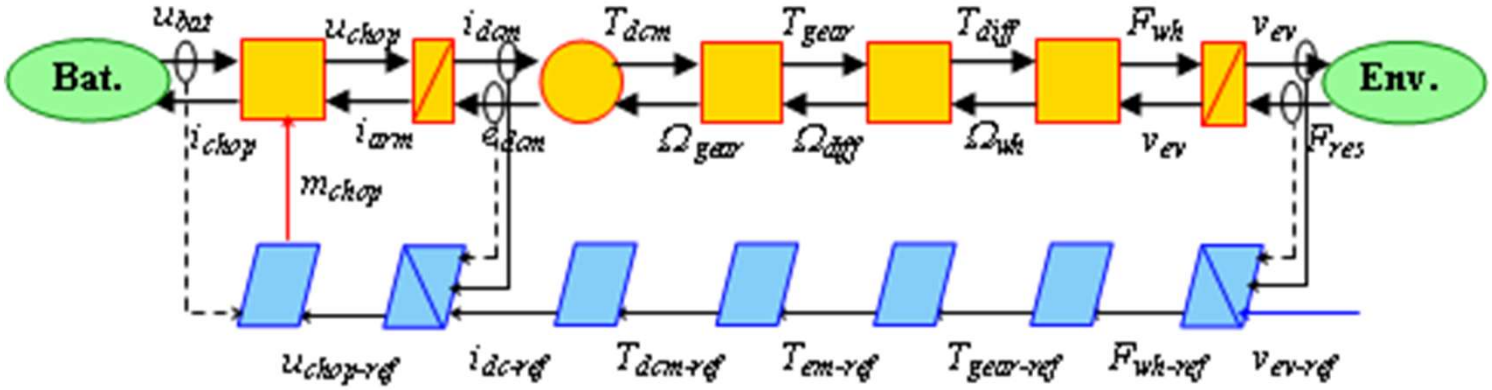
- merging of gains

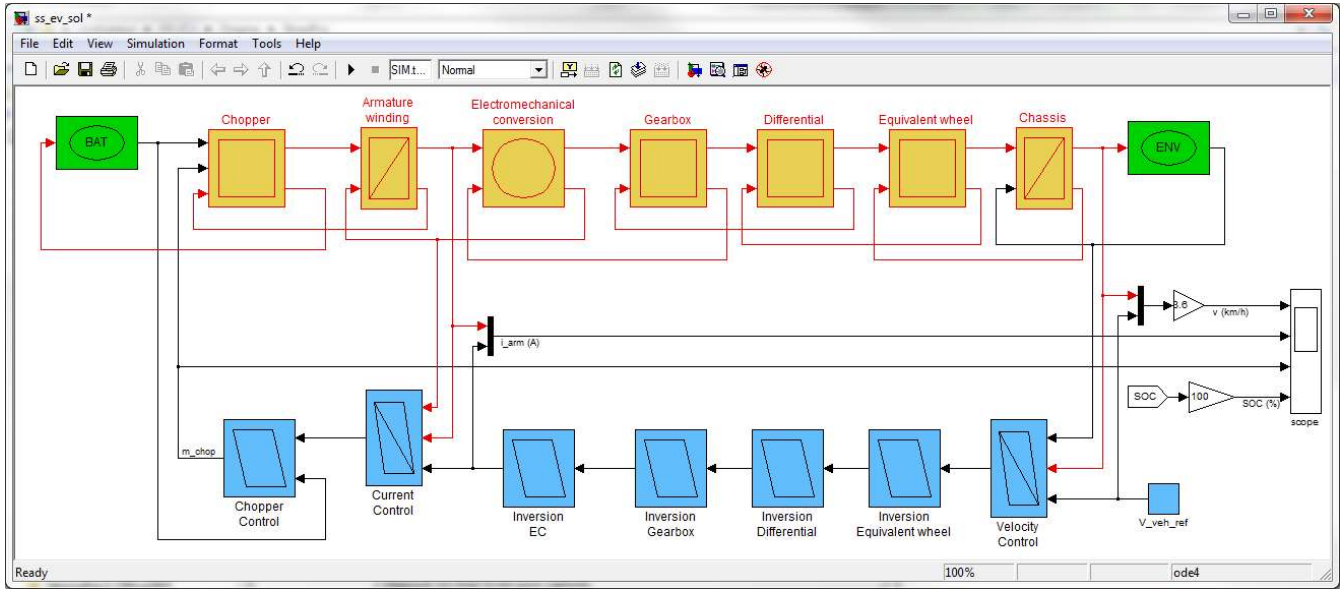
$$k_{tot} = R_{wh} \cdot {}^{1}/_{k_{diff}} \cdot {}^{1}/_{k_{gear}} \cdot {}^{1}/_{k_{dcm}}$$



Example of estimation:

- estimation of velocity





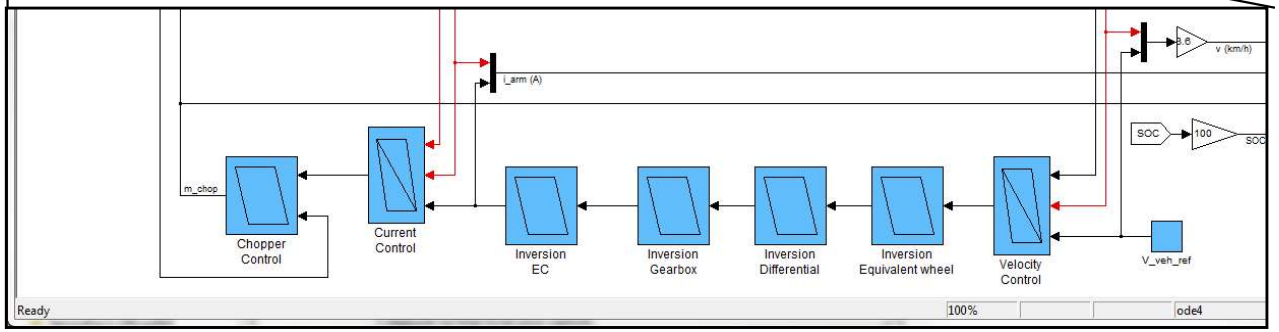
Matlab-Simulink ©, using the EMR library

- Implementation on the real vehicle -

https://www.gel.usherbrooke.ca/e-TESC/wp-content/uploads/2020/09/JoaoPromo.mp4

Electronic Control Unit

sensors



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 »

EMR and Inversion-based Control of an Electric vehicle

- Authors -

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Coordinator of the CUMIN interdisciplinary programme
Coordinator of the PANDA European project
Chair of the steering committee of IEEE-VPP Conference of IEEE-VTS
Ph.D. in Electrical Engineering at University of Toulouse (1995)
Research topics: EMR formalism, HIL testing, control & EV-HEVs

- References -

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[Gonzalez-Rubio 2019] 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, Oct. 2019.