« EMR and Inversion-Based CONTROL of an ELECTRIC VEHICLE »

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1 Studied EV

2 EMR of the studied EV

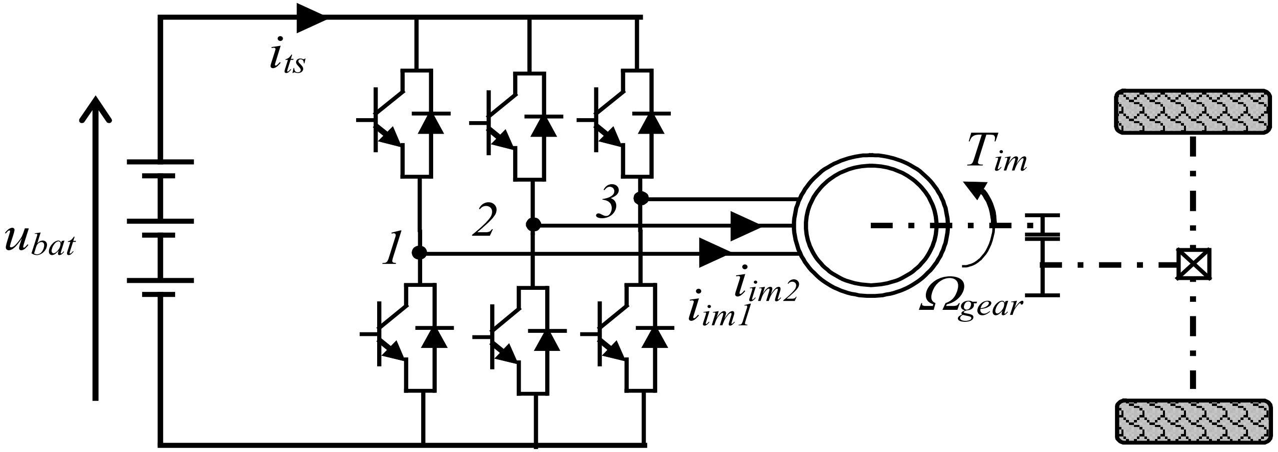
3 Inversion-based control of the EV

1. Studied EV

- Simplified description of a Renault Zoe -

Renault Zoe main characteristics (2018)

- 80kW – 100kW Synchronous Motor
- 41Ah Li NMC battery
- 1555 kg (empty mass)



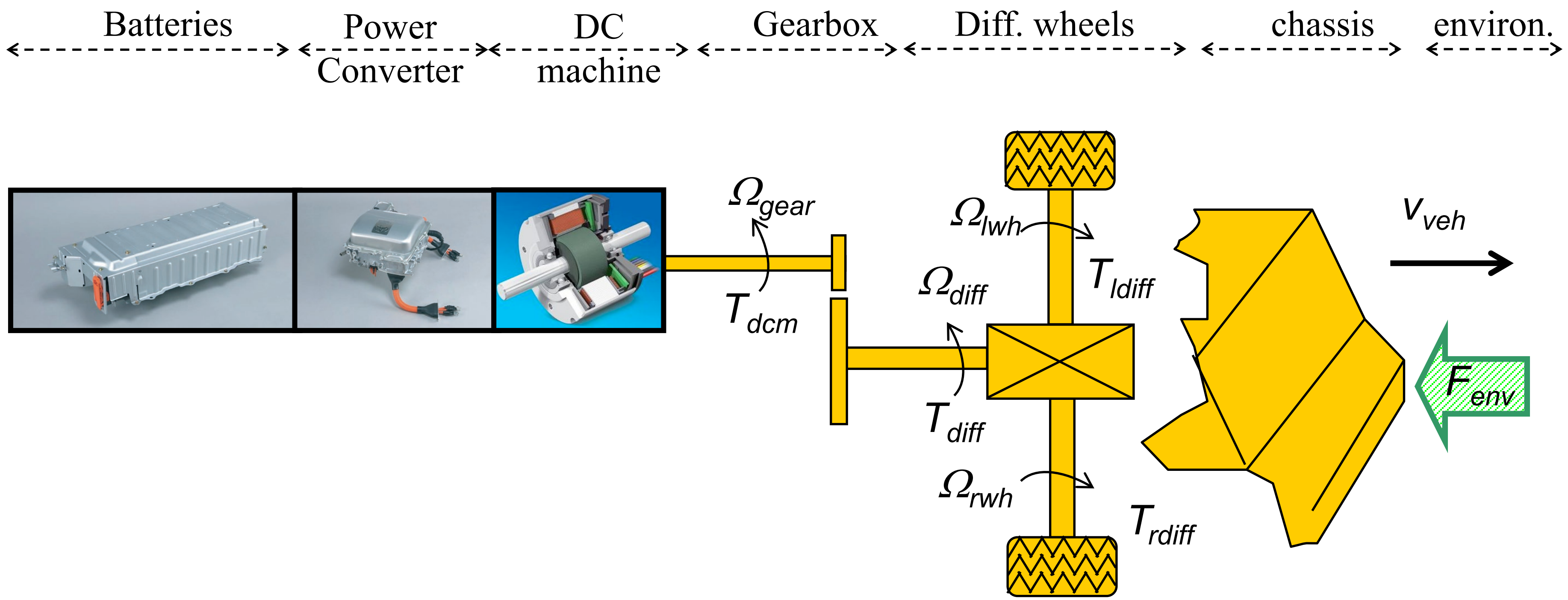
Objective:

- Illustration of EMR-IBC methodology: control of the traction system in straight lines
- Introduction to simulation session

Simplifications and assumptions for analysis and EMR

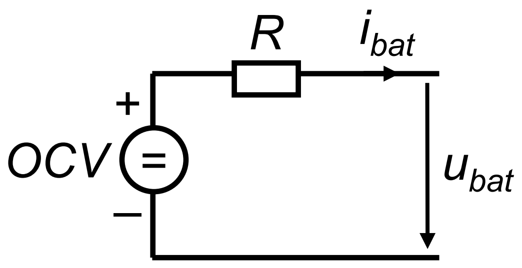
- A non-saturated permanent magnet DC machine is considered (instead of Synchronous machine
- Ideal power converter (no losses)
- Inertia of rotating masses are not taken in account
- Contact wheel/ground with no slip and pneumatic deformation
- Mechanical brakes are not considered

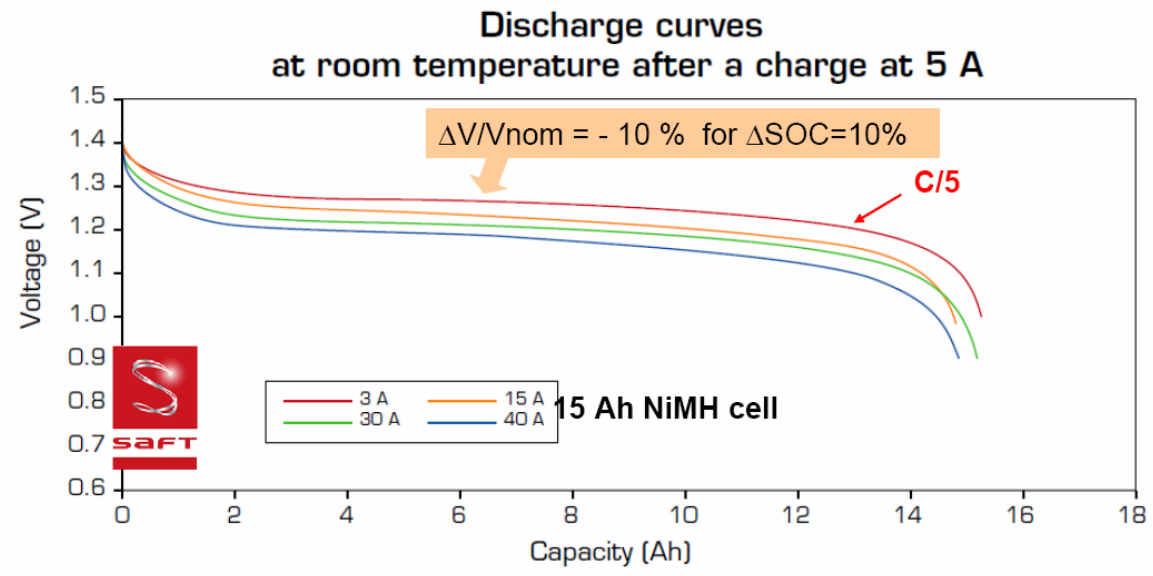
EMR and control of an EV

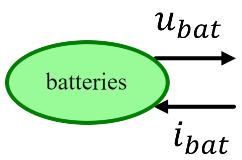


EMR of the studied EV

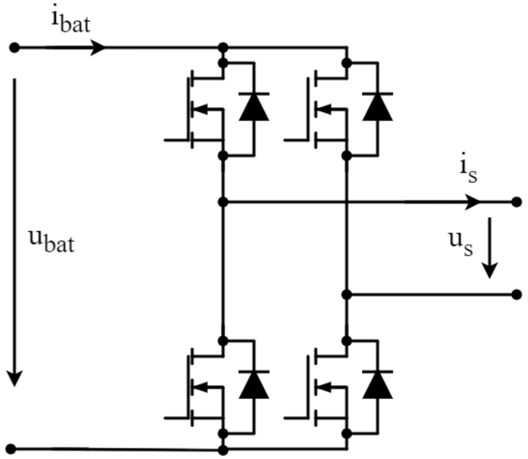
- Terminal element of system – Environnement of system
  - Must be modelled anyway
    - Open Circuit Voltage (OCV)
    - Internal impedance (R):
    - State of Charge (SOC)





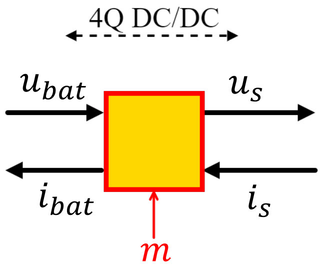


- 4Q DC/DC converter for full reversibility
  - Introducing d as the main duty cycle
  - Definition of an average model ($0 < d < 1$)

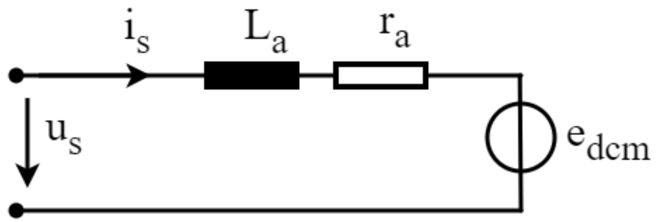


$$\begin{cases} u_s = \underbrace{(2.d-1)}_{m}.u_{bat} \\ i_{bat} = \underbrace{(2.d-1)}_{m}.i_s \end{cases}$$

$$with\ -1 < m < 1$$

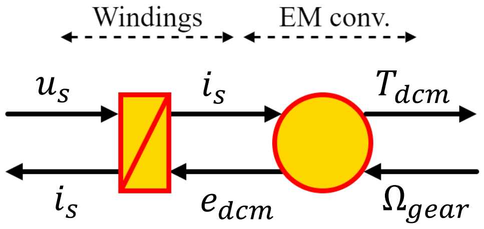


- DC machine with permanent magnets
  - Electrical equations

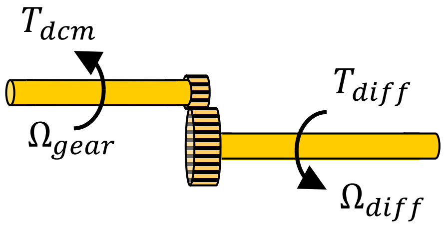


  - Electro-mechanical conversion

$$\begin{cases} T_{dcm} = k_{dcm}.i_s \\ e_{dcm} = k_{dcm}.\Omega_{gear} \end{cases}$$



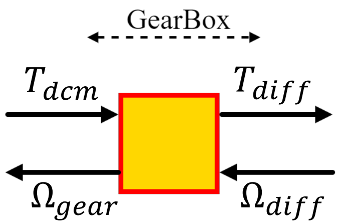
- Gearbox



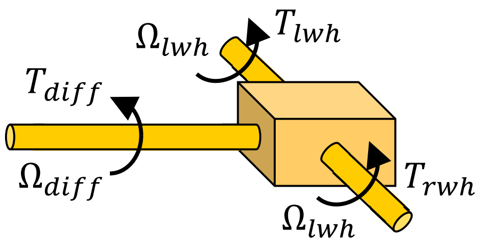
  - k_{gear} : transformation ratio
  - η_{gear} : efficiency, p : correction exponent

$$\begin{cases} T_{diff} = \eta_{gear}^{p} k_{gear} T_{dcm} \\ \Omega_{gear} = k_{gear} \Omega_{diff} \end{cases}$$

$$with \quad \begin{cases} p = 1 \quad if \quad \Omega_{diff} T_{diff} \geq 0 \\ p = -1 \quad if \quad \Omega_{diff} T_{diff} < 0 \end{cases}$$

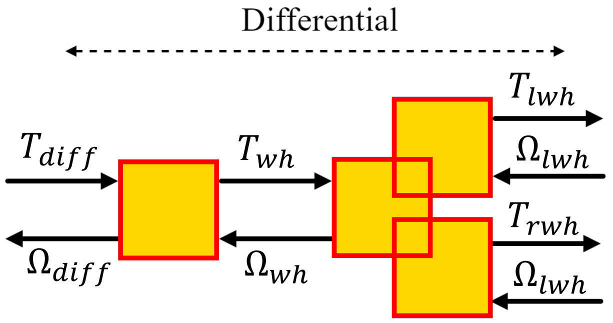


- Differential
  - 2 functions in 1



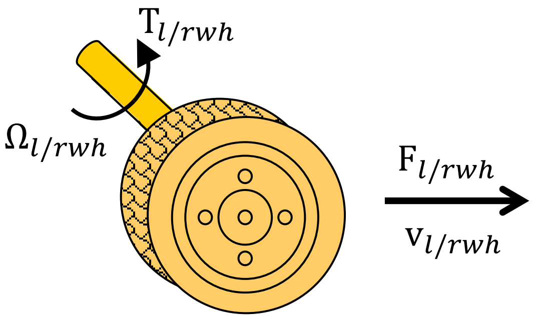
  - k_{diff} : transformation ratio
  - η_{diff} : efficiency, p : correction exponent

$$\begin{cases} T_{wh} = \eta_{diff}^{p} k_{diff} T_{diff} \\ \Omega_{diff} = k_{diff} \Omega_{wh} \end{cases} \quad and \quad \begin{cases} T_{ldiff} = T_{rdiff} = \frac{1}{2} T_{wh} \\ \Omega_{wh} = \frac{1}{2} (\Omega_{lwh} + \Omega_{rwh}) \end{cases}$$



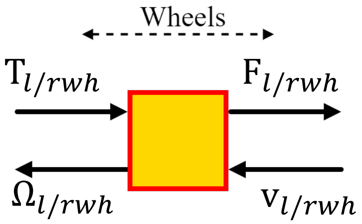
- Wheels and ground coupling -

- Wheels



  - R_{wh} : wheels radius

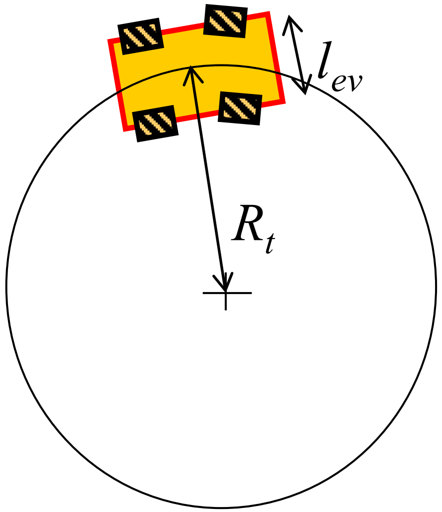
$$\begin{cases} F_{l/rwh} = k_{wh}.T_{l/rwh} \\ \Omega_{l/rwh} = k_{whf}.v_{l/rwh} \end{cases} \quad with \quad k_{wh} = \frac{1}{R_{wh}}$$

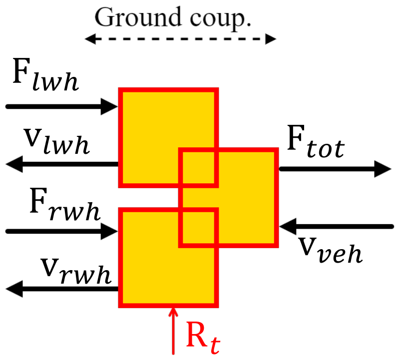


- Ground coupling

  - R_t : turning radius
  - L_{ev}: vehicle width

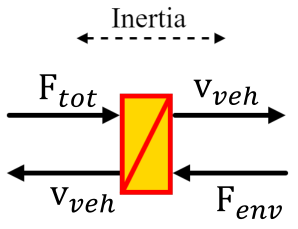
$$\begin{cases} v_{lwh} = \left(1 + \frac{1}{2}.\frac{l_{ev}}{R_t}\right).v_{veh} \\ v_{rwh} = \left(1 - \frac{1}{2}.\frac{l_{ev}}{R_t}\right).v_{veh} \\ F_{tot} = F_{lwh} + F_{rwh} \end{cases}$$





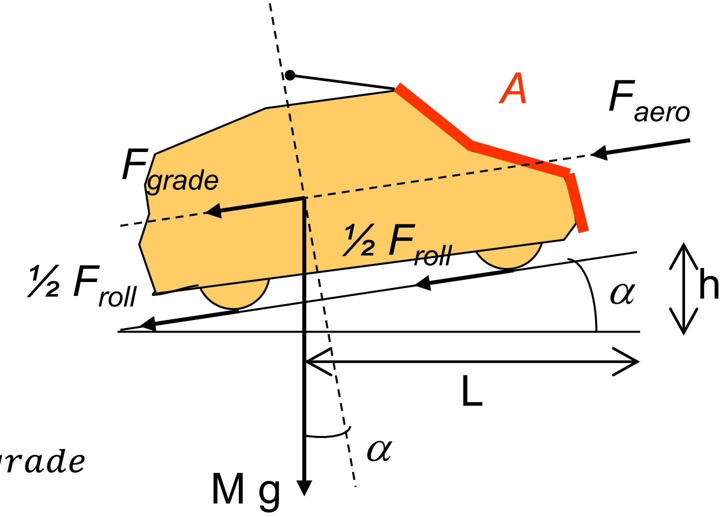
- Inertia (Chassis)
  - M_{veh} : total mass of the vehicle

$$M_{veh}.\frac{dv_{veh}}{dt} = F_{tot} - F_{env}$$

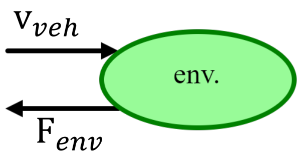


- Environment - Terminal element of system – Must be modelled anyway
  - F_{aero} : aerodynamic resistance
  - F_{roll} : rolling resistance
  - F_{grade} : grade resistance

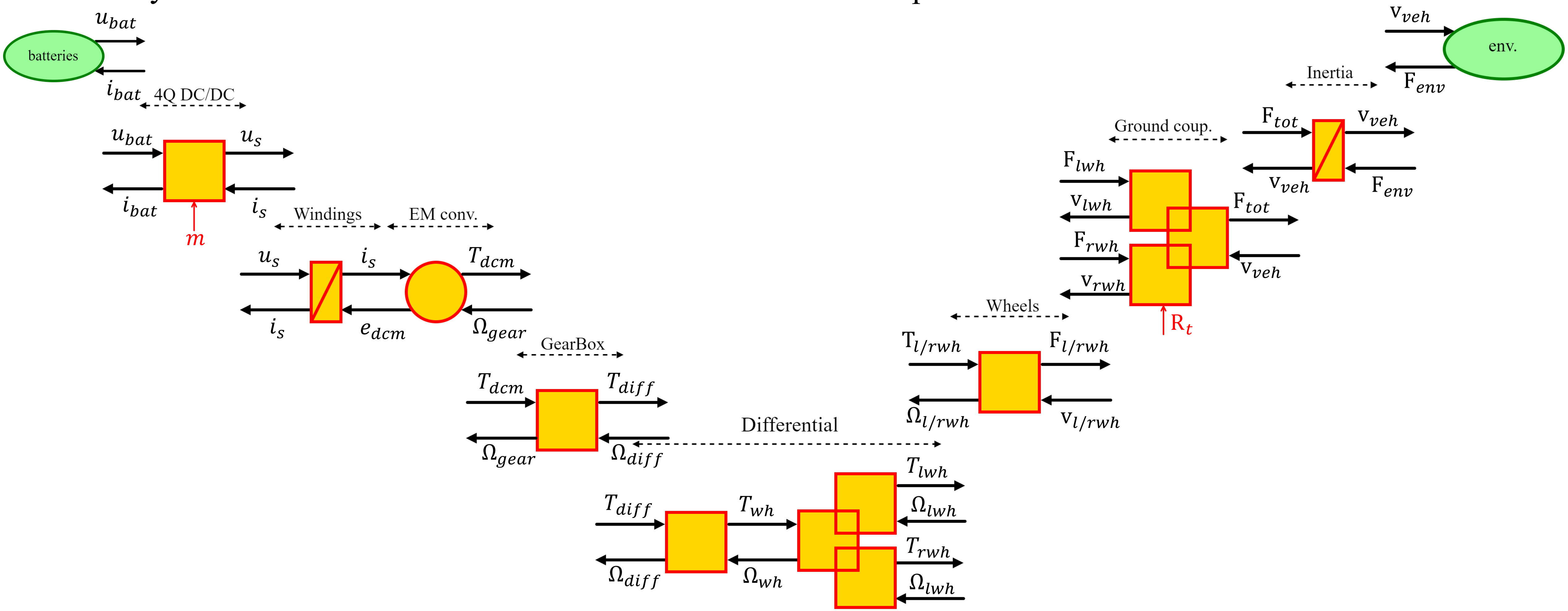
$$\begin{cases} F_{aero} = \frac{1}{2}\rho_{air}.A.C_x.v_{veh}^2 \\ F_{roll} = k_{roll}.M_{veh}.g.cos\alpha \\ F_{grade} = M_{veh}.g.sin\alpha \end{cases}$$



$$F_{env} = F_{aero} + F_{roll} + F_{grade}$$

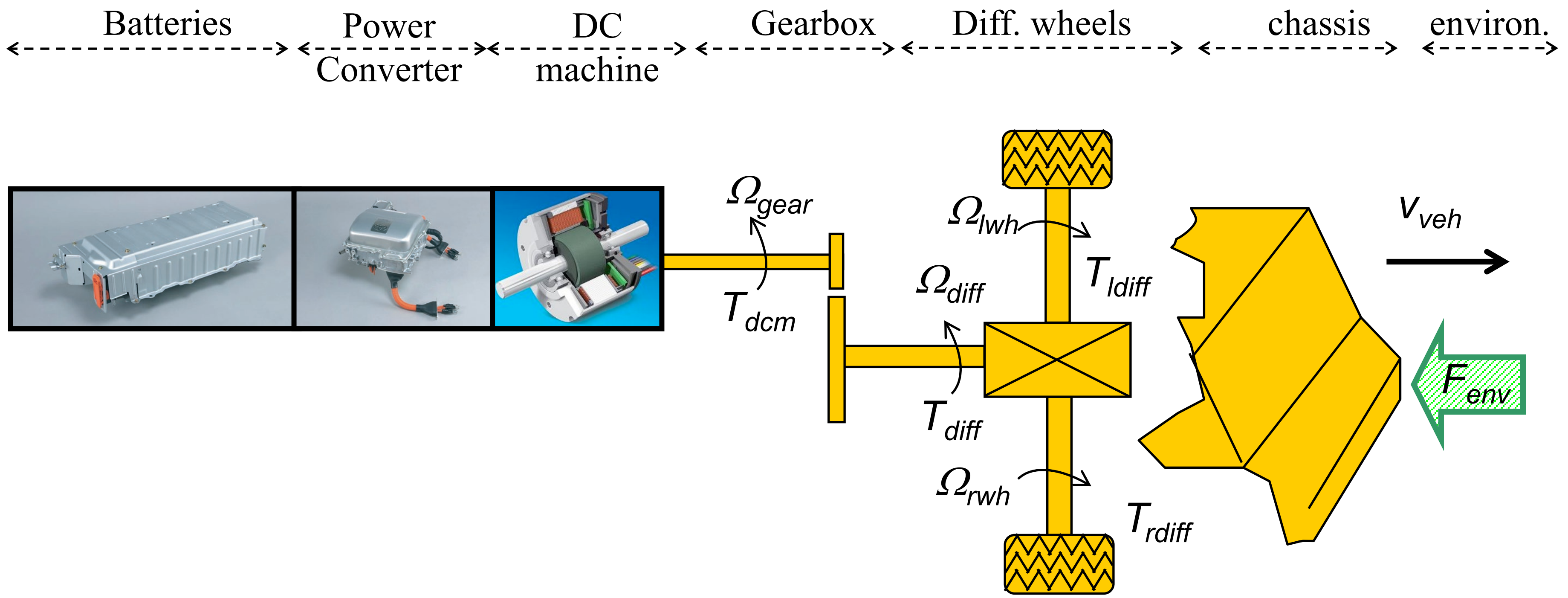


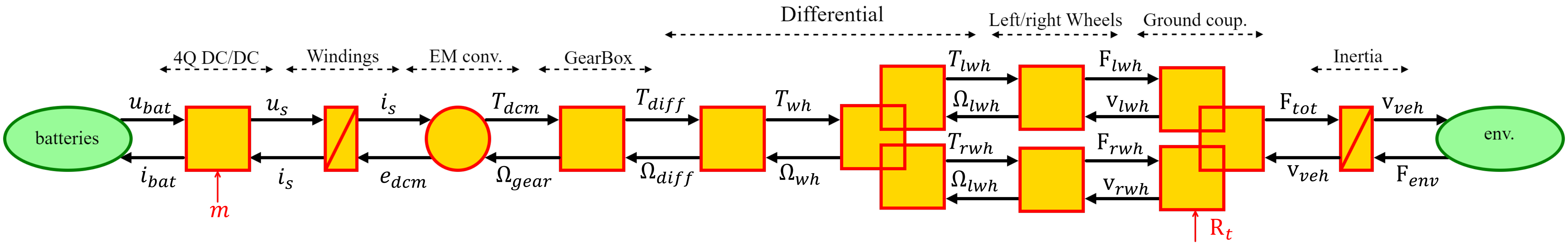
- All subsystems have been modelled and represented
  - They can be associated as far as: IOs for one element are compatible with IOs of the consecutive elements



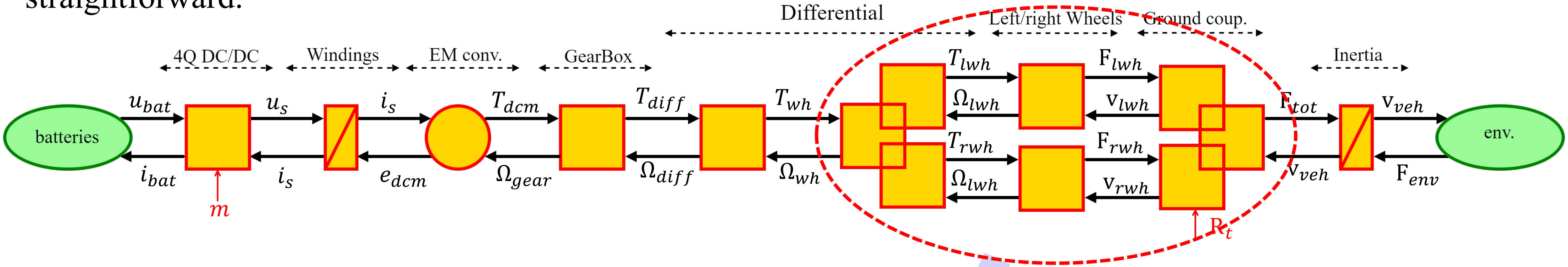
- Structural vs. Functional representation -

EMR'25, Lille, July 2025



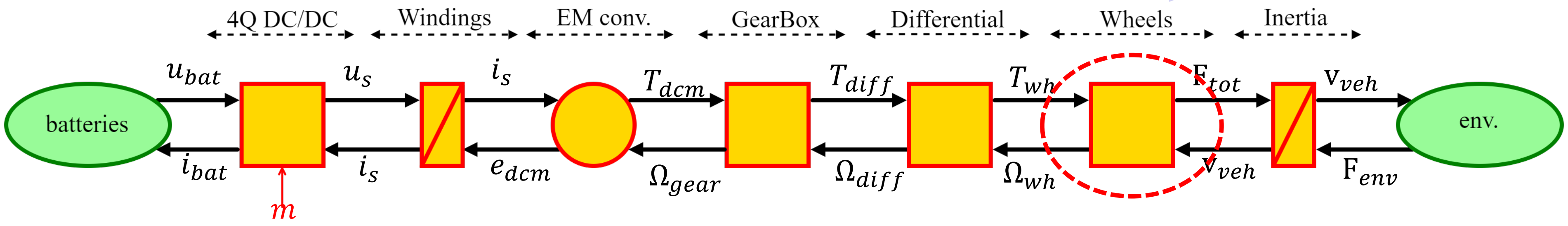


- Simplifications under conditions: Contact wheel/ground with no slip and pneumatic deformation, the vehicle goes straightforward.



If the vehicle drives in a straight line ($R_t = \infty$), an equivalent wheel is sufficient

model reduction

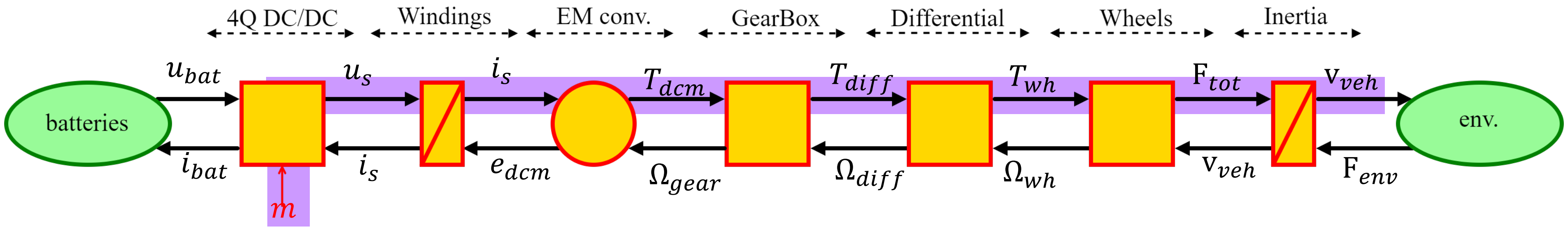


$$\begin{cases} F_{tot} = \dfrac{1}{R_{wh}} T_{wh} \\ \Omega_{wh} = \dfrac{1}{R_{wh}} v_{eh} \end{cases}$$

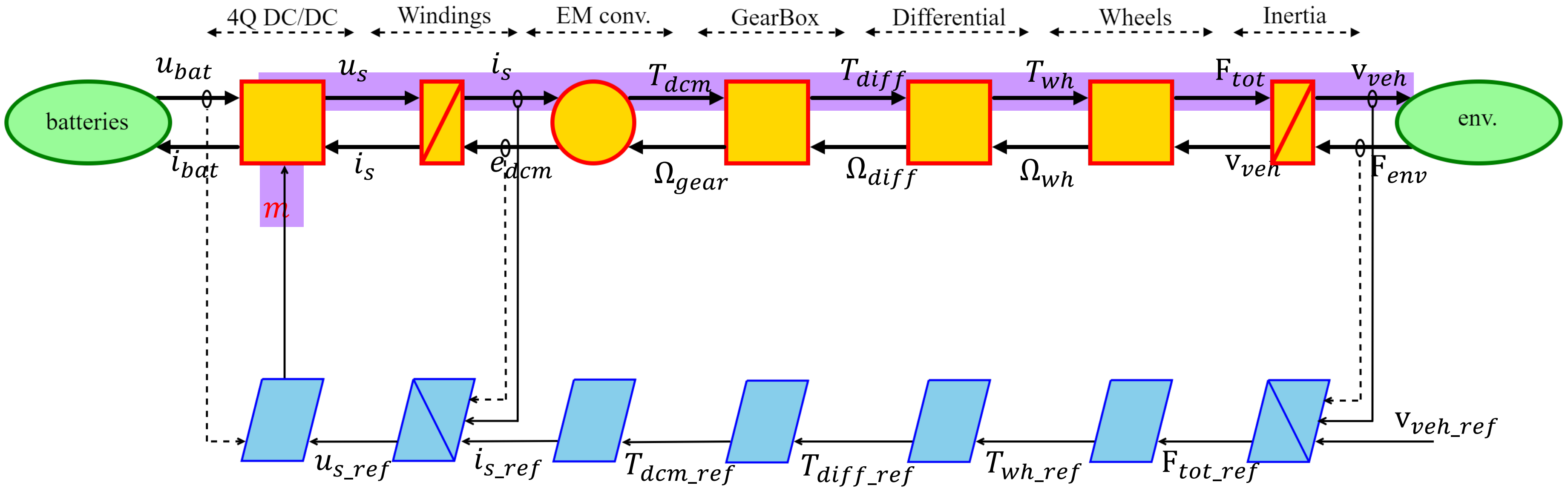
Inversion-based control of the studied EV

- Objectives: control of vehicle speed
- Constraints: DC machine current limitation (Torque limitation)
- Tuning variable: modulation function of the 4Q converter

  – Tuning path: from the tuning variable to the objective through contraints



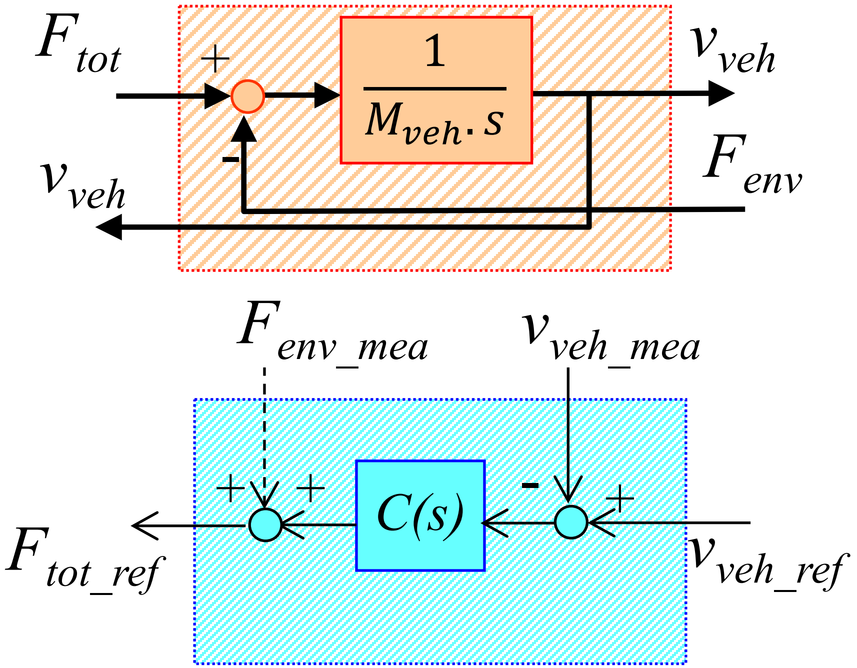
- Inversion of the EMR's éléments, from the objectif to the tuning parameter

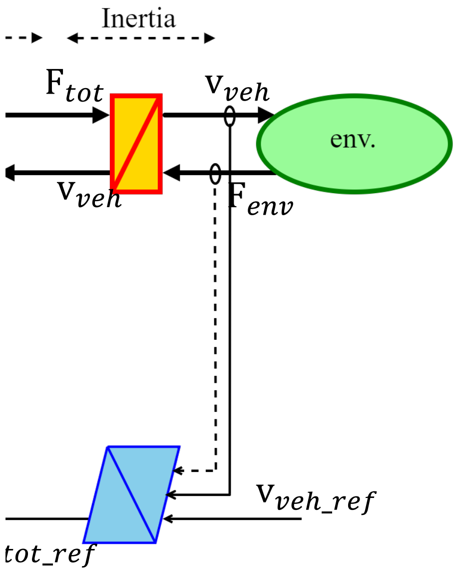


Maximum Control Structure:
- inversion of each element step-by-step
- all variables are supposed to be measurable

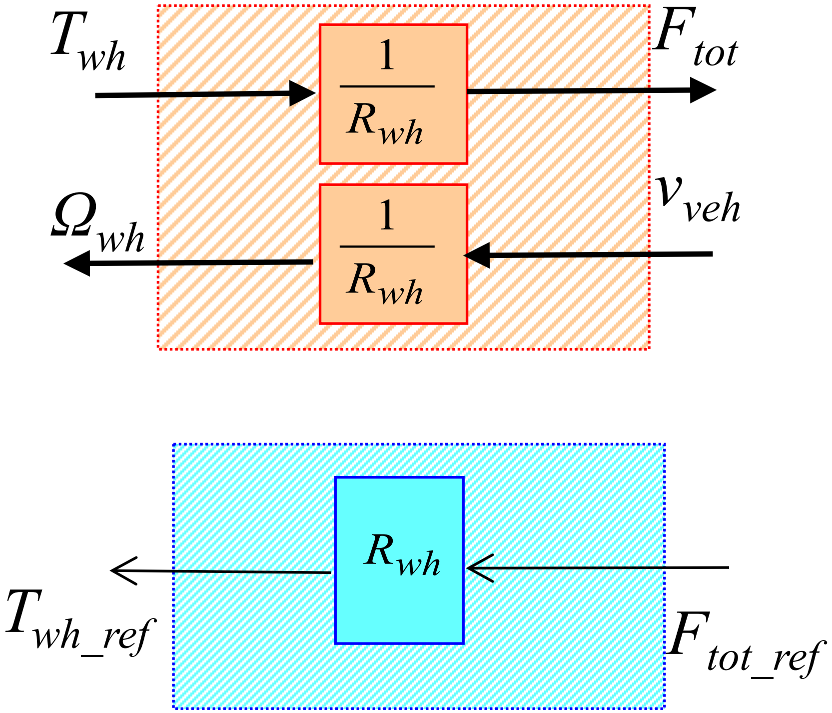
- Direct inversion vs. Undirect inversion -

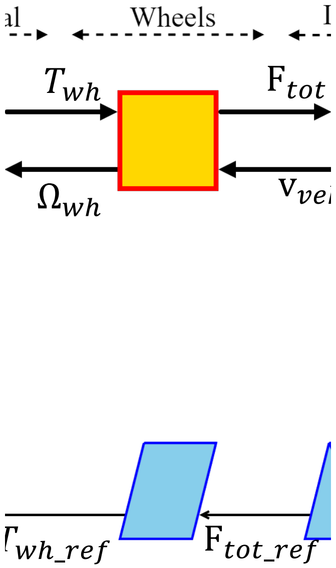
- Undirect inversion: controller for the inversion of accumulation elements



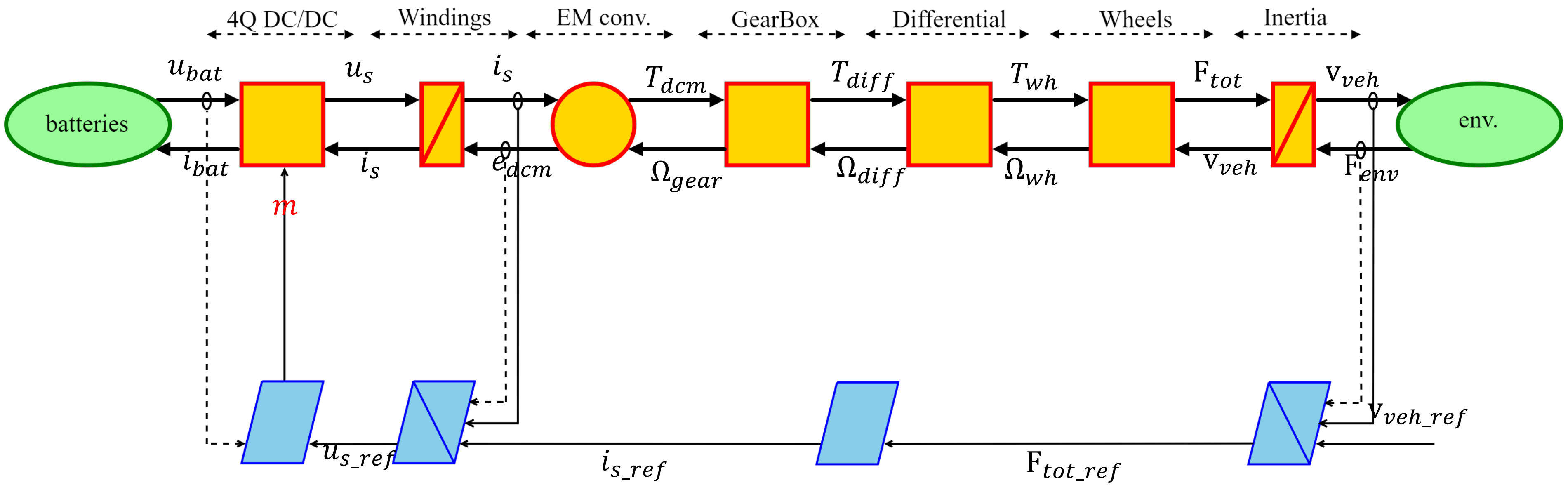


- Direct inversion: pure model inversion



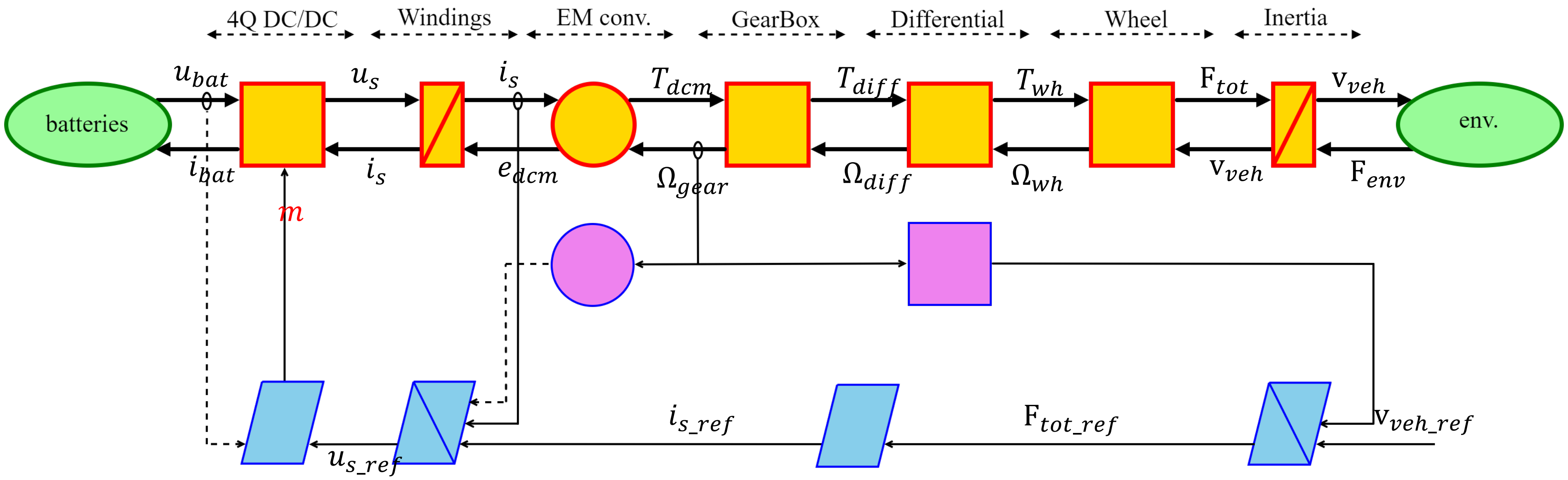


- Merge of all «Direct Inversion» elements that are series connected

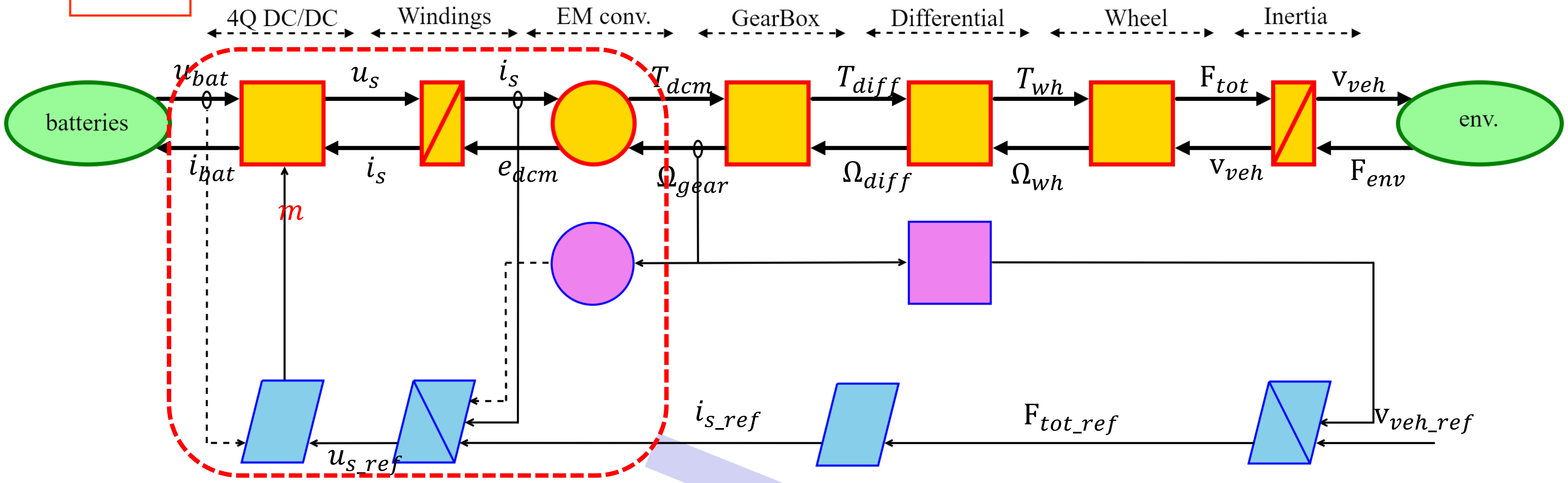


$$F_{tot} = \underbrace{K_{dcm}.K_{gear}.K_{diff}.K_{wh}}_{K}.i_s \Rightarrow \quad i_{s\_ref} = \underbrace{\frac{1}{K_{dcm}.K_{gear}.K_{diff}.K_{wh}}}_{1/K}.F_{tot\_ref}$$

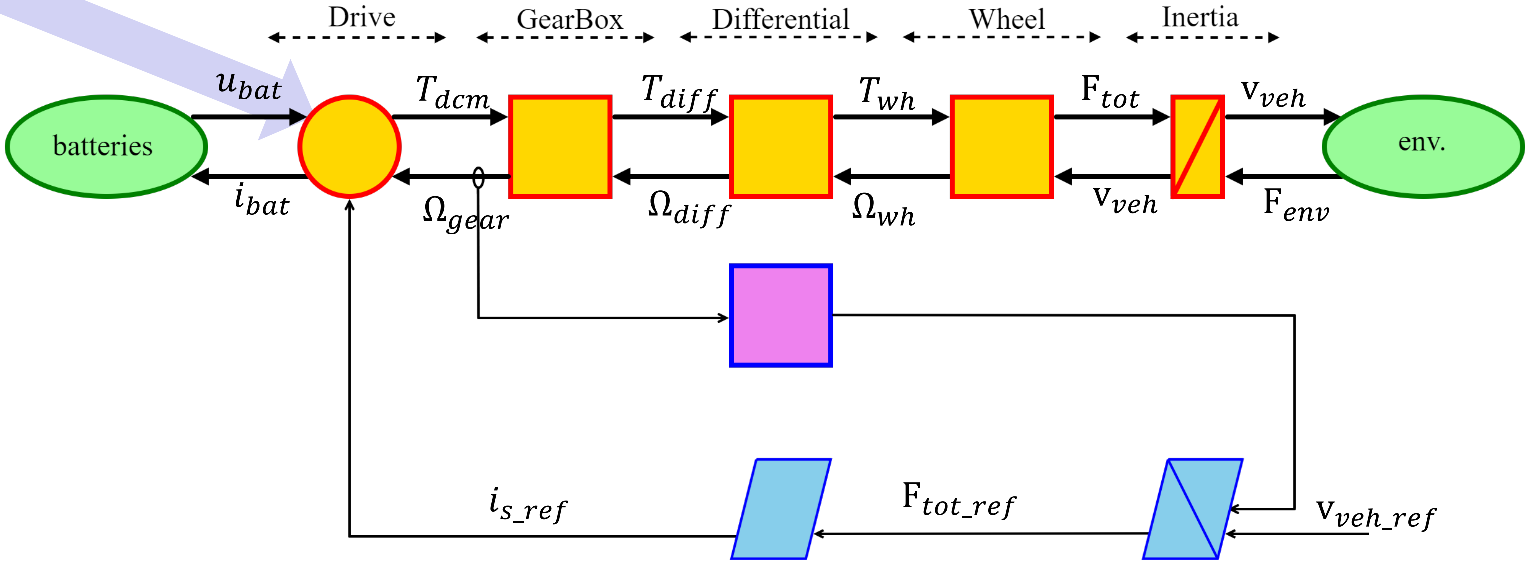
- Check if all measures can be implemented
- For measures that are not physically accessible, check if models behind EMR symbol can be used for estimation,



- Model simplification -



model reduction



- For large simulation time, in case model for the converter and the motor windings require too small time steps.

Conclusion

- Summary-

❖ EMR: powerful approach for describing and representing complex and multiphysic systems

❖ IBC: based on inversion rules, allow a safe design for control design

❖ Case considered in this contribution is based on DC motors, Anyway, such an approach is obviously applicable with benefits to more modern technologies:

- 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: identification of functions linked to sub-systems,
- Inversion-based control, from inversion of EMR functions
- First step for Simulation implementation: in Matlab/Simulink using EMR library (for example)

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Research topics: Power Electronics, Real-time Control, Modelling, Real-time simulation and system design.

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PhD in Electrical Engineering at University of Toulouse (1995)
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