«EMR-based scaling laws for scalable electric vehicle simulation framework»

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Campus of University with Mobility based on Innovation and carbon Neutrality

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- Outline -

1 Context

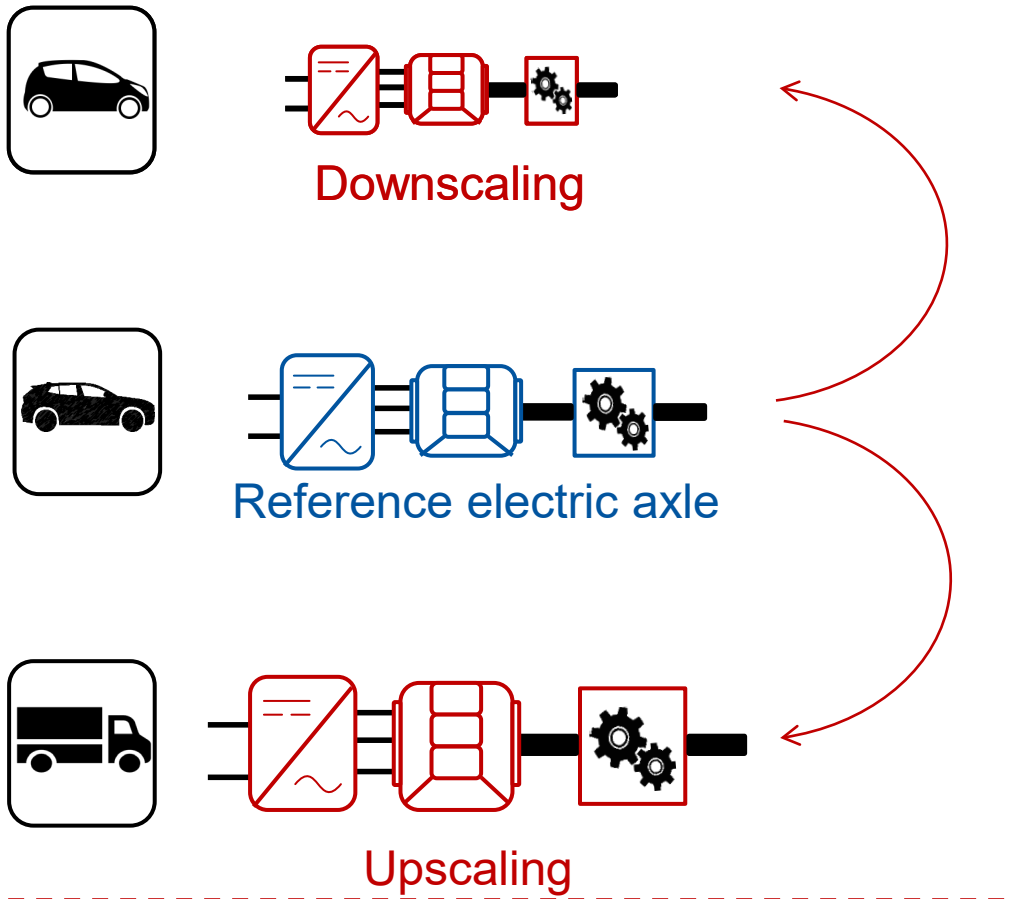
2 EMR-based scaling laws of electric axles

3 Case study: Nissan Leaf

4 Conclusion

-Context: Scalable electrified powertrains-

reference: https://www.renaultgroup.com



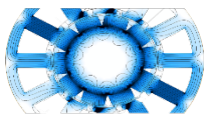
- ❑ Wide range of automotive applications
- ❑ Different requirements, power ratings dimensions,…

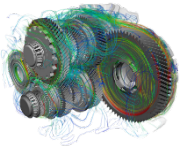
❖ **Objective:**

Develop a tool for transferring/scaling the design solutions of a reference component to promptly derive others for a fast energy consumption assessment

EMR-based scaling laws for scalable electric vehicle simulation framework

-Scalability: what this stands for?-

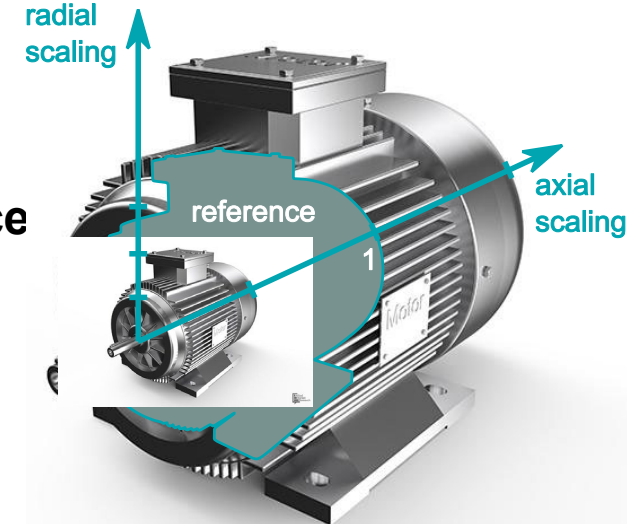




Numerical models
Testing results

Data of a reference component

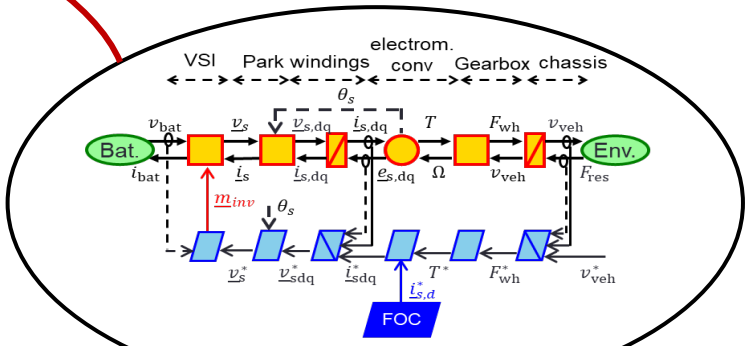
Scaling laws

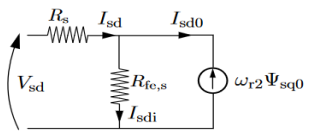


Scaled Data

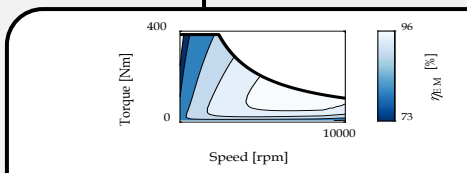
Distinct geometries
Different power rating

System-level simulation
Vehicle model





Analytical models

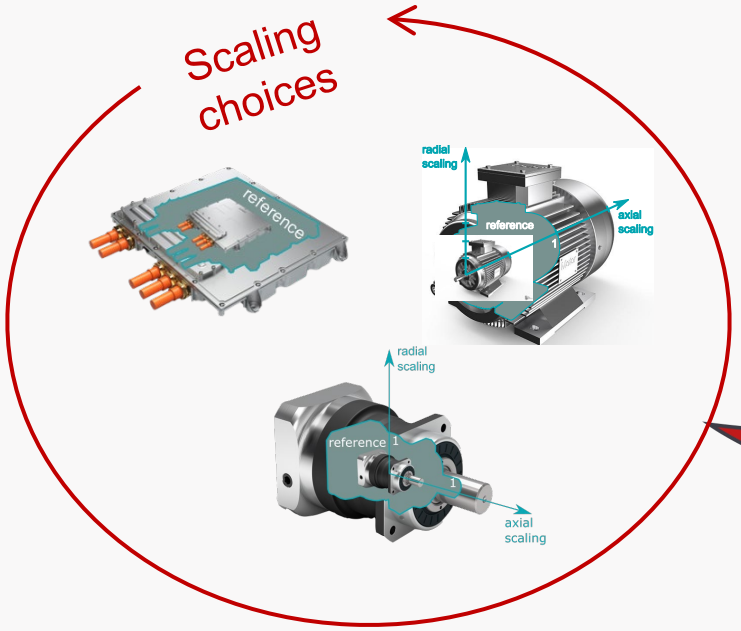


Mapping-based models

EMR-based scaling laws for scalable electric vehicle simulation framework

-Need for a flexible and versatile method to incorporate scaling approach at system-level-

Component scaling

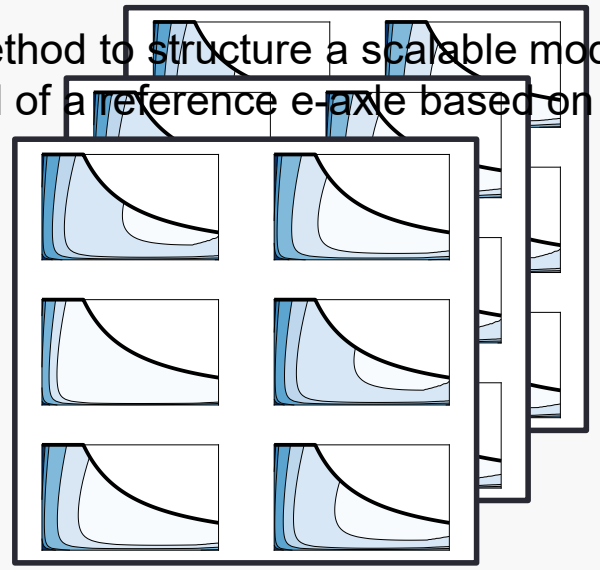


- Considerable number of scaling methods for each component
- Diversity in requirements of automotive applications

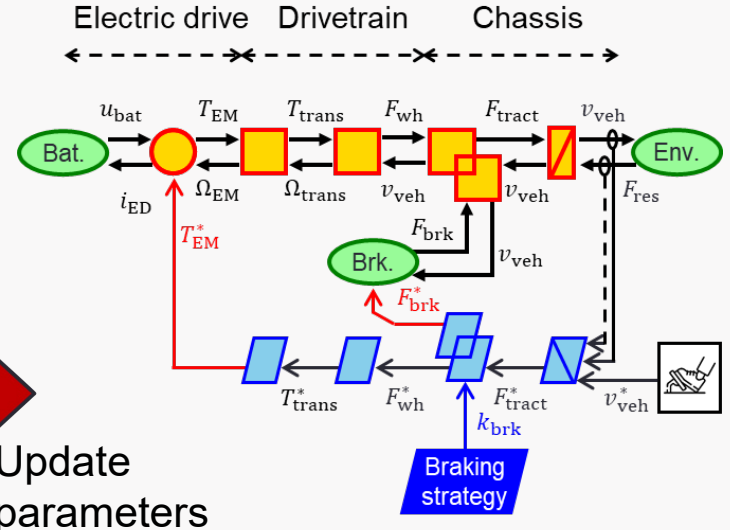
Post-processing phase

- Re-compute parameters and re-tune controllers' parameters
- Generate efficiency maps

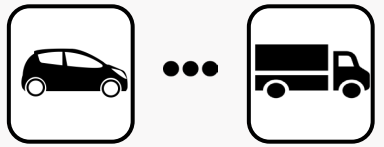
New method to structure a scalable model and control of a reference e-axle based on EMR



System-level simulation framework



Update parameters



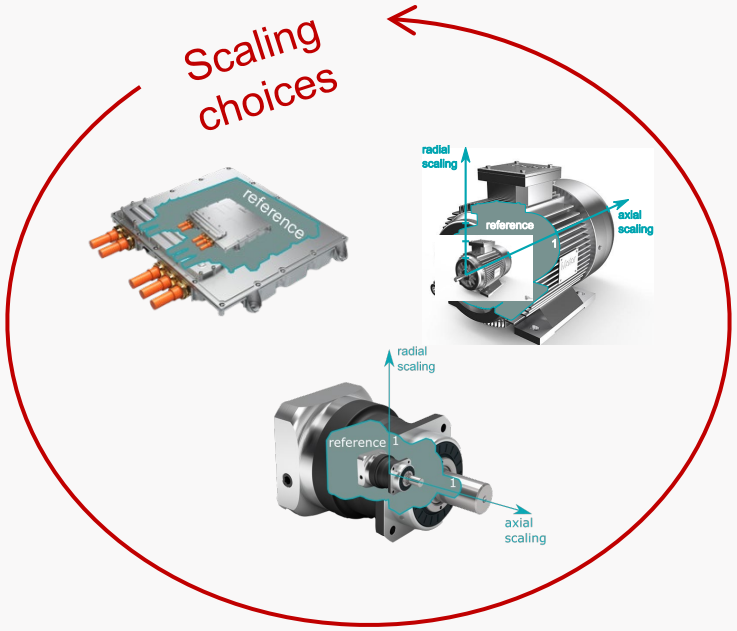
- Powertrain performance assessment for best design selection

How can a scalability approach be integrated?

EMR-based scaling laws for scalable electric vehicle simulation framework

-Need for a flexible and versatile method to incorporate scaling approach at system-level-

Component scaling



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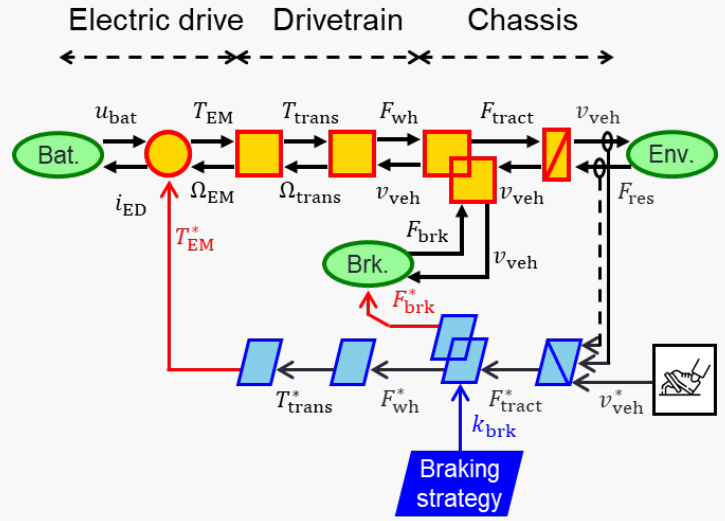
New method to structure a scalable model and control of a reference e-axle based on EMR

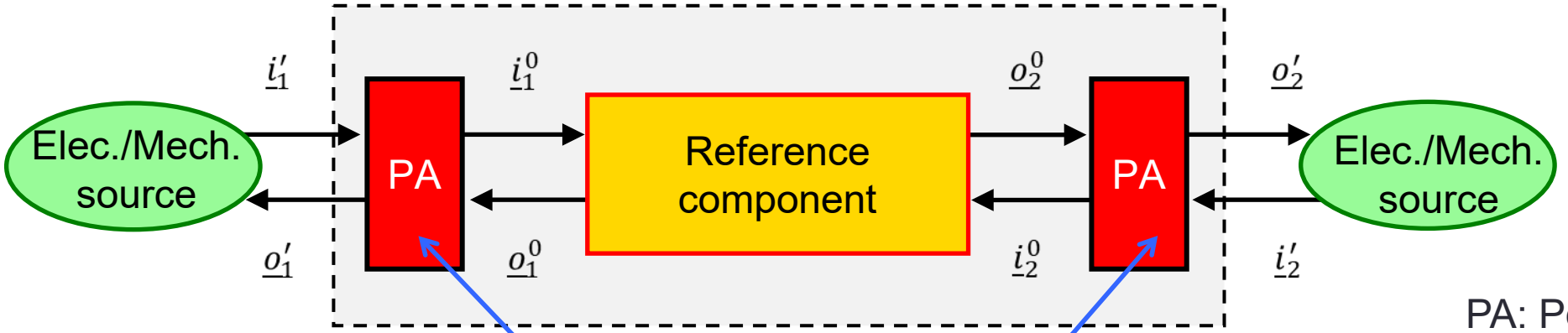
System-level simulation framework



- Powertrain performance assessment for best design selection

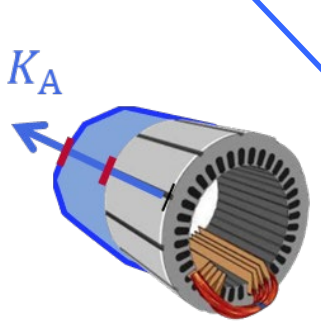
How can a scalability approach be integrated?

"EMR-based scaling laws of electric axles"

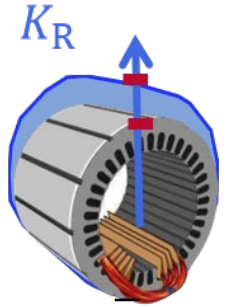


PA: Power Adaptation

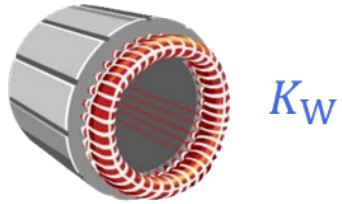
Electric machine scaling



- Axial scaling

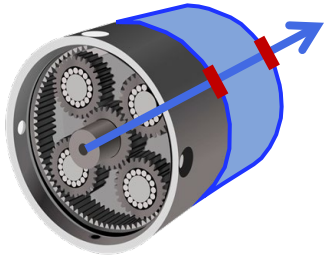


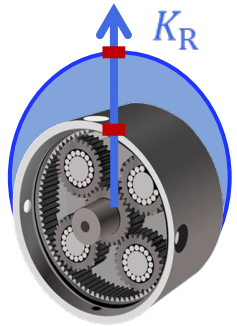
- Radial scaling

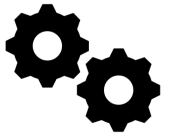


- Rewinding

Gearbox scaling

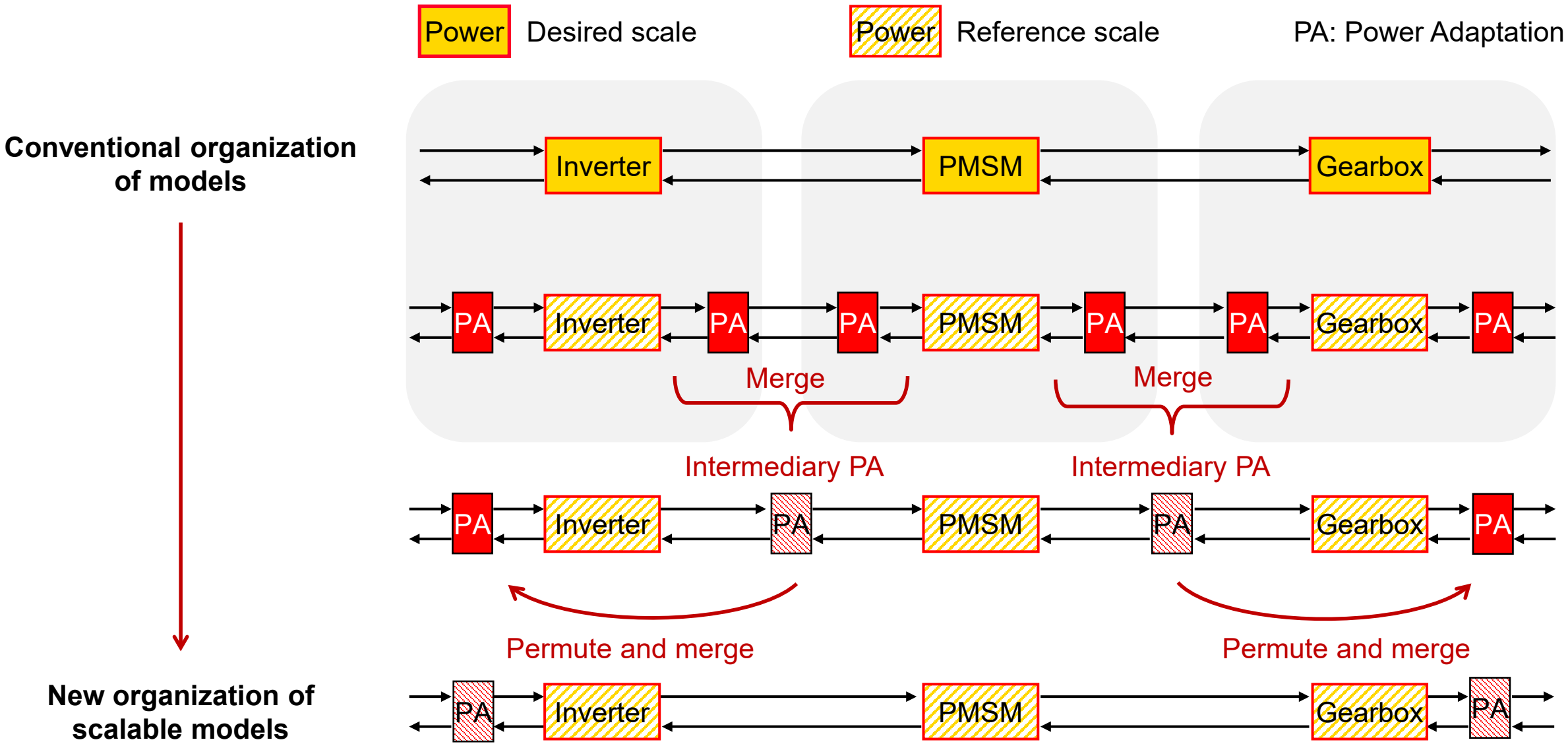






-Gear ratio scaling

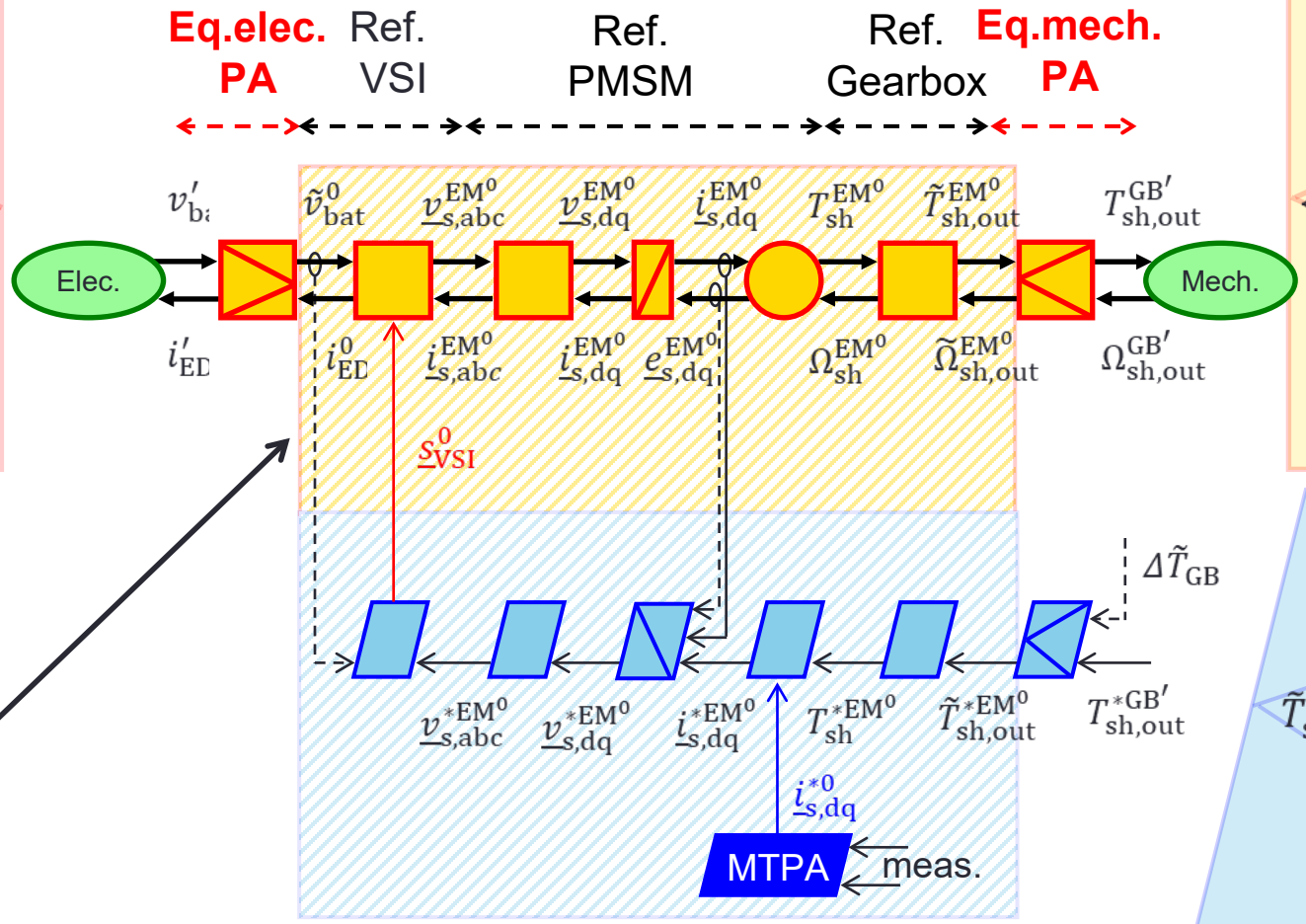
[Lhomme 20]


Power
Desired scale
Power
Reference scale
PA: Power Adaptation
Conventional organization of models
Inverter
PMSM
Gearbox
PA
Inverter
PA
PA
PMSM
PA
PA
Gearbox
PA
Merge
Merge
Intermediary PA
Intermediary PA
PA
Inverter
PA
PMSM
PA
Gearbox
PA
Permute and merge
Permute and merge
New organization of scalable models
PA
Inverter
PMSM
Gearbox
PA

-EMR-based scaling laws of electric axle-

$$\begin{cases} \tilde{v}^{0}_{\mathrm{bat}} = v'_{\mathrm{bat}} - \dfrac{\Delta P_{\mathrm{cu}}}{\eta^{0\gamma}_{\mathrm{VSI}} i^{0}_{\mathrm{ED}}} \\ i'_{\mathrm{ED}} = K_{\mathrm{i}}^{\mathrm{PMSM}} i^{0}_{\mathrm{ED}} \end{cases}$$

Scaled electric axle



$$\begin{cases} T^{\mathrm{GB}'}_{\mathrm{sh,out}} = K_{\mathrm{kgb}} K_{\mathrm{T}}^{\mathrm{PMSM}} T^{\mathrm{EM}^0}_{\mathrm{GB,out}} - \Delta \tilde{T}_{\mathrm{GB}} \\ \tilde{\Omega}^{\mathrm{EM}^0}_{\mathrm{sh,out}} = K_{\mathrm{kgb}} \Omega^{\mathrm{GB}'}_{\mathrm{sh,out}} \end{cases}$$

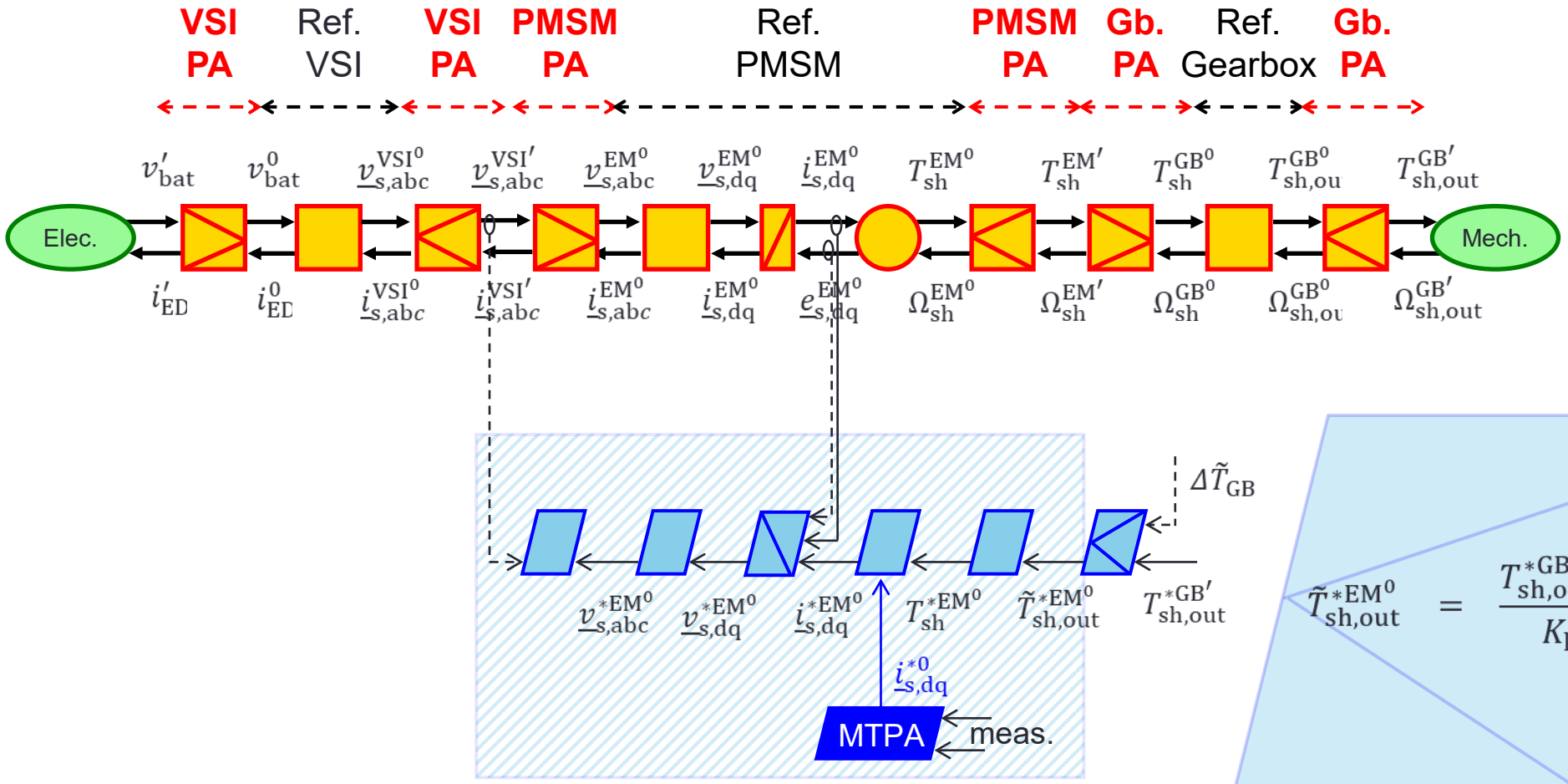
Model of the reference electric axle

Scalable inversion-based control of the reference electric axle

$$\tilde{T}^{*\mathrm{EM}^0}_{\mathrm{sh,out}} = \frac{T^{*\mathrm{GB}^0}_{\mathrm{sh,out}} + \Delta \tilde{T}^{\mathrm{meas}}_{\mathrm{GB}}}{K_{\mathrm{kgb}} K_{\mathrm{T}}^{\mathrm{PMSM}}}$$

[Aroua 21]

-EMR-based scaling laws of electric axle-



Scalable inversion-based control of the reference electric axle

$$\tilde{T}^{*\mathrm{EM}^0}_{\mathrm{sh,out}} = \frac{T^{*\mathrm{GB}^0}_{\mathrm{sh,out}} + \Delta\tilde{T}^{\mathrm{meas}}_{\mathrm{GB}}}{K_{\mathrm{kgb}} K_{\mathrm{T}}^{\mathrm{PMSM}}}$$

[Aroua 21]

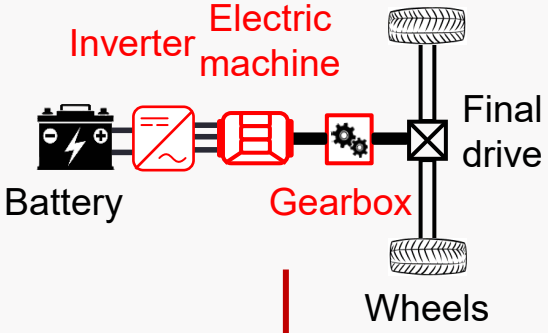
“Case study: Nissan Leaf”

EMR-based scaling laws for scalable electric vehicle simulation framework

-Simulation-based validation of the proposed scalable model-

EMR'25, Lille, July 2025

Study case



Upscaling e-axle

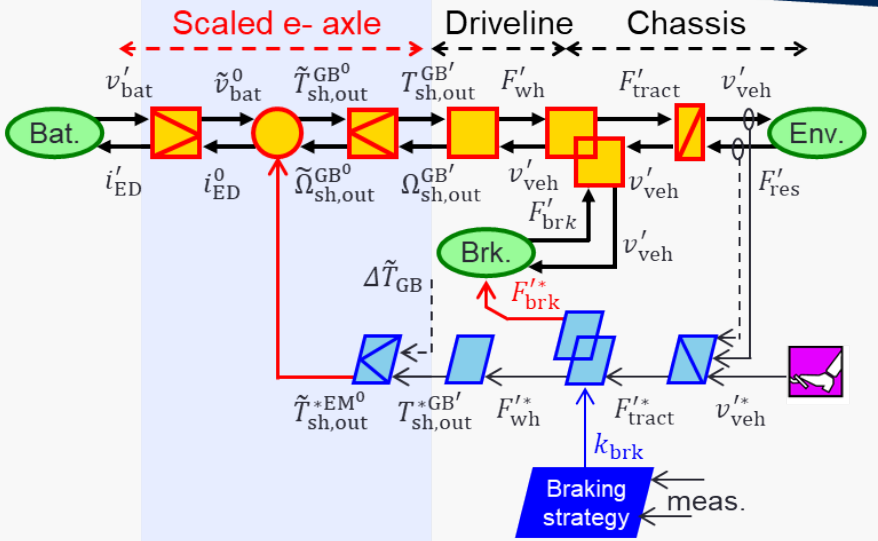
Applied scaling factors

- Power (machine+inverter): 1.33
- Gear ratio scaling: 0.85

Organization of models

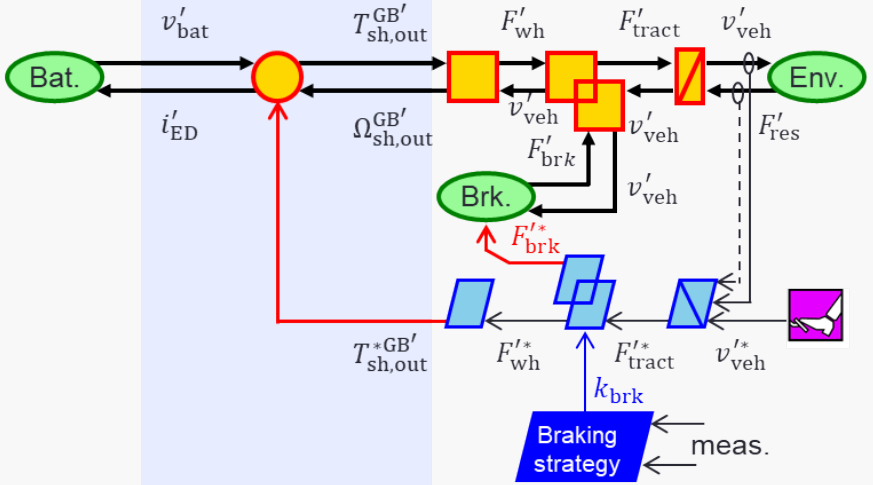
EMR-based scaling laws

Reference efficiency map of electric axle
+
Online adjustment of I/O variables through PA



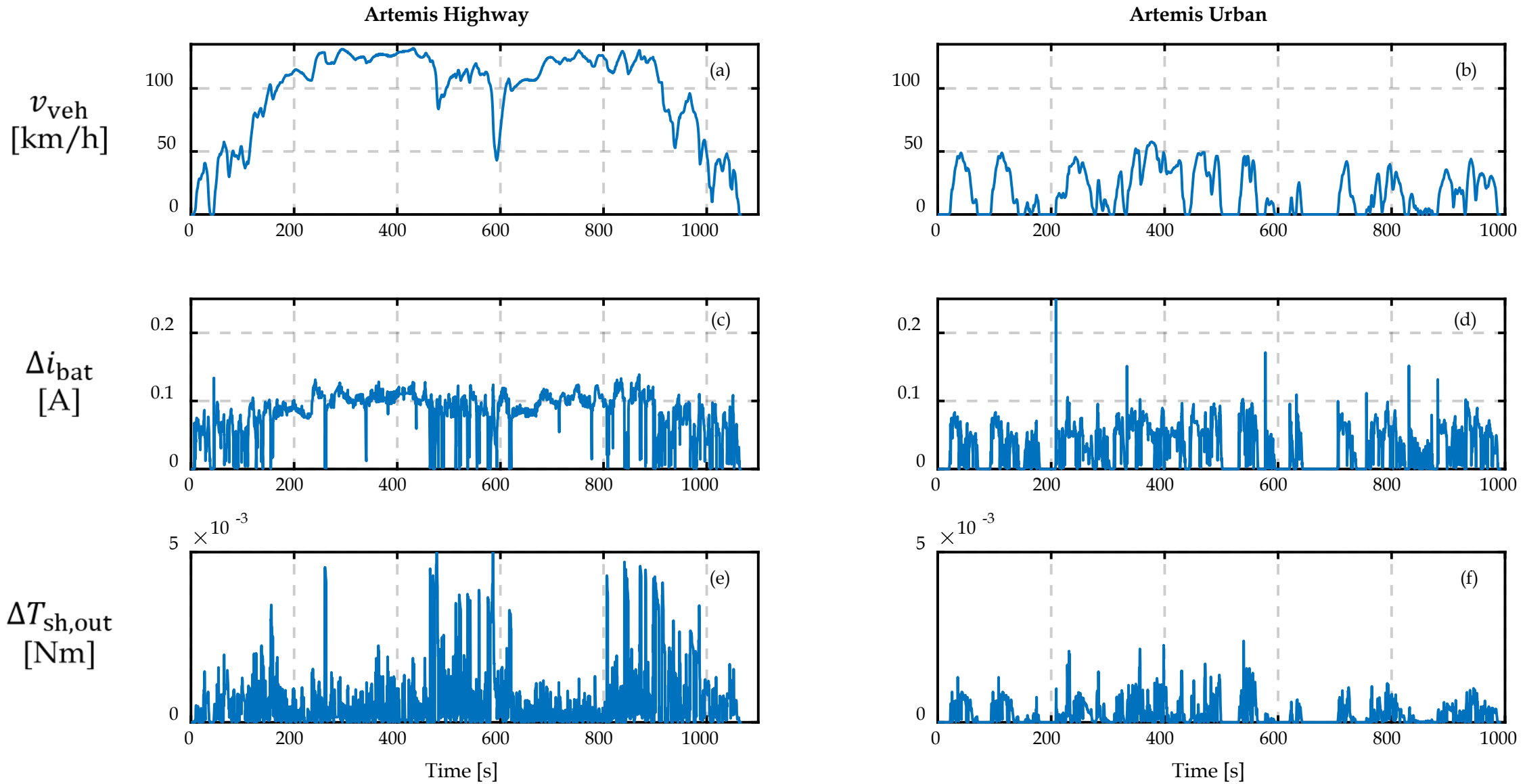
Conventional EMR (no involved PA)

Scaled efficiency map of electric axle Computed offline in post-processing phase



EMR-based scaling laws for scalable electric vehicle simulation framework

-Simulation-based validation of the proposed scalable model-



-Conclusion-

- Scalable and unified simulation framework to analyze the performance of a broad range of EV (model and control reuse)
- Extending the scope of application of the EMR formalism for design assessment using power adaptation elements
- New organization of the scaling laws

➢ Perspectives:

  - Investigation of the applicability of the proposed methodology for Hardware-in-the-loop testing

-References-

[Aroua 21]: Aroua, A., Lhomme, W., Verbelen, F., Bouscayrol, A., & Stockman, K. (2021, October). Inversion-based Control of Scaled PMSM for Battery Electric Vehicles. In *2021 IEEE Vehicle Power and Propulsion Conference (VPPC)* (pp. 1-6). IEEE.

[Aroua 23a]: Aroua, A., Lhomme, W., Verbelen, F., Ibrahim, M. N., Bouscayrol, A., Sergeant, P., & Stockman, K. (2023). Impact of scaling laws of permanent magnet synchronous machines on the accuracy of energy consumption computation of electric vehicles *eTransportation*, *18*, 100269.

[Aroua 23b]: Aroua, A., Defreyne, P., Verbelen, F., Lhomme, W., Bouscayrol, A., Sergeant, P., & Stockman, K. (2023). Power loss scaling laws of high-speed planetary reducers. *Mechanism and Machine Theory*, *189*, 105428.

[Lhomme 20]: Lhomme, W., Verbelen, F., Ibrahim, M. N., & Stockman, K. (2020, November). Energetic macroscopic representation of scalable PMSM for electric vehicles. In *2020 IEEE Vehicle Power and Propulsion Conference (VPPC)* (pp. 1-6). IEEE.