EMR'22
HES-SO Sion
June 2022

EMR'22 Summer School
"Energetic Macroscopic Representation"

Campus of University with Mobility based on Innovation and carbon Neutrality

STeVE

« EMR-based PMSM scaling laws for Electric Vehicles»

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FACULTY OF ENGINEERING AND ARCHITECTURE

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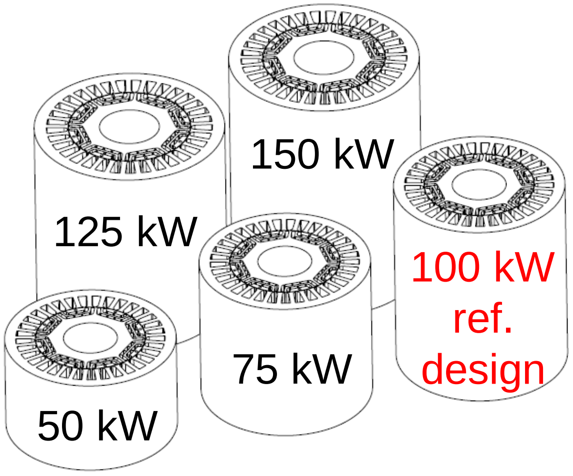
1. **PMSM scaling laws**
2. **EMR-based scaling laws**
3. **Comparison standard EMR vs EMR-based scaling laws**
4. **Conclusion**

reference: https://www.renaultgroup.com

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



❖ A growing interest in scalability for system-level studies:

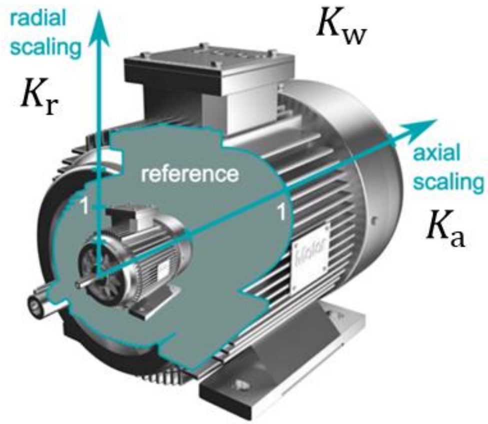
- ➢ Redesign an existing machine design to match the requirement of a new application
- ➢ Fast assessment of different design candidates

❖ **Objective:**

- ➢ Scalable model and control of PMSM using the EMR methodology for different classes of electric vehicle

« Scaling laws for PMSM»

-Scaling laws of PMSM-



- K_a: axial scaling factor (lengthening /shortening of the core length)
- K_r: radial scaling factor (proportional scaling of cross-section)
- K_w: rewinding (changing the number of turns per and parallel coil paths) to fit the voltage requirements

Scaling laws

K_a, K_r, K_w

$$R_s' = \left(\frac{K_w}{K_r}\right)^2 (K_a\, R_{co}^0 + K_r\, R_{ew}^0)$$

$$\underline{L}'_{s,dq} = K_a K_w^2\, \underline{L}^0_{s,dq}$$

Scaling of parameters

$$\psi' = K_a K_r K_w \psi^0$$

$$T' = K_a {K_r}^2 T^0$$

$$I' = \frac{K_r}{K_w} I^0$$

Scaling of properties

$$P'_{cu} = K_a P^0_{cu,co} + K_r P^0_{cu,ew}$$

$$P'_{fer} = K_a K_r^2 P^0_{fer}$$

$$P'_{PM} = K_a K_r^4 P^0_{PM}$$

Scaling of losses

[Stipetic 16]

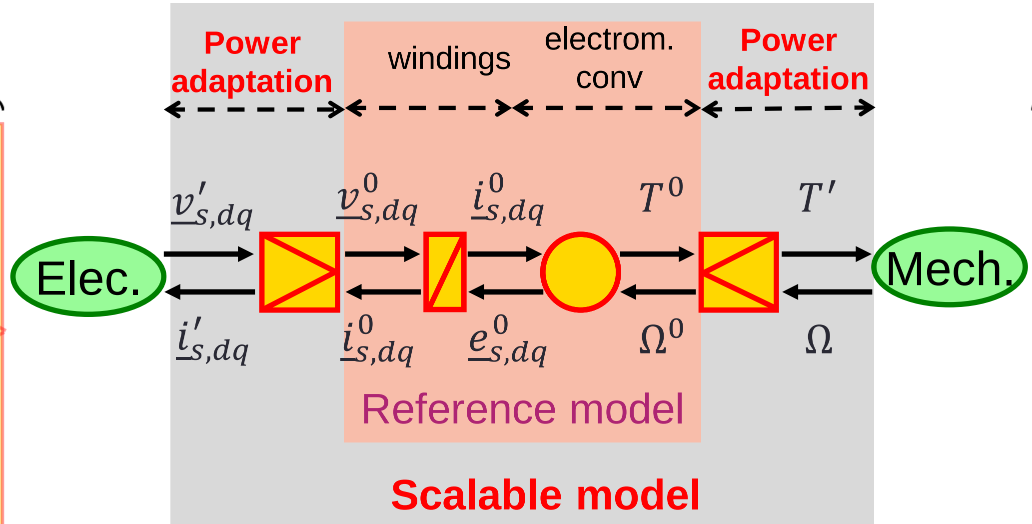
«EMR-based scaling laws»

- EMR-based scaling laws of PMSM -

[Lhomme 20]

Electrical power adaptation

$$\begin{cases} \underline{v}^0_{s,dq} = \dfrac{\underline{v}'_{s,dq}}{K_a K_r K_w} - \Delta_R \underline{i}^0_{s,dq} \\ \underline{i}'_{s,dq} = \dfrac{K_r}{K_w} \underline{i}^0_{s,dq} \end{cases}$$



Mechanical power adaptation

$$\begin{cases} T' = K_T T^0 - \dfrac{\Delta_{PM}}{\Omega} \\ \Omega = \Omega^0 \end{cases}$$

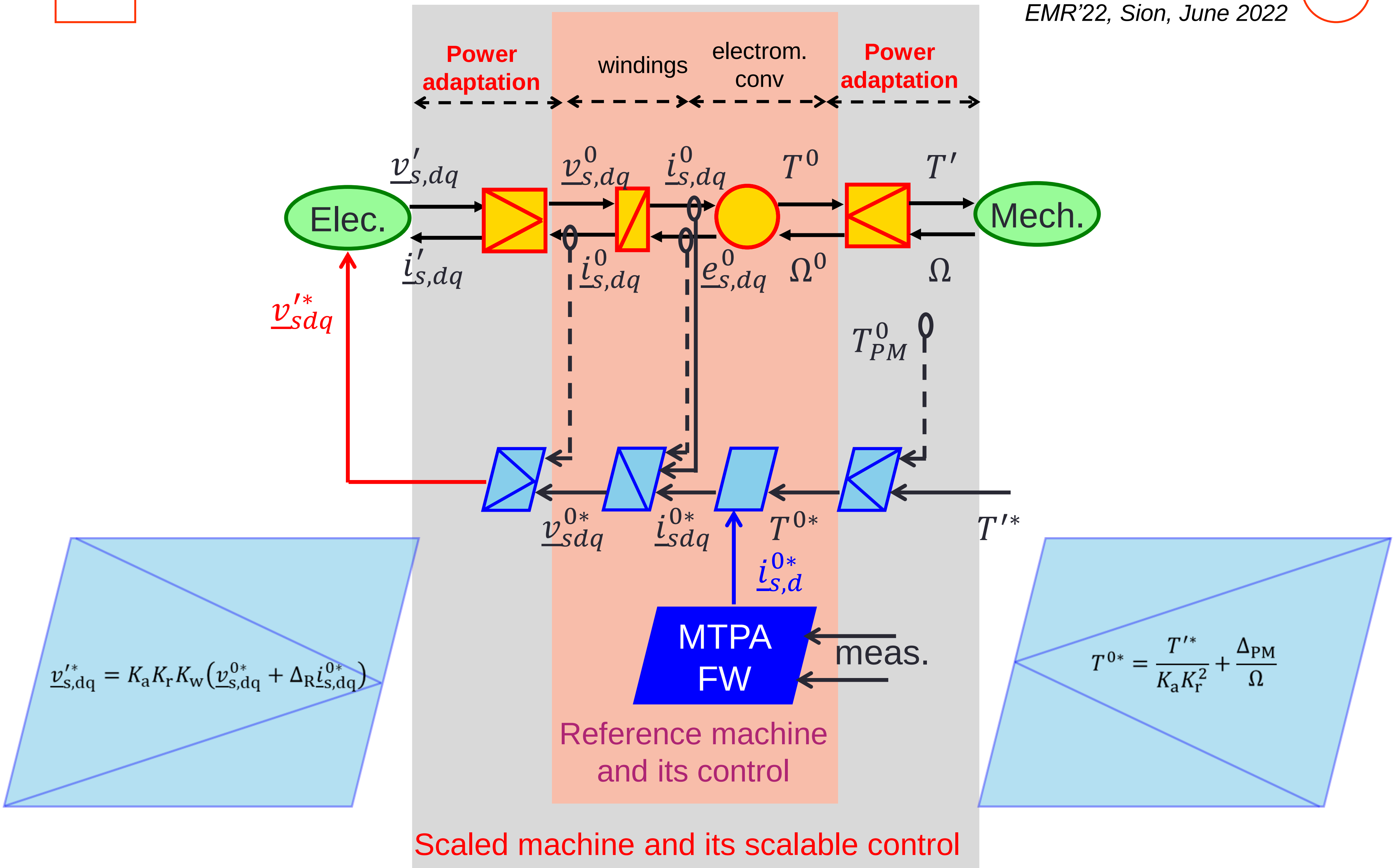
- Fixed reference model
- Scaling only inputs and outputs

$$\Delta_R = \left[R^0_{co} \left(\frac{1}{K_r^2} - 1 \right) + R^0_{ew} \left(\frac{1}{K_a K_r} - 1 \right) \right]$$

$$\Delta_{PM} = (K_r^2 - 1) P^0_{PM}$$

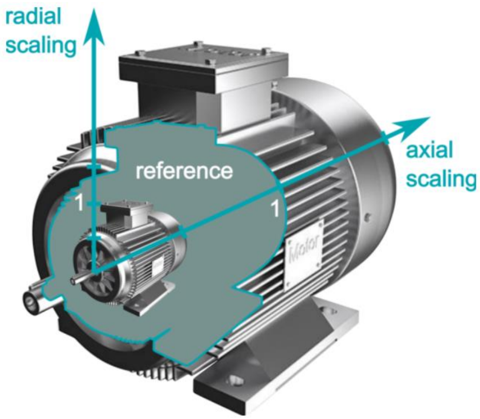
EMR-based scaling laws for EV

-Inversion-based control of the EMR-based scaling laws-



« Comparison of a standard EMR and EMR-based scaling laws »

- Scaled PMSM for battery electric vehicle application-



Component level

⇩

System level - light EV

Tazzari zero of L2EP

Maximum torque [Nm]	70
Rated power [kW]	12.6
Desired torque [Nm]	140
Desired power [kW]	25.2
Axial scaling factor K_a [-]	0.25
Radial scaling factor K_r [-]	2.83
Rewinding scaling factor K_w [-]	1.41

EMR-based scaling laws for EV

- Standard EMR vs EMR-based scaling laws -

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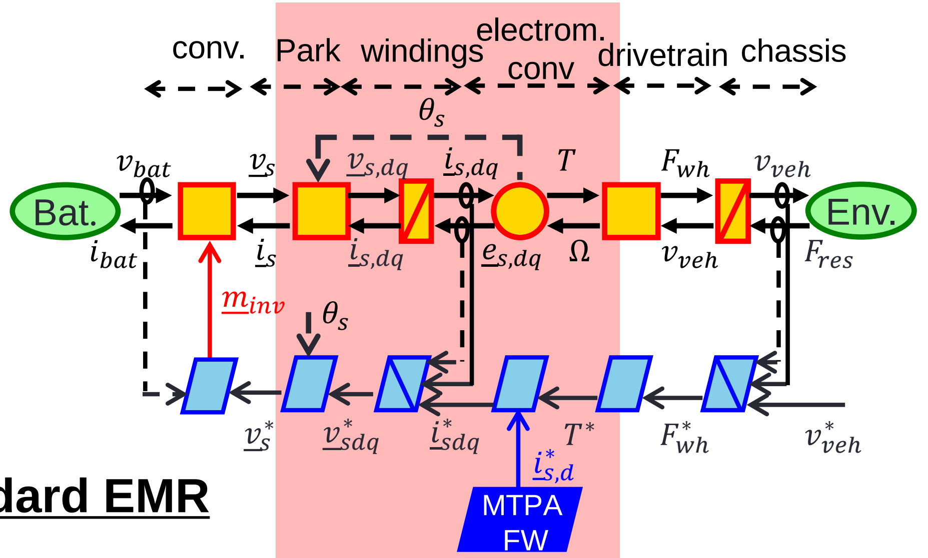
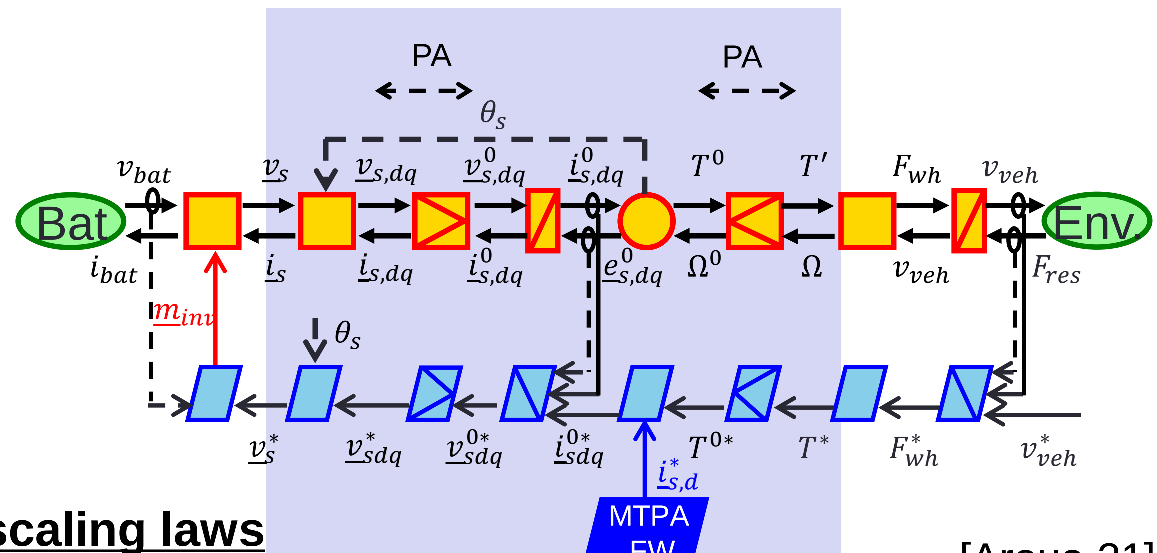


Standard EMR

- New parameters
- Recalculation of losses
- New controllers

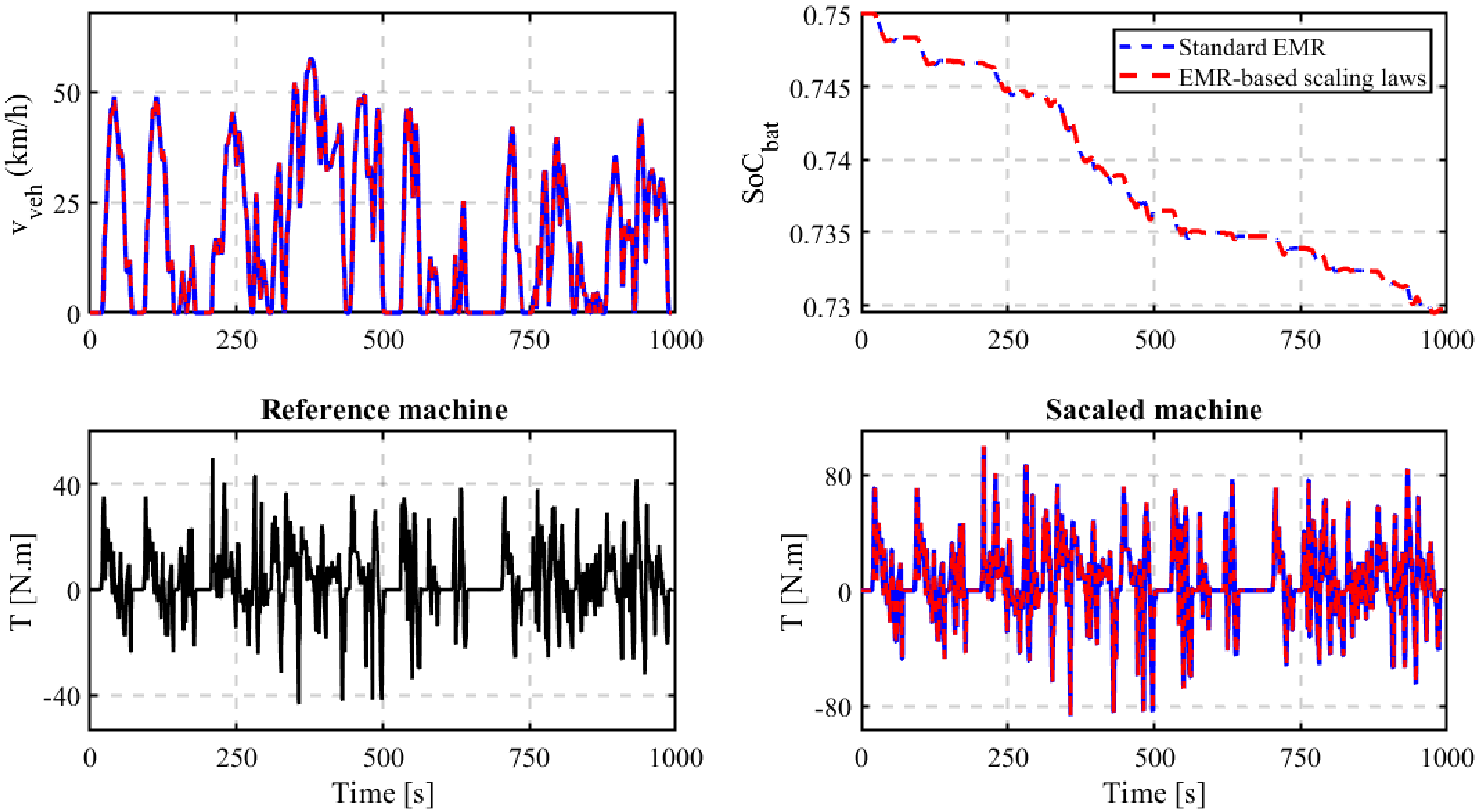
- Model reuse
- Control reuse



EMR-based scaling laws

[Aroua 21]

- Simulation results -



- EMR-based scaling laws allows:
  - Model reuse (reference model + two power adaptation elements)
  - Control reuse of the reference machine
  - Test of several machine designs for different machine ratings

- Perspectives:
  - EMR-based scaling laws for other components (gearbox, inverter,…)

«References »

- References -

[Aroua 21]: A. Aroua, W. Lhomme, F. Verbelen, A. Bouscayrol, K. Stockman, "Inversion-based Control of Scaled PMSM for Battery Electric Vehicles "2021 IEEE Vehicle Power and Propulsion Conference (VPPC), Gijón, Spain, Oct. 2021

[Lhomme 20]: W. Lhomme, F. Verbelen, M. N. Ibrahim, and K. Stockman, "Energetic Macroscopic Representation of Scalable PMSM for Electric Vehicles ", in *2020 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Gijon, Spain, Nov. 2020, p. 1-6. doi: 10.1109/VPPC49601.2020.9330981

[Stipetic 16]: S. Stipetic, D. Zarko, and M. Popescu, "Ultra-fast axial and radial scaling of synchronous permanent magnet machines ", *IET Electr. Power Appl.*, vol. 10, nº 7, p. 658-666, Aug. 2016, doi: 10.1049/iet-epa.2016.0014

[Verbelen 20]: F. Verbelen, W. Lhomme, A. Aroua, A. Bouscayrol, and P. Sergeant, "Scalable Electrical Variable Transmission model for HEV simulations using Energetic Macroscopic Representation ", in *2020 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Gijon, Spain, Nov. 2020, p. 1-6. doi: 10.1109/VPPC49601.2020.9330957.

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