EMR-based Battery Ageing Model for Electric Vehicles

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1 **Context and objective**

2 **Vehicle and battery model**

3 **Impact of user charging habits on EV Batterie ageing**

Context and objective

Important definitions

- Cell : Battery elementary component

x8

- Module

x24

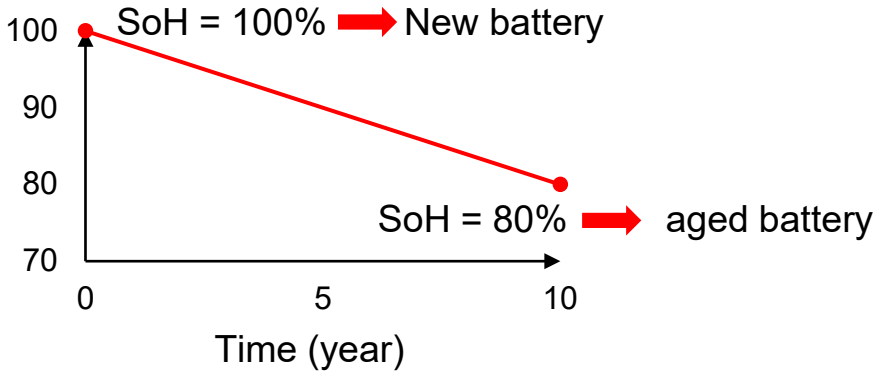
- Battery pack

- State of Charge SoC (%) → Remaining energy

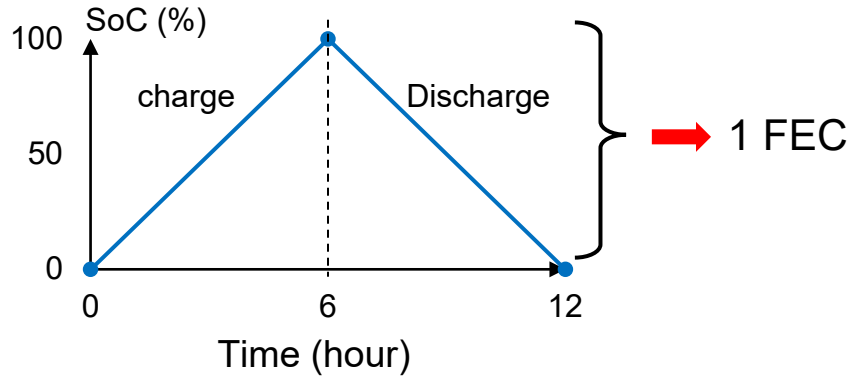
SoC = 0% → Battery empty

SoC = 100% → Battery fully charged

- State of Health SoH (%) → Degradation level

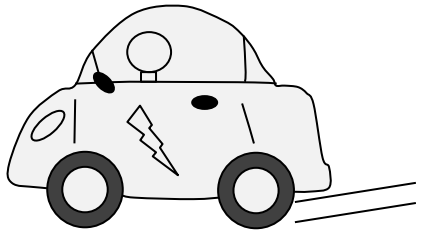


- Full Equivalent Cycle → charge/discharge cycles

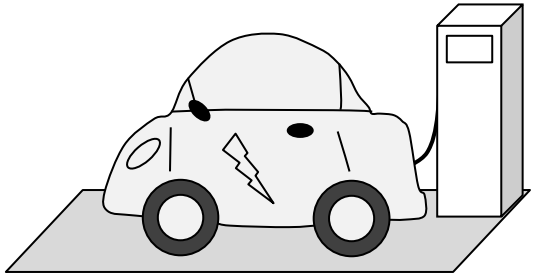


Objective

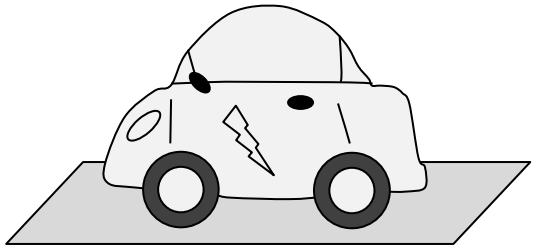
Any EV is used in different modes



Driving



Charging



Parking

Ageing impact factors	SoC variation + Self Heating + Mechanical power	SoC variation + Self Heating + Charger power	SoC Constant + T_{Amb}

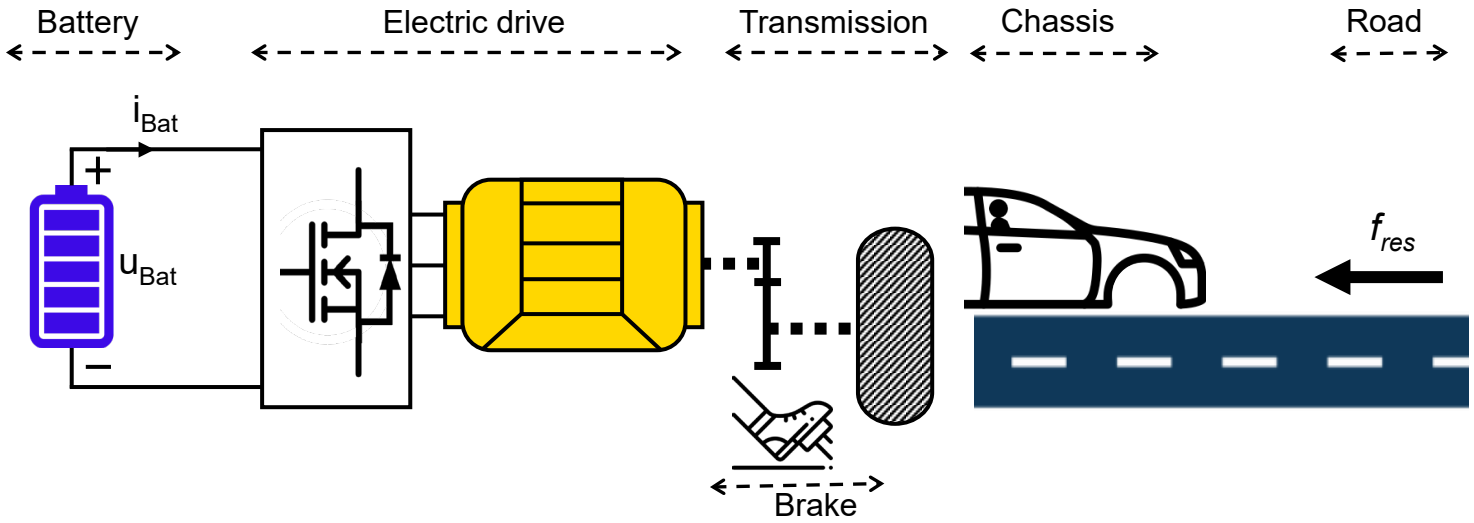
Objective: integrate a battery ageing model into an electric vehicle model

➡ EMR is used as a tool :

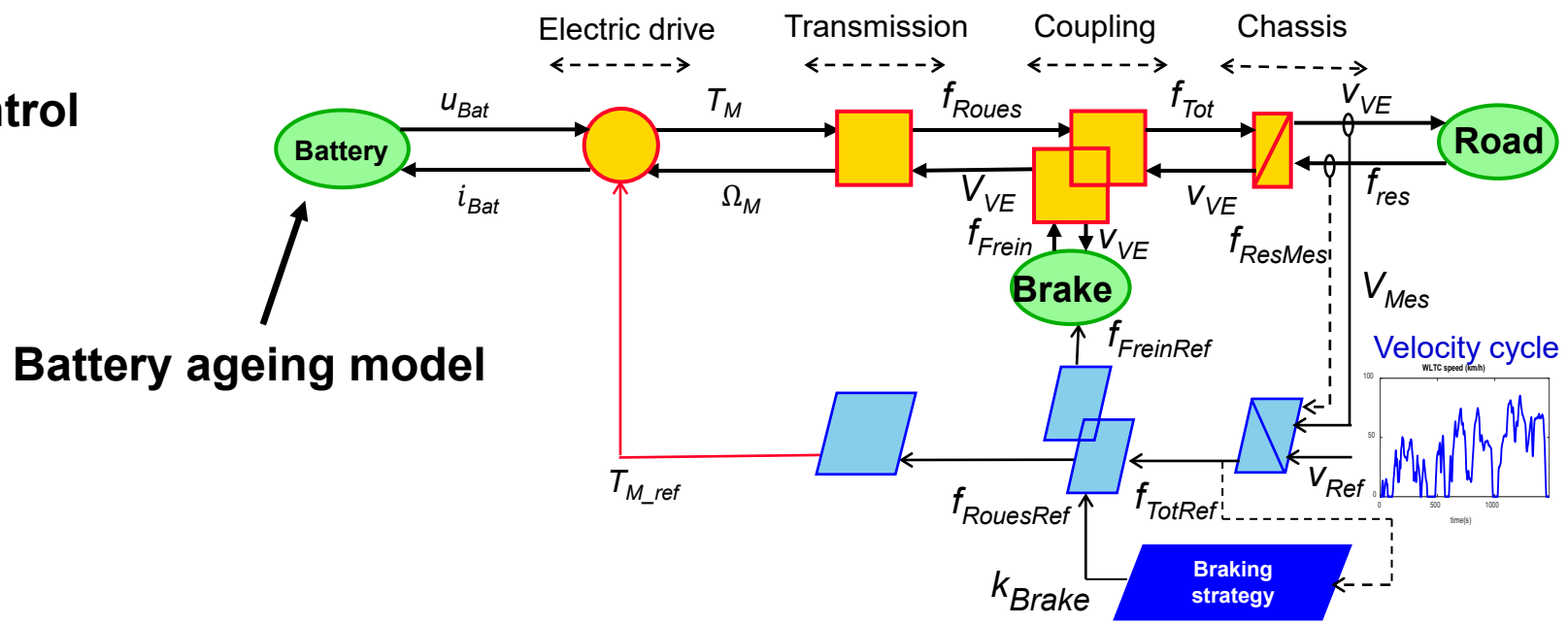
- to couple different domains
- to switch between modes

Global model of the vehicle

Traction model



EMR and control



Battery ageing model

Multi-domain battery and vehicle modelling
Organisation by EMR

Different models to interconnect

Traction model

Nissan Leaf 2018

Battery Modules (x24)

8 modules acquired for characterization

Instrumented to acquire data (SoC, battery current, ...)

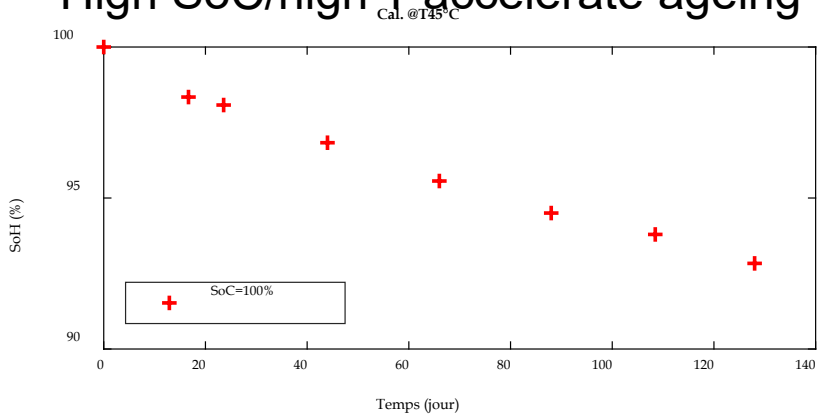
Charger model

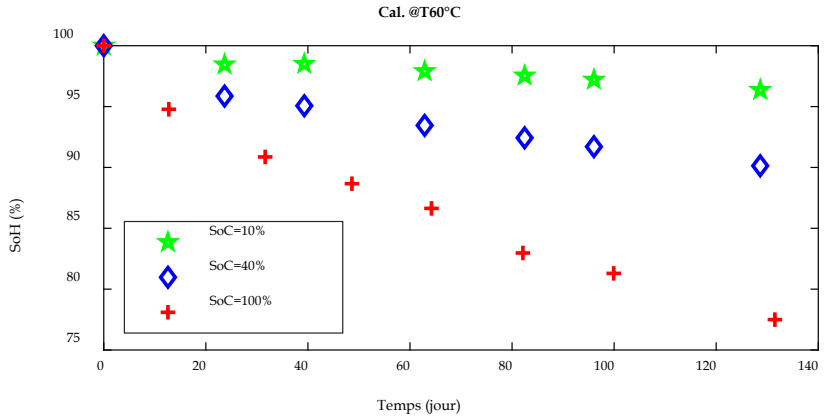
EV-box Charger

Data recordings during charging

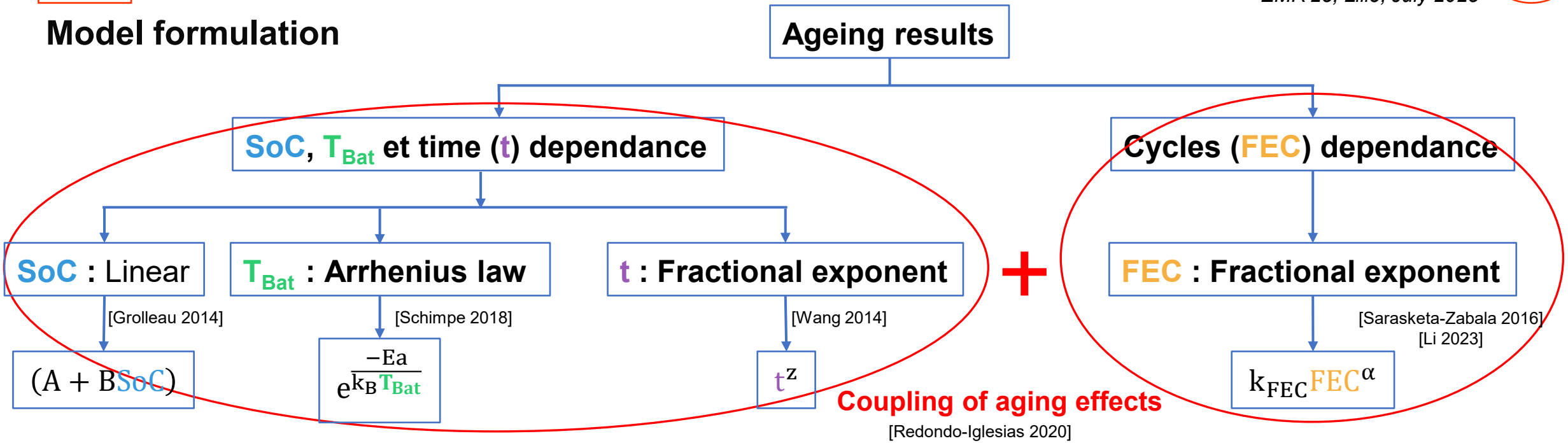
Battery ageing model

High SoC/high T accelerate ageing





Model formulation



Model expression

$$dC_{loss_{t \to t+dt}} = d\left[(A + BSoC)e^{\frac{-Ea}{k_B T_{Bat}}} t^z + k_{FEC} FEC^{\alpha}\right]$$

$$C_{loss_{0 \to t}} = \int_0^t dC_{loss} \quad \rightarrow \quad SoH = 100 - C_{loss_{0 \to t}}$$

SoH : State of Health

Model formulation

Ageing results

SoC, T_{Bat} et time (t) dependance

- **SoC : Linear** — [Grolleau 2014] → $(A + BSoC)$
- **T_{Bat} : Arrhenius law** — [Schimpe 2018] → $e^{\frac{-Ea}{k_B T_{Bat}}}$
- **t : Fractional exponent** — [Wang 2014] → t^z

+

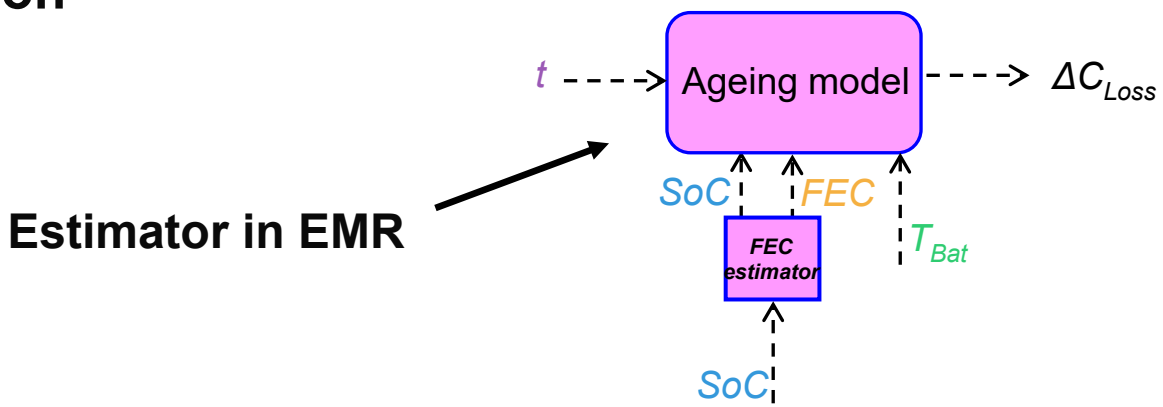
Cycles (FEC) dependance

- **FEC : Fractional exponent** — [Sarasketa-Zabala 2016] [Li 2023] → $k_{FEC} FEC^{\alpha}$

Coupling of aging effects

[Redondo-Iglesias 2020]

Model expression



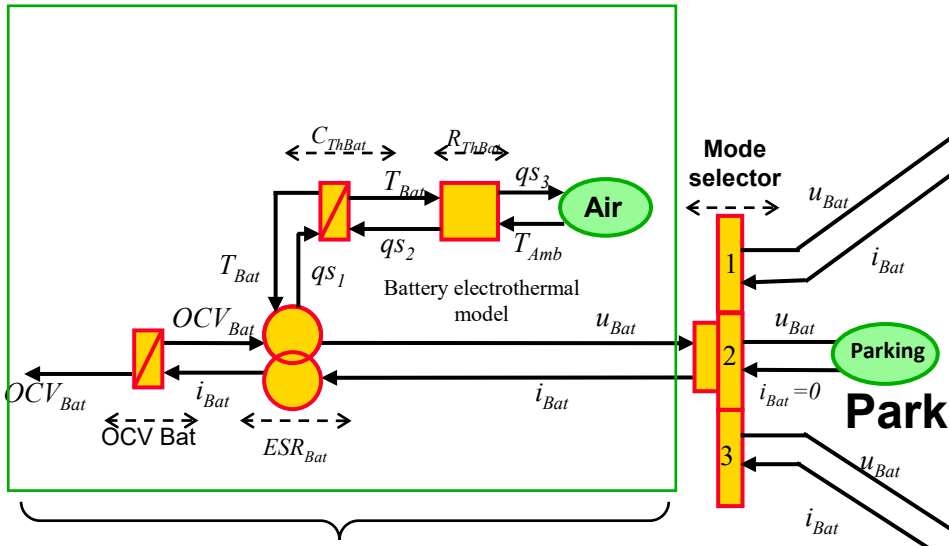
Estimator in EMR

Model organization of the vehicle

Using the Energetic Macroscopic Representation formalism

4 subsystems: battery, traction, charger, parking

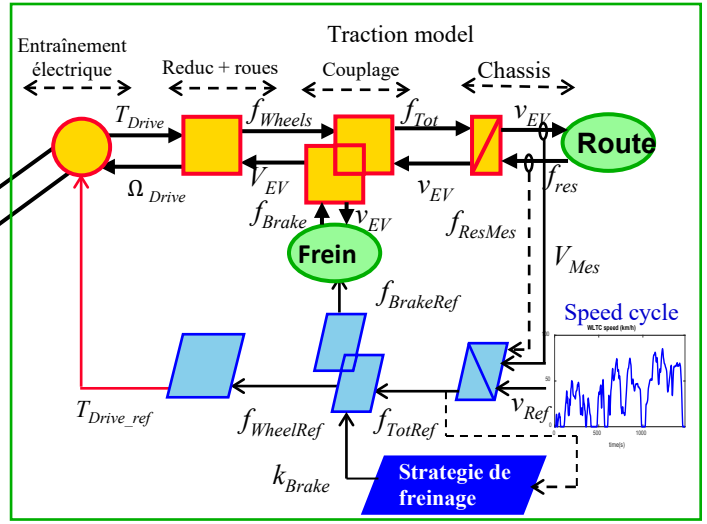
Envison AESC
(Nissan Leaf)



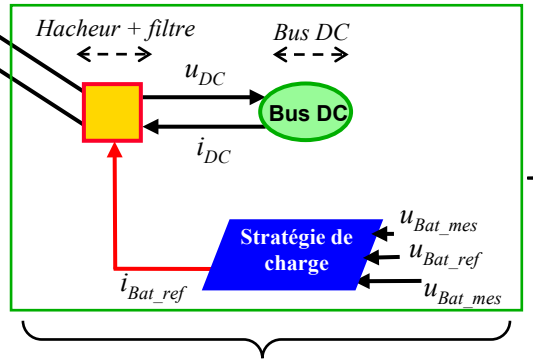
Battery

Park

Traction



Nissan Leaf
2018



Charger

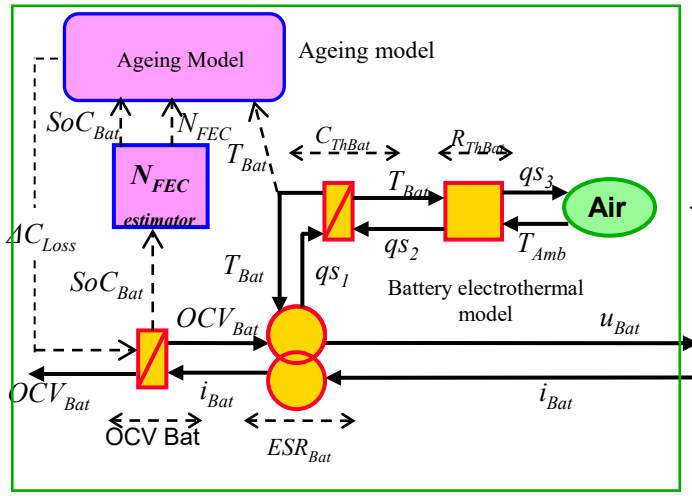
Charger EV-box

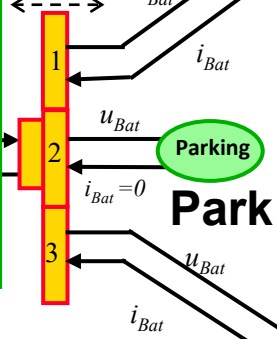
Model organization of the vehicle

Using the Energetic Macroscopic Representation formalism

Integration of the Developed Ageing Model

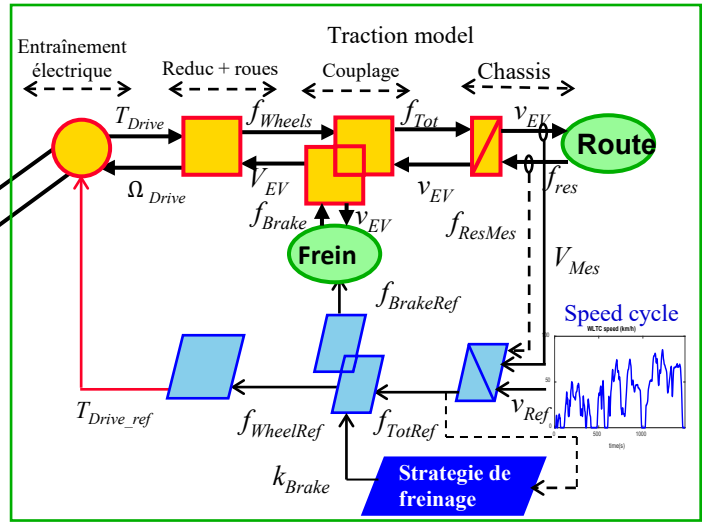
Envison AESC
(Nissan Leaf)



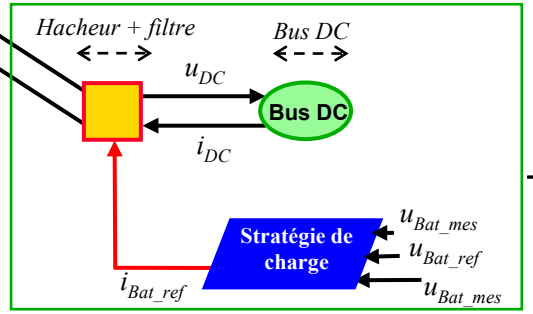


Battery

Traction



Nissan Leaf
2018



Charger EV-box

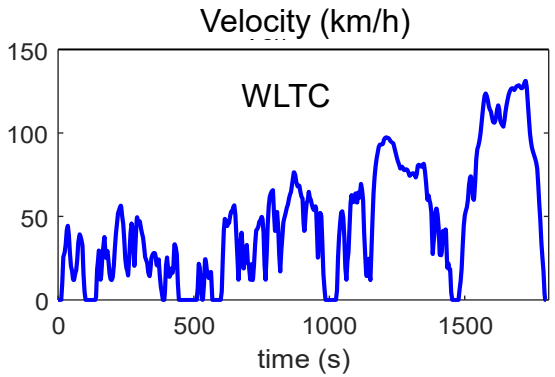
Charger

Impact of user charging habits on EV Batterie ageing

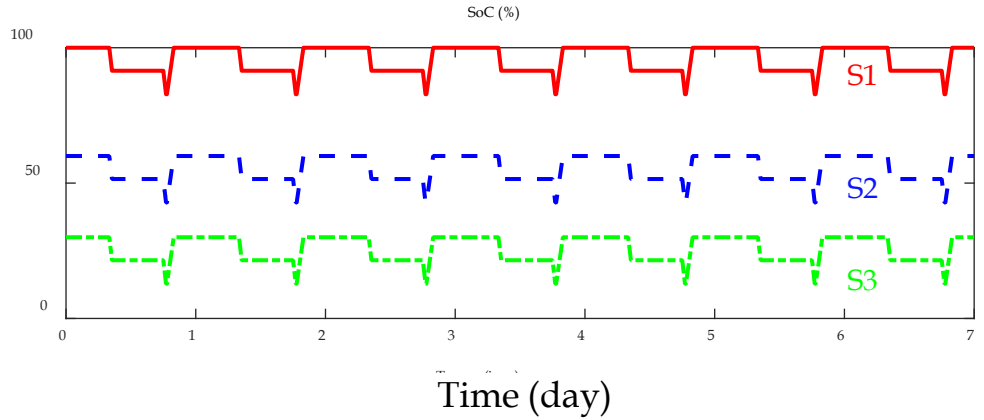
Study of the impact of charging habits

Charging scenarios

Speed cycle: WLTC



S1, S2, S3 → **Daily charge**



Initial SoC

S1 : 100 %

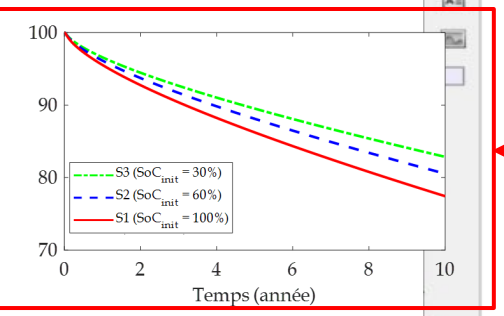
S2 : 60 %

S3 : 30 %

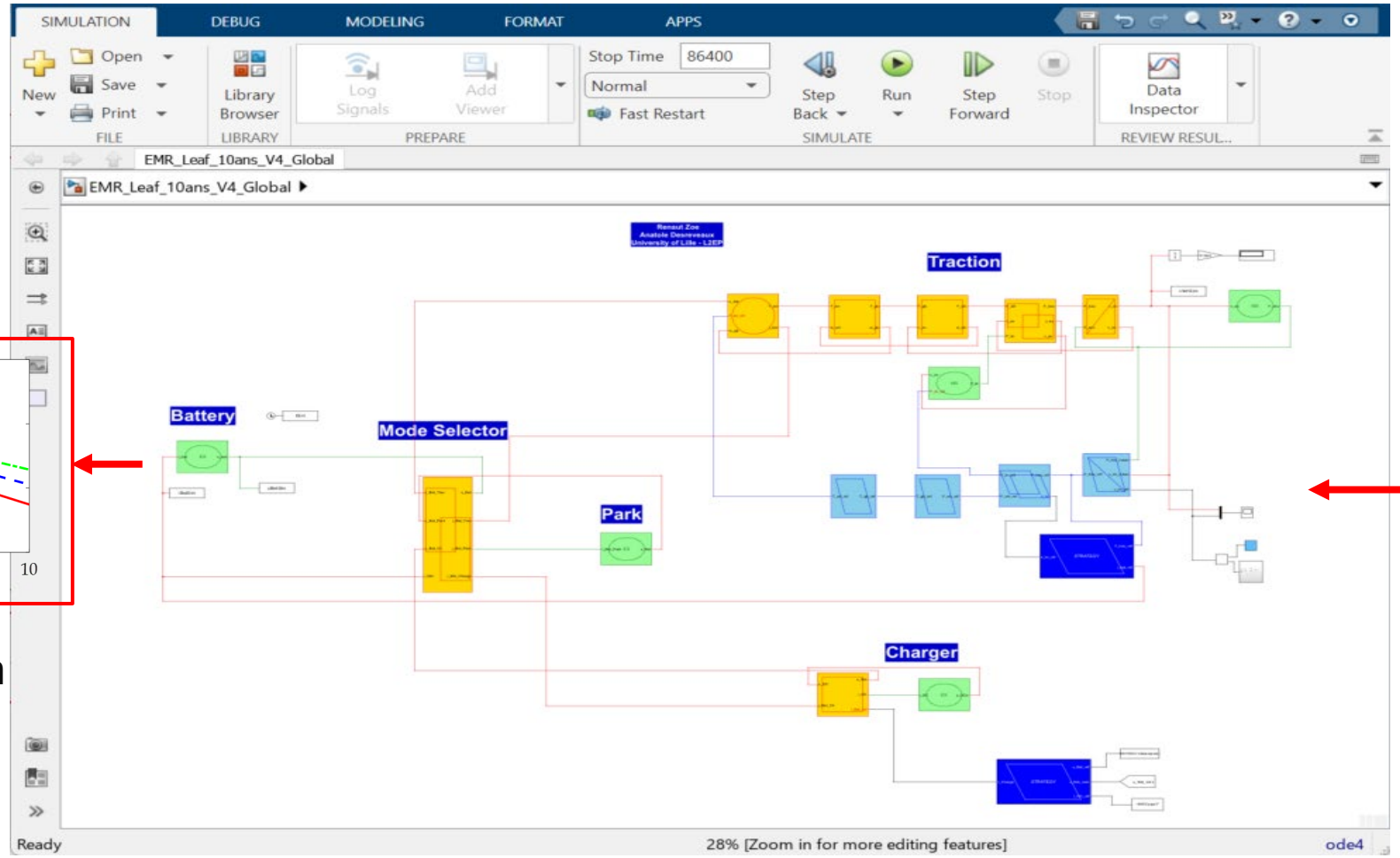
- Same driving distance par day
- Same parking duration

Model organisation in Simulink

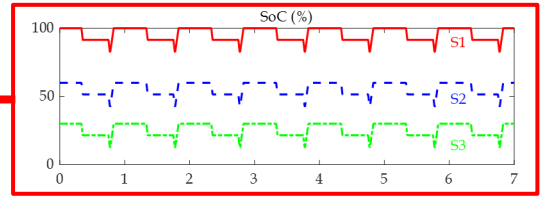
Outputs



SoH (%) evolution



Inputs

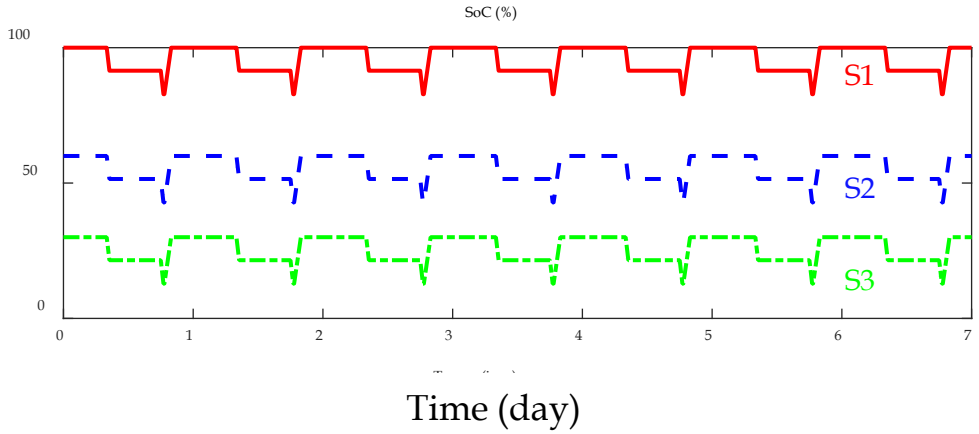


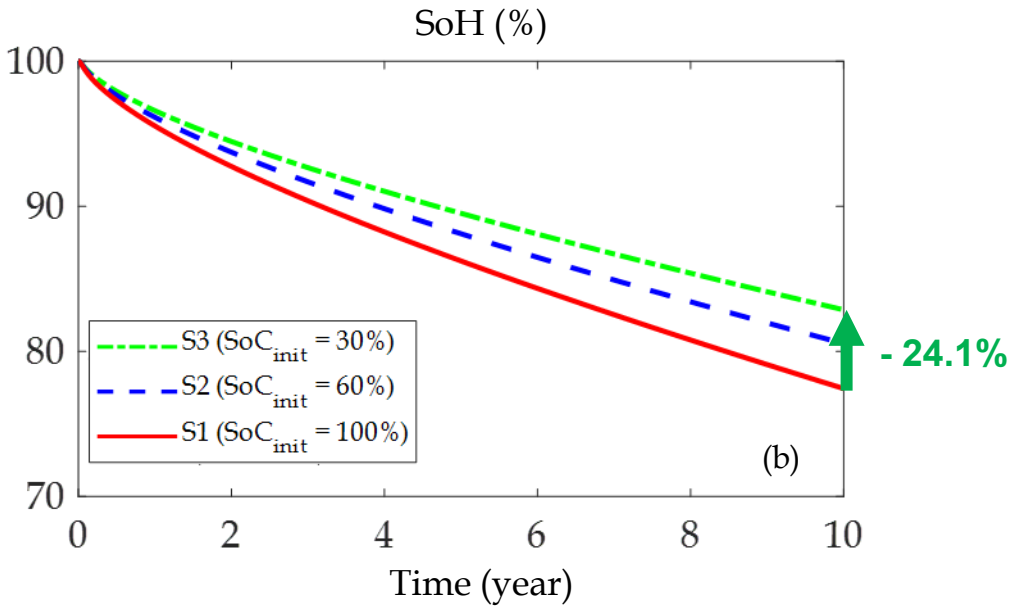
Scenarios

Study of the impact of charging habits

Daily charging scenarios over 10 years

S1, S2, S3 → **Daily charge**





Up to – 24.1% degradation

→ Lower SoC helps to extend the battery's lifespan

[Ndiaye 2024]

Conclusion

EMR

- coupling different vehicle modes
- extend battery model with ageing
- organisation of the simulation

Valuable results obtained from this methodology

- low SoC will increase battery lifetime

Thank you for your attention!

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- References -

[Grolleau et al. 2014] Grolleau, S., Delaille, A., Gualous, H., Gyan, P., Revel, R., Bernard, J., Redondo-Iglesias, E., Peter, J., « Calendar aging of commercial graphite/LiFePO4 cell – Predicting capacity fade under time dependent storage conditions », *Journal of Power Sources*, **255**, pp. 450-458, juin 2014, DOI: 10.1016/j.jpowsour.2013.11.098, ISSN: 03787753

[Ndiaye et al. 2024] Ndiaye, A., German, R., Bouscayrol, A., Gaetani-Liseo, M., Venet, P., Castex, E., « Impact of the User Charging Practice on the Battery Aging in an Electric Vehicle », *IEEE Transactions on Vehicular Technology*, **73**(4), pp. 4578-4588, avril 2024, DOI: 10.1109/TVT.2024.3356116, ISSN: 0018-9545, 1939-9359

[Redondo-Iglesias et al. 2020] Redondo-Iglesias, E., Venet, P., Pelissier, S., « Modelling Lithium-Ion Battery Ageing in Electric Vehicle Applications—Calendar and Cycling Ageing Combination Effects », *Batteries*, **6**(1), pp. 14, février 2020, DOI: 10.3390/batteries6010014, ISSN: 2313-0105

[Sarasketa-Zabala et al. 2016] Sarasketa-Zabala, E., Martinez-Laserna, E., Berecibar, M., Gandiaga, I., Rodriguez-Martinez, L.M., Villarreal, I., « Realistic lifetime prediction approach for Li-ion batteries », *Applied Energy*, **162**, pp. 839-852, janvier 2016, DOI: 10.1016/j.apenergy.2015.10.115, ISSN: 0306-2619

[Schimpe et al. 2018] Schimpe, M., Von Kuepach, M.E., Naumann, M., Hesse, H.C., Smith, K., Jossen, A., « Comprehensive Modeling of Temperature-Dependent Degradation Mechanisms in Lithium Iron Phosphate Batteries », *Journal of The Electrochemical Society*, **165**(2), pp. A181-A193, 2018, DOI: 10.1149/2.1181714jes, ISSN: 0013-4651, 1945-7111

[Wang et al. 2014] Wang, J., Purewal, J., Liu, P., Hicks-Garner, J., Soukazian, S., Sherman, E., Sorenson, A., Vu, L., Tataria, H., Verbrugge, M.W., « Degradation of lithium ion batteries employing graphite negatives and nickel–cobalt–manganese oxide + spinel manganese oxide positives: Part 1, aging mechanisms and life estimation », *Journal of Power Sources*, **269**, pp. 937-948, décembre 2014, DOI: 10.1016/j.jpowsour.2014.07.030, ISSN: 0378-7753

- References -

[Bouscayrol 2000] A. Bouscayrol, & al. "Multimachine Multiconverter System: application for electromechanical drives", *European Physics Journal - Applied Physics,* vol. 10, no. 2, May 2000, pp. 131-147 (common paper GREEN Nancy, L2EP Lille and LEEI Toulouse, according to the SMM project of the GDR-SDSE).

[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

[Lhomme 2014] W. Lhomme, P. Delarue, A. Bouscayrol, P. Barrade, "La REM, formalismes multiphysique de commande des systèmes énergétiques", Les Techniques de l'Ingénieur, Référence D3066, Novembre 2014 (text in French, lift example)

Thanks for your attention !