Commercial Electric Vehicle Battery Degradation modelling and charging assessing using a real driving cycle

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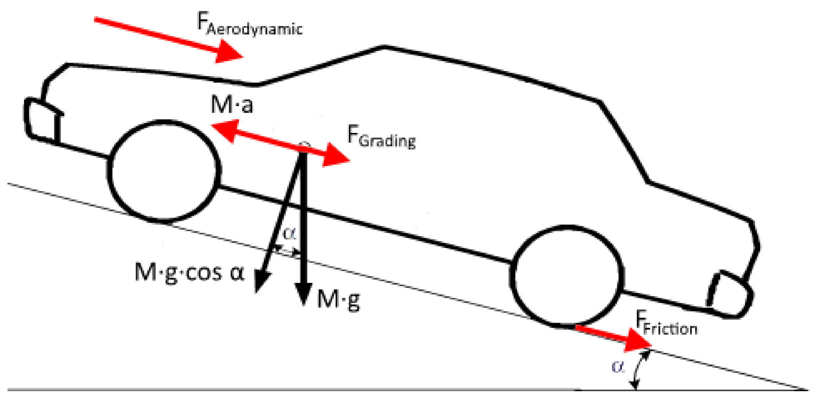
ABSTRACT

This paper proposes a model to study the degradation of li-ion NMC batteries of commercial electric vehicles. The model takes into account operation variables such as operating C-Rate, Depth of Discharge (DoD), Number of Cycles and Temperature using a 4-D Piecewise Cubic Hermite Interpolating Polynomial (PCHIP). Simulations have been done considering the Worldwide Harmonised Light Vehicles Test Procedure 3 (WLTP3) standard cycle. The model has been implemented in MATLAB. In addition, recommendations on charging procedures are given in order to reduce the degradation of batteries.

VEHICLE DYNAMIC MODEL



$$\frac{dv}{dt} = \frac{\sum F_t - \sum F_r}{\delta M}$$

$$\frac{F}{M} = a + \frac{F_{grading} + F_{friction} + F_{aerodynamic}}{M}$$

$$a = \frac{dv}{dt}$$ Moving of the vehicle

$$\frac{F_{grading}}{M} = g \cdot \sin(\alpha)$$ Grading contribution

$$\frac{F_{friction}}{M} = f_r \cdot g \cdot \cos(\alpha)$$ Friction contribution

$$f_r = 0.01 \cdot \left(1 + {}^{3.6 \cdot v}/_{160}\right)$$ Friction coeffcient

$$\frac{F_{aerdoynamic}}{M} = \frac{1}{2} \cdot \frac{\rho \cdot C_D \cdot A \cdot (v - v_w)^2}{M}$$ Aerodynamic friction contribution

The instantaneous electric power demand from the battery is got

$$\frac{F(t)}{M} \cdot M \cdot v(t) = P = V \cdot I$$

Two considerations have to be made, one considering the sign of the energy flow and the other considering the energy exchanged (current throughput). First one is used to calculate the DoD after performing the driving cycle, considering regenerative braking, while the second is used to calculate the C-Rate during the driving period.

$$DoD = \frac{\int_0^t F(t) \cdot v(t) \cdot dt}{N_{cells} \cdot C \cdot V \cdot 3600}$$

$$C - Rate_{Driving} = \frac{\int_0^t |F(t)| \cdot v(t) \cdot dt}{N_{cells} \cdot C \cdot V \cdot t}$$

DEGRADATION MODEL

Several experiments have been performed to obtain experimental data to emulate the degradation. All the curves describing the State of Health (SoH) of the battery have been adjusted to a potential curve form, which has been determined to be the greatest adjust for the data given:

$$SoH\ [\%] = 100 - a(DoD, C, T) \cdot N^{b\ (T,C)}$$

Experimental Test Matrix

Charging Current	Temperature	DoD
C/3	25 ºC 45 ºC	20 % 40 % 60 % 80 %
22 kW	25 ºC	20 % 40 % 60 % 80 %
43 kW	25 ºC	20 % 40 % 60 % 80 %

Interpolation cases

Case	DoD	N	T	C
1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	No
3	Yes	Yes	No	Yes
4	Yes	Yes	No	No
5	Yes	No	Yes	Yes
6	Yes	No	Yes	No
7	Yes	No	No	Yes
8	Yes	No	No	No
9	No	Yes	Yes	Yes
10	No	Yes	Yes	No
11	No	Yes	No	Yes
12	No	Yes	No	No
13	No	No	Yes	Yes
14	No	No	Yes	No
15	No	No	No	Yes
16	No	No	No	No

A degradation model concerning a wide range of C-Rate, Depth of Discharge (DoD), number of cycles and Temperature is obtained. For this purpose, Shape Preserving Hermite Interpolating Method or Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) has been used to obtain the data not explicitly given. 16 cases can be found depending on if the data searched is given or not.

DoD, will be only dependent on driver transport needs, while C-Rate will be also influenced by the charging power. Charging powers considered are the standardised up to the maximum charging power of the vehicle, which is 50 kW.

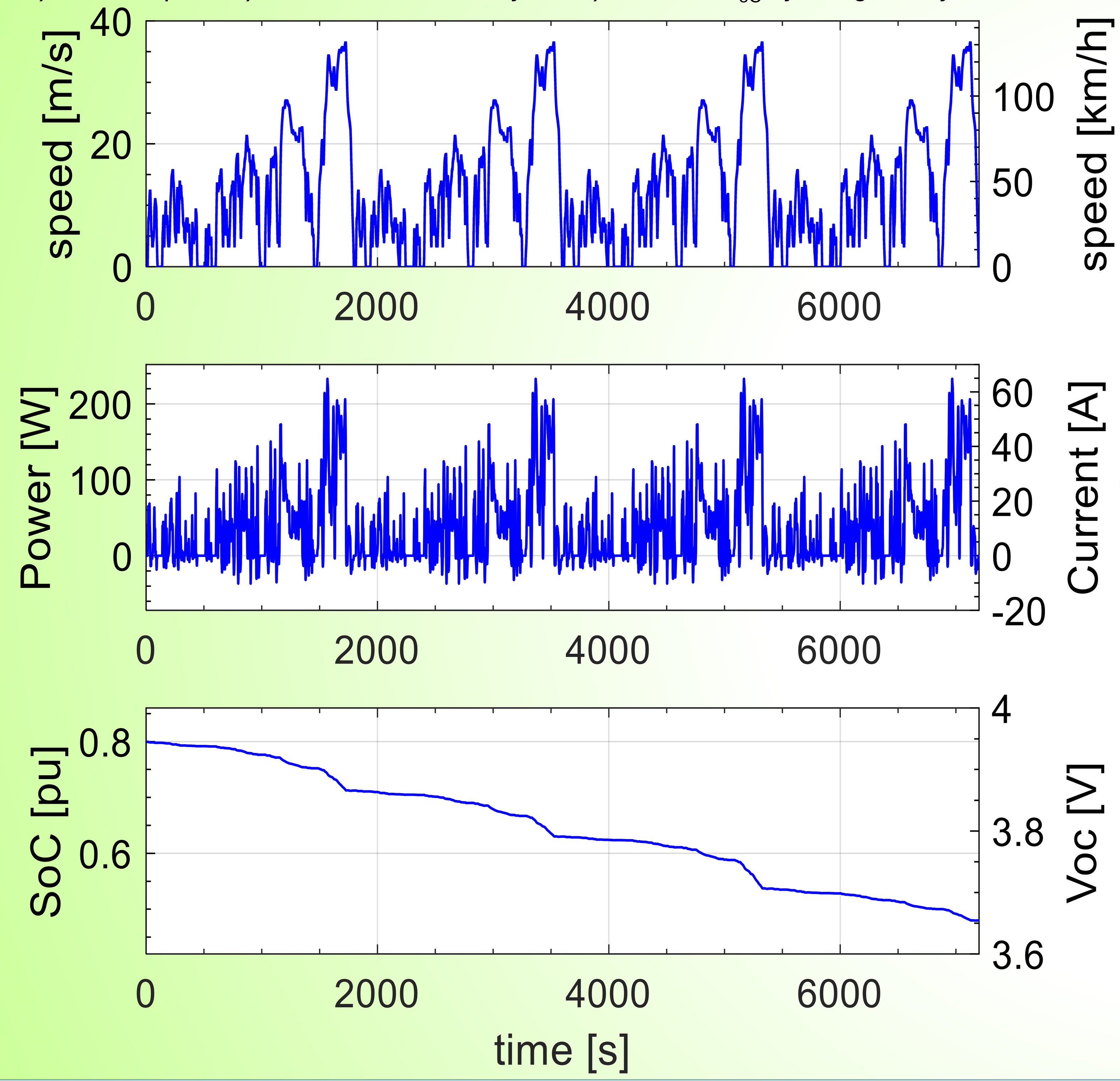
Charging powers, or C-Rates, have been combined with the driving power, or C-Rate, to get the weighted power or C-Rate in a driving-charging cycle

$$C_{Rate} = \frac{C_{Rate\ Driv} * t_{Driv} + C_{Rate\ Ch} * t_{ch}}{t}$$

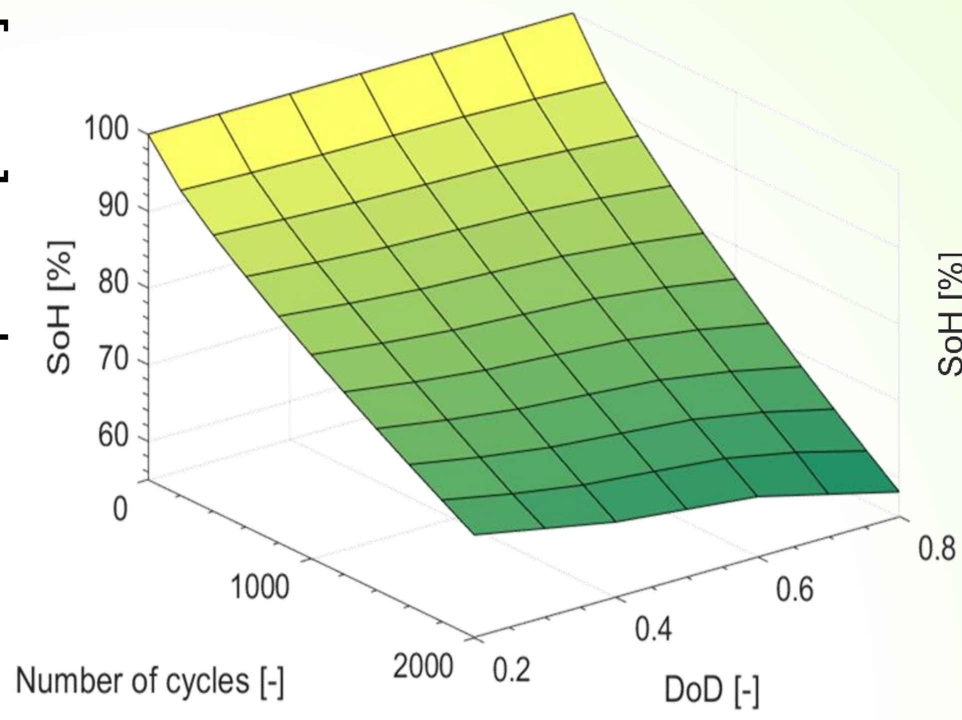
SIMULATION RESULTS

It can be seen that temperature is a key factor when comes to degradation of the battery, but C-Rate has the greatest influence.

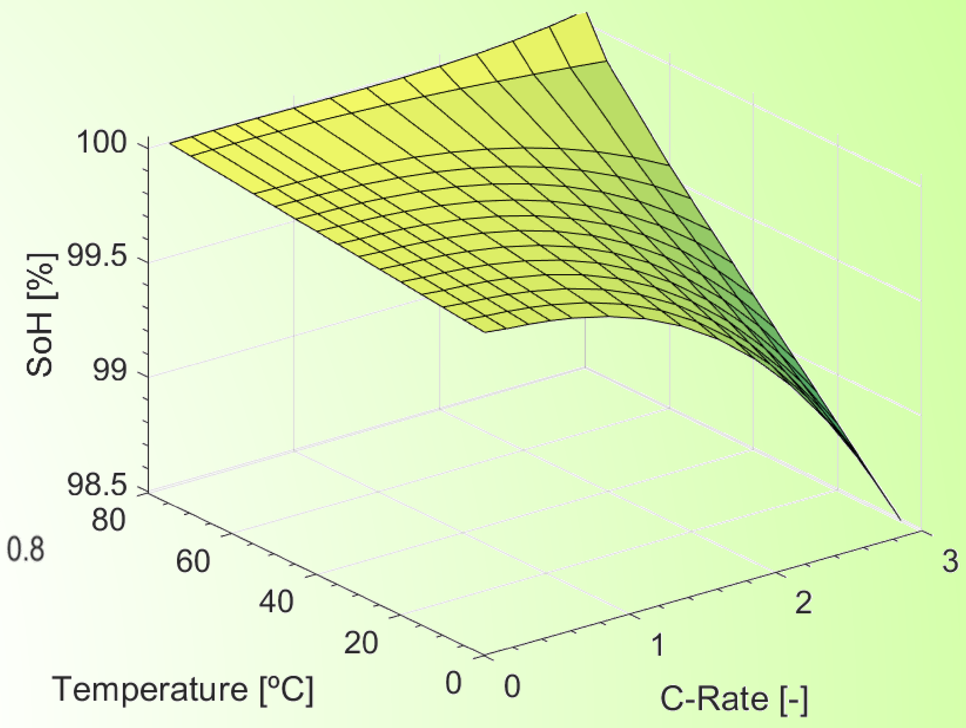
a) Vehicle speed b) Power and Current by cell c) SoC and V_{OC} by cell given by 4xWLTP3



Degradation for 45ºC and 0.5C cycles

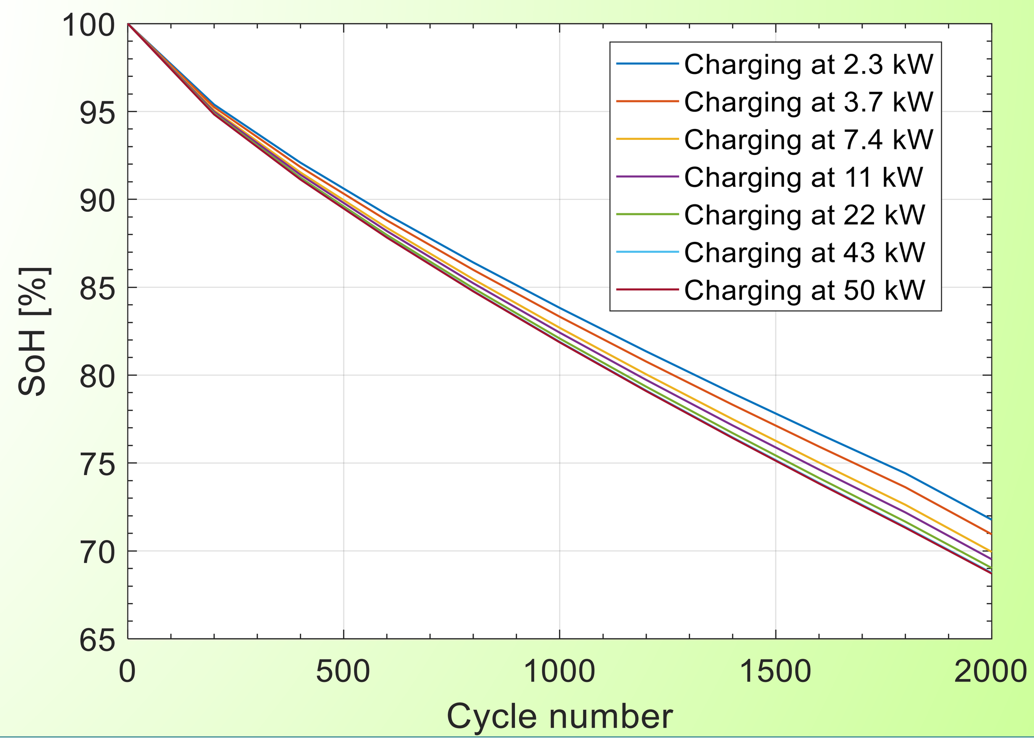


Degradation for 30% DoD unique cycle



Degradation for 4xWLTP3 cycle (DoD=31.2 %) and 45ºC, depending on charging power.

SoH [%]		N=600	N=1000	N=1600	N=2000
Level 2	2.3 kW	89.14	83.83	76.66	71.77
	7.4 kW	88.38	82.69	75.03	69.94
Mode 1	3.7 kW	88.8	83.32	75.94	70.95
	11 kW	88.2	82.42	74.63	69.52
Mode 2	22 kW	87.97	82.08	74.15	69.03
Level 3	43 kW	87.85	81.9	73.88	68.75
Mode 4	50 kW	87.83	81.87	73.84	68.71



CONCLUSIONS

The model developed is able to evaluate the degradation of a commercial NMC lithium-ion battery when it is cycled with a determined C-Rate, DoD and temperature. This model has been evaluated considering an electric vehicle, but it can also be applied to photovoltaic, or any other application. As result of the simulations performed, it can be said that charging power is a considerable factor when batteries lifetime maximisation is aimed. In this sense, Mode 4 fast charging of a Renault Zoe at 50 kW would reduce batteries commercial lifetime by 13.63 % comparing to a Level 2 slow charging of 2.3 kW. In this context, it is necessary to find a later use of electric vehicles batteries, such as could be their use in grid stabilization, or stationary storage in applications where the volume capacity is not determinative, for example, a photovoltaic application.

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