

Electric vehicle battery SOC estimation under different speed references

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Abstract. The present work aims to improve the traction chain system of a leisure electric vehicle equipped with a Li-S battery. For that, an equivalent circuit model of the battery was developed and implanted in the traction chain model in order to investigate the autonomy of the electric vehicle under different drive-cycles. The obtained results show a good quality of the studied vehicle in terms of autonomy and energy consumption.

1 Nomenclature

A: the amplitude of the exponential zone,
B: the exponential zone time constant inverse,
 E_0 : the battery open-circuit voltage,
 i : the battery current,
 i_t : the extracted capacity,
K: the polarisation constant,
Q: the cell capacity,
 Q_{exp} : End of exponential zone capacity
 Q_{nom} : End of nominal zone capacity
R: the battery internal resistance,
SOC: State of charge
V: the battery voltage.
 V_{exp} : End of exponential zone voltage
 V_{full} : Fully charged voltage
 V_{nom} : End of nominal zone voltage

2 Introduction

Batteries play an essential role in electric vehicles. Indeed, the characteristics of this latter are directly related to the autonomy of the vehicle. Despite this, several models ignore this critically important part of the traction system model [1-3]. Currently, many researchers are interested in predicting traction battery performance. In [4], an estimation model of state of charge based on machine learning algorithm is proposed for the real-time back cloud driving data of electric vehicle. Furthermore in [5], current estimation algorithm is constructed based on the dynamics of simple battery model by utilizing internal capacitance update using a set of linear piecewise functions of state of charge and open circuit voltage.

In the present work, we proposed an equivalent circuit model permitting to estimate the state of charge

of battery and give an accurate information about the vehicle autonomy and energy consumption. To do so, this paper is organized as follows: In first, we presented the vehicle specification and the general parameters of the battery. The second part is intended to the modelling of traction battery. Finally, in the last part of this work, we implanted the battery model in the traction chain system in order to investigate the vehicle autonomy under different speed reference.

3 Problem presentation

The considered simulation procedure is illustrated in Fig.1. The traction chain going to be studied consists of a traction battery connected to a PMSM with flux concentration through a conventional six switch inverter and a mechanical gear intended for power transmission to the vehicle's wheels. The traction chain modeling and speed control process are detailed in [6]. Such process was carried out with consideration of the thermal effect on the vehicle propulsion system. In fact, the electrothermal model, Fig.1, permitting to have a real information about the thermal state of electric vehicle's powertrain and losses dissipation during vehicle circulation, which makes it easier to predict the level of current and the powers that the traction battery must provide. The adjustment of the speed regulator parameters (K_i , K_p) by fuzzy logic permitting to acts on this latters to adjust them during the process of control and make the PI controller adaptable to instantaneous variation of vehicle's characteristics under thermal effect during a drive cycle.

The Vehicle specification and the general parameters of the traction battery are respectively illustrate in Table1 and Table.2. The modelling of the traction battery is the focus of the next paragraph.

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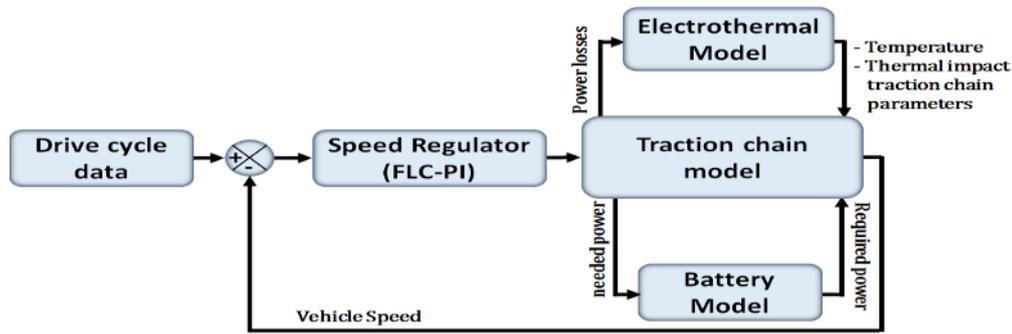


Fig. 1. Simulation procedure.

Table 1. Vehicle specification.

Parameter	Value
Nominal power	15 kW
Voltage	300V
Basic velocity	30 km/h
Maximum speed of the vehicle	80 km/h
Vehicle mass	800 kg
Wheel ray	0.26 m

Table 2. General parameters of the electric battery.

Parameter	Value
Maximum Charge	80 Ah
Nominal Voltage	305 V
Stored Energy	24.2 kWh
Minimum Voltage / Maximum Voltage	290/320 V
Initial Charge	100
Number of Cells per Cell-Row	26
Number of Cell-Row	1
Internal Resistance charge/discharge	1/1 Ω
Operating Temperature	30 °C
Specific Heat Transition	0.08 W/K
Specific Heat Capacity	1650 j/kg*K
Mass of Battery	173 kg
Battery Price	250 €

4 Equivalent circuit model of battery

At this stage, we assumed that the thermal effect on the battery parameters is negligible. The proposed equivalent-circuit model of the battery is shown in Fig.2. Such model is suitable for all battery types. It describes the voltage of the output battery variation according to the charging/discharging current [7-8]. The equation of the battery output voltage is given for the discharge and charge modes by the following equation:

• Charge mode:

$$V = E_0 + k \frac{Q}{Q - i_t} i_t + k \frac{Q}{i_t - 0.1Q} i + Ri + C \quad (1)$$

• Discharge mode:

$$V = E_0 + k \frac{Q}{Q - i_t} i_t + k \frac{Q}{Q - i_t} i + Ri + C \quad (2)$$

The simplest and most direct method to estimate the state of charge for a battery is the Coulomb counting method [9]. Such method consists of the integration of the current. The mathematical expression of the Coulomb counting is defined by equation (3):

$$SOC(t) = SOC(0) - \int_{t-1}^t \frac{i_t}{Q} dt \quad (3)$$

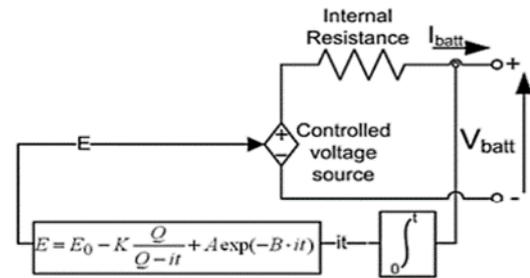


Fig. 2. Equivalent-circuit model.

All the parameters are available from the manufacture's datasheet. However, the amplitude of the exponential zone and the exponential zone time constant inverse should be calculated from the discharge curve of the battery using respectively the equations (4) and (5) [10-11].

Fig.3 shows the battery parameters extraction procedure based on the discharge curve. To calculate "E0" we used the equation (7). Fig.4 shows the electric vehicle simulation model.

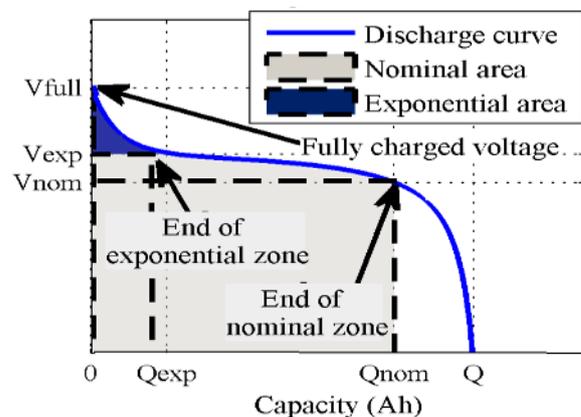


Fig. 3. Battery parameters extraction procedure based on the discharge curve [11].

$$A = V_{full} - V_{exp} \quad (4)$$

$$B = \frac{3}{Q_{exp}} \quad (5)$$

$$C = Ae^{(-BIt)} \quad (6)$$

$$E_0 = V_{full} + K + R \cdot i - A \quad (7)$$

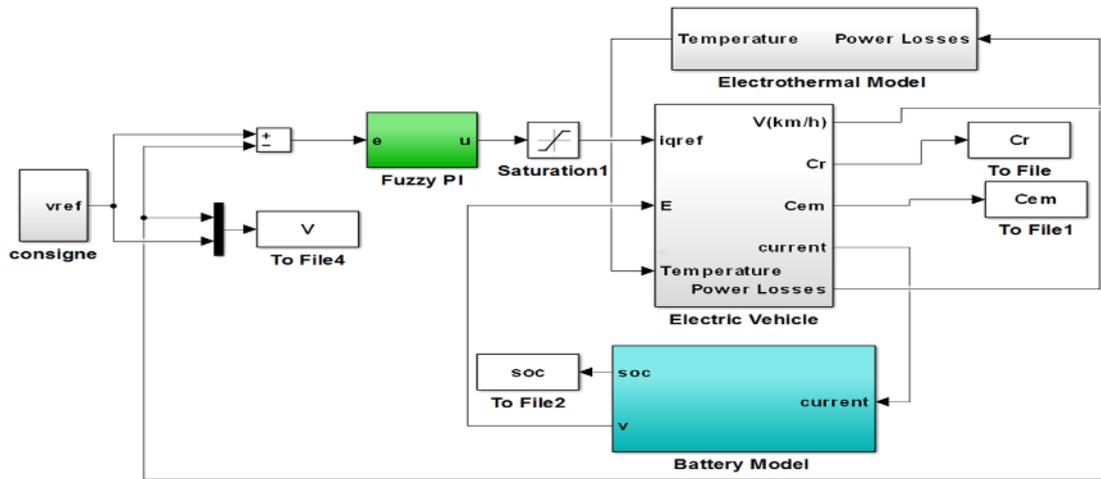


Fig. 4. Electric vehicle simulation model.

5 Results and discussion

The In order to investigate the autonomy of the electric vehicle under different speed reference, two drive cycle are considered: the WLTC class and the Japean 10-15 mode. Table.3 shows the drive cycle characteristics.

Table 3. Driving cycle characteristics.

Cycle	Duration (s)	Average Speed (km/h)	Distance (km)
WLTC class 1	1022	28.5	8.091
Japean 10-15 mode	660	22.7	4.15

The analysis of the vehicle responses, Fig.5, shows that the vehicle speed follows the desired instructions with very satisfactory precision and rapidity. Indeed, the response is practically stuck to the instruction imposed on the system input. Fig.6 and Fig.7 respectively illustrate the evolutions of the stator current as well as the electromagnetic torque developed during each drive cycle. This figures show that all the parameters change

following the speed variation without exceeding the limits required by the specifications.

As Fig.8 shows, the battery respectively loses 2.13% and 2.7% of its charge, on the Japean 10-15 mode and WLTC cycles. The energy consumption values and the vehicle autonomy are obtained from the simulations results, Table.4. The comparison of such values with those of electric vehicles currently in the world [12], reveals that the studied vehicle more efficient than several of these latter in term of autonomy and consumption. In fact, the average range of Renault Twizy and Citroën AMI are respectively about 90 and 70 km, while it exceeding 190 km for the studied vehicle.

Table 4. Simulation results

Cycle	Energy consumption (Kwh/100Km)	Autonomy (Km)
WLTC class 1	8.03	301.3
Japean 10-15 mode	12.25	197.5

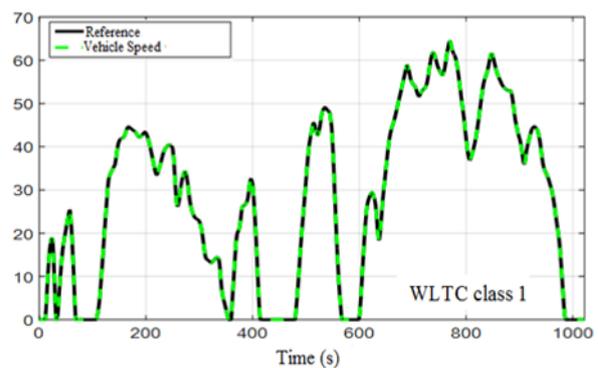
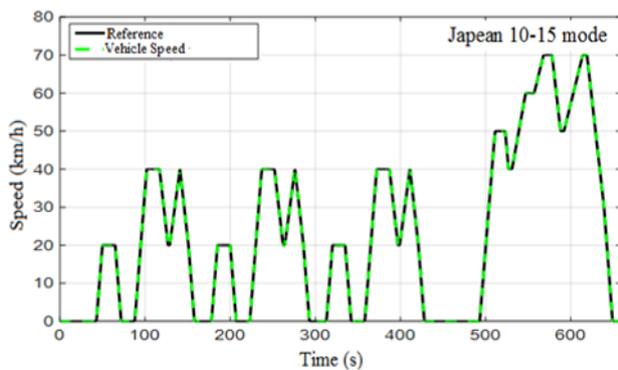


Fig. 5. Vehicle response.

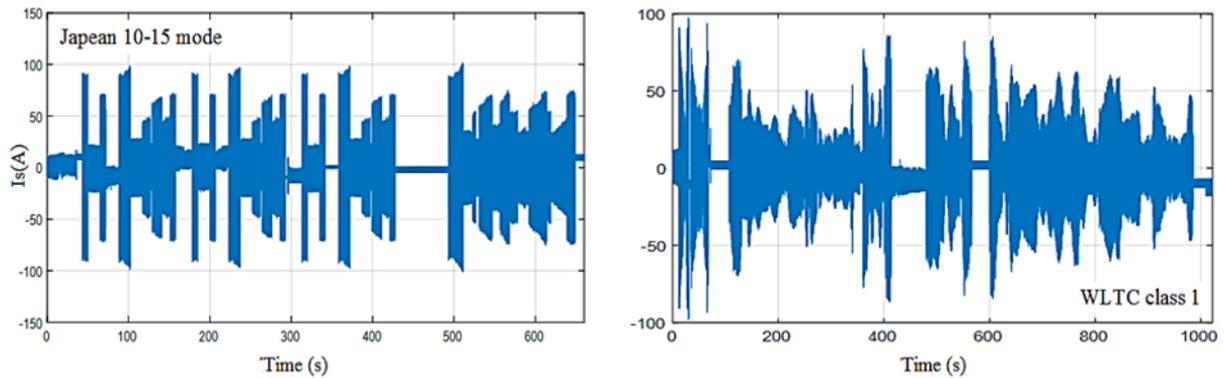


Fig. 6. Evolutions of stator current.

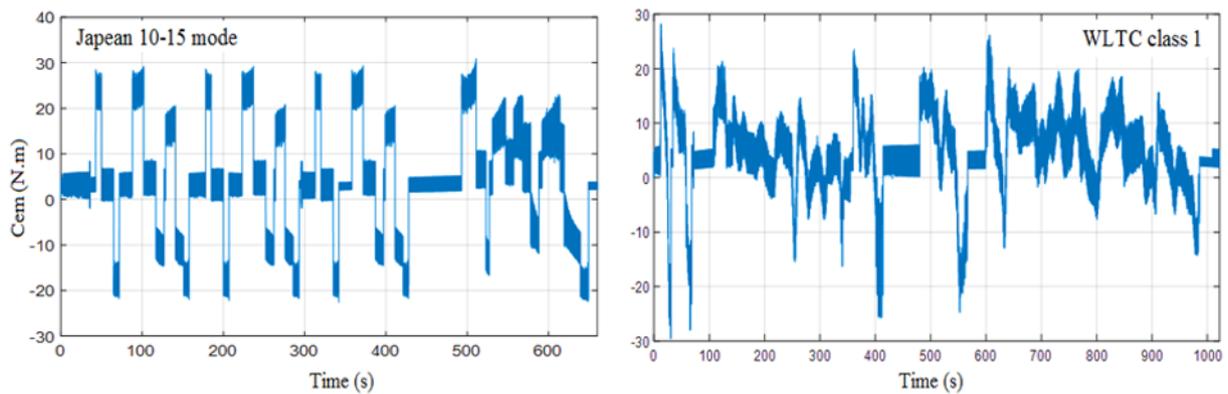


Fig. 7. Evolutions of electromagnetic torque.

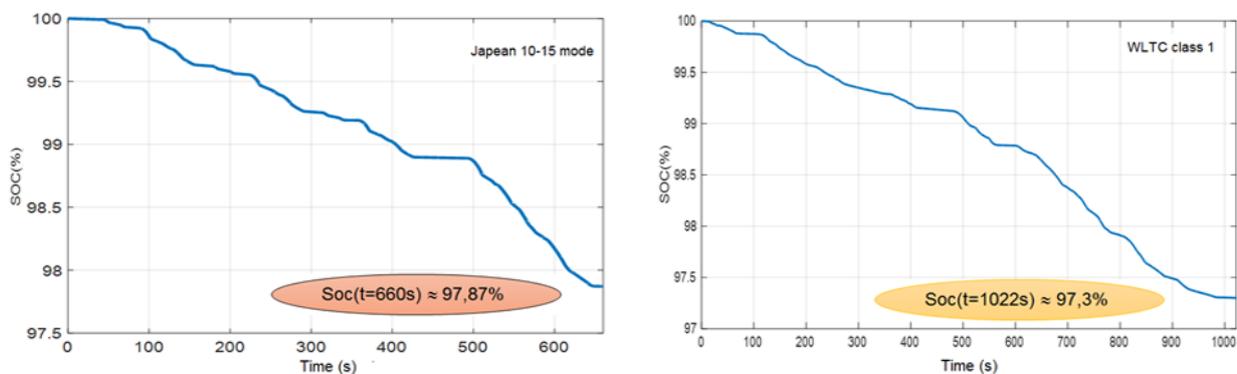


Fig. 8. State of charge for battery.

6 Conclusion

The present work deals with the development of an equivalent electric circuit for a Li-S traction battery in order to estimate its state of charge and have an accurate information about the vehicle autonomy under different speed reference. The obtained results show the good quality of the studied vehicle in terms of autonomy and energy consumption compared to some electric vehicle presented currently in market. The improvement of the traction system model will continue with the analysis of the thermal effect on the battery characteristics which are neglected in this work. In fact, this work present the first step towards the development of an advanced traction system model equipped with a hybrid power source, energy recovery system and a cooling system.

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References

1. O. A. Imran, W. N. Al-Din Abed, A.N. Jbarah. *IJPEDS*. **10**, 6 (2019)
2. Y. Dhieb, M.Yaich, A. Guermazi, M.Ghariani. *JES*. **15**, 8 (2019).
3. E. V. Belousov, M. A. Grigor'ev, and A. A. Gryzlov. *Russian Electrical Engineering*. **88**, 4 (2017).
4. S.Huang, Z. He, X. Li. *ICNSC Conference* (30 Oct.-2 Nov 2020, China, 2020).
5. B. R. Dewangga, S. Herdjunanto, A. Cahyadi, *ICST Conference* (7-8 Aug, Indonesia, 2018).
6. R. Jebahi, A. Ben Jridi, N. Chaker, and H. Aloui. *Electr. Eng.* **10** (2021).

7. P. Bhagyasree, V. A. Shah, *ICESIP Conference* (4-6 July, India, 2019).
8. J. Chang, Zhongbao Wei, H. He, *15th IEEE Conference on Industrial* (9-13 Nov, Norway, 2020).
9. I. Miri, A. Fotouhi, and N. Ewin. *Int. J. Energy Res.* **45**, 19 (2021).
10. M. Afifi Jusoh, M. Zalani Daud. *IJPEDS.* **11**, 8 (2020)
11. O. Tremblay, L.-A. Dessaint. *WEVJ.* **3**, 9 (2009).
12. Site web: <https://www.automobile-propre.com/>