Study of the factors affecting battery electric vehicle range

AIDI Ayoub

RACHIDI Yousra

National School of Applied Sciences

ayoub.aidi@ump.ac.ma/ayoubaidi@gmail.com

Yousra.rachidi@ump.ac.ma/ Rachidi.yousra6@gmail.com

Altran Engineering Solutions

***Abstract*— this project presents a simulation study of the influence of various factors on the energy consumption of an electric vehicle (EV). Because of the limited amount of energy contained in the battery, EVs are very sensitive to parameters that can influence their energy consumption and can then induce huge variations in their actual range. Among all these factors, driving conditions, the impact of auxiliaries, driver aggressiveness, and braking energy recovery strategy should be considered as the main factors influencing EV energy consumption.**

In this project we will model and simulate the electric vehicle's drive train and the factors affecting its range, then we will present some methods for optimizing and improving the range and performance of the electric car.

***Keywords*— Automotive, Battery, Energy consumption, Electric vehicle, Range, MATLAB, Simulink.**

I. Introduction

"Clean" vehicles have indeed become a social issue due to the rise in environmental concerns, the volatility of fossil fuel prices and the strong media coverage of all-electric vehicles. And for several years now, the government has made it a priority by implementing support plans and setting up think tanks on the subject.

The electric vehicle appears as a lever for revival and modernization. Finally, the techno-logical maturity of the lithium-ion battery opens up prospects for the large-scale development of the electric vehicle. Until now, the main obstacle to the development of the electric vehicle has been the battery, whose capacity has been insufficient.

So what factors influence the range of the electric vehicle and how to optimize its consumption?

II. Traction System

The purpose of this chapter is to present in detail the modelling in MATLAB/SIMULINK of the various components of the powertrain and the environment that interact with the vehicle.

A. Electric Motor

Permanent magnet synchronous motors are widely used as traction motors in electric and hybrid electric vehicles (EVs) because of their inherent advantages in terms of efficiency, weight, size and power density.

To study synchronous machines, we can use a representation in a two-phase frame. Using this model allows us to see the effect of rotating fields, modelled as a rotating vector, on the creation of torque. Although it is possible to define the vectors in any frame, we describe them either in the rotor frame (d, q) using the Park transform.

The final model of the PMSM is:

$$\frac{di_d}{dt} = \frac{R_s}{L_d} i_d + \frac{L_q}{L_d} i_q w_m + \frac{1}{L_d} v_d$$

$$\frac{di_q}{dt} = \frac{R_s}{L_q} i_q - \frac{L_d}{L_q} i_d w_m + \frac{\varphi_f}{L_q} w_m + \frac{1}{L_q} v_q$$

$$\frac{dw_m}{dt} = -\frac{f}{J} w_m - \frac{3}{2}\frac{P^2}{J}\left(L_d - L_q\right) i_d i_q - \varphi_f i_q\right) - \frac{P}{J} C_r$$

B. BI-DIRECTIONAL DC-DC CONVERTER

This converter is used to condition and manage the energy in a DC bus. We usually use a buck boost:

- boost mode (traction) mode: energy transfer to the DC bus and the load
- in buck mode we will have energy recovery to the storage elements.

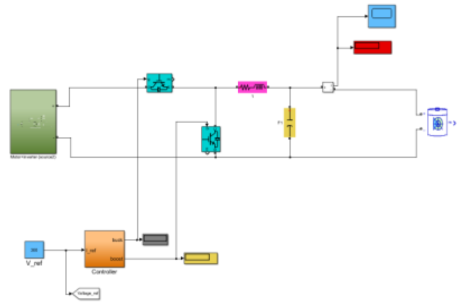


Figure 1 : BI-DIRECTIONAL DC-DC CONVERTER

C. Inverter

This converter is used to transform DC signals (battery side) into AC signals (stator side of the machine), and it is also used for speed variation, usually a sine-triangle PWM inverter is used.

This PWM has the following advantages:

- ✓ Frequency variation of the output voltage.
- ✓ It pushes the harmonics to higher frequencies.

The consequences of these two advantages are:

- ✓ Minimization of current distortion.
- ✓ Low cost of the output filter.

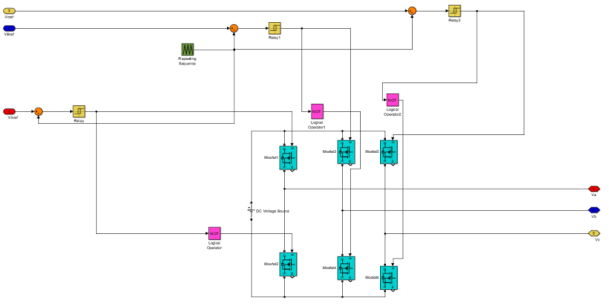


Figure 2 : The inverter

D. Control unit

Traction motors must comply with the specific requirements of EVs: operate at high speeds that require the maximum speed to be two or three times the rated speed. In electric Vehicles we use the flux weakening control.

For a given alternating voltage, the rotor can rotate faster in a weaker magnetic field. Since the PMSM is permanently excited by permanent magnets, the only way to achieve flux weakening is to regulate the armature currents. Another advantage of flux weakening is the constant output power once the motor reaches the rated speed. Typically, the constant power region is half or two thirds of the full speed range.

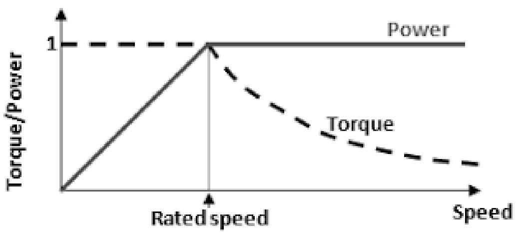


Figure 3 : The flux weakening control

E. Battery

The types of batteries chosen are Lithium Ion batteries, they have mass and volume performances far superior to lead or cadmium based technologies.

The model used is a generic model, this model is based on an equation that allows to reproduce discharge curves of a fairly large number of batteries. The parameters of this equation are calculated from a number of discretised points of a manufacturer's curve.

The terminal voltage at the battery terminals in this model is expressed by the following equation:

$$V_t = V_0 - K\frac{Q * I_b}{Q - I_b t}$$

Adding to this equation the ohmic voltage drop, we get:

$$V_t = V_0 - K\frac{Q * I_b}{Q - I_b t} - R * I_b$$

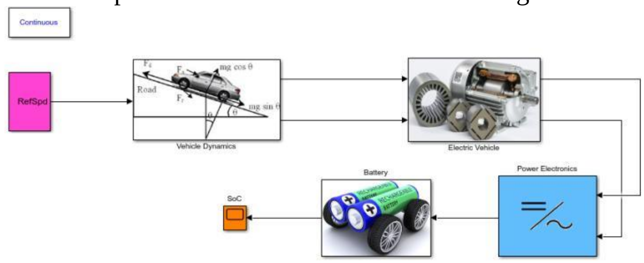
This equation does not include the voltage drop at the beginning of the discharge. This part of the curve can be represented by adding an exponential function, the equation then becomes:

$$V_t = V_0 - K\frac{Q * I_b}{Q - I_b t} - R * I_b + Aexp(\frac{-B}{Q} I_b t)$$

F. Global model

The above model is an overall model of the electric vehicle powertrain which contains: the battery, the control unit, the inverter, the electric machine, the mechanical transmission, the DC/DC converter and the dynamic system of the EV.

The components have been dimensioned to meet the following performance requirements for the WLTP drive cycle, based on the assumptions of an acceleration from 0 to 100km/h in 9s, a gradient capacity of 10% at 100km/h, a maximum speed of 125km/h and a maximum range of 150km.



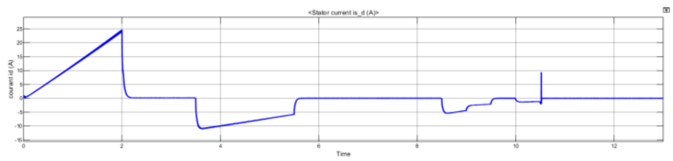


Figure 4 : Id current

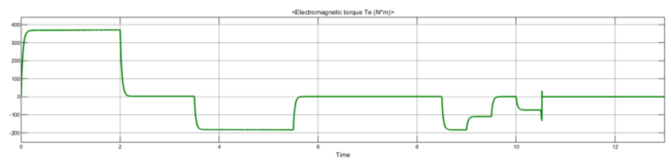
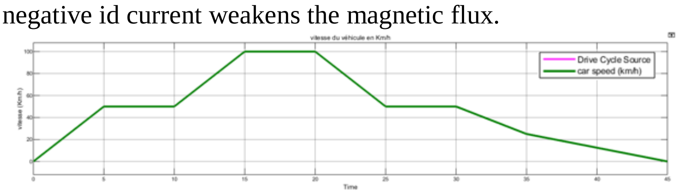


Figure 5 : electromagnetic torque

It can be seen that the interest of the flux weakening (FW) control is validated, each time to reach the necessary torque, a negative id current weakens the magnetic flux.



The speed of the vehicle follows exactly the instruction set by the driver, which validates the correct operation of the traction motor control.

III. FACTORS AFFECTING THE RANGE OF THE VEHICLE "OPTIMIZATION"

A. Effect of speed

The power of the engine that must be supplied to drive the vehicle is proportional to the battery current (discharge current), so each time the engine speed increases, the current demand increases. This implies the discharge of the battery, so the range of the vehicle decreases sharply with speed.

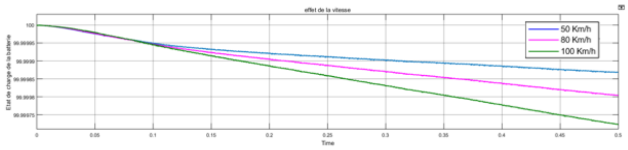


Figure 6: The state of charge for different speed values

.

We conclude that the faster we drive, the more electrical energy we consume, and it's exponential.

B. Effect of acceleration

The way you drive your vehicle has an impact on the range of the electric vehicle. Indeed, nervous driving limits the battery's operating time. It is therefore preferable to adopt a calm driving style.

Acceleration clearly affects the vehicle's range, so every time you accelerate for a short time, you will have a high current draw. This reduces the battery's range.

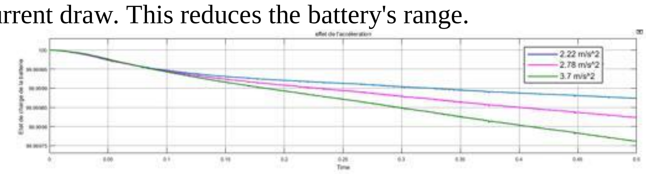
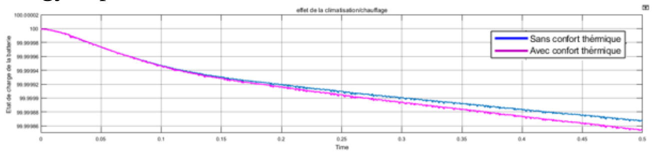


Figure 7 : State of charge of the battery for different acceleration values

The figure above shows the variation of the battery state of charge for three acceleration values, the speed variation from 50km/h to 90km/h is tested in 3s, 4s and 5s (3.7m/S^2, 2.78m/S^2, 2.22m/S^2). The faster you accelerate the more power you consume. .

C. Effect of air conditioning/heating on range.

The use of air-conditioning and heating has a considerable influence on the range of an electric car. When they are switched on, these accessories account for nearly 20 to 30% of energy expenditure.



D. Effect of temperature

The temperature of the Li-ion batteries rises sharply when driving on gradients or at high speeds. However, these batteries are particularly sensitive to the temperature at which they are used. A low temperature considerably reduces the range of the battery and makes it difficult to start vehicles.

Use above 60°C accelerates the ageing of the battery (degradation of service life). This is why it is essential to be able to predict temperature variations in the battery.

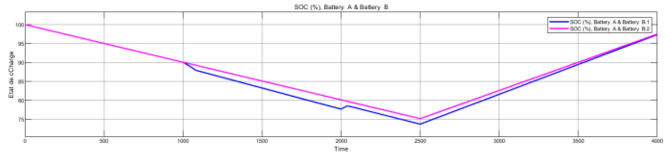


Figure 8 : State of charge of battery A and B

The above simulation consists of comparing in the discharge and charge phase two batteries which have the same characteristics, but one battery (B) with a fixed temperature "20°C" and the other (A) at a temperature which varies between -20°C and 20°C.

The simulation shows that the state of charge of the battery depends on the temperature. At -20°C the battery base has decreased compared to 20°C, and in the charging phase, the battery at 0°C has a slow charging time compared to that of battery B (20°C).

E. Regenerative braking

During the driving of a vehicle equipped with a regenerative braking system, the electric motor draws energy from the battery to turn the wheels, creating the kinetic energy needed to move the vehicle. However, when the brakes are applied, the process is reversed. The kinetic energy initially used to propel the vehicle now turns the electric motor through the wheels, turning it into a type of generator. Instead of consuming electrical energy, the generator produces it, using the kinetic energy of the vehicle. The electrical energy is then stored in a super-capacitor where it will again be used to help propel the vehicle.

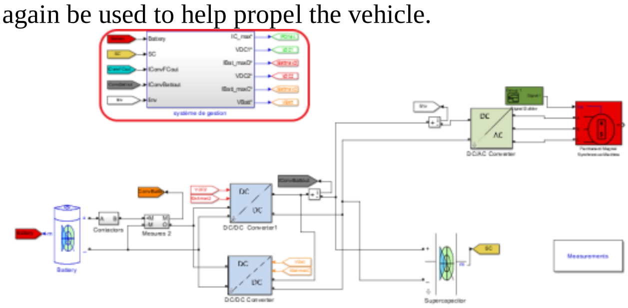
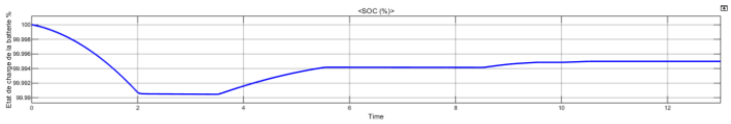


Figure 9 : Hybrid energy management model



We notice that with the help of the storage system, when there is a recovery of kinetic energy, there are phases where the battery is recharged through the bi-directional converter that connects it with the super-capacitor, so the autonomy of the battery is much improved.

F. eco driving mode

Eco mode optimizes the car's properties to achieve a more energy-efficient driving experience.

In our study, we propose to play on the cruise control in terms of speed limit and response time.

Cruise control in Eco mode ensures that the vehicle's acceleration will be more moderate than in normal driving mode.

In order not to impose the driving speed, and so as not to affect the vehicle's performance, the driver was given a choice by means of a button that is used to switch from one mode to the other.

Eco mode changes the cruise control from normal mode to another mode that requires a speed limit and minimal acceleration time.

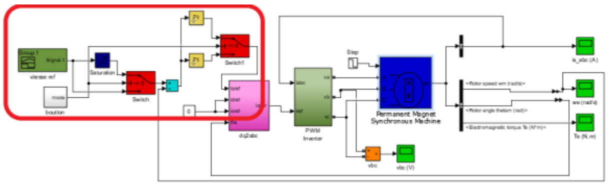


Figure 10 : Eco driving mode model

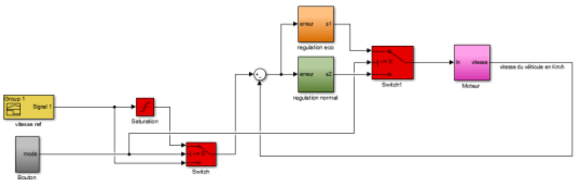


Figure 11 : simplified model

The diagram above is a simplified model of the system created to understand how mode switching works. With the help of the button, the driver makes a choice regarding the acceleration time and the maximum speed that can be reached during the trip.

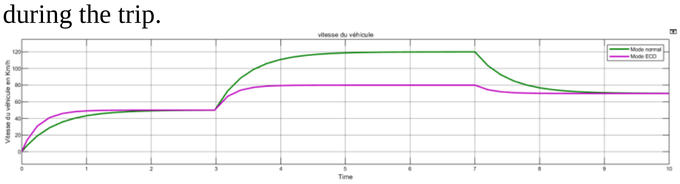


Figure 12 : vehicle speed in Eco mode and normal mode

It is noticeable that in Eco mode, the speed is limited to 80 Km/h, and it is characterized by a reduced acceleration time. As already mentioned in the previous chapter, the speed (acceleration) strongly affects the range, so the gain in Eco mode is very important. The figure above shows the variation in charge state in both modes.

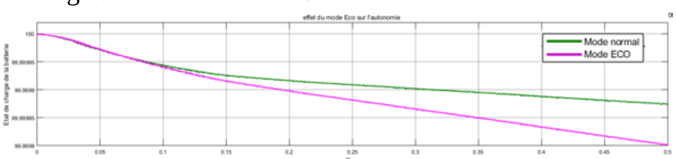


Figure 13 : Battery state of charge in two modes

The Eco system has saved 15% of the battery life, our system is dedicated just for speed control and acceleration, so the percentage of improvement can be improved by playing on the limitation of the use of air conditioning/heating.

IV. CONCLUSIONS

This project illustrates a parametric study of the main factors that influence the energy of an EV and therefore its range.

The main objective is to study the various factors that influence the range and performance of the electric vehicle, as well as to analyze methods for optimizing consumption.

The table above summarizes the improvements brought about by the optimization methods presented above.

Optimization method	Percentage of improvement
Regenerative braking	≃10%
Eco driving mode	≃15%

REFERENCES

[1] Factors affecting electric vehicle energy consumption W.J. Sweeting, A.R. Hutchinson* and S.D. Savage Sustainable Vehicle Engineering Centre, Oxford Brookes University, Oxford, UK (Received 17 November 2010; final version received 9 May 2011).

[2] Samuel, S., et al., 2005. Real-world fuel economy and emission levels of a typical EURO-IV passenger vehicle. Proceedings of IMechE. Part D: Journal of Automotive Engineering, 219 (6), 833–842.

[3] Ehsani, M., et al., 2005. Modern electric, hybrid electric and fuel cell vehicles. New York: CRC Press

[4] Kasseris, P.E., and Heywood, B.J., 2007. Comparative analysis of automotive powertrain choices for the next 25 years. Life cycle analysis and energy or emissions modeling, SAE International, SAE paper 2007-01-1605

[5] Marco, J., et al., 2007. Modelling the acceleration and braking characteristics of a fuel-cell electric sports vehicle equipped with an ultra-capacitor. Proceedings of IMechE, Part D: Journal of Automotive Engineering, 221 (1), 68–81

[6] Moeller, S.T., 2002. Energy efficiency issues and trends. New York: Nova Science Publishers.

[7] Doerffel, D., and Sharkh, S.A., 2006. A critical review of using the Peukert equation for determining the remaining capacity of lead-acid and lithium-ion batteries. Journal of Power Sources, 155 (2), 395–400.

[8] Ye, M., Bai, Z.F., and Cao, B.G., 2008. Energy recovery for battery electric vehicles. Proceedings of IMechE. Part D: Journal of Automotive Engineering, 222 (10), 1827–1839.

[9] Sikha, G., Popov, B.N., and White, R.E., 2004. Effect of porosity on the capacity fade of a lithium-ion battery. Journal of the Electrochemical Society, 151 (7), A1104–A1114.

[10] Rousseau, A., Sharer, P., and Besnier, F., 2004. Feasibility of reusable vehicle modeling: application to hybrid vehicles. In: SAE World Congress, 8–11 March 2004, Detroit, MI. SAE paper 2004-01-1618.

[11] Ye, M., Bai, Z.F., and Cao, B.G., 2008. Energy recovery for battery electric vehicles. Proceedings of IMechE. Part D: Journal of Automotive Engineering, 222 (10), 1827–1839.

[12] ThermoAnalytics, 2010. Battery types and characteristics [online]. Available from: http://www.thermoanalytics.com/support/publications/batterytypesdoc.html [Accessed 17 August 2010].

[13] Volkswagen, 2010. The Golf – technical specification S-1.6 litre TDI 90 PS [online]. Available from: https://www.volkswagen.co.uk/assets/common/pdf/brochures/golf-vi-brochure.pdf [Accessed 11 August 2010].