Modeling the Characteristics of an Electric Propulsion System for a Small Vehicle

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Abstract. The paper propose the modeling and simulate the characteristics of an electric propulsion system that equips a small vehicle that can be used in crowded areas of the cityes in order to reduce the pollution and for this we will use the parameters of Renault ZOE model. Also, in the first part, the paper will present the general architecture of an electric propulsion system and its main components, as well as some aspects related to the high architectural flexibility of this propulsion system.

Keywords: Electric Propulsion System · Battery · Torque · State Of Charge

1 Introduction

In the last 10 years, on the European continent, but not only, the discussions regarding the environmental pollution generated by the road transport branch have been accentuated and with these problems, more and more ideas have appeared to act in the direction considerable reduction in pollutant emissions from road vehicles. Various systems have been developed (Three Way Catalytic converter – TWC; particle filter; NOX Trap; SCR) to reduce some of the harmful emissions, including: HC, NO_x, PM, but another gas generate major problems both in terms of how to reduce it and the extremely dangerous impact on the environment, namely CO_2 (carbon dioxide) the main gas underlying the phenomenon called the greenhouse effect which destabilized more and more meteorological phenomena depending on the season and which, in fact, accelerates global warming. So in order to reduce the amount of CO_2 produced by road vehicles, a considerable reduction in fuel consumption from oil (ex. Gasoline, diesel) is needed, this is possible to a solution where the internal combustion engine will have to support a compromise by reducing its dynamic performances (power and torque) which at some point is no longer possible. In this regard, most road car manufacturers have accelerated an extensive process of developing modern propulsion systems to compensate for this compromise and even to be able to operate with other types of energy that are much less harmful to the environment, if we talk about the vehicle emissions in its operation, called electric-hybrid and full electric propulsion. Nowadays, the electric propulsion system is more and more promoted and it is easy to succeed, but it is sure to assert itself among

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road car users and according to the latest assumptions in the coming years, road car sales will be dominated by those equipped with electric propulsion system with Li-ION battery. In the following chapters, we will analyze different types of constructive and functional arhitectures of an electric propulsion system that can equip a small vehicle useful for a driving in urban areas.

2 Analysis of Different Structures

One of the big advantages of the electric propulsion system is its constructive simplicity, generated by the use of a low number of components compared to a propulsion system equipped with internal combustion engine as well as the strength of the components that make up the system. For this we will further present the general architecture of an electric propulsion system, [1].

The electric propulsion system arhitecture (Fig. 1) consists of a battery (B) which is the electric storage source on the board of vehicle. The most widely used battery technology is the Lithium-ion which, however, has a number of disadvantages: energy storage capacity of the vehicle board, in relation to the mass of the battery, but also its high sensitivity. For this, a control system called BMS (Battery Management System) is used, which has the role of constantly monitoring the operation of the battery through several characteristic parameters: the state of charge and the evolution of the recharging process; the level of gases emitted during operation; the voltage value of a cell or the entire battery pack; battery temperature and thus how it is cooled. Beside to Lithium-ion batteries, electric vehicle manufacturers are in the process of developing and optimizing other sources of electricity to eliminate the disadvantages of Lithium-ion batteries, called: fuel cells or supercapacitors.

Another component is the controller (**C**) is a command and control device, which constantly monitors the electric machine and allows a fine control of its speed by controlling the supply voltage at the terminals. Also, the controller allows the electric machine to operate at overloads (increasing torque or power up to twice the nominal value – peak regime) obviously for short periods of time, [1]. The controller also contain a series

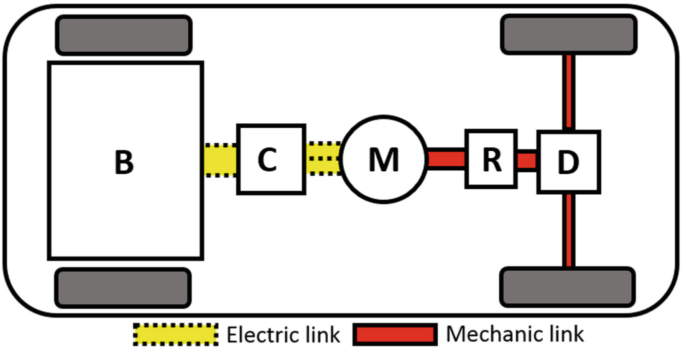

Fig. 1. General architecture of an electric propulsion system. B – battery; C – controller; M – motor; R – reducer (gear); D – Differential.

of specific sensors in order to be able to maintain the correct and optimal operation of the electric machine at all times and to offer it protection; The sensors can be: temperature (thermistor); rotor speed or position (electromechanical - “resolver” or optical - “encoder”) or current transducers (the simplest example being the shunt). The electric motor (**M**) is the component that produces the torque needed for the traction of the vehicle; is a reversible electric machine of three-phase alternative current: synchronous – Permanent Magnet Synchronous Motor/asynchronous – Induction Motor or brushless DC motor. Finally, the architecture of the propulsion system it is completed by the differential (**D**), final transmission and planetary shafts, together with a speed reducer (**R**) with one or two reduction gears that takes over the role of the classic gearbox, speed control is now performed by the controller (**C**), [2, 3].

The use of these electronic components generates a simplification of the operation of such a propulsion system, as well as extremely wide architectural flexibility, which determines multiple solutions of general organization of the vehicle that come bundled with improvements of the capacity, of the useful space and the ergonomic conditions of a road car. In the following sections we will briefly analyze some of these solutions together with their advantages and/or disadvantages.

2.1 Electric Vehicle Equipped with C-M-R Assembly for Each Wheel Without Differential

In Fig. 2 we have presented a first solution of general organization of a vehicle equipped with electric propulsion system characterized by the absence of differential, the wheels being driven directly, each by a planetary gear shaft connected to the exit of the reducer **R** which takes over the rotational movement from the electric motor **M**. Each motor is controlled separately by a controller **C**, and they further communicate with each other through an electronic device called a supervisor (Sup) which has the role of correlate the operation of the two drives and maintain constant connection between them and the battery **B**. The lack of differential in the system leads to an increase in the capacity of the vehicle and a reduction in its own mass, also the center of gravity can be lowered, aspects that improve the dynamics of the vehicle.

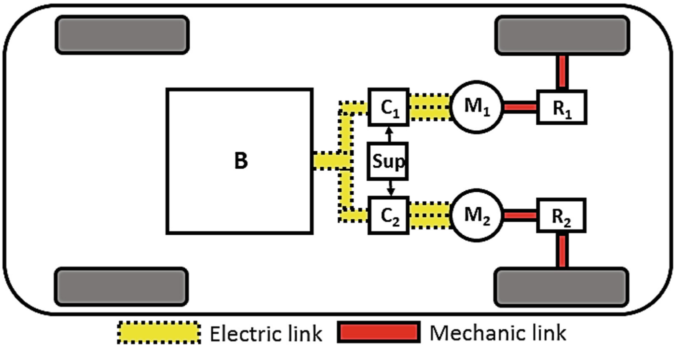

Fig. 2. Electric vehicle equipped with electric motor and reducer for each wheel of an axle, [3].

2.2 Electric Vehicle Equipped with C-M-R Assembly, with Gearbox Mounted on the Wheel

The solution presented above (Fig. 3) proposes an even higher compaction in terms of the arrangement of the components of the propulsion system, the reducer R being mounted inside the wheel, usually a planetary reducer is used in this case and the electric motor and the drive are mounted in the immediate vicinity of the wheel. Obviously, this option also comes with the need for protection of the C-M-R assembly against the various external factors with which the wheel comes into contact during running.

2.3 Electric Vehicle Equipped with the “Electric Wheel” Solution

This constructive solution is characterized by the removal of the gearbox from the propulsion system and the introduction of the electric motor in the wheel of the vehicle, a solution known as the “electric wheel” (Fig. 4).

The main advantage of this solution is that the wheel speed is controlled purely electrically by the value of the supply voltage of the electric motor by the speed variator, which determines an improvement of the stability of the car in the corner by obtaining

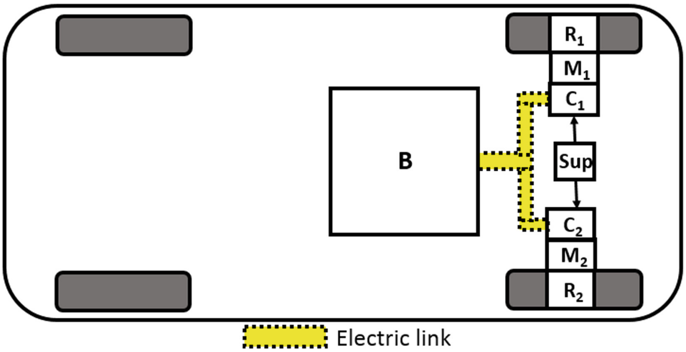

Fig. 3. Electric vehicle equipped with an electric motor for each wheel of an axle and gearbox mounted on the wheel.

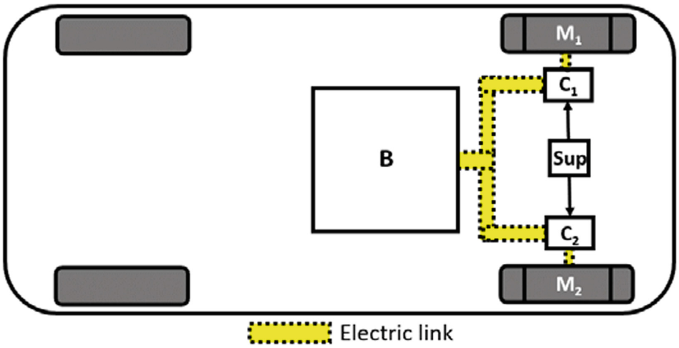

Fig. 4. Electric vehicle equipped with the “electric wheel” solution.

different angular speeds on the wheels of the same axle, which in a classic system is achieved by a differential. It is a compact and innovative solution especially for multi-axle vehicles.

The solutions presented above are a small part of the multiple possibilities of arrangement and general organization of an electric vehicle, but which show extremely well the flexibility of this modern propulsion system and attest to the fact that it can be used in various applications. In the next section we will analyze and present an electric propulsion system already on the market that equips the Renault ZOE.

3 The Studied Vehicle

To create the simulation model of the propulsion system, we chose to use the performance of a small electric car already widespread among users and also the first full electric car launched by the Renault Group, the ZOE model. Until now, several variants have been developed and various optimizations have been made to the battery in terms of energy and supply voltage, as well as related to the performance of the electric motor, which was basically from the beginning of ZOE evolution a three-phase alternating current synchronous machine with permanent magnets, respectively with wound rotor. Thus, we will model the electric propulsion system and we will use as input data, the values of the ZOE model with the 52 kWh battery, respectively the 100 kW motor. First of all we will make a brief presentation of the car with an emphasis on the features of interest.

The architecture of the propulsion system uses the Front Wheel Drive solution (FWD), having both the variable speed drive and the electric motor positioning in the front axle area, together with the one-speed gearbox and the drive axle (Differential, final transmission, planetary shafts) and the battery from the driving position to the rear axle. All this can be seen in Fig. 5.

The ZOE R135 model, the newest in terms of optimizations for both the electric motor, the battery and the recharging system, which allows fast charging at a 50 kW DC station, respectively at one up to 22 kW AC (3-phase). The battery uses Li-ION

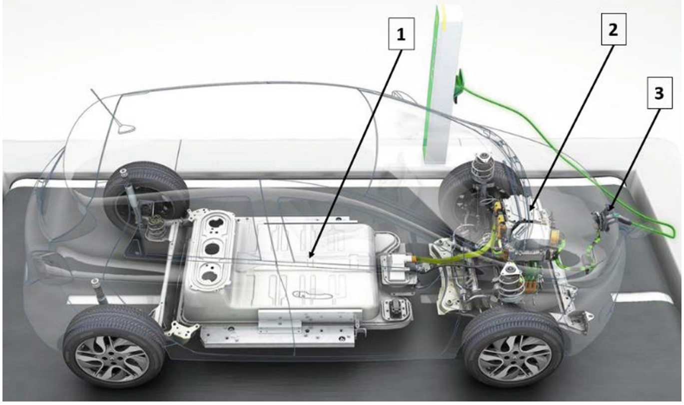

Fig. 5. Arhitecture of the Renault ZOE vehicle, [6].

technology, is cooled with air and is characterized by the following performances: it consists of 10 modules, respectively 192 cells and has a nominal voltage of 400 V, with a useful energy of 52 kWh. As for the electric motor, it is a synchronous motor with wound rotor, identified with the R135 code and characterized by the following performance: it has a power of 100 kW (peak power) reached between 4200 and 11200 rpm, respectively 135 HP and a torque of 245 Nm (peak torque) content between 1500 and 3600 rpm, a value 20 Nm higher than the previous model, R110, [7].

Based on these technical data, a simulation model will be developed to determine traction characteristics of the propulsion system and their variation over time in a peak regime acceleration of the electric motor.

4 The Simulation Model

In order to make the simulation model, different blocks and subsystems existing in the SIMSCAPE library from Simulink were used, these being associated with the characteristics of ZOE, presented above and some informations from [4, 5, 6, 7]. Using the speed range of the electric motor, taking into account the maximum rotor speed 11200 rpm, the torque characteristic was first modeled in EXCEL in peak torque and in continuous torque, after which based on this characteristic the electric motor was parameterized, a synchronous motor. with coiled rotor, a solution less used in the field of electric vehicles, but which Renault has studied and optimized over the years enough to be able to achieve satisfactory dynamic performance. In Fig. 6, we can see the theoretical torque characteristic for the two regimes mentioned.

Based on the data in the graph above, values were entered in SIMULINK which by interpolation shaped the characteristic of the electric motor taken from the SIMSCAPE PowerSystems library and thus generated a reference variation based on which the electric motor simulated the peak acceleration regime, for 2 s. The characteristic obtained is

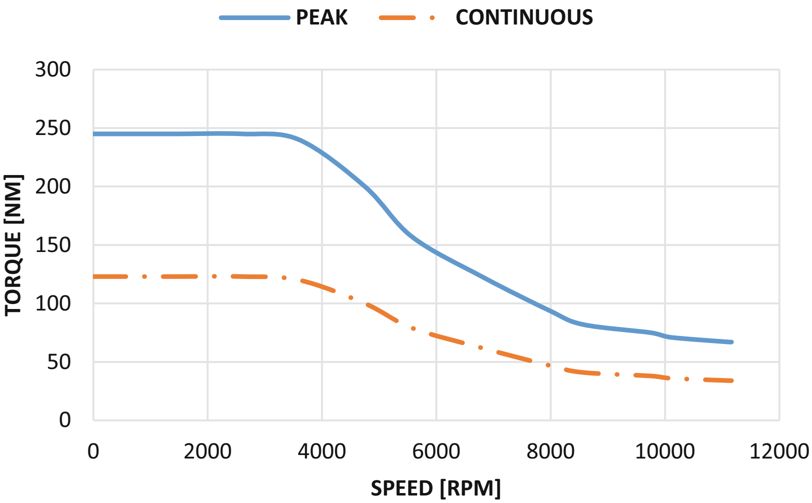

Fig. 6. Theoretical characteristic of the electric motor.

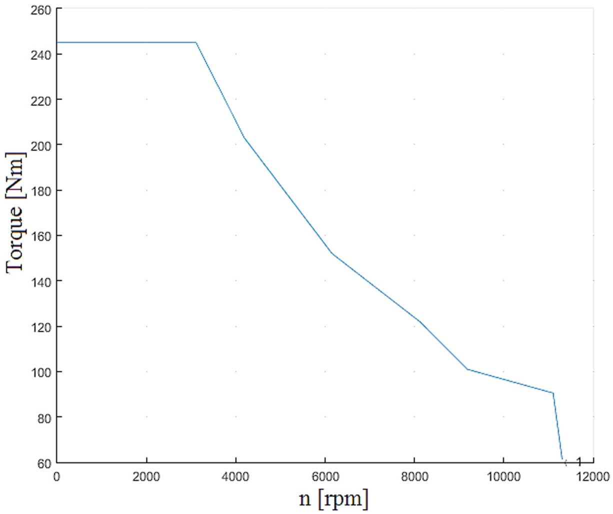

Fig. 7. Electric motor torque obtained in SIMULINK.

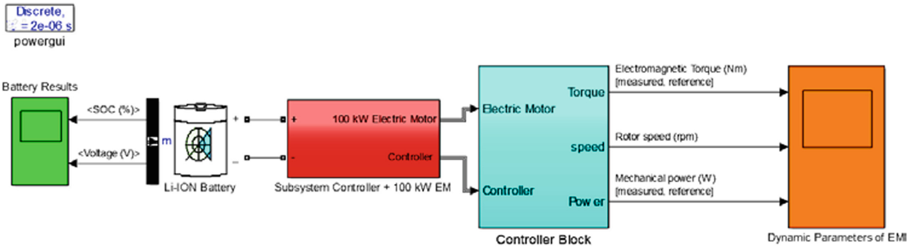

Fig. 8. Simulation model of electric propulsion system.

presented below, with the observation that the program used to perform the simulations was based on a range of speeds used as input data, and after interpolation the point where the speed of the electric motor reaches the maximum value in the data sheet is highlighted. Also, the variation obtained by parameterizing the electric motor is obtained by points, hence the different shape from Fig. 6, made in EXCEL (Fig. 7).

According to Fig. 1, the simulation model follows the general structure of an electric propulsion system, consisting of a Li-ION battery, also taken from the SIMCSCAPE library and adapted to the values in the data sheet of the ZOE electric vehicle. The speed variator, which consists of a Three-Phase Inverter IGBT-Diode, a module for controlling and controlling the speed of the electric motor and a measuring block, which has the role of processing and correlating the results obtained with the theoretical ones. The mechanical power of the electric motor will be modeled considering its mathematic relation "$\mathbf{T} \cdot \boldsymbol{\omega}$", where **T** is the electromagnetic torque, and **ω** is the angular rotor speed of the electric motor, both for the theoretical value and for the one obtained. following the simulation. In Fig. 8 we can see the structure of the model used for simulation:

5 Results

The simulation was performed in peak regime for an acceleration of the electric motor to its maximum speed for a time of 2 s so as to obtain the variation of the main parameters that dynamically characterize the electric motor, as well as the variation of the battery parameters. In this regard the acceleration of the electric motor can be observed by the variation of the rotor speed as shown in Fig. 9.

Based on the theoretical model of the variation of the torque of the electric motor, parameterized according to Fig. 7, following the simulation, the graph of the torque in peak regime was obtained (Figs. 10 and 11)

For the Lithium-ion battery, the variation of the state of charge when accelerating the electric motor was obtained as shown in Fig. 12.

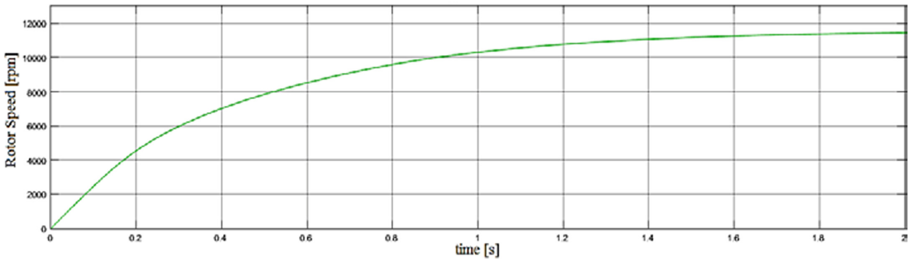

Fig. 9. Rotor speed evolution.

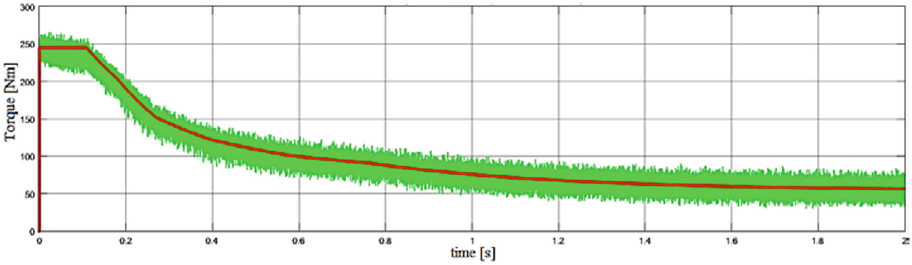

Fig. 10. Torque evolution (simulated – discontinuous line/reference – thick line).

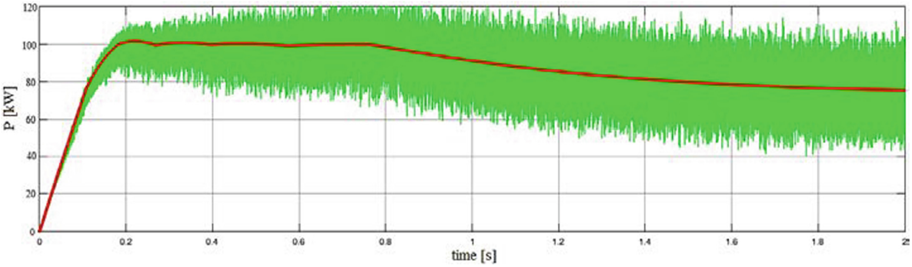

Fig. 11. Power evolution (simulated – discontinuous line/reference – thick line).

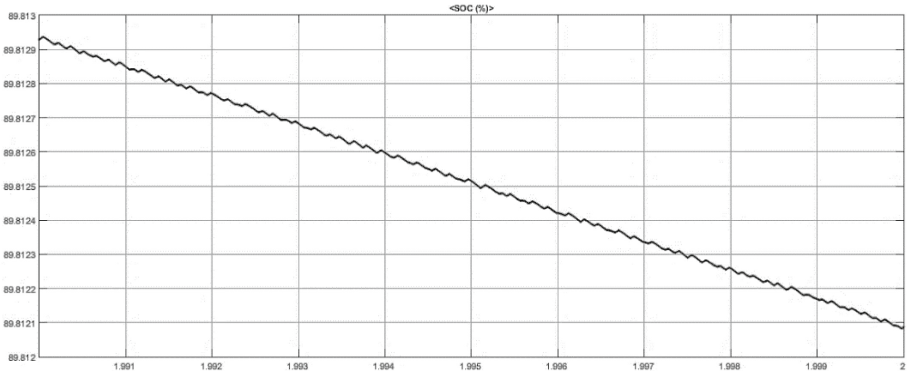

Fig. 12. Lithium-ion state of charge evolution.

6 Conclusions

The torque of the electric motor, measured during the acceleration in peak regime is maximum at the moment of starting the motor and is maintained constant up to a certain value of the speed, called basic speed, which in this case is 3600 rpm, after which the torque starts to decrease. while the rotor speed continues to increase to the maximum measured value 11200 rpm.

The mechanical power, obtained by the product between torque and angular speed, increases directly in proportion to the rotor speed until it reaches its maximum value, after which the power maintains a quasi-constant value, lower than the nominal value in impulse mode.

Maximum starting torque generates superior starting performance of the vehicle and improves traction at low and medium speeds, which is an extremely important advantage of an electric propulsion system.

The state of charge of the battery, initially having the value of ~90%, decreases approximately constantly with the acceleration of the electric motor; for 2 s the SOC decreases by 0.0008% in the case of the simulated model, which means that maintaining this peak regime a few minutes will not discharge the battery completely, but the peak regime can only be maintained for a few seconds in certain situations driving, as a longer life would overload the electric motor and could destroy it.

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