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EV POWERTRAIN USING COMPUTER-AIDED CONCEPTION

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Abstract. One of the simplest ways to rapidly obtain the main characteristics of an EV (Electric Vehicle) powertrain is by calculating the requested values from resistant forces acting on the vehicle. A powertrain covering the operation area of the vehicle can give satisfaction. The autonomy is sustained by the on-board energy source (battery) and the maximum speed and acceleration performances come from the possibility of establishing and maintaining a maximum current through the battery, power electronics, and electric motor. In this context, the present paper is focused on a possible methodology achieved using a computer-aided conception. After determining the characteristics of each powertrain component using calculation and simulation, the behavior of the EV is analyzed under a complete simulation of the powertrain.

1. INTRODUCTION

Electric Vehicles (EV) becoming a more and more accepted alternative to classical ones [1] there is an interest in the conception methodology for EV powertrains, from onboard electric energy sources to electric motors, including all needed power electronics and regulators. The basics in the calculation of a new powertrain [2] request the understanding of resistant forces during the vehicle's displacement [3]. In usual driving conditions, the powertrain must afford such resistant forces and make the vehicle move. How the powertrain can do it, and how long, are questions relative to the powertrain's performance and efficiency.

Inside the powertrain, the electric energy flow between the battery and the electric motor is managed by power electronics devices [4-8] and contributes to the performance of the whole powertrain system. Each subsystem has a specific influence [9]. A specific manner of using powertrain components, especially in multi-motor propulsion systems, can improve the performance and is related to the powertrain control [10]. The first results can be seen using simulation [11], and different manners to emphasize the role of different subsystems and their control [12]. It conducts to first analysis [13-15] and can generate improvement related to the conception of the powertrain and the powertrain control implementation [13-19]. A performance investigation can be realized [20-21]. Going to the real, physical model experiments on a HIL (hardware in the loop) or a low-sale platform [22-23] can confirm the simulation or help to an improvement of its parameters.

Based on precedent experience and documentary research, the present paper has a didactical approach for students to help in the conception of an electric powertrain for an EV. The methodology is based on calculation and simulation on subsystem levels and, also, on vehicle level in a computer-aided approach. It starts with the main vehicle's researched characteristics and goes deeper into the identification and calculation of the components. From components, the behavior of each subsystem is checked under simulation and finally, the entire powertrain is simulated under vehicle constraints. Specific regulators are conceived and verified at components, subsystems, and system levels.

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2. FIRST VIEW ON THE POWERTRAIN

As the methodology of the conception is researched first, the electrical machine is proposed to be a DC one. Voltage control is then possible. A gearbox adapts the shaft speed and torque to cover such vehicle requests at wheel.

There is a first image of the powertrain components given in the Fig. 1.

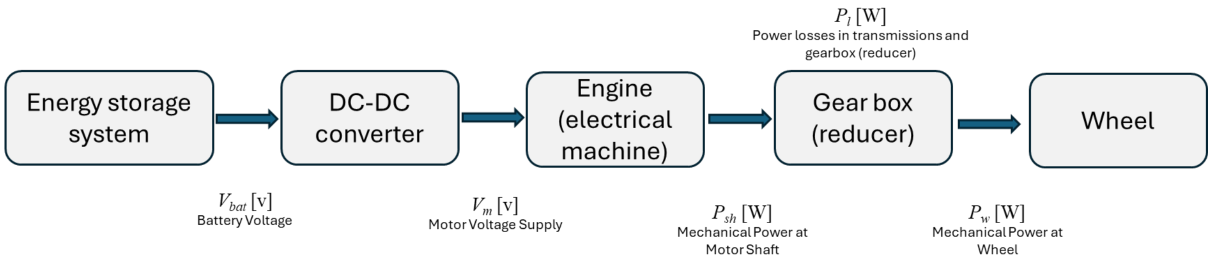


Fig.1 Initial main subsystems of the powertrain

For given vehicle data, the calculation of resistant forces will not be reproduced in the present paper. Details are given in [21].

2.1 Main data for the electric motor

In Fig, 2, the maximum constant speed when running continuously is used to give an autonomy of the vehicle. The time for attempting this speed gives the acceleration of the vehicle. It is mandatory to preserve vehicle stability during this phase and avoid the generation of a propulsion force higher than the adherence one.

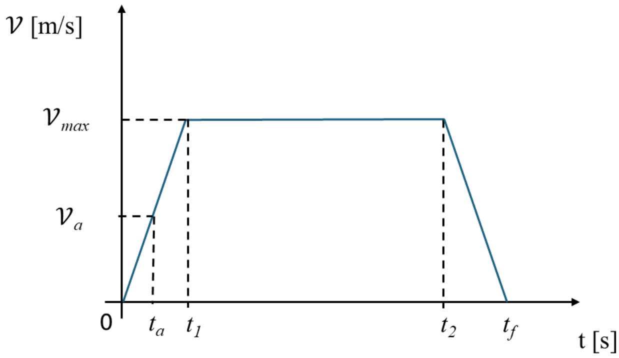


Fig. 2 Initial characteristics of vehicle related to acceleration, maximum speed and autonomy

For a given vehicle, it is now possible to obtain from the calculated tractive force (with acceleration, at maximum speed, etc), the wheel torque, and power:

$$T_W = r \cdot F_t , \quad (1)$$

$$P_W = T_W \, \Omega_W . \quad (2)$$

where r is the wheel radius, F_t is the tractive effort at wheel, and Ω_w is the wheel angular speed calculated for a vehicle (or wheel linear speed), $\mathcal{V}_w$:

$$\Omega_W = r \, \mathcal{V}_W . \quad (3)$$

For maximum values of the tractive effort, it will result a maximum wheel torque.

There is a loss in the power transfer between the electric motor and the wheel:

$$P_{sh} = P_w + P_l \,. \tag{4}$$

As there is a reducer, to simplify the calculation P_l can be considered 1% od the motor power at shaft, P_{sh}. The request for motor power is now estimated, but the torque and speed remain dependent on the reducer ratio. Using a reducer, the motor angular speed must be higher than the maximum expected wheel speed of the vehicle, and the maximum motor torque must be not more than the maximum requested wheel torque.

2.2 Main data for the electric energy storage

From Fig. 2, for a given autonomy of the vehicle (for example, in km), calculating the power to accelerate at a specific running speed, the power to run at this speed, and the power that the vehicle gives during the deceleration phase is possible to calculate the electric energy needed to satisfy the speed cycle from Fig. 2. Increasing $\mathcal{V}_{max}$ and keeping the same running time, t_f, will increase the need in electric energy.

In Fig. 3, there is presented a specific view for the construction of the energetic requests of the vehicle where P represents the power at wheels, d_i, the traveled distance (as the surface under the curve) and W_i the requested energy to travel the respective distance in the respective conditions.

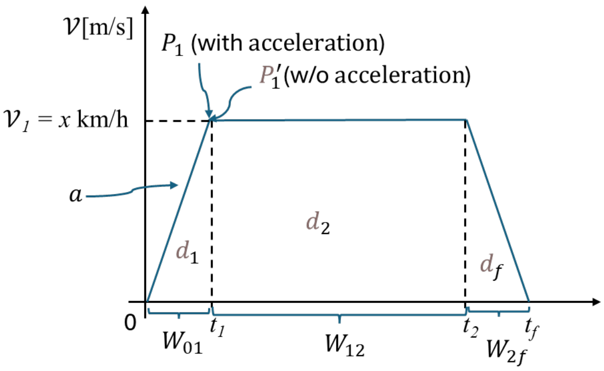


Fig. 3 Energetic considerations for a simple speed cycle.

Considering that the conversion between electric power into mechanical one and vice versa is the same (for example 80%),

$$\eta_{el\text{-}mec} = \eta_{mec\text{-}el}, \tag{5}$$

the requested energy to perform the cycle is:

$$W_{req} = \frac{W_{01}}{\eta_{el-mec}} + \frac{W_{12}}{\eta_{el-mec}} - \eta_{mec-el} W_{2f} \,. \tag{6}$$

For energy storage, W_{bat}, a higher energy will be requested in the calculation (for example 30% more) to offer the same energy during the energy storage life and avoid the situation of a complete discharge.

With W_{bat} is now possible to choose the number of battery cells. The disposal of cells in series will give the battery voltage and in parallel, the battery current. The voltage obtained on e the battery is practically discharged must be higher than the motor nominal voltage. It will allow to continue to control the motor even when the electric energy stored in the battery is low. But when the battery is fully charged, there is a higher voltage to apply to the motor. In the hypothesis of not exposing directly the electric motor to this voltage level dc-dc converters and regulators need to be implemented.

3. POWERTRAIN INCLUDING ADDITIONAL SUBSYSTEMS

The chois of energy storage and the electric motor built on previous considerations request additional subsystems able to adapt and control electric energy parameters during the transformation into mechanical energy at wheel. The schematic from Fig. 1 can be completed resulting an example in Fig. 4.

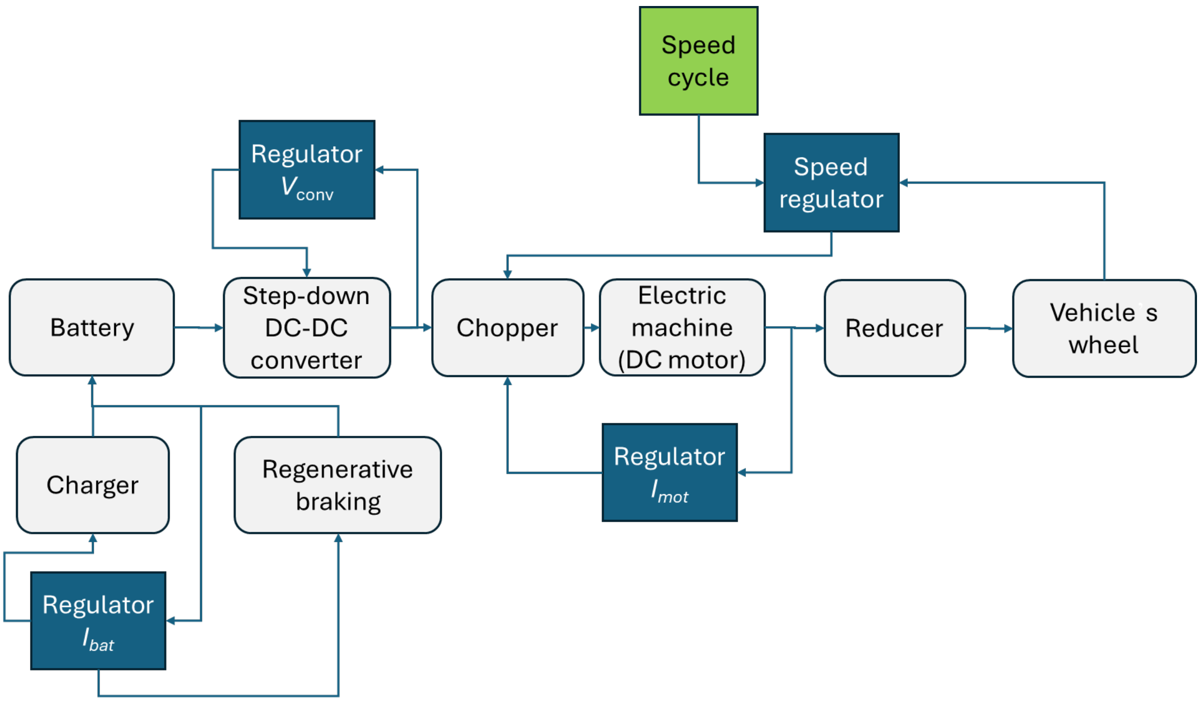


Fig. 4 Powertrain including additional subsystems.

2.1 DC-DC converters

As mentioned before, it is necessary to reduce the battery voltage to the nominal one of the electric motor. An example of a step-down convertor is given in Fig. 5 and realized under simulation in Simplorer.

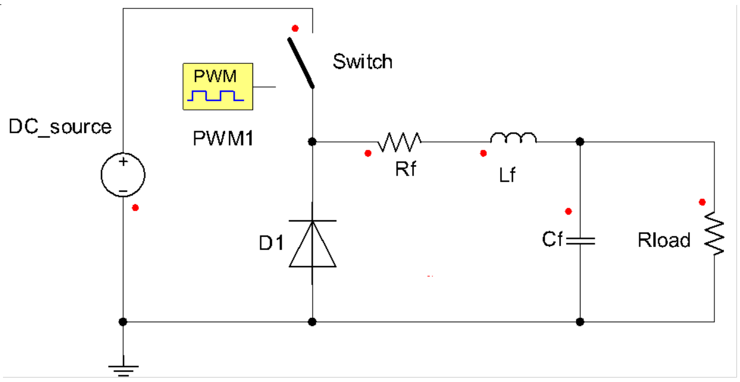
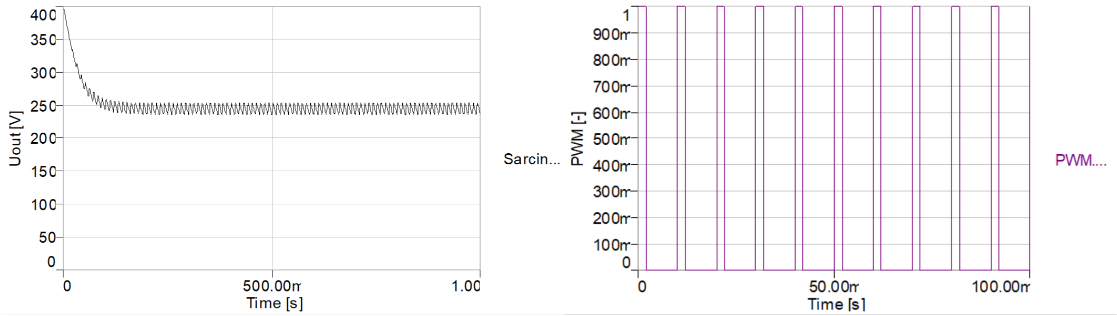


Fig. 5 Buck converter.

It is now possible to certify that a capacitor and coil calculation for a such convertor will give or not satisfaction for the battery voltage level during usage (from low level – battery discharged, to high level – battery fully charged).

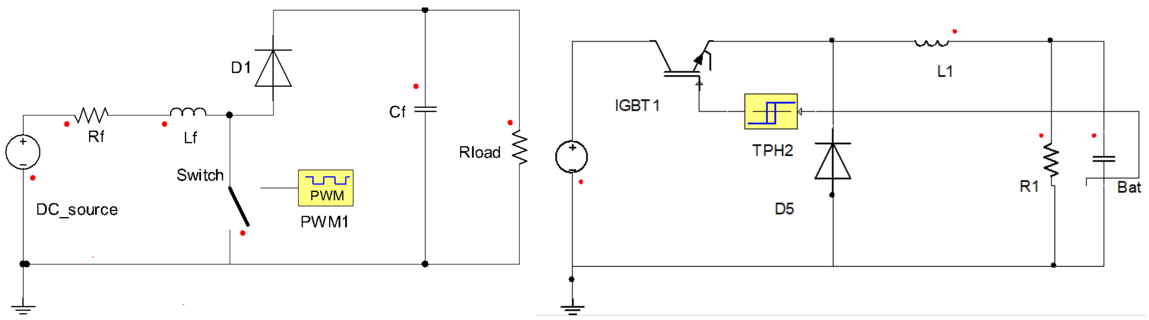
In Fig. 6, there is an example of the PWM command for the switch and the voltage obtained on the load for given data of the components, $R_f = 1\ \Omega$, $L_f = 20$ mH, $C_f = 1000\ \mu F$, $R_{load} = 100\ \Omega$. The results are obtained for a fill factor $D = 0.2$, a switch frequency $f_i = 100$ Hz, and an input voltage $V_{in} = 400$ V.



a). b).

Fig.6 a). Output voltage of the converter; b). PWM signals are used to control the converter switch.

In Fig. 7 are presented additional converters for increasing the voltage level and charging the battery, as for example during regenerative braking or battery charging.



a). b).

Fig.7 a). Boost-converter; b). Battery charger.

The obtention of requested levels for voltage or for current (as for example during battery charging) are the object of regulators. One of the elements for the regulations are the fill factor. In Fig. 6.b). an example with a hysteresis regulator is given.

2.2 Regulators

For the exemplification of regulators usage, an example of the integration of a PID regulator is given in Fig. 8, under MATLAB/Simulink:

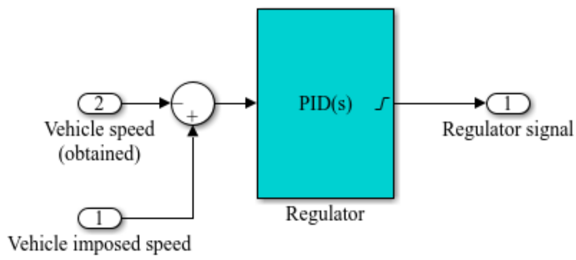


Fig. 8 PID regulator.

A such regulator is expected to deliver the fil factor for the converter generating the input voltage on the motor armature (a buck converter, or directly a chopper).

4. POWERTRAIN SIMULATION

After determining the parameters for the powertrain subsystems and after verification of subsystems behaviors, independently, under simulation and improvement of each subsystem, the next step would consist in the simulation of the whole powertrain in an electric vehicle. Fig. 9 gives the main blocks of the implementation.

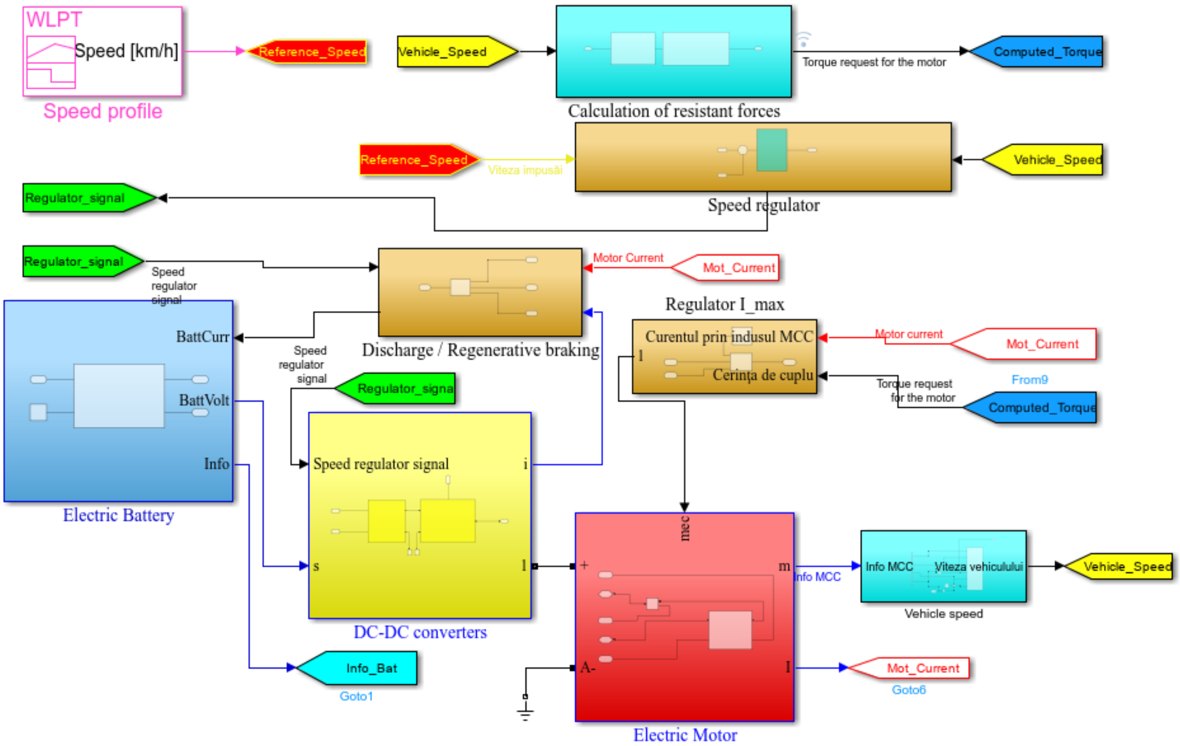


Fig.9 Main blocks of the whole powertrain simulation under MATLAB/Simulink.

The” Speed profile” represents the speed request and can be a simple speed request as shown in Fig. 2, or a normalized speed profile (a standard speed evolution like FTP75 or NEDC). The resistant forces are calculated under the block” Calculation of resistant forces”. The content of this block is presented in Fig. 10. In the block” Speed regulator”, the regulator from Fig. 8 is integrated.” Discharge / Regenerative braking” is a decision block able to control the energy from battery to the electric machine as motor, from the electric machine as generator to battery.” Regulator I_max” supervises the motor current for overheating protection. In” Electric battery”, an electric storage system is implemented, based on Li-Ion cells. An example of battery parameters is given in Fig. 11 for 6750 battery cells of 6.2 Ah each cell. The cell voltage is between 2 V and 3.5 V generating a battery voltage between 550V and 787.5 V. The bloc” DC-DC converters” contain a buck-converter which regulates the battery voltage to the nominal voltage of the motor (in the example, 400V) and a chopper, as presented in Fig. 12. For the chopper, the signal form the speed regulator (Fig. 8) is in fact the fill factor of the chopper allowing to maintain the requested speed of the vehicle. The” Electric Motor” block implements the DC machines with the parameters shown in Fig. 13. From the angular speed of the motor, integrating the reducer ratio, the vehicle speed is calculated (block” Vehicle speed”) as presented in equation (3).

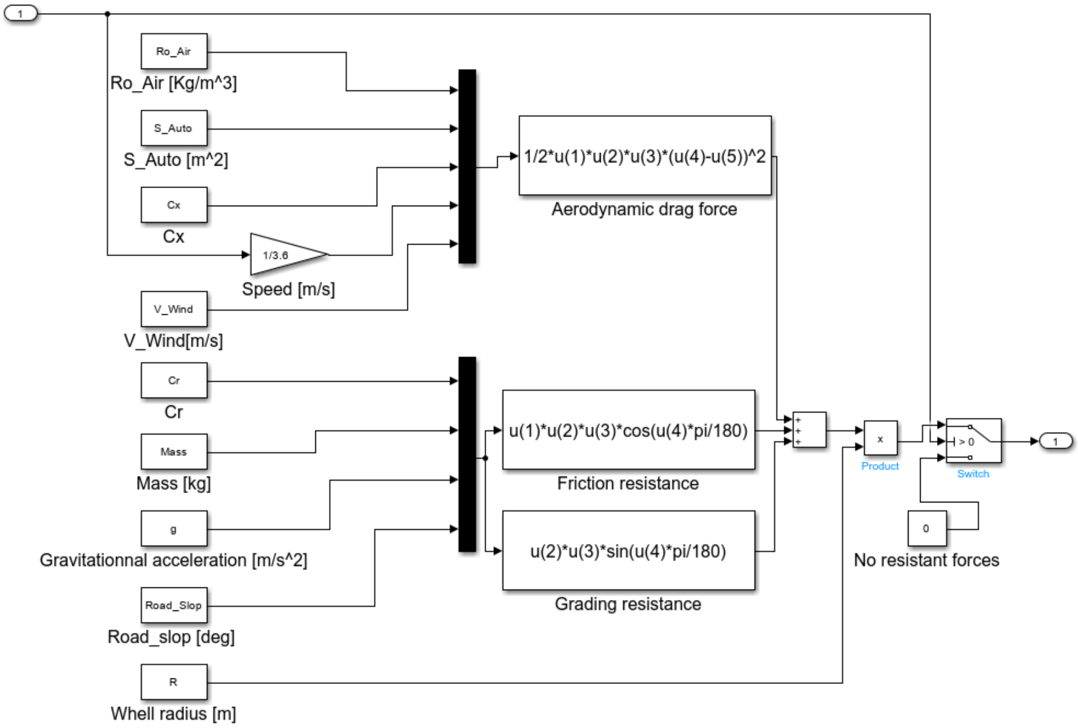


Fig. 10 Example of resistant forces calculation under MATLAB/Simulink [15].

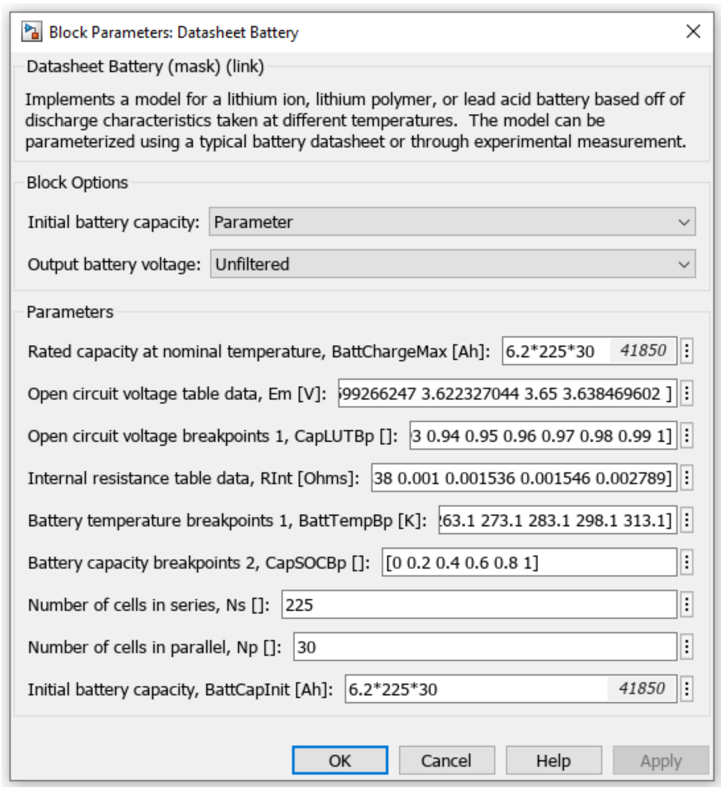


Fig. 11 Example of resistant forces calculation under MATLAB/Simulink [15].

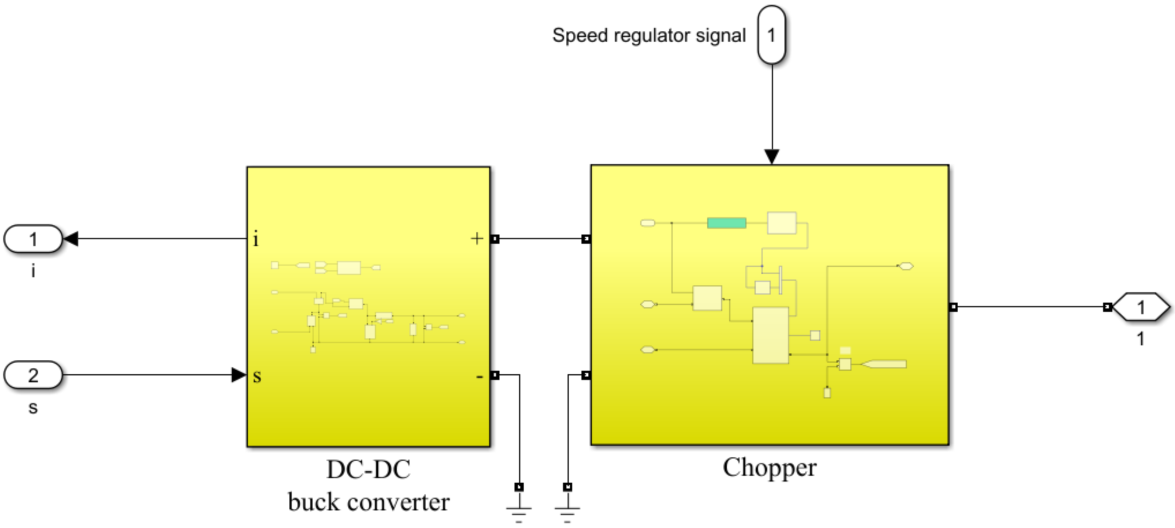
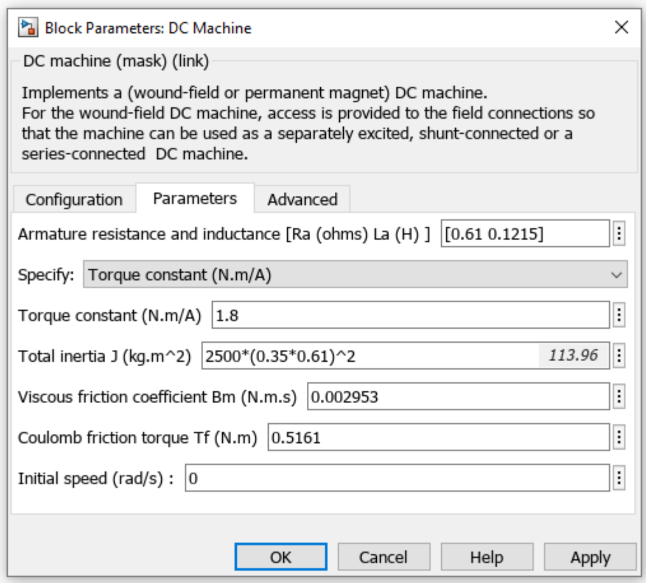


Fig. 12 DC-DC converters between battery and electric motor.



Fig, 13 Parameters of the permanent magnets DC machine

Vehicle characteristics and running conditions are presented in Table 1 and Table 2. The values are integrated into the resistant force's calculation and the shaft inertia for the DC machine.

Table 1.
Characteristics of the vehicle

Characteristic	Value	Measurement Unit
Vehicle mass	2500	kg
Wheel radius	0.35	m
Aerodynamic drag coefficient	0.4	-
Frontal area	2.5	m^2

Table 2.
Data for resistant forces calculation

Characteristic	**Value**	**Measurement Unit**
Rolling resistance coefficient	0.013	-
Maximum tractive effort coefficient	0.8	-
Air density	1.225	kg/m^3
Gravitational acceleration	9.8	m/s^2

5. RESULTS AND DISCUSSION

In the Fig. 14 to Fig. 18, some of the results of the simulation are shown as the evolutions for: battery voltage, buck-converter voltage, battery state of charge, vehicle imposed and real speed, and the speed regulator signal.

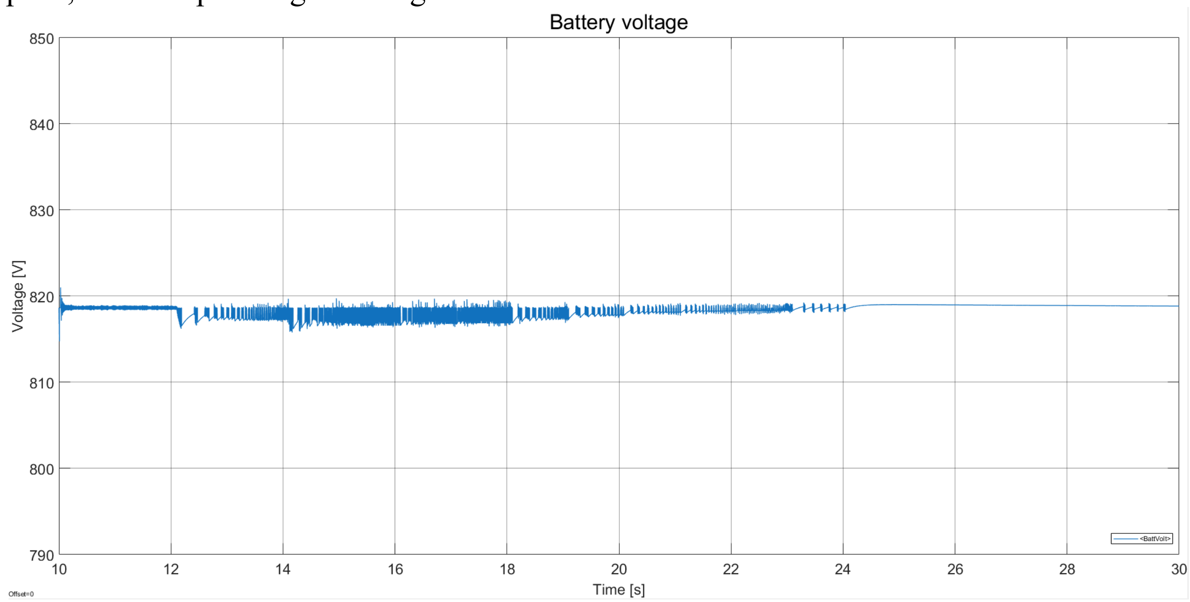


Fig. 14 Evolution of battery voltage.

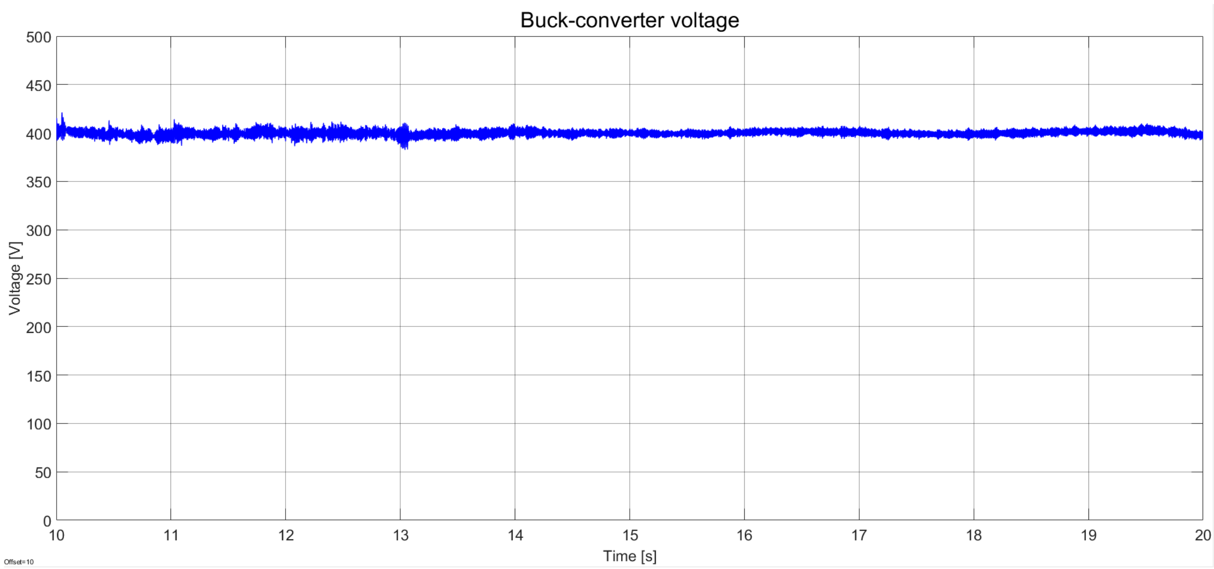


Fig. 15 Evolution of the buck converter voltage.

Oscillations of few volts can be observed to the battery and buck-converter voltages following the chopper frequency and resulting form the current pulses through the DC machine.

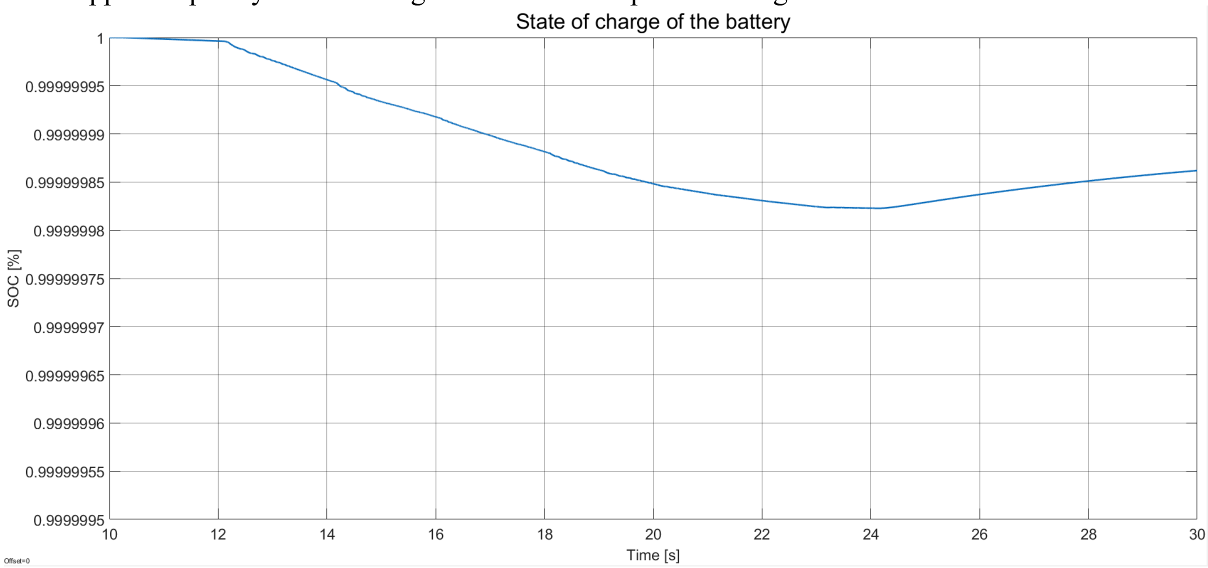


Fig. 16 Battery state of charge

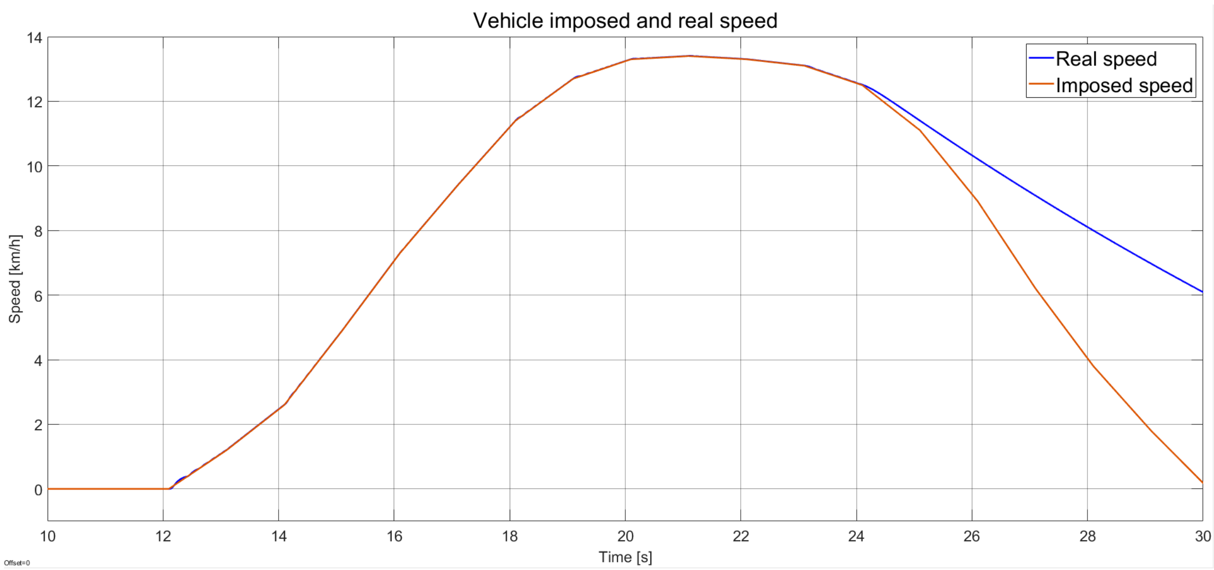


Fig. 17 Speed regulation

The battery state of charge improves during regenerative braking, but this" brake" is not enough to reduce the speed of the 2.5 tones vehicle during decelerations. To control the speed, a supplementary effort must be integrated from the brakes, generating a supplementary resistant force. A specific regulator is needed as the one used to control the fill factor for the chopper.

6. CONCLUSION

A methodology of powertrain calculation has been exemplified in the present paper starting from vehicle request in terms of speed and acceleration.

The initial data gave first estimations related to electric machine power, speed, and torque. From an autonomy request an electric energy storage has been evaluated. The number of battery cells and their modalities of connection resulted using a battery cell data and following to provide at least the nominal voltage of the electric machine with a discharged battery and a requested motor current.

To transform the energy parameters between the source (battery) and the consumers (especially the electric machine), DC-DC converters have been proposed with convenient regulators. At this level, several subsystems have been calculated and checked under simulation to integrate the new powertrain.

Once the subsystems have been verified, the simulation of the entire powertrain in an electric vehicle was possible. This made possible the confirmation of functioning for different subsystems in the powertrain system.

The simulation emphasizes the need for a complementary mechanical system able to create a resistant force to decelerate the vehicle in parallel with the electric machine functioning as electric generator and to stop it at low speed of electric machine.

The steps followed in the present methodology are used for a didactical process to sustain the students in the exploration of vehicle needs and calculation of a specific powertrain able to cover the requests.

CONFIRMATION

The paper was presented at the SME'XX Electric Machinery Symposium, 2024 edition.

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