DIDACTICAL PLATFORM FOR MULTI-MOTOR SOLUTIONS IN ELECTRIC VEHICLES

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Abstract. For electric vehicle powertrains, many activities are performed using simulation of different components and sub-systems and the research and teaching process uses successfully different tools. Following this way, expensive physical elements are avoided, and multiple configurations could be studied, before going to the next step. To capitalize on the virtual results, a physical test is necessary, even if it is performed on a reduced scale. This paper presents a didactical platform for multi-motor solutions in electric vehicles, a platform which can serve also for research activities related to analysis and control of electric powertrains with at least two motors.

1. INTRODUCTION

Before realizing an entire Electric Vehicle (EV), different sub-systems are studied and integrated on specific testing tools. A powerful methodology to test components containing embedded software, Hardware In the Loop (HIL), is usually used to obtain a real time validation and compare the results with the simulation. In [1] a test bench model is proposed to evaluate the performance of a multi-source light electric vehicle energy management system. Regenerative and friction braking have been tested on this manner in a motor/dynamometer test bench [2]-[3]. Similarly, charging systems [4], drives [5] and powertrains [6]-[8], dedicated bench for Control systems [9] and convertors [10]-[11] have been investigated. For electric motors, the testing system is also called dual test-bench [12]. An important attention is payed to load aspects [13]-[15]. The test must be as close as possible to real conditions. Complex electric drives parameters are also requiring dedicated measurement systems [16]. On the other hand, the results obtained on test bench could be used for building simulation models [17]. For range extension, dedicated technics, like series chopper powertrain [18] and bench tests were conducted for more precise evaluation and to realize experimental results with high reproducibility [19].

The premise of analyzing multiple motors represents a challenge, but also a trend for certain car manufacturers of our days [20]. Replacing in an EV one central motor by two identical equivalent motors, one for each axle, could be a source of energy optimization [21]. Different techniques for torque allowance between motors acting on front and rear axles of a vehicle [22]-[23], opens new opportunities for an improved usage of the onboard energy. In this context, a bench able to offer the perspective of developing such activities in the educational environment, represents an interesting topic.

In the present paper, a complete didactical platform is proposed integrating a support with a bi-motor powertrain system with dedicated control and battery for each motor. From academic point of view, different practical studies and specific measurements can be realized by students, and researchers. It can confirm the characteristics of the motors and the optimization results from simulation. Real situations could be deepened on an identical or a reduced scale using the platform. New techniques for load repartition between the two motors

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have the possibility to be investigated, but also aspects related to vehicle stability and onboard energy efficiency improvement.

2. CONSTITUTION OF THE DIDACTICAL PLATFORM

2.1 Main Objectives

The objectives of the didactical platform are multiple. They are attempted trough the functions offered to users as:

- operational area and efficiency investigation for each motor of the powertrain;
- implementation of a powertrain load request depending on vehicle characteristics and speed profile, as entry data;
- transformation of the powertrain load request in individual load request for each motor using diverse strategies;
- performance investigation for the vehicle such as acceleration and gradeability;
- analysis of the energy efficiency following a vehicle speed profile for different load distributions scenarios between motors.

A real environment for EV propulsion systems with two motors is proposed. The motors can receive simultaneously different dedicated variable load and can be controlled individually in terms of torque and speed. Two cases can be analyzed: when the powertrain covers one axle of the vehicle, with a dedicated motor for each wheel of the axle, and the case of a dedicated motor for each vehicle axle. If a motor integrates a reducer, the platform can survey the torque and speed after the reducer.

Different kind of traction motors could integrate the platform, with a predilection for in-wheel solutions. A specific attention is payed to Permanent Magnets (PM) motors. For such motors, the power density and their controllability and reliability, as mentioned in [20], generate specific attention to use it in building powertrains for EV. It represents one of the most efficient solutions to create vehicle movement using electric energy.

Depending on the investigations, the electric motors will be accompanied by their specific control devices and batteries. A traceability related to the charge and discharge processes is necessary in this case to follow the state of charge (SOC) of the batteries and the maximum amount of stored energy. Additionally, the battery aging process could be followed storing systematically batteries data.

The load evolution for the powertrain will result from vehicle characteristics and the requested speed profile, usually from a normalized testing cycle. Aa calculation example is given in section 3. Diverse criteria to distribute the load between motors can be investigated using an optimization programming process for improving performance and energy consumption.

For the verification of the powertrain limits, additional vehicle mass, towable mass and grading resistance can integrate the calculation of the load profile for the powertrain. Following the diverse conditions, the investigation will be able to confirm a maximum acceleration of the vehicle, a maximum speed, the ability to climb a slopping road at a certain speed, the capacity to follow integrally a testing cycle profile.

Today’s simulation tools offer large perspectives. After powertrain simulation, a first physical confirmation can be done on the platform. An additional physical two-driving wheels vehicle is proposed for real road test.

2.2 Schematical view

The platform integrates physical supports for the driving wheels, security, and resistant rollers. Main physical components are represented in Fig. 1.

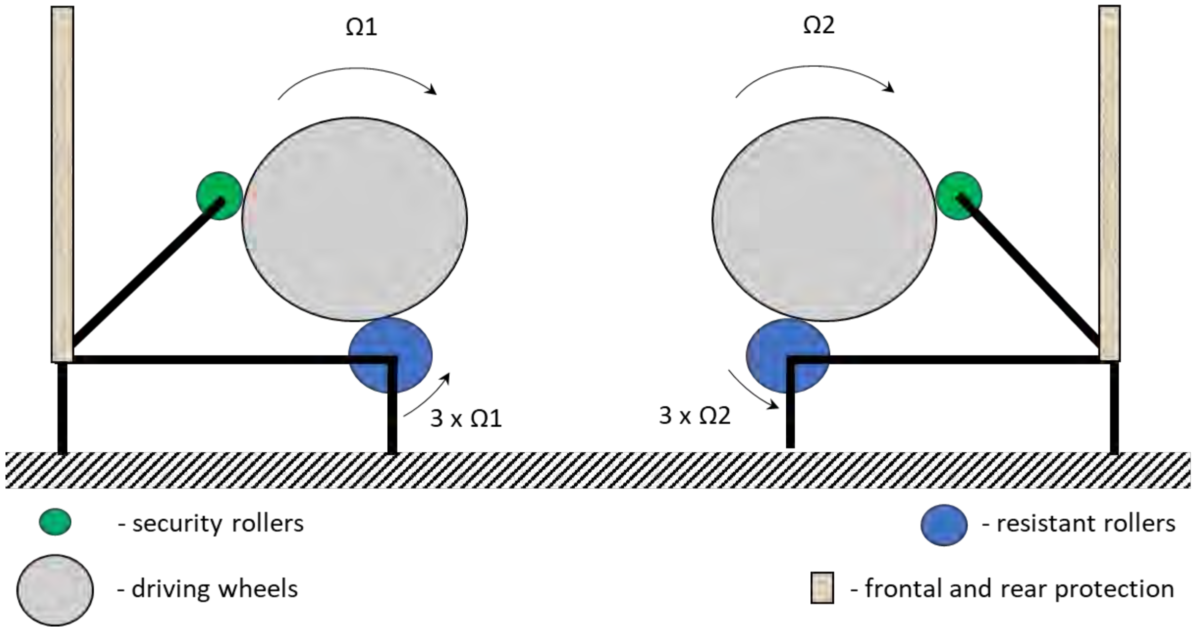

Figure 1. Schematical view on mechanical components of the platform

The activities could be realized at a reduced scale, depending on the platform capabilities. The resistant rollers ensure the requested load evolution for each motor.

2.3 Platform control

The control management of the platform is presented in Fig. 2.

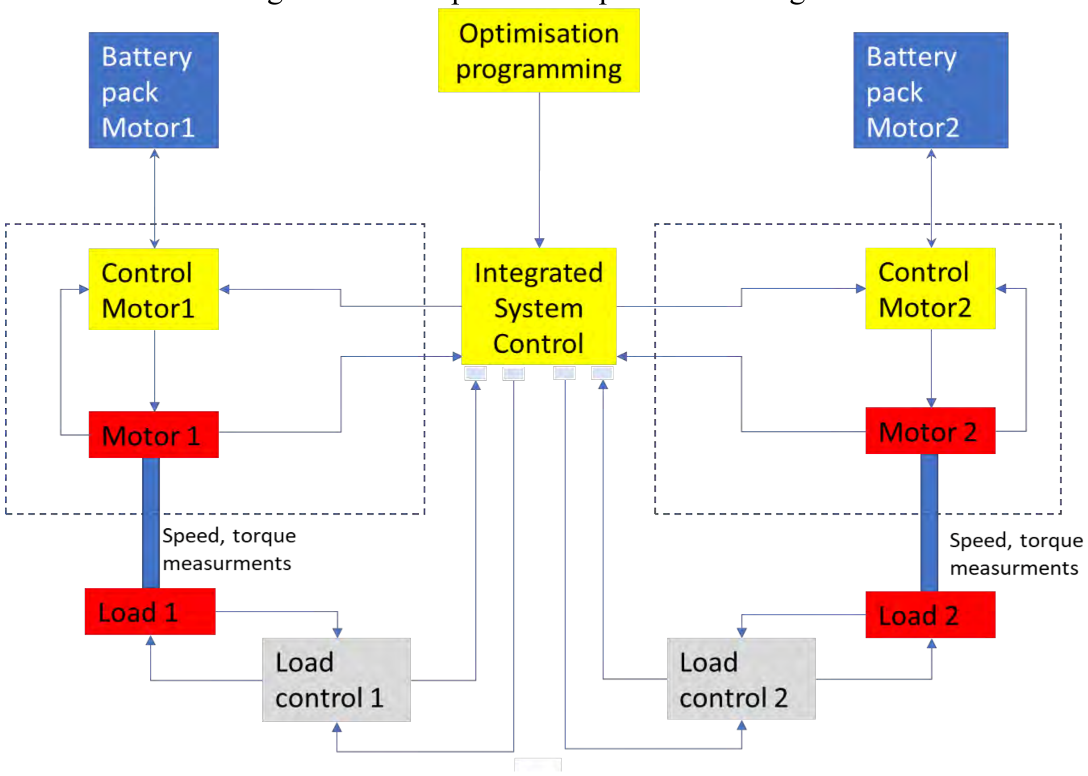

Figure 2. Platform management

The integrated system control transforms the load request for the powertrain in load requests for Motor1 and Motor 2: Load 1 and Load 2. From the needs of controlling each electric motor and its load it results the entry data for each individual control. The obtained physical values are continuously surveyed. At each step a correction of the entry data could be applied to approach the physical values to the expected ones. From this point of view, a previous calibration would be necessary. However, the continuous measurements of speed and torque remains active during the test. Also, the correction loop must remain operational.

3. SPECIFIC CONSIDERATIONS

3.1 Calculation of resistant forces and speed of the electric motors

A bi-motor electric vehicle (EV) with the characteristics shown in Table 1 is considered to determine the resistant forces to be developed by the platform.

Table 1. Characteristics of the vehicle

Characteristic	Value	Measurement Unit
Maximum mass (M)	550	Kg
Wheel radius (r)	0.3	M
Aerodynamic drag coefficient (C_x)	0.46	-
Frontal area (S)	0.92	m^2
Transmission ratio (motor to wheel)	1	-

Table 2 presents the resistant forces coefficients used for the calculations.

Table 2. Resistant forces coefficients

Characteristic	Value
Tractive effort coefficient (c_t)	0.8
Rolling resistant coefficient (μ)	0.013

Following the resistant forces calculation in [23], in natural conditions, on the vehicle is acting the aerodynamic force

$$F_{ra} = \frac{1}{2}\rho S C_x (V - V_w)^2, \tag{1}$$

where ρ is the air density (1.225 kg/m^{3}), S, the vehicle frontal area and C_x, the aerodynamic drag coefficient. V is the vehicle speed and V_w the wind speed on the vehicle direction.

The gravitational force acting on the vehicle is

$$G = Mg, \tag{2}$$

where M is the mass of the vehicle and g is the gravitational acceleration (9.81 m/s^2). A slope angle α could be integrated to calculate the normal component

$$G_n = Mg\cos\alpha, \tag{3}$$

and the tangential component acting as grading resistant force

$$G_t = Mg\sin\alpha. \tag{4}$$

The rolling resistant force is

$$F_{\mu} = \mu M g \cos\alpha \, , \tag{5}$$

where μ is the rolling resistant coefficient.

To produce movement, a resultant tractive effort generated by the powertrain must be equal or superior to the sum of resistant forces from (1), (4) and (5)

$$F_t \geq F_{ra} + G_t + F_{\mu} \, . \tag{6}$$

F_t has a superior limit given by the product between the normal load from (3) and the tractive effort coefficient, c_t, from Table 2.

For moving the vehicle with an acceleration a

$$F_t = F_{ra} + G_t + F_{\mu} + Ma \, . \tag{7}$$

As the transmission ratio is 1, considering r the wheel radius, the theoretical powertrain speed) is

$$\Omega = \frac{V}{r} \, . \tag{8}$$

3.2 Resistant torque

The platform must generate resistant forces at various speed in coherence with the testing cycle request for the vehicle. As in [23], a WLTC speed evolution could be considered. It is represented in Fig. 1.

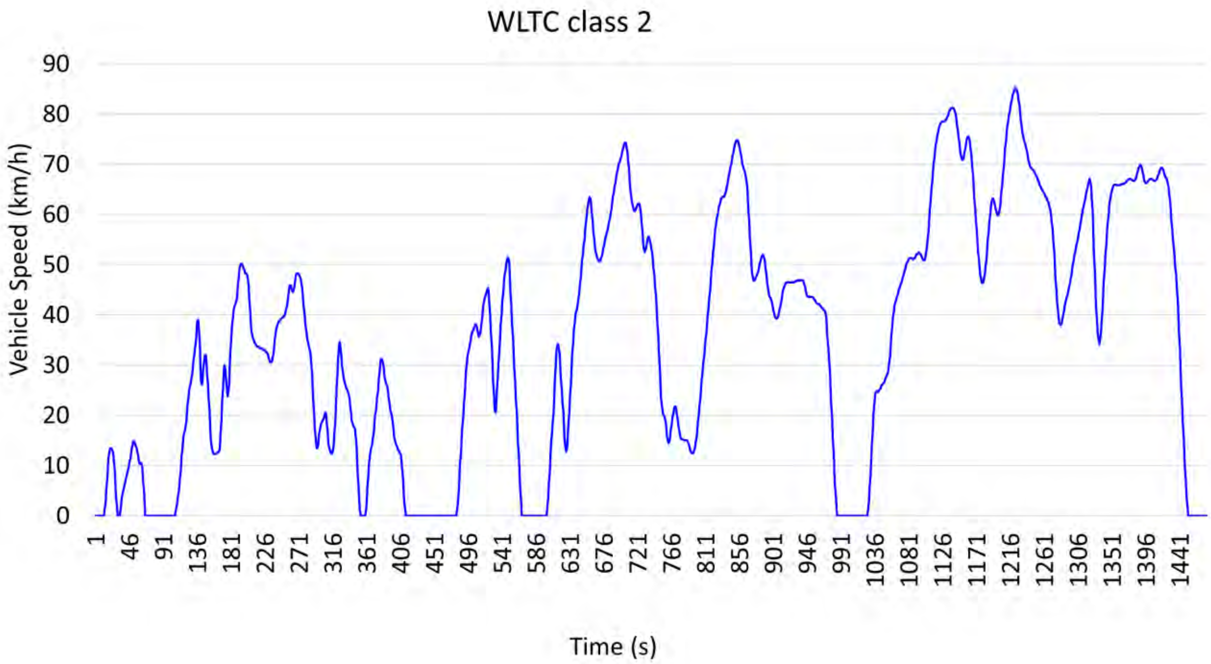

Figure 3. Speed profile of the testing cycle

From the speed evolution is possible to calculate the acceleration profile.

The acceleration for each moment, k, is calculated by numerical derivative of the speed V [23]:

$$a_k = \frac{V_{k+1} - V_{k-1}}{2 \cdot \Delta t}. \tag{9}$$

where Δt is the sampling time step of the curve in the precedent figure.

Using the calculation model in the previous section it results the resistant torque request for the platform, represented in Fig. 4.

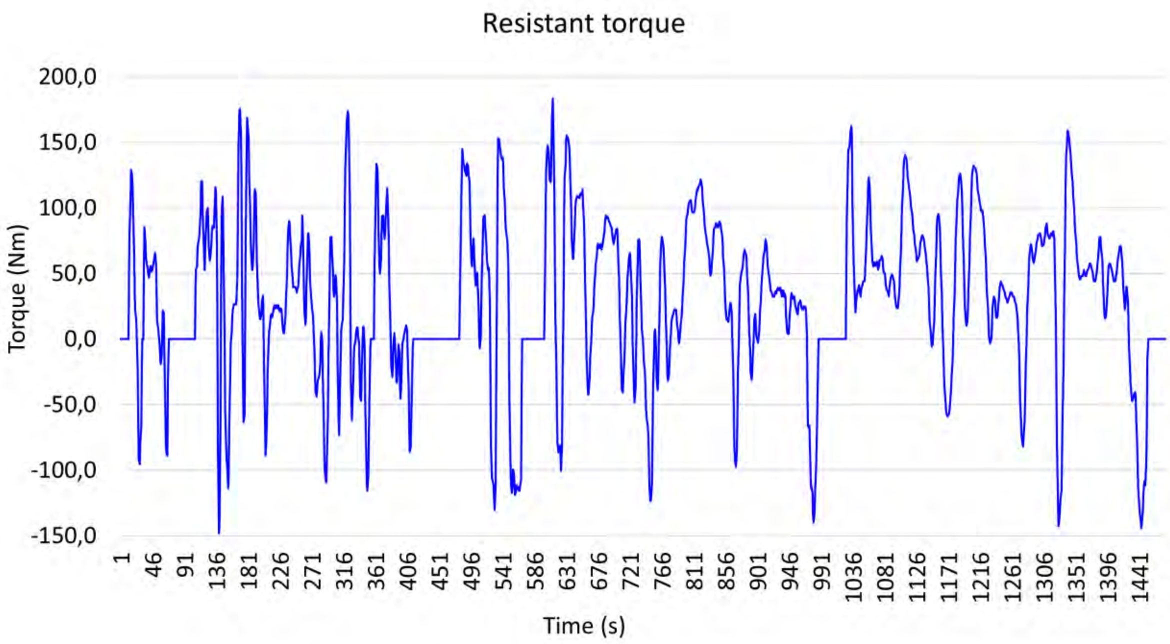

Figure 4. Resistant torque request for the platform

3.3 Data integration on the platform

For running the platform, two set of data need to be integrated initially via the *Optimization Programming* module from Fig. 2: the speed profile of the testing cycle from Fig. 3 and the resistant torque request from Fig. 4. One possibility is to introduce for both files discrete values using the sampling time step for acceleration calculation. Another possibility is to introduce only the speed profile as a discrete file and to implement the equations (1) to (9) inside the module and obtain internally the evolution of the resistant torque request.

The same module needs to be documented with the load distribution between each motor during the testing cycle.

4. EXPECTATIONS

4.1 Usual measurement, calculations, and experimental confirmations

Typical measurements and determinations of the motors are possible in order to:
- confirm data given by manufacturers,
- build equivalent circuits,
- compare results from calculation with the ones obtained using the platform,
- build mechanical characteristics of the motors.

An example of similar motors characteristics as in [23] is given in Fig. 5 and respectively in Fig. 6.

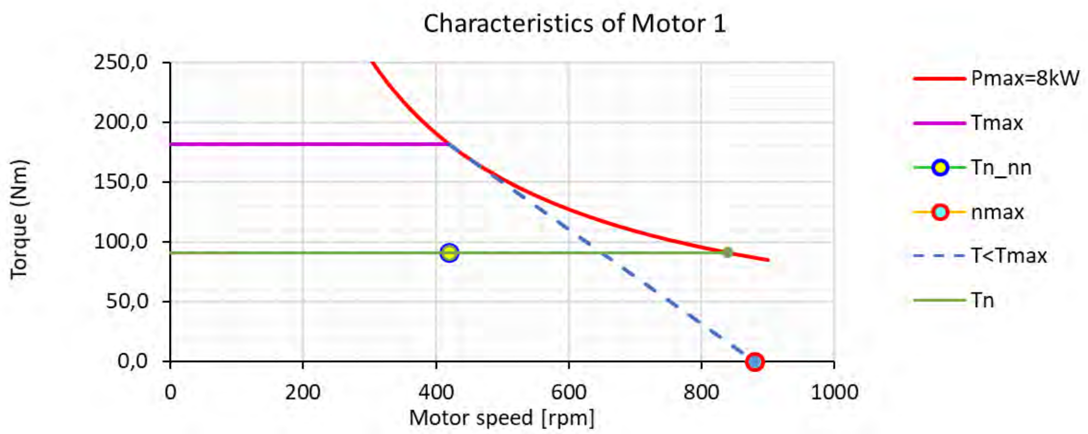

Figure 5. Calculated characteristics for Motor 1

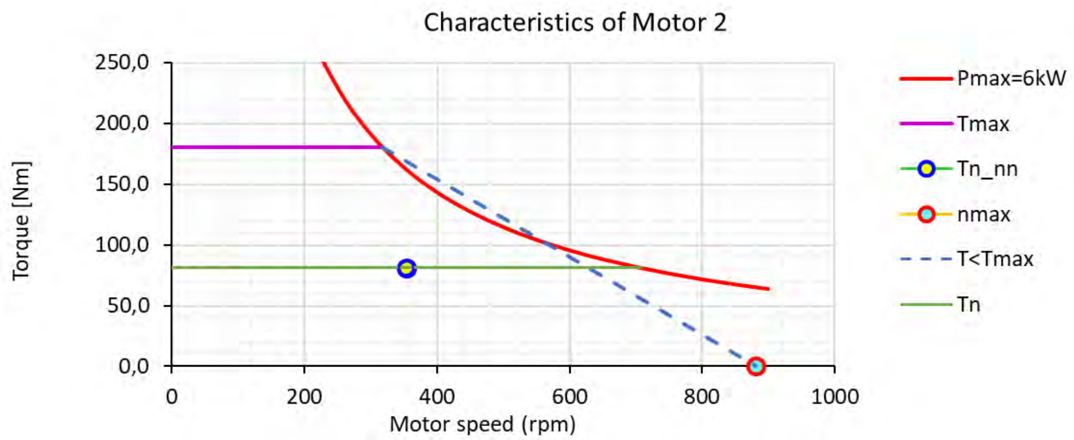

Figure 6. Calculated characteristics for Motor 2

The main motors data are listed in Table 3.

Table 3. Motors Data

Data	Motor 1	Motor 2
Nominal / Max Power	4 / 8 kW	3 / 6 kW
Torque constant	1.655 Nm/A	1.800 Nm/A
Internal resistance	0.128 Ω	0.130 Ω
Maximum torque	182 Nm	180 Nm
Maximum speed	880 rpm	880 rpm
Hysteresis losses coefficient	0.0938 W/rpm	0.0651 W/rpm
Eddy currents losses coefficient	0.0001 W/rpm^2	0.00009 W/rpm2

4.2 Motors involvement during a driving cycle

Using the calculation example given in section 3, the operating points for the powertrain could be determined. It gives the correspondent output in terms of torque and speed to cover the requests from the testing cycle.

With above data, the Fig. 7 represents the couple torque-speed for each step of the testing cycle.

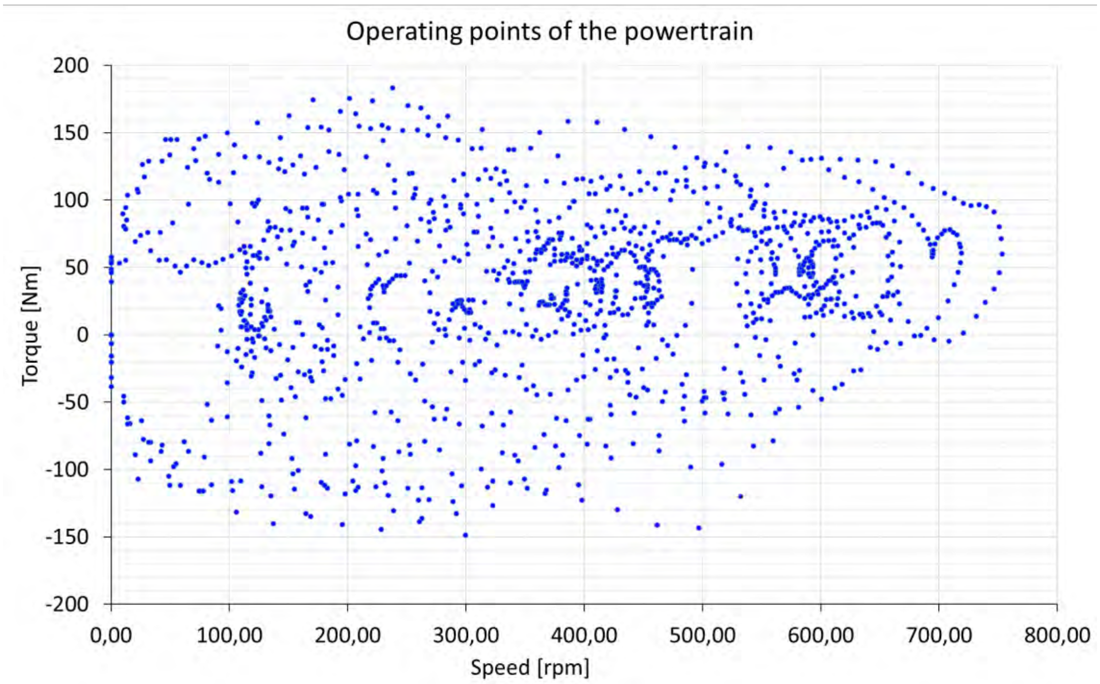

Figure 7. Operational area for each step of the testing cycle

Depending on the capabilities of each motor, one operating point could be covered by one single motor or both motors. A theoretic repartition of the load between two motors can be defined using optimization criteria. The resistant torque, T from Fig. 2 is

$$T = c_1 T_1 + c_2 T_2, \tag{10}$$

where, T_1, T_2 are the torque generated by each motor and c_1, c_2 are the load repartition coefficients. Both coefficients are positive or negative simultaneously. The sum of the contributions from each motor must cover the resistant torque request.

In real conditions, the adhesive capability between the tire and the ground will limit the maximum tractive effort on each wheel [21]. The vertical load can be different between tires (especially between front and rear ones), and, V_r, the product between the wheel radius, r, and the angular speed of the wheel, Ω, are superior to the translatory speed of the wheel center, V_t. The slip of the tire,

$$s_{tr} = \left(1 - \frac{V_t}{V_r}\right) \cdot 100\ [\%] \tag{11}$$

has accepted limits for performance (15-20%). Superior values generate vehicle instability.

When a motor is running as electric generator, during braking, V_t is superior to V_r and the tire slip is

$$s_{br} = \left(1 - \frac{V_r}{V_t}\right) \cdot 100\ [\%]. \tag{11}$$

If the motors are powering the same vehicle axle (for example, one motor for each wheel), when cornering it is more evident that the motors will run at different speeds.

From these points of view the platform accepts controlled and different angular speed of the motors (Fig. 1).

4.3 Additional expectations

The results from calculations and simulations could be compared with physical results obtained on the platform, generating possible improvements for the models used in simulation. Theoretically, each moment of the testing cycle, the motors must run at the same speed. The differences measured on the platform conduct to the analysis of the vehicle stability and can generate an improved control of the multi-motor solution. A distribution of such differences could be built as a function of requested speed and requested torque.

During a testing cycle, different criteria to involve each motor could be applied, resulting different scenarios of load distribution. The energy efficiency is confirmed at the end of the testing cycle using the SOC of the batteries, and the measurements during the test.

The platform can allow an experimental determination of the efficiency map for each motor. Depending on the load distribution scenario between the motors, a similar determination could result for the entire multi-motor powertrain.

5. CONCLUSION

In this paper, a didactical platform for bi-motor solutions in electric vehicles is presented. It allows the confirmation of a multi-motor solution improvements compared to a mono-motor solution, as the simplification of the mechanical power transmission by approaching the mechanical power generation to the wheels (as in-wheel motors), the increase in energy efficiency, vehicle performance and control. The platform allows the integration of the motors with dedicated controls and batteries.

Specific measurements and determinations can be realized on the platform, as motor data confirmation and the capabilities of the powertrain with two motors. Starting form vehicle data and a normalized testing cycle, a powertrain request calculation is presented. The calculated powertrain can be tested on the platform at real or reduced scale. The results obtained by simulation can be verified on the platform. The platform opens new possibilities for research activities to analyze and control electric powertrains with at least two motors. An important aspect is related to energy efficiency improvements. After defining theoretical strategies to reduce onboard energy consumption or increase the recuperated energy during braking, an experimental study is possible. There is an occasion for students to be introduced in a real e-drive system environment, to perform experimental activities with electric traction systems and to have a physical support for projects.

Future studies will allow the integration of a third and fourth motor on the platform. In parallel an important attention is payed to the integration of the motors investigated on the platform in a real vehicle, as physical support, with the possibility to run on the platform and confirm the results in real environmental conditions.

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