MODELING AND SIMULATION OF ELECTRIC CARS USING MATLAB - SIMULINK

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Abstract: The desire to reduce pollution and price instability generated by the major share of fossil fuel use requires firm solutions for ecological transition of the economy, which must provide access to clean, safe and affordable energy. An important, seriously affected sector, being a competitive field with consistent limitations, is the transport system, where the use of alternative fuels or the use of electric cars is definitely a solution.

The present paper presents an evaluation, through simulation in MATLAB-Simulink, of influence of parameters such as: vehicle frontal area, tire pressure, wind speed, road slope, aerodynamic coefficient and rolling resistance coefficient, in the power and energy balance and aspects that influence the optimal dimensioning of batteries and electric motor.

Keywords: electric car, modeling and simulation, MATLAB – Simulink, environmentally friendly transport

1. INTRODUCTION

Desire to reduce pollution and price instability generated by the major share of fossil fuel use requires firm solutions for ecological transition of economy, which must provide access to clean, safe and affordable energy. An important, seriously affected sector, being a competitive field with consistent limitations, is the transport system, where the use of alternative fuels or use electric cars is definitely a solution.

Affinity towards electric cars is also encouraged by economic programs provided by all the member states of European Union and not only. Therefore, the use

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of electric cars is a solution for the decarbonization of industrial processes and economic sectors where carbon reduction is as urgent as it is difficult to achieve. All these efforts are essential to support the EU's commitment to climate neutrality on the one hand and to the global effort to implement the Paris Agreement on the other.

Transport of the future will look different: green, ecological, with minimum consumption and maximum efficiency. Already the first signs are visible on the European market. Sales of clean cars are increasing, charging stations are multiplying, we have sustainable means of transport in cities. But it's not only car manufacturers who are making efforts to reduce climate impact of vehicles as much as possible.

Clean cars have been in development for a long time, more than 100 years, going through several stages and periods of stagnation, and in the last decade there has been a new wave of enthusiasm, this comes with increase in the price of oil, a new approach of climate policy, development of storage technologies and charging infrastructure. Thus, only through a common conscious choice can we have a healthier way of life and a cleaner environment.

For the period 2030-2050, the headline climate targets require European states to set an intermediate target for 2040 to drive the transition to a climate-neutral economy. This proposal will consider input and evidence from scientific sources.

2. MODELING AND SIMULATION OF ELECTRIC CARS

The Environmental concerns and energy issues have led to a massive shift of efforts in the automotive industry from the internal combustion engine (ICE) to the electric vehicle (EV) as the primary source of transportation. Air pollution problems in urban areas, the fact that internal combustion diesel vehicles are the second largest contributor to global warming with around 21% of greenhouse gas emissions, as well as the depletion of fossil fuels and their rising prices, have significantly increased interest in electric vehicles.

This is due to advantages of electric vehicles as a clean and silent technology, as well as the fact that they offer better efficiency than vehicles with internal combustion engines, and electricity is a cheaper source of energy than fuel. Numerous simulation and modelling packages have been developed to study the operation of electric and hybrid powertrains, such as CarSim from AeroVironment Inc., SIMPLEV from DOE's Idaho National Laboratory, MARVEL (Argonne National Laboratory), V-Elph (Texas A&M University) and ADVISOR (DOE National Renewable Energy Laboratory, USA). there is currently a four-vehicle powertrain modelling, simulation, and analysis package for a VE, a parallel hybrid VE (HEV), a series HEV, and a conventional ICE using MATLAB-Simulink. The purpose is to investigate fuel economy, efficiency and emissions. Using visual programming allows the user to quickly change parameters, architectures and graphically examine the output.

Past researchers have devoted much effort to modelling a VE. The model made by focuses on the electric drive unit and drive evaluation to meet performance desires using a switched reluctance motor (SRM). Study demonstrated the effective use of IT tools in preliminary design stage of an EV. A popular vehicle modelling package written in MATLAB-Simulink. Thus, it is clarified that the software is a tool for evaluating and quantifying impact at vehicle level of advanced technologies applied to vehicles. Simulations and analysis of a series hybrid EV (SHEV) using the correct matching of vehicle's powertrain were carried out, and results satisfied the vehicle's performance requirements and improved vehicle's driving range, examined the performance of small EVs and analysed power flow of required electrical energy. A MATLAB-Simulink model was developed to identify the best power flow for EV. Driving range and battery usage are determined by the required battery capacity and EV specifications. A simulation model has been developed that encompasses multidisciplinary domains such as electrical, mechanical, thermal, power electronics, electrochemical and control. Thus, studies used the iterative process in designing procedures and included all component losses to obtain realistic energy calculations for vehicle.

Trends in the automotive industry being full simulation for electric vehicle and self-driving applications even before 2018.

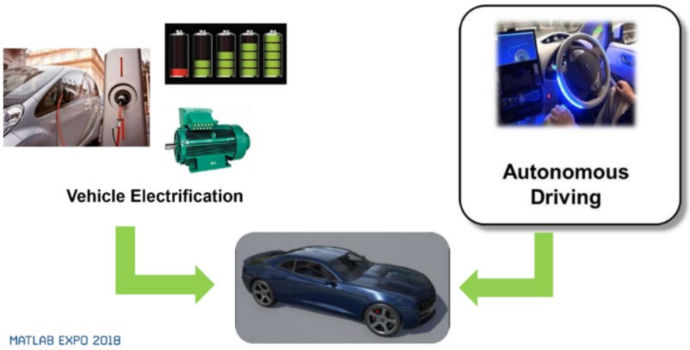

Fig.1 Automotive industry trends presented at MATLAB EXPO 2018

Full electric vehicle simulation model addresses the new challenges raised by main trends in the automotive field. Thus, at a minimum level, it is necessary, for realization of a simulation model, to design the power supply module, accumulators and the propulsion system, figure 2, and obtain information of main parameters speed, current, etc., figure 3.

Fig.2 Essential components of an electric car

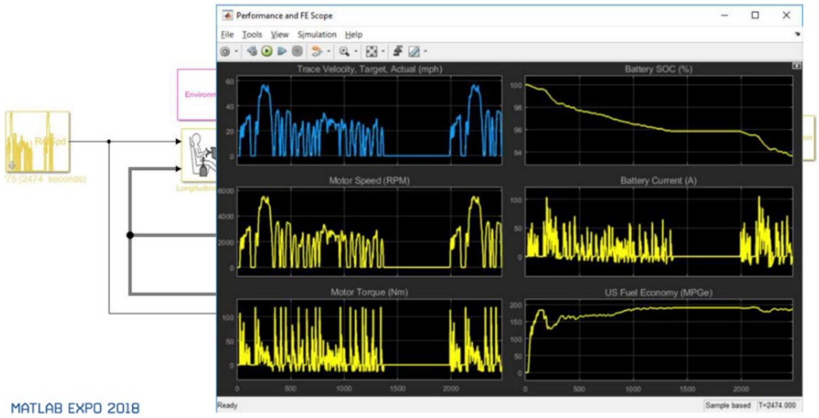

Fig.3 Expected results of the main parameters

3. MODELING ELECTRIC CAR OPERATION IN DIFFERENT DRIVE CYCLES

A simulation model of an all-electric vehicle on the MATLAB-Simulink platform is presented to examine the energy flow during motorization and regeneration. Powertrain components consist of a motor, a battery, a motor controller and a battery controller; modelled according to their mathematical equations. All simulation results are plotted and discussed. Torque and speed conditions during motorization and regeneration were used to determine power flow and drive system performance. This study forms the basis for further research and development.

It is desired to improve the dynamic design methods of electric vehicles by creating simulation models in Simulink. The models are represented by simulation schemes that are made up of blocks of mathematical operators, interconnected based on mathematical calculation formulas. The initial input sizes, specified in Table 1, can be easily modified, giving the possibility of obtaining several models for different design ideas. The results of the simulations are materialized in graphical charts and provide real-time data on the vehicle's speed, acceleration, engine torque, power to the wheels, energy consumed and distance travelled. In the first simulation scheme, the input variable is a motor torque generator, with values between 0-132 Nm. In the 2nd simulation scheme, the input variable is speed, according to the ECE-15 urban cycle scenario.

Global warming is one of the results of "greenhouse effect" gases (carbon dioxide, methane, etc.) in the atmosphere. These gases trap infrared radiation reflected by the earth, keeping energy in the atmosphere, increasing the temperature. The increase in temperature at the Earth's level results in the destruction of ecosystems and the production of natural disasters that also affect the planet's population.

Motor vehicles with internal combustion engines (ICE) are currently a major source of urban pollution. Electric vehicles are part of the only group of cars with "0" emissions. At the same time, electric vehicles reduce the level of noise pollution. The main problem facing electric cars is the low autonomy due to the low energy storage capacity in the batteries. In order to increase autonomy, one of the solutions is energy efficiency through the correct dimensioning of the components of an electric vehicle. For the correct sizing of the components, it is necessary to know the energy consumption and the power requirement at the wheels. Next, two simulation models of the interaction of a motor vehicle with the roadway and the atmosphere are presented in order to obtain relevant results on the dynamics parameters of the car when interacting with the roadway and the atmosphere. Simulation models are made up of blocks of mathematical operators. Some blocks are represented by constants according to table 1, others by input variables and output variables. In the first simulation model, the input variable is represented by a random generating block of engine torque values, with influence on the output variables: speed, acceleration, power to the wheels, energy consumed, distance travelled. The simulation time is 20 seconds. In the second scenario, an ECE-15 urban cycle is represented, with speed as an input variable, represented by several values at different time points.

The results of the two simulation scenarios are concretized in several graphical diagrams with the numerical display of the values of interest on the graph.

The MATLAB/SIMULINK language was used to simulate the interaction of the vehicle with the roadway and the atmosphere. The simulation scheme is presented in figure 4, and to create the simulation scheme using Simulink, the values from table 1 were entered.

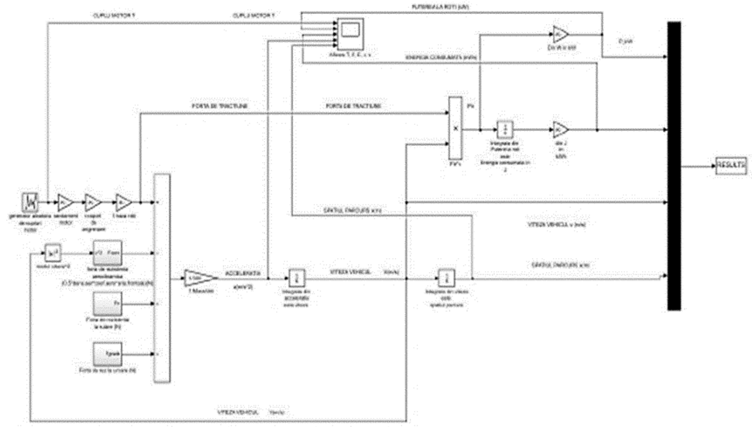

Fig.4 Scheme for simulating the interaction of vehicle with the roadway and atmosphere by generating motor torques

Table 1 **Car specifications**

The rolling resistance coefficient	f	0.0055
Total weight with driver	m	300 kg
Gravitational acceleration	g	9.8 m/s^2
Air density	ρ	1.22 kg/m^3
Air resistance coefficient	Cd	0.35

Projected frontal area	A	1 m^2
Wheel radius	R_d	0.345 m
The gear ratio	I	2.685
Instantaneous vehicle speed	V_{inst}	16.6 m/s
Wind speed	v_0	0 m/s
The angle of inclination of the slope	α	0
Engine speed at maximum power	n	21.6 rot/sec
Max. engine torque		1300 rot/min
Efficiency of the electric motor	T	132 Nm
Gravitational acceleration	η	0.95

To obtain simulation data, the following formulas were applied:

- force of resistance to the advance:

$$F_{ri} = F_r + F_{aero} + F_p + F_a \quad (1)$$

- rolling resistance force:

$$F_r = f \cdot m \cdot g \quad (2)$$

- aerodynamic drag force:

$$F_{aero} = \frac{\rho}{2} \cdot C_d \cdot A \cdot (v + v_0)^2 \quad (3)$$

- uphill resistance force:

$$\overrightarrow{F_p} = m \cdot g \cdot \sin\alpha \quad (4)$$

- force of resistance to acceleration:

$$\overrightarrow{F_p} = m \cdot \vec{a} \quad (5)$$

Sum of the blocks of resistance forces is embodied in value of traction force F_t, which helps us to obtain the following:

- Power to wheels:

$$P_{roti} = \overrightarrow{F_t} \cdot \overrightarrow{v_{inst}} \quad (6)$$

- Energy consumed:

$$E_{const}(t) = \int_0^t P_{roti} \cdot dt \quad (7)$$

- Acceleration from relationship:

$$a = \frac{F_t - (F_{aero} + F_t + F_r)}{m} \quad (8)$$

- Speed:

$$\vec{v}(t) = \int_0^t \vec{a}(t) \cdot dt \quad (9)$$

- Travelled distance:

$$\vec{s}(t) = \int_0^t \vec{v}(t) \cdot dt \quad (10)$$

For power and energy relations, power was written as the product of sum of resistive forces and speed, and energy was written as integration of power at wheels. Virtual simulation time is 20 seconds. Following simulation, the following results were obtained.

By generating engine torques, the car's behaviour is simulated when accelerator pedal is pressed, resulting in different values of power to wheels, energy consumed, speed of vehicle and the distance travelled by it, during 20 seconds.

Figure 5 shows the simulation of interaction vehicle with roadway and the atmosphere by generating motor torques.

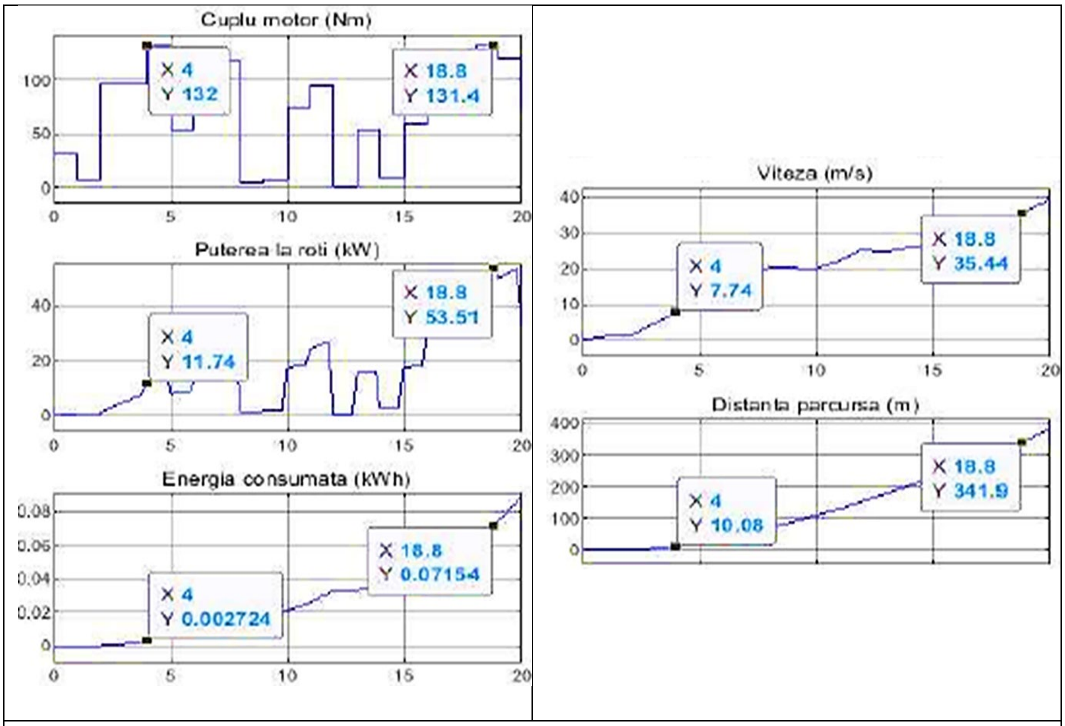

Fig.5 Result of simulation for interaction of the vehicle with roadway and atmosphere by generating engine torques

The X axis represents time axis. The Y axis represents:

- Section 1 - engine torque (N);
- Section 2 - wheel power (kW);
- Section 3 - consumed energy (kWh);
- Section 4 - vehicle speed (m/s);
- Section 5 - distance travelled (m).

During *20 seconds* respecting values of speed and acceleration, our vehicle will cover a distance of *379.1 m* and consume an amount of energy of *0.09 kWh*. Thus, we can conclude that to move vehicle at a speed of *35.44 m/s* i.e. *127.58 km/h*, we need a power provided by batteries and solar panels of approximately *55 kW*, in ideal wind conditions and without road inclination.

From figure 5 it appears that vehicle reaches maximum force torque of *132 Nm* after *4 seconds*, and has equivalent to a wheel power of *11.74 kW*, an energy consumption of *2.7 Wh* at a vehicle speed of *7.74 m/s* and a distance travelled of *10.08 m*.

The vehicle reaches maximum power to wheels of *53.51 kW*, at an engine torque of *131.4 N* after *18.8 s*, with a speed of *35.44 m/s (127.58 km/*h) and covering a distance of *341.9 m*.

Proposed simulation scheme gives us facilities for changing certain constant parameters, such as vehicle mass, slope inclination, rolling friction coefficient, projected frontal area, wind speed.

In figure 6 the urban cycle was simulated, regarding the energy consumed by the vehicle with the above characteristics, with a slope inclination of 1°, and in figure 7 with a slope inclination of 5°.

It can be seen that in figure 6, the energy consumed reaches value of *0.025 kW·* at simulation time *195.3 s*, while in figure 7 the energy consumed reaches the value of *0.079 kW* at simulation time *195.4 seconds*, from which the influence of slope inclination on energy consumption.

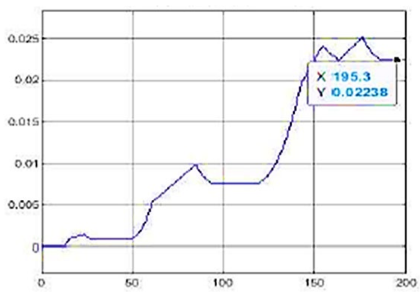

Fig.6 Energy consumed in urban cycle for slope 1°

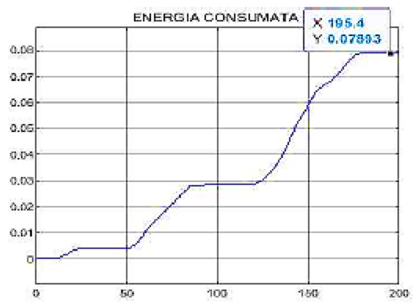

Fig.7 Energy consumed in urban cycle for slope 5°

In figure 8 and figure 9, the influence of vehicle mass on variables is highlighted: power to wheels, the motor torque and energy consumed for a value of vehicle mass of *350 kg* and one of *400 kg* at a road inclination of 1°.

From figure 8 and figure 9 we can draw the following conclusions:

- Value of the maximum power at wheels for the 350 kg vehicle is *4154 W*, while for the *400 kg* vehicle it is *4667 W*, which tells us that for the choice of batteries we need at least *4.2 kW* in the case of the *350 kg* mass vehicle kg and *4.7 kW* for the vehicle with a mass of *400 kg*, if we consider the slope of the road of 1°.
- Value of the maximum engine torque is reached around *155.1 Nm* for the vehicle with a mass of *350 kg* and *177.5 Nm* for the one with a mass of *400 kg*. Thus, for propulsion of vehicle, when choosing the electric motor, we will need a motor with a maximum torque of at least *160 Nm* for the vehicle with a mass of *350 kg* and *180 Nm* for the one with a mass of *400 kg*.

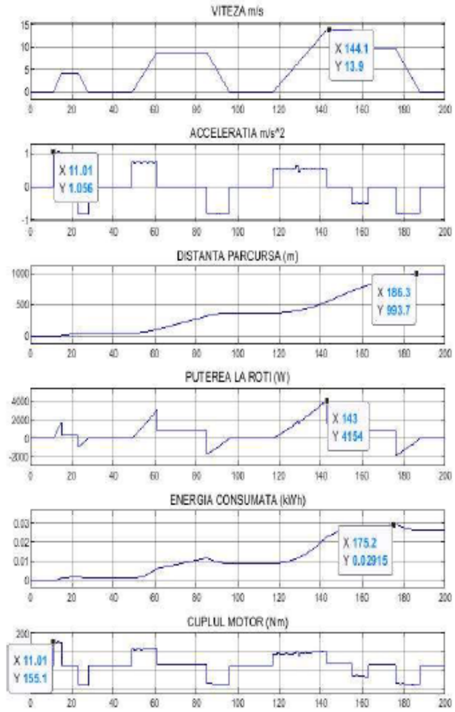

Fig.8 The simulation result for the vehicle mass of 350 kg

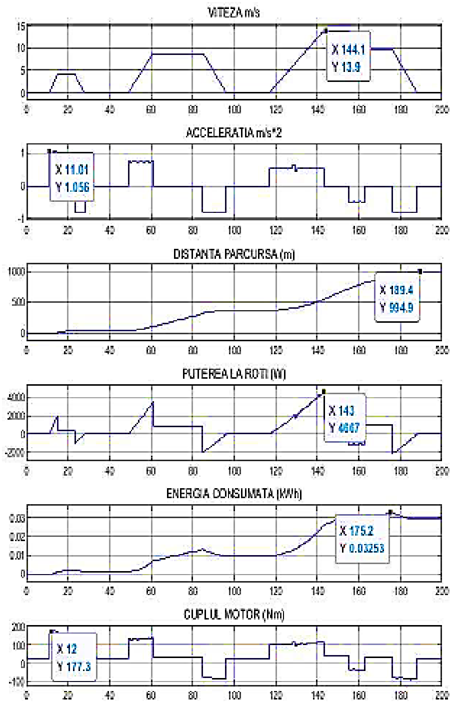

Fig.9 The simulation result for the vehicle mass of 350 kg

Two simulation models were made using MATLAB – Simulink, based on which results were obtained in virtual time. The simulation schemes were established based on mathematical models of the dynamic design of a motor vehicle. Results of the simulations are materialized in power and energy balance diagrams. The first model used as an input variable a motor torque generator, in which *0-132 Nm* torques equivalent to pressing the accelerator pedal were generated.

The 2nd model represents an urban cycle, made for a study of the energy consumption of an electric vehicle. The simulation uses as input variables, a set of speeds corresponding to the urban cycle. Both simulations are for *200 seconds*.

4. CONCLUSIONS

By its nature, transport activity synthesizes and forces the use of knowledge accumulated during studies, to solve situations that it creates and constitutes in the means of completion of production processes, providing services, etc.

In this study, a critical analysis is carried out regarding the advantages and limitations of predominantly non-polluting solutions in transport system. The significant aspects of use of electric vehicles are analysed through modelling and simulation using the MATLAB – Simulink program, with the aim of identifying all significant parameters that can positively or not influence transport activity, but especially due to the general directions towards a country, continent and a world energy independent and with zero pollution. This approach being a major international priority in context of reducing greenhouse gases but also efficiency of this sector as a result of the major increase in the price of traditional, petroleum fuels, as a result of the military situation in the region. Results of simulations are the basis for dimensioning of electric motor and batteries of an electric vehicle. In the present work, it was shown with help of diagrams and calculations, the influence of parameters such as: the frontal area of vehicle, pressure in the tires, wind speed, inclination of the road, aerodynamic coefficient and the rolling resistance coefficient, in balance of power and energy. This helps us not only to precisely size the batteries and electric motor, but also to estimate the remaining distance to travel until the energy in batteries is exhausted and energy efficiency by identifying the optimal values of speed and acceleration to increase the autonomy.

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