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Evaluation of the correctness of the SciLab program in a simulation of an electric vehicle run

Abstract. *The article presents an evaluation of the usefulness of the Scilab environment in the context of an electric vehicle run simulation. The simulation was performed using the Scilab numerical computation environment. The results were compared with a run of an e-bike electric vehicle which was equipped with Li-ion cells. Measurements made during the real electric vehicle run differ significantly from the Scilab computer simulation results.*

Streszczenie. *W artykule przedstawiono ocenę przydatności środowiska Scilab w kontekście symulacji pracy pojazdu elektrycznego. Symulacja została wykonana z wykorzystaniem środowiska obliczeń numerycznych Scilab. Wyniki porównano z przebiegiem pojazdu elektrycznego z napędem elektrycznym na rowerze elektrycznym wyposażonego w ogniwa litowo-jonowe. Pomiary wykonane podczas rzeczywistej jazdy pojazdu elektrycznego różnią się istotnie od wyników symulacji komputerowej Scilab.* ***(Ocena poprawności programu SciLab w symulacji pracy pojazdu elektrycznego)***

Keywords—electric vehicle, Scilab
Słowa kluczowe: *pojazd elektryczny, Scilab*

Introduction

In recent years, electric vehicles are increasingly appearing on the roads. It is connected with ever more perfect technical solutions regarding both the accumulation of energy in batteries and its processing in inverters, and the conversion of electric energy into mechanical energy. In order for a given vehicle to appear on the road, it is necessary to carry out many experiments related to the creation of vehicle prototypes and testing them. This process is tedious and consumes a lot of financial expenses. In this situation, it seems very reasonable to use computer simulations that will help to reduce financial outlays.

Simulation of moving objects is their approximate behavior during acceleration, movement in steady or braking. The simulation must take into account various external factors such as weather conditions, elevation of the terrain, type of surface or aerodynamic resistance. Adequate selection of these parameters allows for the most faithful reproduction of the actual conditions of passage.

The paper attempts to verify the correctness of a simulated journey of an electric vehicle carried out in a computer program with actual measurements made using a bicycle with an electric drive.

Computer simulation avoids many errors in device design. When it comes to a moving vehicle, aerodynamic properties are important. These properties can be checked e.g. in a wind tunnel, but here a vehicle model and advanced measuring equipment will be needed. Simulation of an electric vehicle journey can also be carried out in one of the simulation programs, such as Matlab, Mathcad, Maple, Maxima, Modelica and Scilab [7].

The Scilab computer program was chosen to carry out the simulation. The choice of is the result of several factors that influenced the decision. The program is free and the software is licensed as "open source". The program can be downloaded from the website. On the manufacturer's website one can find many ready and tested examples of programs. The software is equipped with a large library of external methods and procedures which is constantly updated.

Assumptions and examination

To carry out the research, an electric bike, the SciLab program and the CycleDroid application installed on a mobile phone were used, which allowed to precisely measure the distance travelled and the climbs to be covered.

Table 1 lists the parameters of the electric bike which was used to carry out the tests.

The battery supplying the bike consisted of 18650, 3.7 V, 2.2 Ah (Li-ion) cells connected in 5 parallel sections. Each battery section consisted of 13 cells connected in a series. The voltage of the whole battery was 48.1 V, assuming that the voltage of one cell is 3.7 V. Parallel connection of the sections allowed to obtain a capacity of approximately 11 Ah.

Table 1. Technical data of the electric bike [3]

Own weight	21 kg
Top speed	32 km/h
	9 m/s
Synchronous motor	600 W, 48 V
Power supply	48 V, 11 Ah

The cell battery parameters are given in Table 2.

The battery was also equipped with a BMS (battery management system).

Table 2 Technical data of the battery package [1]

Capacity	11 Ah
Nominal voltage	48 V
Cell applied	18650, 3,7V, 2.2Ah (Li-ion)
Internal resistance of the cell	101,21 mΩ
Number of cells connected in a series	13
Number of cells connected in parallel	5
Total number of cells in the battery	65

The bike was powered by a synchronous motor with a power of 600 W and a supply voltage of 48 V. The motor was powered from an inverter which transformed the DC voltage into AC necessary to power the motor [2].

The bike ride route was 16.17 km and was recorded by the CycleDroid application installed on the smartphone. The application allowed for detailed recording of the route along with changes in speed and changes in altitude above sea level. The cycling speed curve recorded by the CycleDroid application as a function of time for one of the road sections is shown in Figure 1.

The application installed on the smartphone allows real-time recording of the electric bicycle's journey, taking into account geographical coordinates (longitude, latitude and altitude) read from the GPS receiver. During the application's operation, the instantaneous speed, geographical position and altitude are also recorded. The whole route can be analysed, including its main data such as: average speed, maximum speed, preview on the route map, maximum speed. In addition, the application also has a module for generating charts (speed in time, speed in the function of the distance travelled, a.s.l. height in the function of the distance travelled).

The application gives the possibility to export the course of the route to *.csv files, which allows to import data into a spreadsheet. Thanks to this, one can develop readings from the journey. The software saves all values in intervals of one second, using the POSIX system, in tabular form.

On the basis of data recorded from cycling along the entire section, data for the SciLab program were prepared.

During the ride of the electric-powered bicycle, the voltage on the terminals of the battery was also recorded, which was the determinant of the degree of discharging the battery.

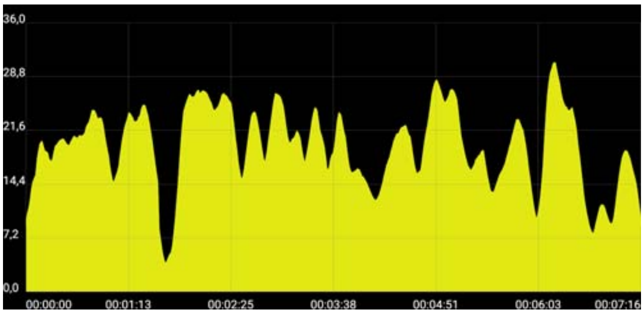

Fig.1. Graph of cycling speed variation during the travel of the road section [3]

On the basis of data recorded during the ride of the electric bike, the battery voltage characteristics were determined as a function of bicycle ride time. The obtained characteristics are shown in Fig. 2.

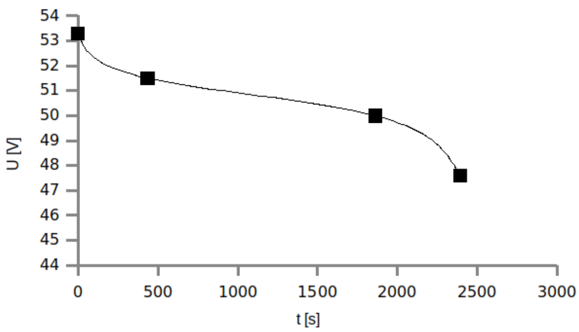

Fig.2. The course of voltage over time on the batteries powering the bike's driving motor

Table 3 presents measurement points from individual road sections with latitude, longitude and altitude.

For simulation in the SciLab program, it is necessary to write a program that maps the ride of the bike taking into account many parameters. The mathematical model of the problem considered consists of a series of calculations made on the basis of formulas by which we determine the values we need. The model of this event boils down to dividing each segment into three phases of movement (uniformly accelerated motion, uniform motion and uniformly delayed movement). The calculation of individual phases of motion also takes into account aerodynamic resistance, rolling resistance as well as losses resulting from the spinning of elements in a given system.

Table 3. Above-sea-level height value for individual routing points.

Road section	Measurment points	Latitude [DD]*	Longitude [DD]*	Altitude
1	1	46.461133	30.750083	65
	2	46.465969	30.748928	61
	3	46.483415	30.748847	43
2	4	46.484626	30.746491	18
	5	46.493307	30.732406	13
	6	46.497944	30.726609	16
	7	46.555735	30.769052	11
3	8	46.557497	30.772788	23
	9	46.564139	30.786522	29
	10	46.565004	30.788061	47
	11	46.568142	30.790526	46
	12	46.575814	30.796012	39
	13	46.577399	30.797198	39

*DD – decimal degrees

This model is saved in the program file in SciLab, and the entire simulation sequence is consecutively saved as vectors. The results are presented in tabular and graphical form as the courses of particular values of the simulated object.

Table 4. Electrical vehicle parameters.

Parameter	Symbol	Value	Remarks
Weight	m	92 kg	21 kg – vehicle weight 71 kg – weight of the driver
Mass increase factor	f_m	1,0	Mainly due to wheels
Coefficient of rolling resistance	C_{rr}	0,0375	Based on [8] the average value for road and other bikes.
Wind resistance coefficient	C_x	0,9	The maximum value has been assumed
Front surface area	A	0.511 m^2	Based on the table after conversion from Ft^2 to m^2
Top speed	V_{max}	32 km/h 8,89 m/s	For the calculations in the simulation, we assume the average speed of travel
Maximum power	P_{max}	600 W	
Wind speed	V_w	0 km/h 0 m/s	Windless weather during the passage
Ambient temperature	t	10 °C	
Air density	ρ	1,25 kg/m^3	Air density for the temperature of 10 °C

The route has been divided into 11 sections in which the vehicle will pass through 3 traffic phases. This division was made on the basis of the analysis of the reading from the passage record from the CycleDroid application and the compilation of this data with the description of the driver during the measurements. As a result, 12 points were set in which the vehicle stopped or slowed down to speeds in the limit of 1-3 km/h. Based on the geographical data of the course of the route, which is 16170 m long, the distances between the points and the a.s.l. height in the given points were read. This is necessary to calculate the necessary values to simulate each segment of the route. Each section is considered as a transition through 3 phases of movement:

1 acceleration phase,
2 driving phase with constant speed,

3 braking phase [6].

Table 6 presents the characteristic points of the route. The angle of inclination was calculated using trigonometric functions.

Table 5. Division of movement phases into sections.

No	Section length [m]	Road phase 1 [m]	Time phase 1 [s]	Road phase 2 [m]	Time phase 2 [s]	Road phase 3 [m]	Time phase 3 [s]
1	650	50,96	14	590,6	81,8	8,35	2,89
2	2160	50,96	14	2100,6	290,9	8,35	2,89
3	1580	50,96	14	1520,6	210,6	8,35	2,89
4	730	50,96	14	670,69	92,8	8,35	2,89
5	8050	50,96	14	7990,6	1106,7	8,35	2,89
6	1030	50,96	14	970,6	134,4	8,35	2,89
7	420	50,96	14	360,6	49,9	8,35	2,89
8	390	50,96	14	330,6	45,8	8,35	2,89
9	350	50,96	14	290,6	40,2	8,35	2,89
10	690	50,96	14	630,6	87,3	8,35	2,89
11	120	50,96	14	60,6	8,4	8,35	2,89

Table 6. Comparison of every section

Section No.	Section length [m]	Inclination angle [°]
1	650	-0,35
2	2160	0,48
3	1580	0,18
4	730	-0,24
5	8050	0,04
6	1030	-0,33
7	420	-2,45
8	390	0,15
9	350	1,15
10	690	0
11	120	0

Table 7. Comparison of energy consumption

Section No.	Length [km]	Energy consumption phase 1 [Wh]	Energy consumption phase 2 [Wh]	Energy consumption phase 3 [Wh]
1	0,65	9,69	8,93	-0,55
2	2,16	33,68	32,88	-0,54
3	1,58	22,56	21,84	-0,56
4	0,73	9,03	8,41	-0,57
5	8,05	110,31	109,63	-0,56
6	1,03	12,34	11,75	-0,58
7	0,42	1,06	1,01	-0,66
8	0,39	5,42	4,70	-0,56
9	0,35	6,38	5,41	-0,52
10	0,69	9,23	8,56	-0,56
11	0,12	1,50	0,83	-0,56
Suma	16,17	221,24	213,97	-6,25
Energy consumption [Wh]				
Energy consumption with recuperation				424,96
Energy consumption without recuperation				431,21

For each of these phases of movement, simplifications were adopted in which it was assumed that the vehicle accelerates to the speed of 26 km/h in 14 seconds and BRAKES within 2.89 seconds. These values were calculated on the basis of data from the CycleDroid application.

After calculating these values, Table 5 was created for each segment.

Results and discussion

Table 7 contains a comparison of energy consumption in individual sections. The vehicle covered the entire route in 2335.04 seconds, i.e. in 38 minutes and 54 s.

The Table shows that the vehicle without energy recuperation consumed a total of 431.21 Wh, and considering the recovery of 30 % [5, 8] of energy, this value will decrease by 6.25 W, which gives 1.4 % of energy consumed. The unit energy consumption is 26.91 Wh/km without recuperation and 26.52 Wh/km with recuperation. The battery charge after travelling the recuperative route is 53.67 %, and including recuperation, the value is increased to 56.6 %.

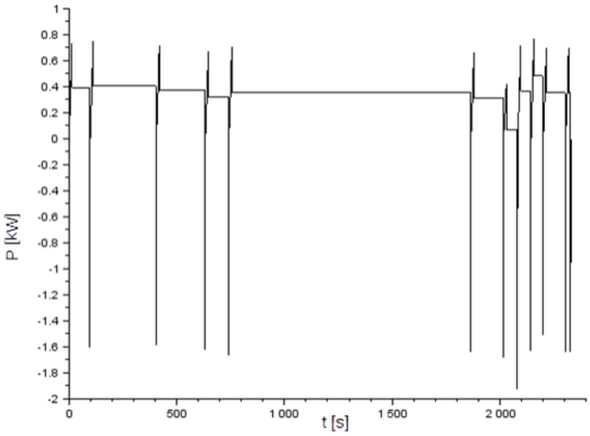

Fig. 3. Power plot P=f(t) as a function of time

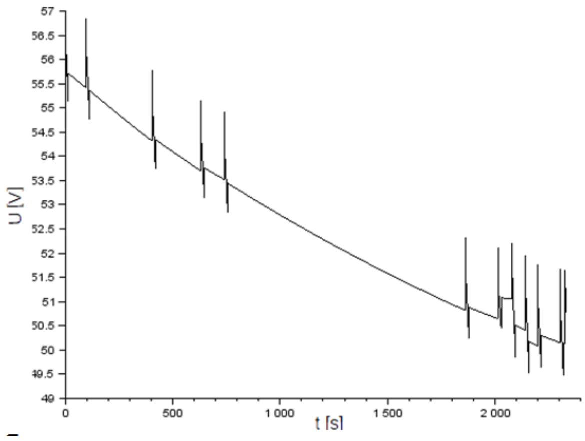

Fig.4. Voltage graph on the accumulator with recuperation

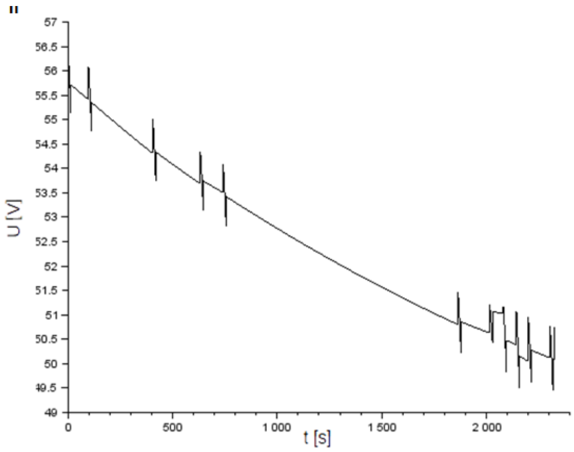

Fig.5. Voltage graph on the accumulator as a function of time, without recuperation

The results presented show that the use of recuperation in the case of an electric bike has no justification, the energy return during braking is too small in relation to the costs associated with the additional function of the inverter.

Based on the obtained characteristics, it can be stated that the simulation was carried out correctly, the data from the actual measurement are close to the simulation. They show typical behaviour of the chemical source of voltage under the influence of discharge.

Table.8. Comparison of results, journey and simulations

Measurement	Simulation	Measurement	Simulation
Voltage [V]	Time [s]	Voltage [V]	Time [s]
53,3	0	53,3	0
51,5	436	51,5	436
50	1860	50	1860

The voltage measured on the accumulator battery as a function of time is presented in the form of a graph in Figure 2, a graph showing these simulation data is shown in Figures 4 and 5. As can be seen in the charts, the actual reading shows a voltage drop to 47.6 V which means that the battery is discharged (0 %); this is actually true. Simulation results indicate higher voltage and battery charge level equal to 56.6 %, but these are purely theoretical assumptions for batteries corresponding to the rated parameters.

Comparing the results one can find discrepancies of several dozen percent. This is most likely due to the discontinuity of driving during measurements, as well as the traffic and continuous return to the minimum speed. In addition, it is worth noting that the power source was used, which also affects the level of energy stored in this battery.

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