Optimization Source Structure of Electric Vehicle Using Calculation of Energy Consumption in Matlab GUI

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Abstract. *The capacity of the primary energy source is the main parameter participating in a range of the electric vehicle (EV). The final choice of an appropriate structure of sources integrated into the vehicle can consist of one or a variety of energy sources/storages. This way increased effectiveness, thus an increase in driving range as well as regenerative braking energy, can be achieved. Energy storages for EV applications are rated on the basis of three parameters namely, specific energy, energy density and specific power. These are the key parameters taken into account in selecting appropriate energy sources. The article provides an analysis of collaboration of an ultracapacitor module with an accumulator battery.*

Keywords

Driving cycle, electric vehicle, energy consumption, hybrid energy source, power consumption, specific energy, specific power, traction battery, ultracapacitor module.

1. Introduction

Nowadays the modern concept of a hybrid energy system is dedicated for the electrical vehicle (EV). The reason for use of such energy source is optimization of energy handling capability. Traction batteries or fuel cells are known as a source of energy. Different type of energy device is a source of power like capacitors. Source of power contains a small amount of energy compared to the battery, but they can deliver huge power level. The source of energy hasn't ability to supplying a load by high power level without undesirable decreasing efficiency or energy volume, but contains a lot of energy. One of the ways to avoid above mentioned is a hybridization of energy storage system. So is desirable battery or fuel cell appended with ultracapacitors [1], [2], [3].

2. Calculation of Required Power and Energy for the Propulsion of the Vehicle

According to the second Newton's law of acceleration of the vehicle the following relationship applies:

$$\frac{dV}{dt} = \frac{\sum F_t - \sum F_r}{\delta m_v}, \tag{1}$$

where, F_t is traction force, m_v is the total mass of the vehicle and δ is a weighting factor representing the inertia of the vehicle as well as its rotating parts, F_r is force caused by the action of driving resistance acting on the vehicle. Depending on the chosen layout concepts of electric powertrain, it is necessary to include the efficiency of individual components that are involved in

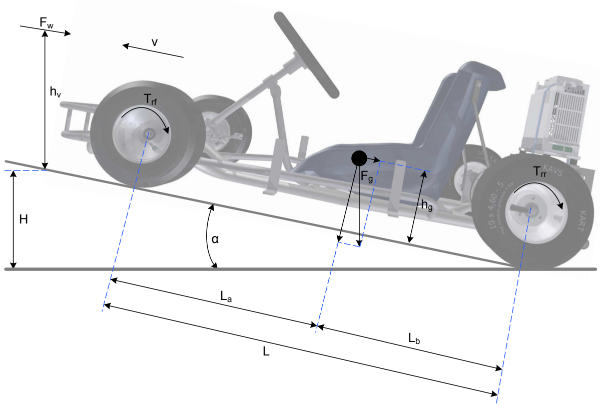

Fig. 1: Graphic representation of forces acting on the vehicle.

the transmission. In this case, the traction force F_t is transmitted from the motor shaft through a gear with the constant ratio to the tires of the drive axle. Adapting to RPM of the engine and the wheels driven axles a single speed gearbox was chosen. A transmission was sized on the basis of the engine RPM range and a maximum speed of the vehicle. Transfer was made using a toothed belt and pulleys.

To describe the motion of the vehicle in Fig. 1 it is necessary to carry out the basic kinematic analysis. This defines the action forces that must be overcome during movement of the vehicle. To simplify the calculations, the only linear movement was considered. The total size of the traction force F_t is given by the sum of the individual forces acting on the vehicle as follows:

$$\sum F_t = F_{rr} + F_\alpha + F_{aero}, \tag{2}$$

where F_{rr} is the rolling resistance, F_α is the force caused by climb and F_{aero} represents the aerodynamic drag of the vehicle [1] and [2]. In the next section, individual components of tractive resistance will be discussed alongside formulae for calculating them. Rolling resistance F_{rr} is the result of hysteresis of tire material on the road surface. Action force required to overcome the rolling resistance of the tire on a flat surface can be expressed as:

$$F_{rr} = \frac{T_r}{r} = \frac{F_r \cdot a}{r} = F_r \cdot f_r, \tag{3}$$

where, F_r is a force acting on the center of the wheels and a is length of displacement of reacting force. Coefficient of rolling resistance depends on the road surface and falls within the range of 0.006 regarding the concrete surface to a value of 0.35 for the dirt road. In this case, it is assumed that the movement of vehicles happens on the asphalt road surface and the rolling resistance coefficient of 0.013 is taken into account. Climbing resistance F_α depends on the profile of the terrain of the chosen path and its corresponding climbing and decline. The strength of slope is given by:

$$F_\alpha = m_v \cdot g \cdot \sin(\alpha), \tag{4}$$

m_v is the total mass of the vehicle, g is the gravitational acceleration, α represents the angle of climb or descent on particular route section. Magnitude of the climb gradient as a percentage is given by:

$$\alpha_{\%} = \tan^{-1}(\alpha). \tag{5}$$

Aerodynamic resistance F_{aero} is breaking force applied to the vehicle while driving due to inter-molecular bonds in the air. This causes that the air pressure is higher in front of the vehicle rather than behind it. Aerodynamic force is defined as:

$$F_{aero} = \frac{\rho_{air} + A_f + C_D(v - v_w)^2}{2}. \tag{6}$$

Optimization of the aerodynamic forces acting on the vehicle presents an issue for comprehensive analysis necessary to eliminate the amount of the total aerodynamic force action. Magnitude of the aerodynamic coefficients is present in conventional vehicles within the range 0.15 to 0.7. To calculate the size of the frontal area we have created a Matlab GUI. Based on the technical documentation, a black and white image that represents the face of the go-kart with rider has been created. In the calculation program, the user enters the number of pixels that corresponds to a specific distance in accordance with the technical documentation. Calculation then determines the number of pixels corresponding to a surface size of 1 cm^2 and this value will remodel the total number of black pixels in the desired slide of frontal area. This value is subsequently used for further calculation [1], [2] and [3].

3. Electric Go-Kart Parameter Estimation

Based on the analysis that have been previously carried out and based on similarities (with the solutions having been in use), the following electric go-kart parameters were determined necessary to perform sizing, see Tab. 1.

Tab. 1: Estimation of driving of the vehicle parameters.

Parameter	Symbol	Value	Unit
Total weight of vehicle	m_v	200	kg
Frontal area	A_f	0.5	m^2
Rolling resistance coefficient	f_r	0.007	-
Drag coefficient	C_d	0.6	-
Air density	ρ	1.25	[kg·m^3]
Climbing	α	2	%
Wheel diameter	r_d	0.15	m
Efficiency drive transfer	η	0.95	[-]

4. Obtaining Data for Custom Driving Cycle

For defining the path parameters, we have created a graphical interface using php code. User can access the interface by a conventional website. On this page

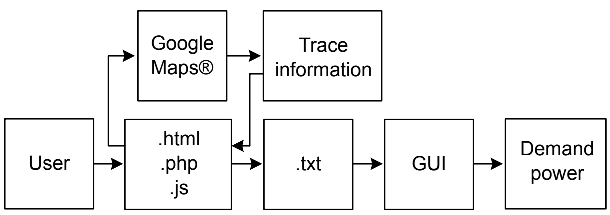

Fig. 2: Basic block diagram of the assembled graphical interface.

the option of defining individual data, such as the start and end point of the trip, or entering several consecutive points for driving vehicle can be accessed. The actual input can be implemented through touch interface or by entering individual route points in the form of their real addresses. Once they have been entered and confirmed, a query is sent on Google Maps® to load the map that provides the required information about the route. These data are then listed and exported to a file that ensures calculation of climbing of terrain on the basis of the obtained altitude of the chosen route.

The terrain profile obtained is then processed in the calculation of the electric go-kart sizing. This terrain profile is then provided with its own, compiled driving cycle of our chosen path. The driving cycle was supplemented by additional data gained from real traffic situation. These data were collected using records from the camera of a vehicle riding behind us on the defined route. For statistical evaluation and implementation of the data a total of 30 runs were included in our driving cycle. Based on the evaluation of individual video records a table has been compiled that includes data about inevitable stops of the vehicle caused by current traffic situation. This information was subsequently included in our compilation of the driving cycle [4].

5. User-Defined Driving Cycle and Calculation of Power Demand of Vehicle

Parameters obtained from the route showed in Fig. 3 through php code were reconstructed so we get elevation profile. Data obtained this way are included into calculation software showed in Fig. 4.

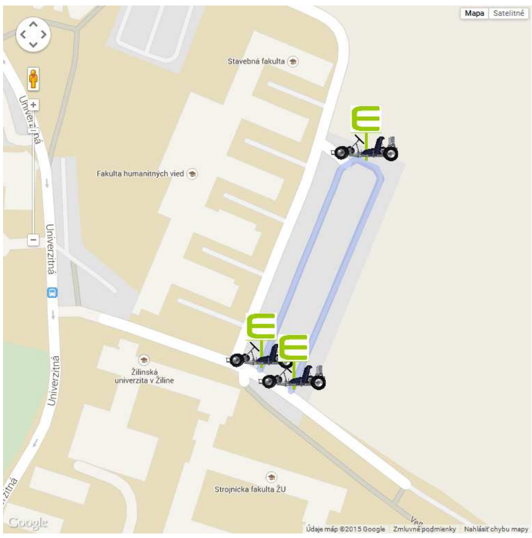

Fig. 3: Driving trace obtained from a web browser (Google Maps®).

For the track, a driving cycle was compiled subsequently, which corresponded to traffic conditions based on data obtained from recorded rides. Speed profile of custom driving cycle is shown below in Fig. 5. The waveforms obtained were used for further calculation of acceleration, forces and actions necessary for overcoming them. Waveforms obtained on this way are presented in Fig. 5 where, the first on the top is the elevation profile of the terrain and the middle part shows the course of the climb-angle alpha for this route.

6. Energy Sources for Electric Vehicle

It is necessary that the energy storage complies the following requirements shown in Fig. 6:

- specific energy,
- specific power,
- life cycle,
- price.

Based on previous calculations obtained from energy and power profiles we proceeded to the choosing the appropriate source configuration. The choice of the power structure was established on the ratio of the power and energy consumption during the driving cycle which is generally shown in Fig. 7.

Regarding to improve parameters performance of accumulation elements, efficiency and a lifetime of the source structure, we decided for the realization of hybrid source structure. Solution consists of using $LiFePO_4$ battery cells Tab. 2 commonly with ultraca-

Fig. 4: GUI of results of power dimension.

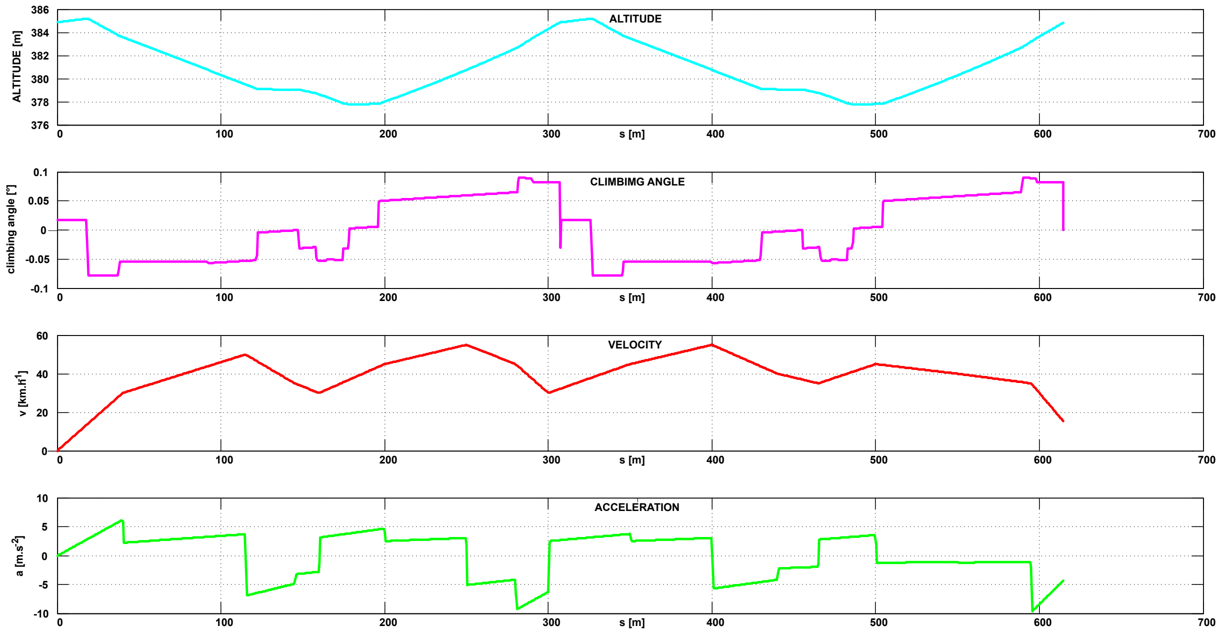

Fig. 5: Profile of chosen trace.

pacitor module. Size of specific energy battery cell is:

$$E_{BAT\_spec} = \frac{U_{BAT\_cell} \cdot C_{BAT\_cell}}{m_{BAT\_cell}} = 88 \ \frac{\text{Wh}}{\text{kg}}, \quad (7)$$

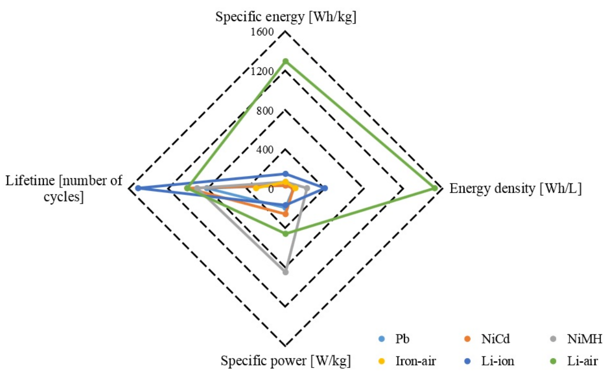

Fig. 6: Comparison of different energy sources.

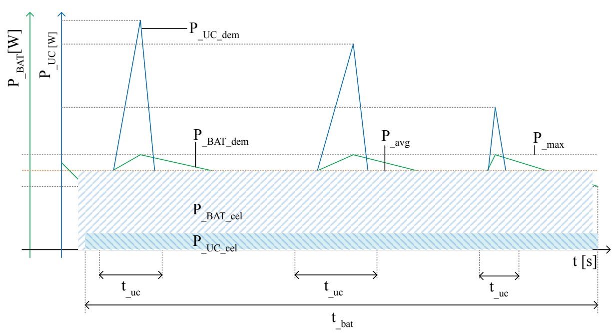

Fig. 7: Theoretical waveforms performance in hybrid supply structure.

specific power is:

$$P_{spec} = 0.12 \frac{U^2_{BAT\_cell}}{R_{D\_BAT\_cell}} m_{BAT\_cell} = 490.05 \ \frac{\text{Wh}}{\text{kg}}, \quad (8)$$

and overall energy accumulated of sources:

$$E_{BAT\_total} = E_{BAT} \cdot \Delta E_{BAT} \ [\text{Wh}], \quad (9)$$

where E_{BAT_spec} is the specific energy of battery cell, U_{BAT_cell} represents voltage of battery cell with the nominal capacity C_{BAT_cell}, and m_{BAT_cell} is a mass of battery cell.

Overall accumulation energy E_{BAT_total} is equal to energy consumption pre driving range E_{BAT} multiplied

Tab. 2: Parameters of battery cell.

Parameter	Value	
Nominal voltage of battery cell	3.2	V
Nominal capacity	20	Ah
Operating voltage	3.65–2.8	V at 80 % DOD life min. 1500 cycles
Min. voltage	2.6	V
Max. voltage - charging	3.8	V
Discharge current	0.5 C	optimal value
Max. discharge current	<3 C	<15 min.
Max. peak discharge current	<10 C	<5 s
Max. charging current	<1 C	monitor temperature
Max. temperature during operation	60	°C
Dimensions	152 × 71 × 42	mm
Mass	0.75	kg

Tab. 3: Parameters of ultracapacitor module.

Parameter	Value	
Nominal voltage	160	V
Capacity	6	F
Max. voltage	170	V
Max. discharge current	170	A
Temperature range min./max.	-40/+65	°C
Discharge current	12	A
Dimensions	367 × 235 × 79	mm
Mass	5.2	kg

by energy reserve ΔE_{BAT}. A similar method was use for elected a secondary energy source [5], [6], [7] and [8]. Regarding the parameters indicated by the battery cell manufacturer, see Tab. 2 and Tab. 3, optimum discharge current is less than 0.5 C, which is 10 A. In case of using only the battery pack as the primary source of energy, it is necessary to ensure that the available current within the range prescribed uses the voltage level 480 V. Weight in case of the single source solution, see Fig. 7, is about 128 kg, volume is 58 l and cost almost € 3,500. In case of two-source structure the total mass is 47 kg, volume is 57 l and cost around € 3,300. The voltage for the hybrid source is partially limited by the ultracapacitor voltage (160 V) and other compromises.

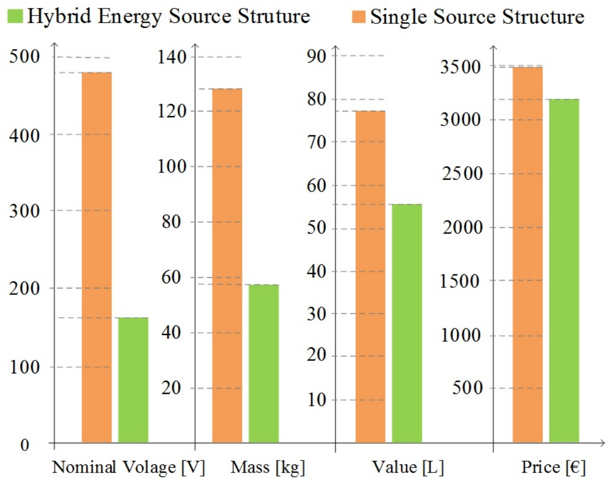

Fig. 8: Comparison of various parameters of power supplies.

7. Conclusion

In the introduction a method is described how to obtain data for terrain grading for the waypoints defined for particular route. These points are used to define our own driving cycle that has been used to calculate elevation profile of the terrain. This cycle also contains actual traffic information obtained from videos recorded during the ride along the route chosen by us. Subsequently, a graphical interface was compiled to calculate the frontal area of the vehicle and other parameters needed for the following operations were determined. Then, a calculation using a compiled GUI for power sizing electric go-kart was performed. Article also deals briefly with a hybrid energy storage system where LiFePO4 batteries and ultracapacitors have been used as energy sources.

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Peter CUBON was born in 1987 in Zilina Slovakia. In 2011 he graduated M.Sc. Degree from the University of Zilina, Faculty of Electrical Engineering at Department of Mechatronics and Electronics. The scientific degree of Ph.D. was conferred upon him in the branch of Power Electrical Engineering in 2014. His latest research has been focused on development of optimization energy system with hybrid source structure in a small electric vehicle.

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