Consumption of battery electric vehicles

SW for analysis of consumption of battery electric vehicles (BEV).

SW version 1.0

Description from 20th December 2013.

Content

1 Introduction

Software for analysis of consumption of battery electric vehicles (BEV) is described in this document. This software is result marked as TE01020020V017 WP19V001 within research project "Centrum kompetence automobilového průmyslu Josefa Božka". This modular simulation software assigns vehicle power needed for moving at desired speed to given operation mode and state of surrounding environment based on vehicle model in every time step. SW determines demand on energy storage, usually traction battery, within further computation. SW module of the model of the battery contains detailed calculations of state quantities of each traction accumulators (actual state of charge, voltage, internal resistance, temperatures, etc.) based on author's measurements made particullary on accumulator technology $LiFePO_4$. Model determines the price of following charging of the battery as well as the cost of utilization of the battery, when price parameters are given.

2 Basic description of the software

2.1 Run the program

Software is developed in environment LabVIEW 2011 SP1 of American company National Instruments, Inc. The software is distributed as a standalone executable application (with extension .exe). To start it is either necessary to have installed software LabVIEW, or it is sufficient to install the LabVIEW Run-Time Engine 2011 SP1 in the computer. This engine can be freely downloaded on the website of National Instruments. For example, for Windows 32b appropriate Run-Time Engine can be downloaded at http://joule.ni.com/nidu/cds/view/p/id/2897/. The program alone will then start by opening the file SpotrebaBEV.exe.

2.2 The graphical user interface (GUI)

The following figures show the look of the graphical user interface.

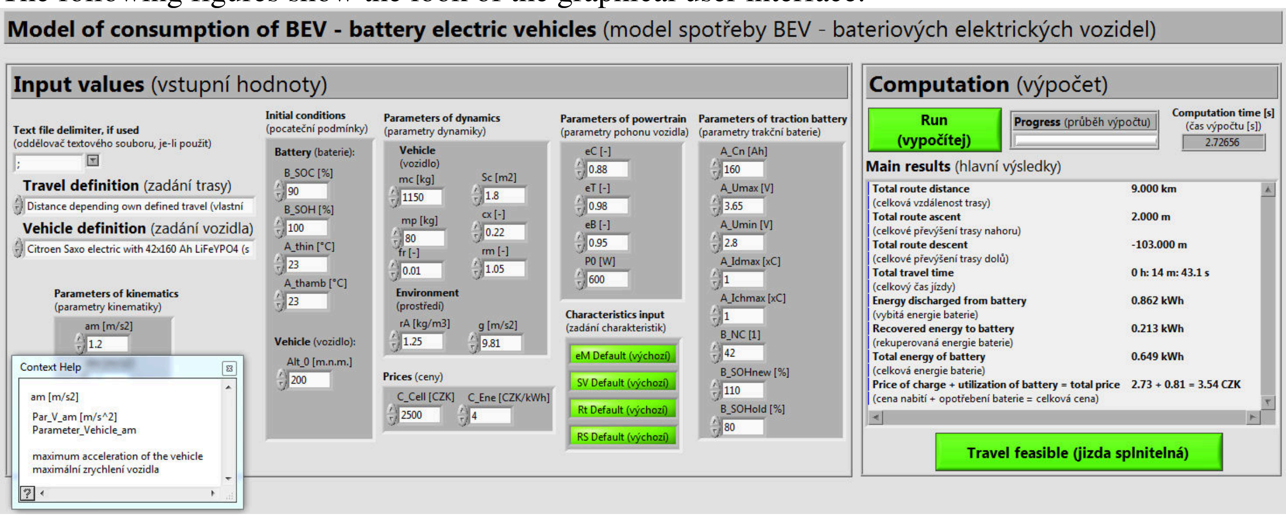

Fig. 1: Illustration of input parameters entering.

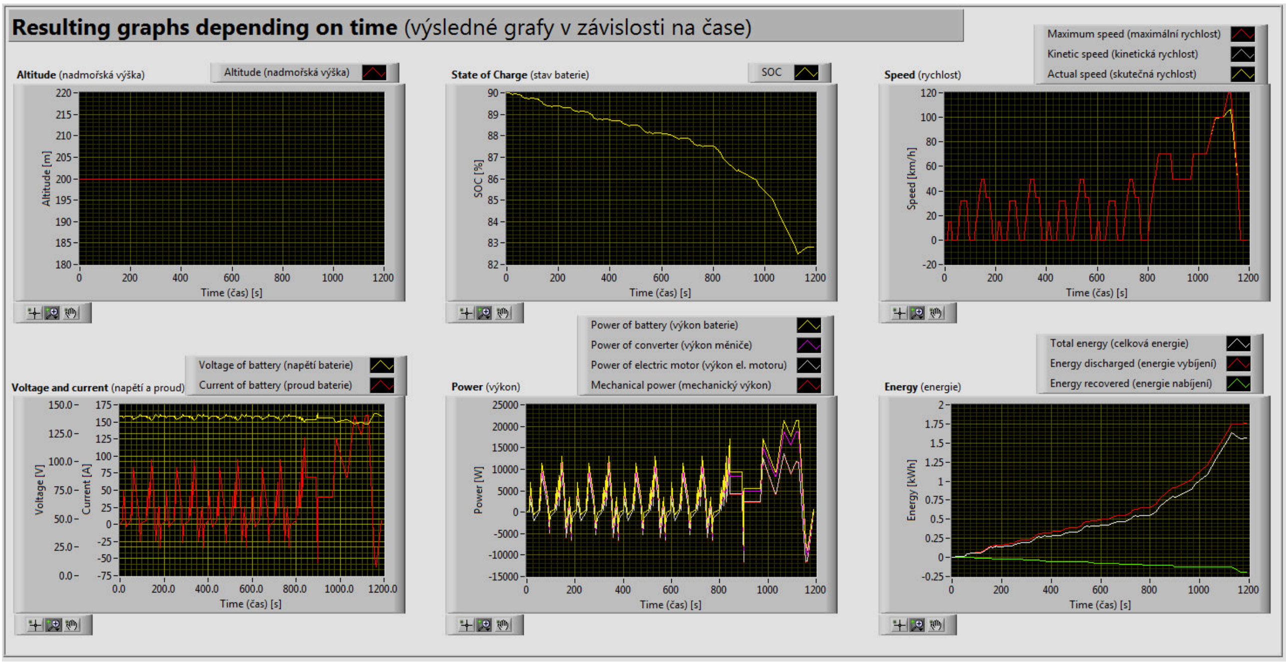

Fig. 2: Illustration of results for the simulation of vehicle driving under conditions of NEDC cycle.

2.3 Language

Software is designed as bilingual. All text is stated first in English and then in Czech in brackets.

2.4 Help

For proper working with the program it is advisable to read this document. During own work with the program it is recommended to have opened a contextual help. Keyboard shortcut Ctrl + H or bar sequence (Help-Show Context Help) will open contextual help. Contextual help is is also shown in Figure 1.

2.5 Working with the program

First it is needed to choose the travel and the vehicle in the left part, where one can select the preset values or use his own input. It is also necessary to check or change all the parameters, initial conditions and prices. Then the calculation can be started by pressing "Run". If the calculation takes longer time, the calculation process is shown by respective indicator. The table and indicator of the ability to fulfill the specified drive with the specified vehicle build the main results, that are shown in the right part of the GUI. Another part of the results is shown in the graphs below depending on time and even more below in the graphs depending on distance. Each graph can be zoomed in and out using the icons below the corresponding graph. Zooming into area defined by mouse is used as the deafult zooming mode. Another option is zooming graphs in horizontally, vertically, or zooming them out. Selecting Edit-Reinitialize to Default Values returns all the values to the originally set values.

2.6 License

To use the program, there is no need of license. Program can not be modified. For more information contact the author (sadil@fd.cvut.cz).

3 Detailed description of the model

This chapter contains detailed description of the inputs, states, parameters, outputs, characteristics and computational modules used in the software model of BEV consumption.

3.1 Inputs

Preset waveform of standardized driving cycles (NEDC, FTP-75) can build input of the model. For Own created text file can build input of the model for advanced users. This text file contains fractional numbers delimited by specified delimiter in meaning define below. There are two possibilities of input file:

- The firs possibility of the input file is **assumed profile of the travel** (distance is an independent variable). This corresponds to the travel from the start point to the end point following determined route with given parameters of separated sections of the route. Route sections may not be the same length. Columns of the text file have following meaning in case of input profile of the travel:
  - 1. column: distance traveled [m],
  - 2. column: maximal speed at point [km/h],
  - 3. column: stop duration at point [s],
  - 4. column: slope of previous section [%].
- The second possibility of the input file is **assumed waveform of the travel** (time is an independent variable). This corresponds to testing driving cycles or verification of the model by measurements. Columns of the text file have following meaning in case of input waveform of the travel:
  - 1. column: time [s] (note: stop duration is given by dependency of the velocity on time),
  - 2. column: actual speed at point [km/h] (note: this speed can be further limited by maximal allowed acceleration or deceleration),
  - 3. column: slope of previous section [%].

3.2 States

Initial condition have to be entered for all the states.

Symbol	Unit	Name	Meaning
B_SOC	%	State of charge of the battery	Actual state of charge of the battery. Ratio of actual remaning battery capacity to the rated capacity.
B_SOH	%	State of health of the battery	Actual state of health of the battery. Ratio of fully charged battery capacity to the rated capacity in actual life state.
A_thin	°C	Internal temperature of the accumulator	Average value within the accumulator.
A_thamb	°C	Ambient temperature of the accumulator	Temperature of the ambient air (remains constant for the whole time of simulation).
Alt_0	m	Altitude	in meter above see level

3.3 Parameters

3.3.1 Parameters of kinematics

Symbol	Unit	Name	Meaning
am	$m.s^{-2}$	Maximal acceleration	respects comfort and driving style
dm	$m.s^{-2}$	Maximal deceleration	respects comfort and driving style

3.3.2 Parameters of dynamics

Symbol	Unit	Name	Meaning
mc	kg	Curb weight	Weight of the equipped vehicle without passengers and freight.
mp	kg	Passenger and goods weight	Weight of traveling passengers and freight.
fr	1	Rolling coefficient	Note: depends also on roughness of the road surface.
Sc	m^2	Cross-sectional area of the vehicle	
cx	-	Coefficient of air-drag of the vehicle	
rm	-	Coefficient of rotation mass movement	Increase of effective mass for calculation of kinetic energy.
rA	$kg.m^{-3}$	Density of the ambient air	
g	$m.s^{-2}$	Gravity constant	

3.3.3 Parameters of vehicle powertrain

Symbol	Unit	Name	Meaning
eT	-	Efficiency of transmission	
eC	-	Efficiency of traction converter	
eB	-	Efficiency of traction battery	Ratio of electrical energy taken from the battery during discharging to electrical energy delivered to the battery during previous charging.
P0	W	Base power of the vehicle	Base power of the vehicle switched on without traction.

3.3.4 Parameters of battery (B) and accumulators (A)

Symbol	Unit	Name	Meaning
A_Cn	Ah	Rated capacity of the accumulator	(Rated) capacity determined under stated conditions and declared by producer of the accumulator.
A_Umax	V	End-of-charge voltage	Voltage reached at the end of charging by stated constant charging current (maximal voltage of the accumulator).
A_Umin	V	Cut off voltage	Determined voltage of the accumulator, when discharging has to be finished (minimal voltage of the accumulator).
A_Idmax	xC	Maximum discharge current	of the accumulator (cell)
A_Ichmax	xC	Maximum charge current	of the accumulator (cell)
B_NoC	1	Number of cells	Number of cells connected in the battery in series.
B_SOHnew	%	SOH of the new battery	State of health (SOH) of the weakest cell of the new traction battery
B_SOHold	%	SOH of battery being changed	Assumed SOH of the weakest cell of traction battery being renewed (replaced).

3.3.5 Parameters of prices

Symbol	Unit	Name	Meaning
C_Cell	CZK	Cost of one cell	Price of one accumulator (cell) of the traction battery.
C_Ene	CZK/kWh	Cost of electricity	Price of 1 kWh of electrical energy from the grid.

Note: when entering prices in other currency, the result can be used for this other currency.

3.4 Characteristics

The following characteristics are specified for the DC commutator motor used in the battery electric vehicle Saxo electrique and accumulators $LiFeYPO_4$.

Advanced users can change these characteristics by specifying the input files. The values entered using any number of characteristics points are interpolated.

Symbol	Unit	Name	Meaning	Specification of file format for advanced users (with using of defined delimiter)
eM	1	Efficiency of traction motor	Efficiency map (2d dependency of efficiency on the voltage [V] and current [A] of commutator traction motor)	File defining voltage: first row contains voltage values (first independent variable). The first row repeats as many times as the number of values of current. File defining current: first column contains current values (second independent variable). The first column repeats as many times as the number of values of voltage. File defining efficiency: contains values of efficiency of traction motor (dependent variable). Column defines voltage of the motor, row defines current of the motor.
SV	V	Dependency OCV (SOC)	Dependency of open-circuit voltage OCV [V] on the state of charge SOC [%]	1. row: values of SOC from 0 to 100 2. row: respective values of OCV (open-circuit voltage)
Rt	1	Temperature correction of Ri	Multiplication coefficient, that corrects internal resistance of the accumulator for respective temperature.	1. row: values of temperatures of the accumulator 2. row: respective values of temperature correction coefficient.
RS	1	SOC correction of Ri	Multiplication coefficient, that corrects internal resistance of the accumulator for respective SOC.	1. row: values of SOC of the accumulator 2. row: respective values of SOC correction coefficient.

3.5 Results (outputs)

The result of consumption model of BEV is a summary table of the main results (details are apparent from the GUI shown on figure 2). Resulting graphs of the selected output variables depending both on time and distance build another result of the software (regardless of whether the entry model of the profile or during the ride). Output values of the model are shown in the following table:

Symbol	Unit	Name	Meaning
B_SOC	%	State (see above)	
vk	$km.h^{-1}$	Kinetic speed	Speed of the vehicle with respect to maximal allowed acceleration and deceleration.

v1	$km.h^{-1}$	Actual speed	Achievable speed of the vehicle (from the powertrain point of view) at the end of travel section.
UBat	V	Voltage of battery	Voltage of the traction battery
IBat	A	Current of battery	Current of the traction battery
PTBat	W	Power of battery	Power of the traction battery
PPC	W	Power of converter	Power of the traction converter
PTMot	W	Power of electric motor	Power of the electric traction motor
Pmech	W	Mechanical power	Mechanical power needed
Wcelk	Ws	Total energy	Total energy of the traction battery (delivered from battery...>0, recovered to the battery...<0)
Wdis	Ws	Energy discharged	Energy delivered from the traction battery during discharging
Wch	Ws	Energy recovered	Energy recovered to the traction battery during recuperation.
feas	Yes /No	Travel feasible?	If the battery is not able to deliver the power needed for desired final speed of the respective section, speed decreases and thereby the driving time extends. If the travel is not feasible even with extended travel duration, it is necessary to stop the travel (the indicator will show "Travel impossible").

3.6 Computation modules

Computation modules of BEV consumption model are described in this chapter.

The software contains the following software modules:

- Input detailed kinematic module
- Computation model for one step of computation, which contains
  - module of basic kinematics,
  - module of dynamics,
  - module of powertrain,
  - module of traction battery and
  - module of traction accumulator.

3.6.1 Input detailed kinematic module

Input detailed kinematic module performs basic kinematic calculations (quiet, uniform motion, uniformly accelerated respectively decelerated motion, including transitions between these movements) based on input data defining travel (see chapter 3.1).

3.6.2 Computation model for one step of computation

Output values of input detailed kinematic module are input values or computation model for one step of computation. Computation model calls computation modules listed below (module of basic kinematics, dynamics, powertrain, battery and accumulator) for the purpose of calculating the appropriate quantities. If any of the components of the vehicle is not able to ensure required characteristics of the travel (e.g. acceleration demand implicates too high current from the traction battery in actual route ascent), the demand for the final speed of the section is automatically reduced, so that all the components are operated in allowed limits.

3.6.3 Module of basic kinematics

Module of basic kinematics only checks, whether the maximum acceleration is not exceeded in the calculation step. This could occur if the previous step was impossible for the original input demand, which reduces the actual speed at the end of the previous step (i.e. the initial speed of the current calculation step). In the current step, the model tries to return to the original values of the required speed, but can never exceed the value of maximal acceleration.

3.6.4 Module of dynamics

Outputs of above stated computation modules are inputs of the module of dynamics. Module of dynamics determines each forces acting on the vehicle, mechanical energy and mechanical power needed, based on respective physical relations.

3.6.5 Module of powertrain

Outputs of above stated computation modules are inputs of the module of powertrain. Module of powertrain takes efficiencies into account. In the case of simpler components such as gear mechanism, efficiency is considered constant, in the case of more complex components, such as traction electric motor, the efficiency map is considered depending on the voltage and current of the traction motor at selected points between which 2d linearization is performed. Power demand on the battery is the output of the module of powertrain in the respective calculation step.

3.6.6 Module of traction battery

Outputs of above stated computation modules are inputs of the module of traction battery. Module of traction battery distributes required power between individual cells (traction accumulators) of the traction battery.

3.6.7 Module of traction accumulator

Outputs of above stated computation modules are inputs of the module of traction accumulator. The open-circuit voltage OCV is determined based on the output values of state of charge (SOC) of the last step and on characteristics OCV (SOC) for a given battery technology. The internal resistance of the battery is then determined based on empirical relation determined by measurements according to the current temperature and state of charge. Furthermore, required battery current is determined based on the required power, the current values of the OCV and internal resistance. It is monitored, whether voltage limits are not exceeded for given accumulator technology and whether the current of the accumulator is not too high with respect to to durability at the same time. In case of too high current the requirement to the target speed is reduced and the calculation is performed again starting from the basic kinematics module. The energy and the charge removed from or delivered to the battery respectively is further determined for maximum possible allowable current. Furthermore, the module of accumulator utilization determines the state of health (SOH) decrease corresponding to one step of the calculation. Loss of SOH is based on empirical relationships based on performed measurements. Furthermore, the values of the open circuit voltage and internal resistance are updated at the end of the calculation step. Finally, heat module of the accumulator is called, which determines heat balance and computes generated heat, heat shared by conduction and convection and final temperature values inside the accumulator and on the case surface based on actual flowing current, internal resistance and ambient temperature.

4 Experimental verification of the model

The research team of the Czech technical university in Prague, Faculty of transportation sciences, disposes of battery electric vehicle Citroën Saxo Electrique, where the traction battery had been changed to the one composed of 42 series connected cells of 3.2 V, 160 Ah of Chinese produces Winston Battery, technology $LiFeYPO_4$. This vehicle has installed an automated monitoring system to record important operating variables. The monitoring system uses built-in as well as additional sensors and after preprocessing data are stored each second into data text files. Between recorded parameters are the following measured values :

- date, time,
- meteorological data (temperature, pressure, humidity),
- GPS receiver data (time, location, altitude, etc.),
- odometer speed and distance,
- voltage and current of the traction battery and
- calculated values of traction battery power and energy (at discharge and recovery).

The model has been calibrated using measurements made on this vehicle, and achieves an accuracy of over 90%.