STUDY OF ENERGETIC BALANCE OF REGENERATIVE ELECTRIC VEHICLE IN A CITY DRIVING CYCLE

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Abstract. The article describes the research of electrical system for the electric vehicle Melex 963 of city driving cycle. Vehicle intended for use in airports and aerodromes, national parks, hotel complexes, tourist trips and for passenger transport in manufacturing areas. The lead-acid batteries (nominal voltage 48 V) and electric motor (nominal power 3.9 kW) with a 16:1 gear and specific power 3.44 kW·t^{-1} are used. The battery charge and discharge curves at constant current and the load were measured for three city drive cycles. The speed and acceleration were logged with the GPS data logger device.

Keywords: electric vehicle, regenerative braking, city cycle run.

Introduction

With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, the electric, hybrid, and fuel cell vehicles have attracted more and more attention by automakers, governments, and customers. The need to reduce fossil fuel consumption and emissions in automobiles and other vehicles predominately powered by internal combustion engines is well known. If fuel cell vehicles go into production in the near future, their degree of hybridization will significantly impact the vehicle price due to high manufacturing and material costs of fuel cells and batteries. Vehicles powered by electric motors attempt to address these needs. The global optimization of energy management systems are based on knowledge of the future driving conditions, as provided by scheduled driving cycles. In this approach, two main constraints must be accounted for:

- very limited a priori knowledge of the future driving conditions is available during the actual operation
- the charge of the reversible energy source must be sustained without external sources, but based only upon fuel conversion or regenerative braking during the vehicle operation [1].

For many hybrids and electric vehicles the regenerative battery charging is used, when the braking energy is converted into electrical energy and therefore recharge the battery.

In literature it is noted that up to 60 % of braking energy can be recovered, it depends on the total mass of vehicle [2]. Similarly, in city modes, at low speeds, significantly more energy can be recover, the less impact on the aerodinamic properties and more brake are used [3]. Regenerative braking is the energy recovery benefit of hybrid vehicles. The former is strictly through regenerative braking while the latter uses the energy recovered through regenerative braking and steady speed driving when vehicle energy conversion is optimal [4].

In the experiments electric vehicle Melex 963 was used, wich has such a regenerative energy recovery method implemented in SepEx motor controller. The vehicle has lead-acid batteries with nominal voltage 48 V, 190 Ah at 75 A discharge rate, 3.9 kW electric motor with a 16:1 gear and 3.44 kW·t^{-1} specific power. Total mass of the vehicle during the experiments was 912 kg.

Materials and methods

Fig. 1. shows the main power components and the experimental setup on the test vehicle. During the test runs battery voltage and current were measured. The current measurements were performed using Hall-type current transducer S1 placed at the positive lead before motor controller and other consumers; voltage was measured at the leads of batteries using voltage divider R1-R2. APPA32 was used as a current sensing device with voltage output, 100 A measurement range was set, accuracy ±(2 % + 2 A) = ±4 A, which corresponds to 0…1 V ±40 mV voltage output. Coefficient of the voltage divider was (46.99 ±0.027 kΩ)/(1.178 ±0.0027 kΩ) = 27.35. Error of resistor values in the voltage divider output was neglected. The measured data were acquired using Pico ADC-24 logger and a portable PC. The measurement voltage range of the data acquiring unit for current was set to

-1250…+1250 ±1.3 mV and for voltage -2500…+2500 ±5.4 mV, conversion time of both signals 60 ms. The total maximum measurement error for I_{batt} was 4.1 A or 4.1 % of measurement range (including partial errors of the current transducer and logging device), maximum error for U_{batt} was ±0.15 V or 0.3 % of nominal battery voltage (accuracy of the logging device and voltage divider). The data logging interval for both signal was set to 1 s.

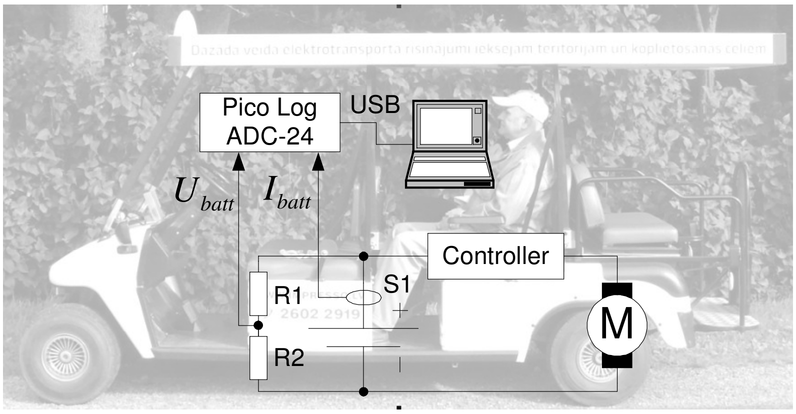

Fig. 1. **The main power components and the experimental setup on Melex 963**

GPS data (current coordinates and speed) were logged independently using Holux GPSport245 logger based on MediaTek MT3318 GPS chip, which provides 3 m position accuracy. Speed is calculated from the time and coordinate difference by the GPS logger device. Speed accuracy is not specified, but it can be evaluated from error difference of two concurrent position measurements. The Holux GPSport245 logs position and speed data with 1 s interval. The ambient temperature during all tests was 5 – 8 ºC. Batteries were charged to 51 V open circuit voltage before each test. Three test runs were performed in Jelgava on a route shown in Fig. 2.

As the electrical and GPS signals were logged using different devices and consequently they have different time basis the synchronization is required. Taking into account comparatively large logging interval, synchronization was done by visually aligning the speed and current consumption curves.

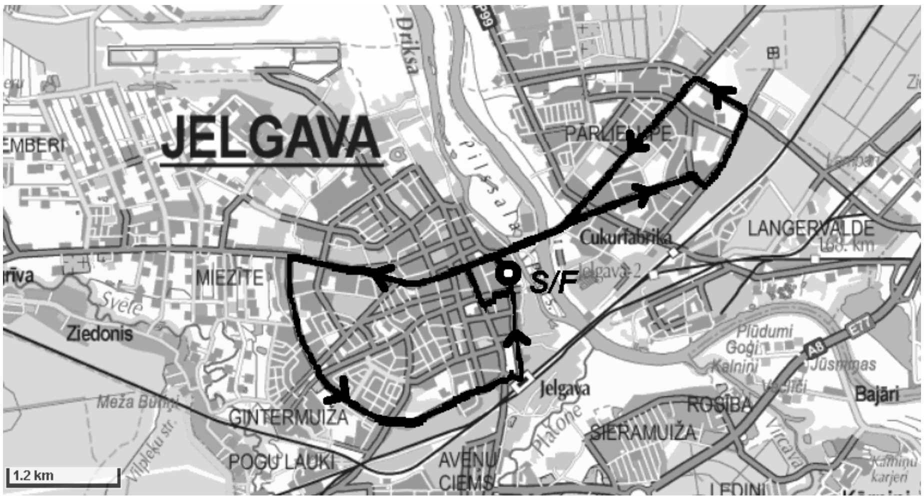

Fig. 2. **Route of the performed test runs:** 2 laps, total distance: 30.94 km

Results and discussion

Electricity is being considered as an alternative to petroleum fuels as an energy source. A pure battery electric vehicle is considered a more efficient alternative to hydrogen fuel propelled vehicle as there is no need to convert energy into electricity since the electricity stored in the battery can power the electric motor. Besides an all electric car is easier and cheaper to produce than a comparable fuel-cell vehicle. The main barriers to the development electric cars are the lack of storage systems capable of providing driving ranges and speed comparable to those of conventional vehicles. The low energy capacity of batteries makes the electric car less competitive than internal combustion engines using gasoline. Yet, as technology improves, cost effective batteries will become available.

Fig. 3. shows the overview of the test run 1 including momentary speed, distance, voltage and current of the battery. As the voltage and current measurements were performed directly on the battery total consumed energy is calculated and also the energy acquired from electrical braking and used for the battery charging can be evaluated. The idle current with the vehicle control electronics and low beams turned on is 1.4 – 2.4 A, which is within the limits of measurement error. Total time of the run is 5346 s, at the end of the run open circuit voltage of the battery was 40 V. Changes in voltage correspond to a typical lead-acid battery discharge curve, and consequently the momentary speed decreases as well.

Table 1 summarizes the main statistics for all runs. The energy flow in the battery was calculated using formula (1) by taking into account that measurement interval is constant.

$$W = \sum_{t=0}^{t_n} \frac{U_{batt}(t) I_{batt}(t) \Delta t}{3.6 \cdot 10^{-6}}, \quad (1)$$

where W – energy, kWh;
U_{batt} – measured battery voltage, V;
I_{batt} – measured battery current, A;
Δt – measurement interval, 1 s.

Energy inflow and outflow were calculated separately using positive and negative I_{batt}. The calculations show that only 1.6 – 2.1 % of consumed energy is regenerated during electrical braking and used for battery charging.

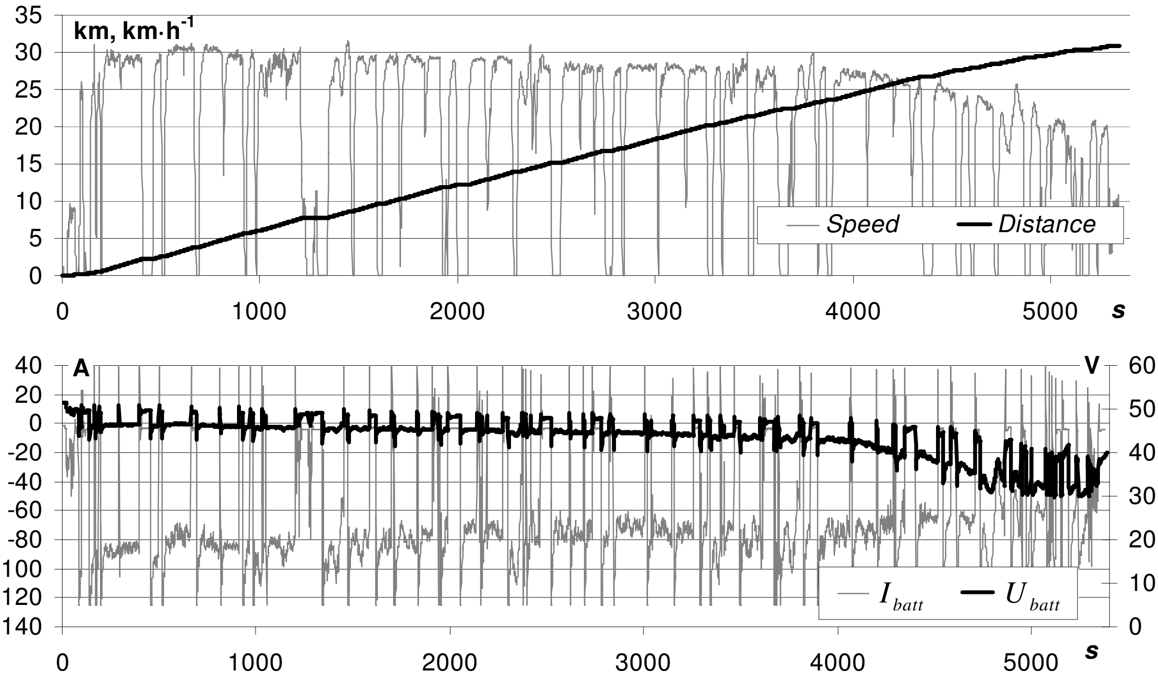

Fig. 3. **Overview of the test run 1**

Typical start-stop cycles are shown in Fig. 4. The battery discharge current ($I_{batt} < 0$) increases with positive acceleration. During travelling at constant speed I_{batt} changes insignificantly, but at the braking points 1 and 2 battery current becomes positive and begins charge.

The histogram of battery power for the three test runs is shown in Fig. 5. As the period of observation is 1 s, histogram value for each point at horizontal axis shows the time in seconds when the corresponding power was applied to the battery for charge and discharge. The largest value is for idle state of the vehicle (low beams and electronics are turned on).

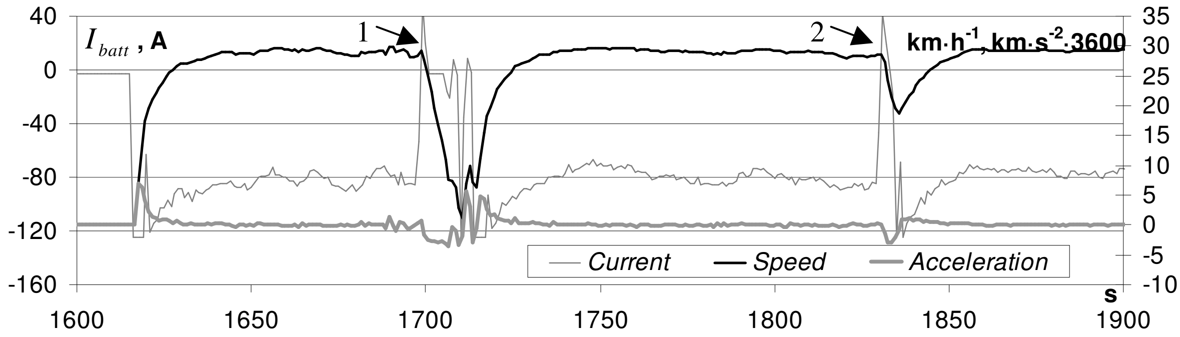

Fig. 4. **Battery current dependence on acceleration**

Table 1

Statistical summary of three test runs

Run	Distance, km	Total time, s	Average speed, $km \cdot h^{-1}$	Energy consumed, kWh	Energy regenerated, kWh	Energy regenerated, %
1	30.94	5346	20.84	3.88	0.06	1.6
2		5738	19.41	3.66	0.06	1.6
3		6121	18.20	3.47	0.07	2.1

The most of the travel time the vehicle consumed power close to motor nominal. Battery power ranged from 3.1 to 3.9 kW varied 25 to 37 % depending on the run. There was no load applied to batteries for 15 % of total time due to stops during the run. Battery charging with the braking energy (positive power on the graph) occurred only in 5 % of the total time for the run 1 and 3 and 4 % for run 2.

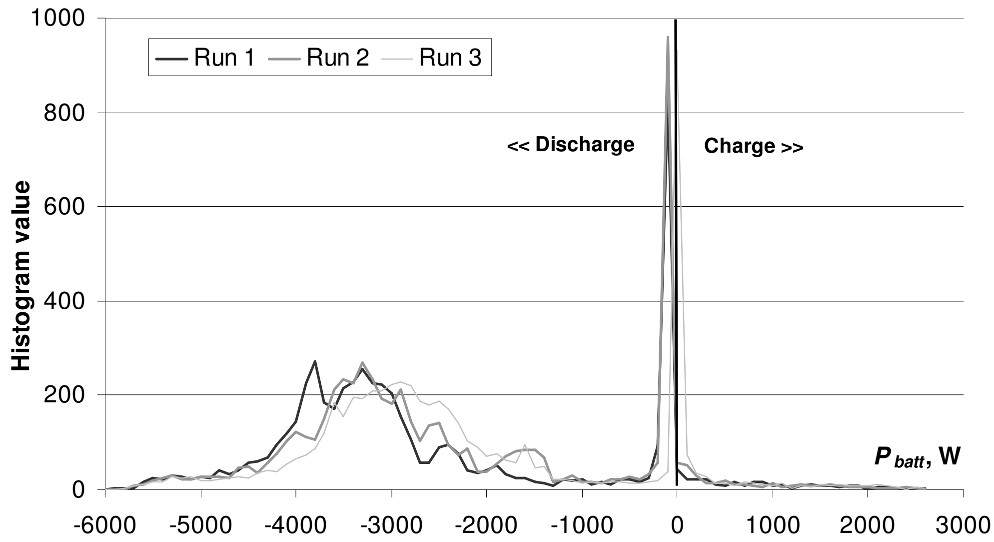

Fig. 5. **Histogram of battery power**

Conclusions

1. Three city-cycle test runs were performed on the Melex 963 electric vehicle on the same route in order to determine portion of regenerated energy during the electrical braking. Total distance of the test run was 30.94 km. The experimental data was logged with 1 s interval; both electrical (battery voltage and current) and moving (speed, absolute position) parameters were measured.
2. Experiments show, that regenerated energy fraction increased with the drop of the average speed.
3. Battery charging with the braking energy occurred only in 4 – 5 % of the total city-cycle drive time and 1.6 – 2.1 % of the consumed energy was regenerated. The same percentage of total traveling distance can be expected.

4. More tests with different factors that can affect the performance of battery, regenerative braking controller and drive e.g. varying mass, ambient temperature, relief, different average speeds, disabled regenerative braking etc. should be performed.

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