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TOWARDS AN ENERGY EFFICIENT OPERATION OF A SUPERCAPACITOR ELECTRIC BUS

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RESEARCH ARTICLE

ABSTRACT: Energy efficiency and reliable range prediction are important for all vehicles, especially for public transport vehicles such as a supercapacitor electric city buses. This research was conducted experimentally and has shown that most energy can be saved by adequate acceleration and coasting (i.e. deceleration without braking) between two stops. For this particular vehicle the most efficient acceleration is achieved when the driver presses the accelerator pedal for the full travel (100%) until reaching the required speed, then coast-down. Speed oscillation and unnecessary "hesitation" to fully depress the pedal during acceleration are highly undesirable. Coasting was found out to be most effective in energy recuperation, but other constant low intensity deceleration modes have also positive effects. Proposed driving style can lower the energy consumption by around 28%, extending the driving range and reducing the need for recharging. For the fleet of 4 buses, the total annual energy saving could amount to around 86.8 MWh.

KEY WORDS: *eco-driving, electric bus, energy efficiency, public transport, supercapacitor*

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KA ENERGETSKI EFIKASNOM RADU SUPERKANDACITORSKOG ELEKTRIČNOG AUTOBUSA

REZIME: Energetska efikasnost i pouzdano predviđanje dometa su važni za sva vozila, posebno za vozila javnog prevoza kao što su superkondenzatorski električni gradski autobusi. Ovo istraživanje je sprovedeno eksperimentalno i pokazalo je da se većina energije može uštedeti adekvatnim ubrzanjem i kretanjem (tj. usporavanjem bez kočenja) između dva zaustavljanja. Za ovo konkretno vozilo najefikasnije ubrzanje se postiže kada vozač pritisne papučicu gasa za puni hod (100%) dok ne postigne potrebnu brzinu, a zatim spusti. Oscilacije brzine i nepotrebno „oklevanje" da se pedala potpuno pritisne tokom ubrzanja su veoma nepoželjni. Utvrđeno je da je kočenje najefikasnije u rekuperaciji energije, ali i drugi režimi usporavanja konstantnog niskog intenziteta takođe imaju pozitivne efekte. Predloženi stil vožnje može smanjiti potrošnju energije za oko 28%, produžavajući domet vožnje i smanjujući potrebu za punjenjem. Za vozni park od 4 autobusa, ukupna godišnja ušteda energije mogla bi da iznosi oko 86,8 MWh.

KLJUČNE REČI: *eko-vožnja, električni autobus, energetska efikasnost, javni prevoz, superkondenzator*

TOWARDS AN ENERGY EFFICIENT OPERATION OF A SUPERCAPACITOR ELECTRIC BUS

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INTRODUCTION

Belgrade, the capital of Serbia has long tradition in using electric vehicles in public transport, with the first electric tram launched in 1892 and the first trolleybus in 1947. Recently, the city has been looking at new alternatives, hydrogen fuel cell, battery and supercapacitor as a source of energy for the propulsion of city buses. In 2015 the city acquired five supercapacitor Higer buses, with the aim to operate four full time on a specific route and keep one as a backup. Although initial experience was very positive, some problems were experienced with the driving range and the research presented here was focused on understanding the energy requirements for vehicle propulsion and looking at the ways of making the operation more energy efficient, primarily in extending the driving range, but also in saving the energy and reducing the associated costs.

In the last decade, a considerable experience has been accumulated with electric passenger vehicles using batteries. Much less information is available about commercial vehicles and even less on using supercapacitors as energy source.

Typically, the advantages of electric vehicles in urban driving conditions are not only related to their zero emission, but to the fact that they are more energy efficient due to the lower speeds and more frequent recuperation of electrical energy [1]. There is no doubt that in urban driving the range is not often a critical issue, due to low speeds and inevitably shorter distances covered. The advantages of regenerative braking cannot materialise when the battery temperature and/or the state of charge are high [2]. The authors of [3] concluded that increased vehicle mass and payload have not so detrimental effect on energy consumption as electric propulsion is more efficient than IC engines at higher loads and a "by-product" of higher mass is an increase of the recuperated energy. Results of the simulation conducted in [4] showed that the impact of the passenger load in an electric bus is more pronounced in urban driving conditions, characterised by lower average speed and higher number of stops. Furthermore, the impact is pronounced when the driver is driving more aggressively.

The results of the simulations showed that coasting with no energy recuperation is always more efficient than braking with energy recuperation, even in case it could be 100% energy efficient [5]. Furthermore, aggressive driving can increase energy consumption by around 30% compared to the economical driving style [6]. Even the most efficient energy recuperation is no match for good driving.

Similarly to the research conducted in [6], research [7] concludes, by performing simulation in MATLAB/Simulink, based on a modified NEDC test cycle, that economical driving leads to a 32% longer range compared to aggressive driving, for a battery electric vehicle with energy recuperation.

There are three main factors affecting the energy efficiency of electric vehicles (not related to the vehicle design) – ambient temperature, traffic conditions and driving style [8]. Research [9] showed that impact of ambient temperature on electric bus range can be significant (increased usage of heating or air conditioning system), while the usage of heating system during winter has the most negative impact on vehicle range. The fact that electric vehicles are more economical in urban driving conditions, primarily due to the frequent braking with energy recuperation, is advantageous for public transportation. Research [10] comes to the similar conclusion, stating that drivers should avoid excessive speeds, accelerate moderately, drive in an anticipatory manner, minimise the auxiliary loads, and use advantages of energy recuperation during braking and coasting as much as possible. Likewise, research [11] investigating energy-saving driving style for electric bus, recommends vehicle speed interval and acceleration modes. It was shown that, for the considered electric bus, speed range from 30 to 35 km/h gives the best results in terms of energy efficiency, but the recommended speed range is extended to 40 km/h to follow the traffic flow. It suggested that the curve that represents speed versus time during acceleration should have a convex shape in order to minimise energy consumption. Developed energy-saving driving strategy reduced energy consumption during short sections of acceleration between 12.3% and 18.7%, while about 2.5% of energy was saved on entire electric bus route. Another research developed a model for determination of a specific driving style from collected data during real-world driving. It was shown that the model can successfully recognise different driving styles [12].

1 AIMS AND OBJECTIVES OF THE RESEARCH

The aim of this research is to evaluate an electric supercapacitor bus and develop the most energy efficient driving style. This research concentrates particularly on:

- Evaluating the supercapacitor electric bus and operating route characteristics.
- Defining the electric bus operating parameters to be recorded and the method of their measurement.
- Defining the driving cycles and vehicle payload for trial tests and giving the appropriate recommendations for energy efficient electric bus operation.
- Implementation and verification of a driving style in passenger service for the most energy efficient operation on the specific route.

2 THE VEHICLE

Higer KLQ6125GEV3 bus is an electric vehicle that uses supercapacitors as an energy source and two inter-connected motors for propulsion. Maximum permissible mass of the vehicle is 19,000 kg, while maximum passenger capacity is 90. The vehicle can reach maximum speed of 70 km/h and is configured as a 2 axle single deck bus with 3 doors. It is propelled by two permanently coupled Siemens 1PV5135-4WS28 electric motors [13], having maximum power of 90 kW and torque of 360 Nm each. Motor supply and control is provided via Siemens DC-DC/IGBT Mono inverter drive, drawing current from 20 kWh Aowei supercapacitor.

Supercapacitor charging can be accomplished by connecting to a standard electric grid as well by a pantograph, while the vehicle is at a bus stop or in a garage equipped with a fast charger. There are two 150 kW fast chargers located on each end of service route, where the electric bus charging is accomplished by a pantograph.

3 BUS OPERATING ROUTE

The bus operates on a city route (divided in directions A and B for the purpose of presentation in this research), characterised by high traffic frequency, numerous junctions and traffic lights. The route is 7 km long in direction A and 8 km in direction B. There are

16 bus stops and 26 intersections regulated by traffic lights in direction A and 17 bus stops and 29 intersections regulated by traffic lights in direction B. Bus dedicated lane is present only on a smaller part of the route. The change in elevation is about 60 meters, between starting and finishing point of the route.

As mentioned earlier on, the traffic is very dense on the operating route. To illustrate that, a typical speed profile in service conditions (with passengers) in direction A of the operating route is shown in Figure 1. The speed of 40 km/h is drastically exceeded only on the straight part of the route, in the bus dedicated lane and with no stations or traffic lights.

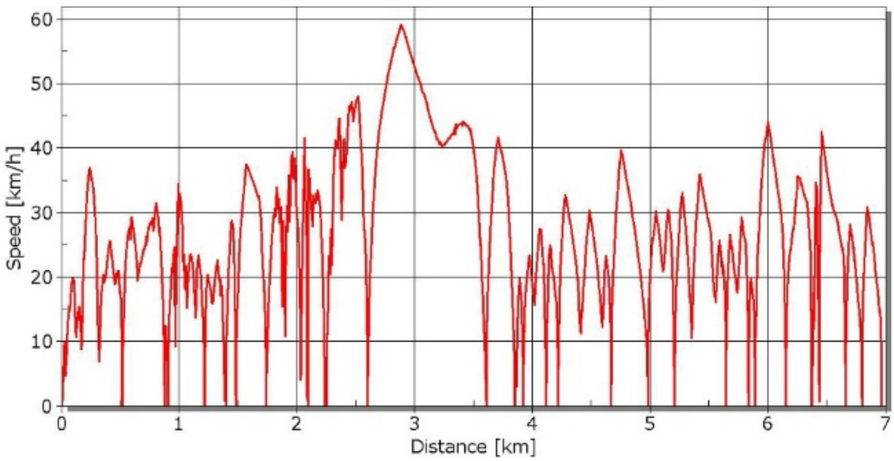

Figure 1 Typical speed profile in passenger service for direction A

4 INSTRUMENTATION USED AND BASIC DRIVING MODES

4.1 Instrumentation used

Bus operating parameters were monitored and recorded both in test trials and passenger service.

These included:

- Vehicle speed (v) [km/h].
- Vehicle position on the route (and driving direction, A or B).
- Accelerator pedal position (APP) [%].
- Brake pedal position (BPP) [%].
- Supercapacitor current (I_{uc} and I_{recup}) [A].
- Supercapacitor voltage (U_{uc}) [V].
- Supercapacitor state of charge (SoC) [%].
- Electric motor torque (T, T_{recup}) [Nm] and speed (ω) [min^{-1}].
- Ambient temperature [°C].

Some parameters were measured directly (e.g. supercapacitor voltage and current), with the values of others obtained through CAN bus. Some cross-checks were also performed. For example, in order to check the accuracy of vehicle speed acquired through CAN bus, Racelogic speed sensor was used. By comparing the data, it was concluded that CAN bus values are of a lower accuracy. Data acquisition was done with the help of HBM QuantumX, while sampling rate was set to 50 Hz. During testing, heating and air conditioning systems were turned off as their power is considerable (26 and 32 kW respectively), which would make final results difficult to correctly interpret.

4.2 Vehicle loading and test drivers

For this particular bus and the route studied, an average in-service payload was 50% of the maximum payload, which is identical to the value defined by UITP PROJECT "SORT", used to determine and compare energy consumption of different buses [14]. Consequently, such a payload was used in all tests, which was achieved by evenly distributed bags of sand with a total mass of 3,060 kg, corresponding to 45 passengers of 68 kg each. Furthermore, there were also seven examiners in the vehicle, adding 490 kg and bringing the total loading to 3,550 kg and the mass of the bus to 16,100 kg.

All driving during testing was conducted by 2 experienced bus drivers, each having more than 10 years of experience with diesel-powered buses and about 4 years with this electric bus operating on this very route. Consequently, when the reference was made to "usual driving" that is how they used to normally drive prior to this research and the establishment of a more energy efficient, economical driving style.

4.3 Acceleration modes

Considering that vehicle speed can rarely exceed 40 km/h, all acceleration trials were performed up to that speed, for both constant and variable accelerator pedal positions. To overcome the subjectivity problem, a guidance for the driver was implemented. Several acceleration curves were established, each representing speed versus time spent to reach the same maximum speed value, defined by equation (1), following the research [11]:

$$v = v_0 + (v_f - v_0)\left(\frac{t - t_0}{t_f - t_0}\right)^{\beta} \tag{1}$$

where v is vehicle speed, t is time, the subscripts 0 and f relate to: 0 – initial; f – final, β is a parameter defining the intensity of acceleration, with typical values between 0.2 and 4.0.

The driver was following a curve with the prescribed acceleration parameter β displayed on a tablet computer mounted in front of him (Figure 2). Accelerator and brake pedal position and speed values were also shown. Maximal acceleration achieved during testing was slightly below 1.2 m/s^2, which is acceptable from the aspects of traffic safety and passenger comfort. This was within a range of comfortable longitudinal accelerations and decelerations from 0.9 to 1.47 m/s^2 [15]. During the tests, it was found that curves defined by $\beta < 0.7$ could not be achieved due to the limits of powertrain dynamic characteristics of the bus. Furthermore, it was concluded that when the β coefficient is equal or greater than 2, the bus needed at least 10 s to reach the speed of 10 km/h, which is considered to be too slow.

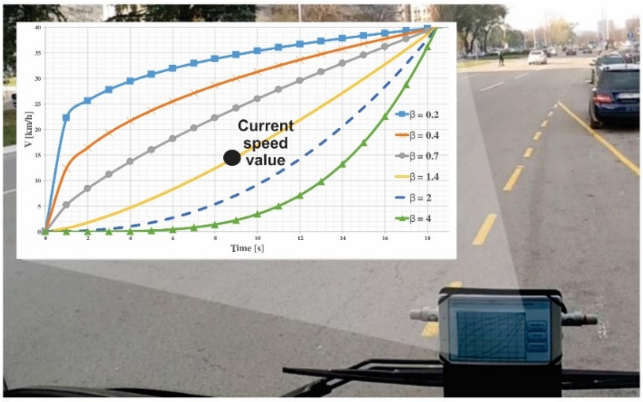

Figure 2 Target acceleration curves and tablet computer installed in the bus Deceleration modes

Trials with different deceleration rates were performed in order to determine the most energy efficient driving mode and the amount of recuperated energy for different brake pedal positions and vehicle speeds. The bus is set up in such a way that regenerative braking is provided as soon as the driver releases acceleration pedal, even when not pressing the brake pedal. This “free rolling” (coasting) mode provides gentle deceleration. When the driver presses brake pedal, in the first portion regenerative braking is gradually increased, and when pressing further friction braking is being activated.

4.4 Determination of consumed and recuperated energy

Power (P) and energy (E) during acceleration and deceleration are governed by the well-known relationships (Equation (2)):

$$P = U_{uc} I_{uc} \quad (2)$$

where U_{uc} and I_{uc} represent supercapacitor voltage and current, respectively.

Consequently, the energy equals (Equation (3)):

$$E = \int_0^t P dt \quad (3)$$

The consumed energy can be calculated from the measured current and voltage supplied from the supercapacitor through the inverter to the electric motors during acceleration. The recuperated energy can be calculated from the measured current and voltage recharging the supercapacitor, during coasting and braking periods.

5 VEHICLE TEST TRIALS

Unfortunately, it was not possible to experimentally study acceleration and deceleration driving modes on a dedicated test track, hence a suitable street section was used, having wide, smooth and horizontal surfaces, with little traffic and availability of the fast charger. The route consisted of 3 distinctive sections named “P”, “M” and “B” for more convenient presentation of the results. The mean altitude is around 80 m and various driving cycles were completed consecutively on each of the sections with several repetitions. The ambient temperature during tests was between 12°C and 16°C and there was no precipitation during tests (the road was dry).

5.1 Acceleration and deceleration cycles

Starting from the beginning of section "P" driving cycles were conducted, which consisted of an acceleration, followed by a deceleration, for each section "P", "M" and "B", until a full circle ("lap") was completed. After that, at the end of section "B", the supercapacitor was recharged using fast charger. That was to ensure equal state of charge for all tests. In total, over 100 driving cycles were completed, varying acceleration and deceleration parameters, but repeating the same cycles multiple times.

The results presented here will relate to accelerating to the speed of 40 km/h, for different acceleration rates, defined by the values of β coefficient (see Figure 2). The driver was achieving this by controlling the accelerator pedal position APP [%]. As soon as the speed was reached and stabilized, a chosen deceleration mode followed. The deceleration was also conducted with different intensity BPP [%], from gentle coasting, prolonged light braking, short heavy braking and various combinations. The goal was to determine which deceleration mode leads to the most efficient energy recuperation, still ensuring smooth and safe driving.

The procedure used and the results obtained will be explained here on an example, test cycle 8/M, conducted on section "M". Figure 3 shows the test cycle 8/M. The driver is pressing the accelerator pedal to around 50% (APP) from the very start, but hesitantly increasing and even slightly decreasing the pressure on the pedal until 15 seconds into the cycle, when he depressed the pedal fully (APP = 100%). Vehicle speed (v) is increasing relatively linearly to 40 km/h at about 22 seconds into the cycle. At this point the driver is releasing the accelerator pedal (APP dropping to 0). The total (cumulative) energy E consumed during acceleration is increasing relatively gently for the first 10 seconds, with the increase at a higher rate in later stages of acceleration. As soon as the desired speed of 40 km/h is reached and the driver releases accelerator pedal, the total energy consumed reduces due to recuperation which start instantly when the acceleration pedal is released.

Approximately one second after releasing the accelerator pedal, the driver presses the brake pedal relatively gently to about BPP = 20% over around 3 seconds and then keeps it in that position. The recuperation current I_{recup} rises sharply to around - 140 A (negative value), holding at that value for several seconds and dropping to 0 when the vehicle comes to a stop. The recuperation torque T_{recup} increases to about - 60 Nm, staying approximately constant throughout the deceleration period. The total energy consumed drops throughout the braking period, though the drop is modest in the last 3 seconds.

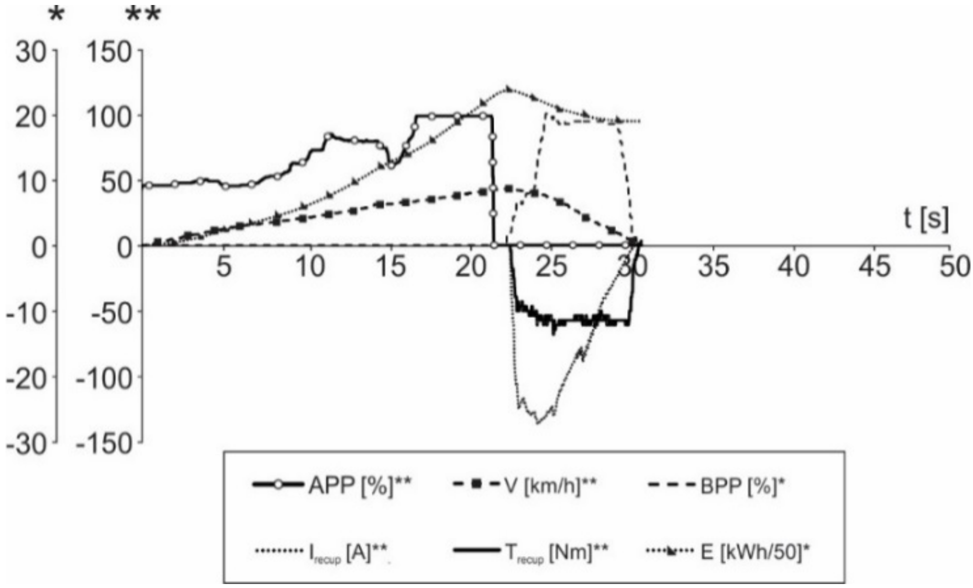

Figure 3 Test cycle 8/M

The actual values obtained for test 8/M are included in Table 1, together with test results for 5 more characteristic driving cycles which have been chosen for the comparison.

The energy efficiency of each driving cycle should be evaluated based on energy consumed during acceleration - acceleration rates were predefined (as said before), while decelerations were performed randomly and covered variety of scenarios (coasting, heavy and light braking, combined coasting and braking, etc.). Consequently, each acceleration can be combined with any deceleration scenario and should be regarded separately.

Table 1 Drive cycle results

Cycle number/ section	**Energy consumed to reach 40 km/h [kWh]**	**Accel. par. β [-]**	**Energy recuperated during braking [kWh]**	**BPP[%]**	**Cycletime [s]**	**Supercap. voltage: start / end of cycle [V]**
8/M	0.399	≈ 0.85	0.095	≈ 20	30	554 / 533
26/M	0.381	≈ 0.7	0.045	≈ 2	45	542 / 523
9/B	0.389	≈ 0.85	0.094	≈ 18	32	546 / 526
27/B	0.367	≈ 0.7	0.139	≈ 7	36	535 / 516
13/P	0.410	var.	0.093	≈ 4	42	576 / 560
25/P	0.376	≈ 0.7	0.094	≈ 17	28	545 / 527

Starting with cycle 8/M, Table 1 shows that the energy consumed to reach 40 km/h was 0.399 kWh, with the driver following acceleration parameter $\beta \approx 0.85$. Only 0.095 kWh was recuperated during braking which was conducted keeping the brake pedal relatively steady at approximately BPP = 20%. Supercapacitor voltage remains high, dropping only by 21V, from 554 to 533 V at the end of the cycle.

The analysis of other cycles (presented in Table 1) leads to some interesting conclusions:

- overall, the least energy during acceleration was consumed with $\beta \approx 0.7$, which corresponds to the maximum displacement of accelerator pedal (APP = 100%). The cycles with β ≈ 0.85 were least energy efficient. However, in reality by far the worst possible manner of acceleration, from the consumed energy point of view, is oscillating (variable) increase/decrease in accelerator pedal displacement.

- when decelerating, the most energy was recuperated in the cycle 27/B - 0.139 kWh. However, it should be pointed out that when operating a vehicle, the energy used over a distance should be minimised. From this point of view, coasting is the most energy efficient method. Practically, the driver should accelerate "hard" and then release the accelerator without applying the brake pedal, when road and operating conditions permits. City buses have to stop regularly at bus stops, but often other traffic conditions (traffic lights, traffic jams etc.) also require more frequent stopping.
- the manufacturer of the bus recommends that the brake pedal should be depressed not further than 28% of the full displacement, which ensures best energy recuperation of the electric motor acting as a generator. During testing, for a partly loaded bus (as said earlier on) brake pedal position (BPP) did not exceed 20% - even this level of brake pedal position lead to a deceleration exceeding 2 m/s^2, which is becoming uncomfortable and even unsafe for standing passengers.

5.2 Energy efficiency maps

Research [16] established energy efficiency maps for this vehicle powertrain by testing the motor-inverter combination on a powertrain dynamometer. The contour lines (Figure 4 and Figure 5) indicate an overall efficiency between 0.5 to 0.92. Following vast amount of tests and processed data it was necessary to be selective in presenting the most interesting findings, which in this case relates to the driving cycles performed in sections "B" and "P". Acceleration modes are particularly important in determining powertrain efficiency, so this driving condition was used here. The torque versus engine speed points were entered into a map for section "B" in Figure 4 and for section "P" in Figure 5.

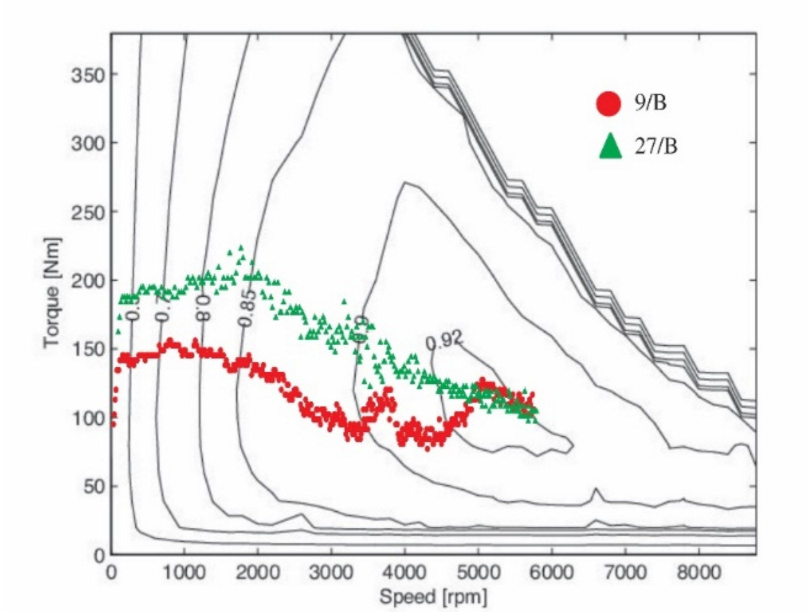

Figure 4 Energy efficiency map for driving cycles on section "B"

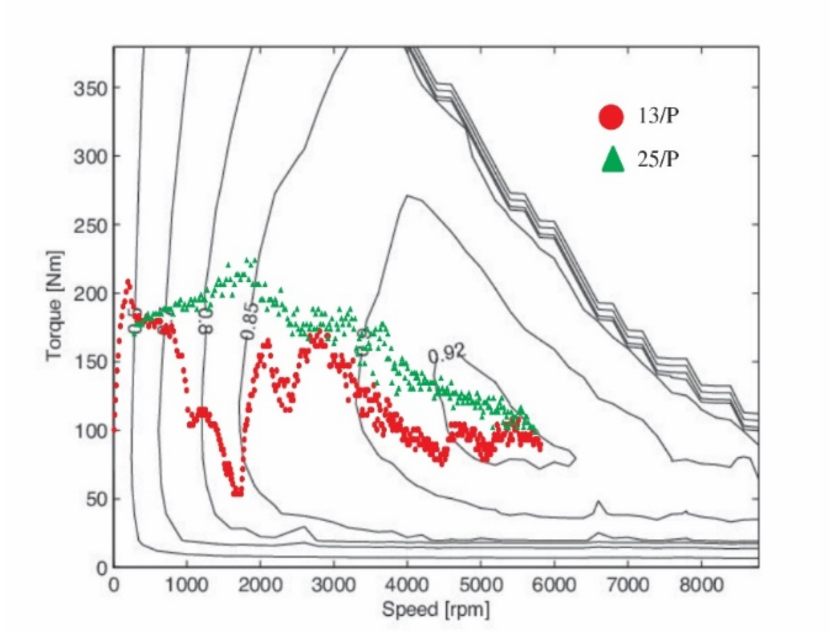

Figure 5 Energy efficiency map for driving cycles on section "P"

With intense acceleration (see Table 1) the path made of torque versus engine speed points follows the shortest possible distance to the area of highest energy efficiency (0.92) and the higher number of points will concentrate in this area for cycles 27/B and 25/P, as shown in Figures 4 and 5. In contrast, cycles 9/B and 13/P, which features oscillating displacement of accelerator pedal, show lower efficiencies on Figures 4 and 5, which is more pronounced in cycle 13/P.

6 IMPLEMENTATION IN OPTIMISING THE DRIVING ON THE BUS ROUTE

Following the measurements and analyses presented, a strategy was developed to implement the findings, in order to achieve more energy efficient bus operation. Acceleration and deceleration habits of the drivers needed to be improved. Consequently, the results were obtained for the newly developed "economical" driving alongside the "usual" driving prior to the implementation of the new techniques and the corresponding driver training. All driving has been conducted in the normal passenger service, in the same time of the day and similar vehicle loading, traffic and climatic conditions.

A selection of the results obtained are presented in Table 2, concentrating specifically on:

- Energy aspects (consumed, recuperated and net energy used).
- Total travel time and the time the vehicle was in motion.
- The average speed when the vehicle was in motion.
- Braking portion in total route time.
- Coasting portion in total route time and distance.

Table 2 Comparison of economical and usual driving styles

Parameter	**Route direction and driving style**			
	A to B		**B to A**	
	Usual	**Economical**	**Usual**	**Economical**
Consumed energy [kWh]	11.766	9.559	16.907	12.944
Recuperated energy [kWh]	2.890	2.789	2.453	2.258
Net energy used [kWh]	8.876	6.770	14.454	10.736
Difference [kWh]	-	- 2.106	-	- 3.718
Relative difference [%]	-	- 26.9	-	- 29.5
Trip duration [min:sec]	27:30	30:23	35:48	34:20
Time difference [min:sec]	-	+ 2:53	-	- 1:28
Relative time difference [%]	-	+ 9.5	-	- 4.3
Time in motion [min:sec]	17:37	20:17	20:37	24:52
Braking time portion [%]	17.4	11.4	13.5	6.3
Coasting time portion [%]	12.4	27.4	9.3	32.2
Coasting distance as a percentage of route [%]	21.5	49.7	17.9	50.0
Average speed [km/h] (when in motion)	24.17	20.67	24.41	19.96

By analysing the data presented in Table 2, some fundamental conclusions can be drawn:

- When driving economically, the average saving in used energy is around 28% (26.9% in direction A to B and 29.5% in opposite direction).
- The above reduction is the result of lower consumed energy, with the recuperated energy being actually lower in economical driving (by 3.5% A to B and 8.3% B to A).
- Economical driving leads to about 10% longer average driving times when travelling from A to B, but 4% shorter when driving in opposite direction. Generally, it can be concluded that an overall average increase in driving time is around 5%.
- Time that the electric bus spends in motion is longer for around 15% while driving economically. At the same time, braking time portion is lower for around 6.5% on average, while the time share of coasting is higher for 15% to 22.9%.
- It can be seen that while driving economically, the electric bus can cover around 50% of the route distance by coasting, compared to around 20% while driving as usual.
- The average speed is decreased for around 18% while driving economically, but without a significant impact on a trip duration.

The fundamental difference between the usual and newly developed economical driving style can be best explained by a speed vs. time graph shown in Figure 6. Even without the need to change the acceleration or deceleration rates or vehicle speed, the drivers had a habit of varying the speed (usual driving on Figure 6) which led to unnecessary increase in energy usage. Brake pedal should be used only gently, but again constantly (steeper speed decline at around 49 seconds in Figure 6) bringing the vehicle to a stop, with friction brakes applied only at the very end. Obviously, this is somewhat simplified scenario, but essentially shows how the driving needs to be improved.

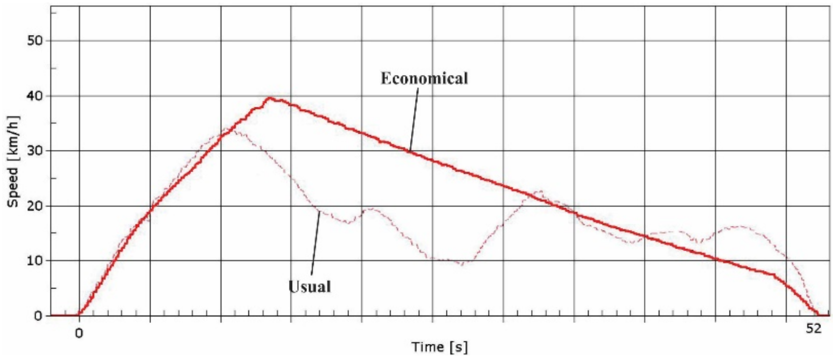

Figure 6 Speed profile between two stops recorded for "economical" and "usual" driving style in passenger service conditions

7 CONCLUSIONS

Indeed, for any propulsion system, energy efficient driving assumes diligent traffic observation, timely anticipation and use of vehicle momentum, avoiding unnecessary acceleration and braking whenever possible. However, the research presented here clearly demonstrates the most efficient acceleration and deceleration modes, followed by driver training to develop an appropriate driving style, different to the one they got used to when driving diesel powered buses.

In particular, the research showed that acceleration modes (defined by accelerator pedal position) have a major impact on energy efficiency of the electric bus. For this particular vehicle the simplest and most energy efficient manner of acceleration is by pressing fully the acceleration pedal. This is by no means causing excessive acceleration or any discomfort or danger to the passengers.

The vehicle needs to be brought to a required speed with constant acceleration (preferably APP=100%) and let to coast-down to a stop, at the next bus stop or traffic light. Brake pedal should be only used when necessary, depressed to a certain position and kept there, ensuring constant deceleration. Such driving is not only more economical, but is also safer for all road users and in particular for standing passengers. It is more comfortable too.

Proposed driving style lowered the net energy used on this route for 26.9% and 29.5%, depending on the direction (A or B). This reduction is practically between 2.1 and 3.7 kWh per direction, which represents considerable total saving of 5.8 kWh. Consequently, it is possible for the electric bus to complete the entire route (in both directions) without charging, as with economical driving the net energy used is 17.5 kWh and the supercapacitor capacity 20 kWh.

Charging at the end of the route will depend on other parameters too, but such a saving is more than welcomed in urban transport when the vehicle may need to make an immediate return, without waiting at the end of the route (turning point). Even if needed, the recharge can be shorter. When driven as recommended, tested electric bus can save about 65 kWh per day. For the fleet of 4 electric buses operating on this route, total saving is about 260 kWh per day, which accounts to about 86.8 MWh per year. And this is one of the "lighter" routes in Belgrade bus public transport.

This research and presentation focused on energy usage for propulsion of the bus. The bus uses around 10 kWh per direction or around 20 kWh for the entire round-trip route, which actually equals the capacity of the supercapacitor. However, HVAC systems can present heavier load on the energy demand. The heating system is rated at 26 kW and air conditioning (A/C) at 32 kW. Obviously, both systems will not be used simultaneously (although this is possible) and not be used at full power all the time. If any of the systems is used 50% of the time in one direction, with travel times of about 30 minutes, that amounts to about 8 kWh, which is approximately equal to the energy used for bus propulsion (also in one direction). Advanced control in using these systems and driver notification would need to be developed. This particularly relates to the use of A/C for heating which can be more energy efficient that using the resistor heaters in suitable atmospheric conditions.

Furthermore, more advanced driver information system would be beneficial, in terms of energy status, energy usage, route traffic, timetable and perceived passenger numbers. Driver training and suitable incentives and awards for energy efficient driving and punctuality would need to be also established. Looking to the future, this opens a unique line of potential research looking into how traffic variables (road lengths, traffic lights and congestion) can be taken into account for the provision of driver instructions. These recommendations could be applicable for different road sections, such as those between two points (bus stops, traffic lights) and distance to the vehicle in front, allowing for informed, dynamic speed control.

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