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MEASUREMENT OF RECOVERY ELECTRICITY ON THE E-BUS HIGER KLQ6125GEV3 ON EKO 1 LINE IN BELGRADE AND IMPACT ON ENERGY EFFICIENCY

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RESEARCH ARTICLE

ABSTRACT: One of the most important features of an electric bus (E-bus) is the ability to recover electricity generated during the braking and deceleration phase of the vehicle's movement. The specificity of the bus operation in urban transport is reflected in the dynamic mode of vehicle's operation, especially in terms of frequency and intensity of acceleration and braking. Recovered electricity during the braking and deceleration phase of E-bus drive is determined by the performance of the drive electric motor, the strategy choice (algorithm) for regenerative braking control, driving cycle, terrain configuration, the ability of the supercapacitor to receive as much electricity as possible and the driving style of the driver. The researches of the electricity recovered on the EKO 1 line was performed in 2018 and 2019. The time of year has been chosen when heating and air-conditioning systems were not used or minimally used only in certain periods of the day, in order to more realistically look at the effect of the achieved recovery and the impact on the energy efficiency of the E-bus. The measured values of the supercapacitor voltage, the discharge and recuperation current of the supercapacitor and the SOC (State of Charge) values were taken from the SD memory card BMS (Battery Management System) of the control unit that performs data acquisition from the V-CAN of the E-bus. The value of the recovered electricity, under the assumption that the regenerative braking system is used correctly, is mostly affected by the terrain configuration, i.e. the presence of inclined sections.

KEY WORDS: E-bus, recovered electricity, energy efficiency

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MERENJE OBNOVLJIVE ELEKTRIČNE ENERGIJE NA E-AUTOBUSU HIGERU KLK6125GEV3 NA EKO 1 LINIJI U BEOGRADU I UTICAJ NA ENERGETSKU EFIKASNOST

REZIME: Jedna od najvažnijih karakteristika električnog autobusa (E-bus) je mogućnost regeneracije električne energije proizvedene tokom faze kočenja i usporavanja vozila. Specifičnost rada autobusa u gradskom saobraćaju ogleda se u dinamičkom načinu rada vozila, posebno u pogledu učestalosti i intenziteta ubrzanja i kočenja. Obnovljena električna energija tokom faze kočenja i usporavanja pogona E-autobusa određena je performansama pogonskog elektromotora, izborom strategije (algoritmom) za kontrolu regenerativnog kočenja, ciklusom vožnje, konfiguracijom terena, sposobnošću superkondenzatora da primi što više električne energije i načina vožnje vozača. Istraživanja obnovljive električne energije na liniji EKO 1 vršena su 2018. i 2019. Izabrano je doba godine kada se sistemi grejanja i klimatizacije nisu koristili ili su se minimalno koristili samo u određenim periodima dana, kako bi se realno sagledali efekat postignutog oporavka i uticaj na energetsku efikasnost E-autobusa. Izmerene vrednosti napona superkondenzatora, struje pražnjenja i rekuperacije superkondenzatora i SOC (stanje napunjenosti) preuzete su sa SD memorijske kartice BMS (Sistem za upravljanje baterijom) upravljačke jedinice koja vrši prikupljanje podataka sa V-CAN E-autobusa. Na vrednost obnovljene električne energije, pod pretpostavkom da se sistem regenerativnog kočenja pravilno koristi, najviše utiče konfiguracija terena, odnosno prisustvo deonica pod nagibom.

KLJUČNE REČI: E-autobus, obnovljena električna energija, energetska efikasnost

MEASUREMENT OF RECOVERY ELECTRICITY ON THE E-BUS HIGER KLQ6125GEV3 ON EKO 1 LINE IN BELGRADE AND IMPACT ON ENERGY EFFICIENCY

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INTRODUCTION

The operation of the electric bus drive system is characterized by typical operating modes: vehicle acceleration mode to reach the set vehicle's speed, constant speed driving, and vehicle deceleration and braking mode. Electric and mechanical power flows when the vehicle is in acceleration mode are shown in Figure 1 (a), while the mechanical and electric power flows in braking mode are shown in Figure 1 (b) [1]. An electric generator is an electric drive motor in regenerative braking mode (recuperation).

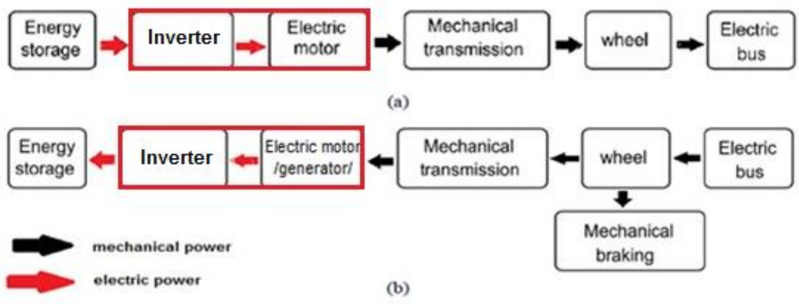

Figure 1 Electrical and mechanical power flows

The required power of the electric motor for the movement of the E-bus and the consumed electricity depends on the load of the vehicle, the resistance forces that occur in the phase of the movement (rolling resistance, grade resistance, aerodynamic and inertial resistance) and speed. The achieved energy recovery in the E-bus in the braking and deceleration phase is determined by the performance of the electric drive, the choice of regenerative braking control strategy (algorithm), driving cycle, terrain configuration, battery/supercapacitor to receive as much current as possible and driving style. According to the recommendations of the vehicle manufacturer "Higer" for the electric bus KLQ6125GEV3, the highest energy recovery in the braking phase and energy efficiency is achieved [2]:

- When the E-bus is moved at speed of about 30÷35 km/h.
- When the drive electric motor operates with the highest efficiency, when the ''rpm'' is above 2000 min^{-1}.
- When the command of service brake is depressed up to 28% of the pedal stroke, because the optimal recovery corresponds to a command angle of 9° (maximum angle is 32°), which represents 28% of the brake pedal stroke.
- When the E-bus moves with a speed higher than 5 km/h, while the engine speed is greater than 600 min^{-1},
- When the deceleration of E-bus is inertial, the braking torque generated by the electric motor has constant value up to 34 Nm and acts on the drive wheels axles.

By reducing the speed of the electric motor to 200 min^{-1}, there is a gradual reduction of braking torque up to a value of 0 Nm.

- Manufacturer of buses ''Higer'', states that a better recuperation effect is achieved by activating the service brake up to 28% of the pedal stroke than by decelerating by inertia under the same conditions in terms of achieved speed before direct braking/deceleration by inertia and duration of braking/deceleration by inertia.
- In cases when the service brake is depressed more than 28% of the pedal stroke, the activity is present of regenerative braking on the wheels of the drive axle, and the pneumatic system of the vehicle that acts on the wheels of the steering and drive axles. In this case, it is reduced regenerative braking efficiency.
- When driving downhill, it is recommended applying light pressure on the service brake pedal in order to activate regenerative braking and to maintain a constant speed of movement for the vehicle, thus achieving the best effect of electricity recovery.

The aim of this paper is to investigate the realized recovery energy on the EKO 1 line in real working conditions and the influence of factors, primarily terrain configuration, and driving style.

1. THEORETICAL BASES OF MOVEMENT AND REGENERATIVE BRAKING OF E-BUS

When the E-bus is in acceleration mode, the forces and power are represented by the equations:

$$F_{vu} = F_f + F_v \pm F_u + F_a \tag{1.1}$$

$$P_{mov} = \left(F_f + F_v \pm F_u + F_a\right) \cdot v_{ebus} \tag{1.2}$$

F_{vu} - traction force on drive wheels [N]

F_f - rolling resistance force [N]

F_v - aerodynamic resistance force [N]

grade resistance force (rise, fall) [N]

F_a - inertial resistance force [N]

P_{mov} - required power for the movement of the E-bus [W]

v_{ebus} - speed of E-bus [m/s].

The torque on the drive wheels is shown by equations:

$$\sum_{j=3}^{4} M_{tj} = F_{vu} \cdot r_d \tag{1.3}$$

M_{tj} - the torque on the drive axle wheels [Nm]

$j = 3,4$ - wheels of the drive axle

r_d - dynamic radius of the drive wheel [m].

Electric current flows from the power storage source (battery or supercapacitor) and supplies the drive electric motor via an inverter, which form one unit. From the drive motor, through the transmission to the drive wheels, a flow of mechanical power is generated. These flows are represented by the equations.

$$P_{ucd} \cdot \eta_{uc} = P_{em} \quad (1.4)$$

$$P_{em} \cdot \eta_i \cdot \eta_{em} \cdot \eta_t = \frac{M_{em} \cdot i_t \cdot v_{ebus}}{r_d} \cdot \eta_t = \sum_{j=3}^{4} M_{tj} \cdot \omega_{tj} \quad (1.5)$$

P_{ucd} - storage power for driving of discharge (supercapacitor, battery) during acceleration [W]

P_{em} - the power of the driving electric motor [W]

M_{em} - the torque of the driving electric motor (traction mode) [Nm]

η_{uc} - coefficient of storage efficiency and internal losses

η_{em} - coefficient of efficiency of the driving electric motor (traction mode)

η_i - coefficient of inverter efficiency

η_t - coefficient of transmission efficiency

i_t - total transmission ratio

ω_{tj} - angular velocity of the drive axle wheels [rad/s]

ω_{tj} - angular velocity of the drive axle wheels [rad/s].

Power of the electric motor is proportional to the size of the current and voltage, according to the load and operating modes (acceleration, motion with constant velocity).

$$P_{em} = U_t \cdot I_t \quad (1.6)$$

- current value of electric motor voltage [V]

- current value of electric motor current [A].

The power of electrical losses in the electric motor and inverter depends on the coefficient of efficiency of these two systems is represented by the equation.

$$P_{gem} = P_{ucd} \cdot \eta_{uc} - P_{ucd} \cdot \eta_{uc} \cdot \eta_i \cdot \eta_{em} = P_{ucd} \cdot \eta_{uc} \cdot (1 - \eta_i \cdot \eta_{em}) \quad (1.7)$$

P_{gem} - power losses of electric motors and inverters [W].

If the operation of the propulsion electric motor is observed in the mode of acceleration of the vehicle or movement at a constant speed in a certain time interval, the consumed electricity can be represented by the equation:

$$E_{em} = \int_{t_1}^{t_2} U_{ti} \cdot I_{ti} \cdot dt \quad (1.8)$$

E_{em} -electricity consumed of driving electric motor [J]
t_1 - start time [s]

t_2 - end time [s].

From the aspect of total engaged electric power: electric motor drive, auxiliary devices, air conditioning and heating systems, as well as losses that occur in the drive electric motor, inverter, battery and electrical installation, it is represented by the equation:

$$P_{ebus} = P_{em} + P_{pu} + P_{ac} + P_h + P_{gem} + P_{gbk} \quad (1.9)$$

P_{ebus} - total engaged power of E-bus [W]

P_{pu} - engaged power auxiliary equipment E-bus [W]

P_{ac} - engaged power of E-bus air conditioning system [W]

P_h - engaged power of the E-bus heating system [W]

P_{gbk} - power losses in supercapacitors (batteries) and E-bus cables [W].

The total power of the drive in equation 1.9, in the time interval, gives the total energy consumed by the E-bus expressed in kWh, which represents the energy consumed from the supercapacitor (battery) in the acceleration phase represented by the equation:

$$E_{p_{uc}} = \frac{1}{3600000 \cdot \eta_{uc}} \int_{t_1}^{t_2} \left(P_{em} + P_{gem} + P_{pu} + P_{ac} + P_h \right) \cdot dt \quad (1.10)$$

$E_{p_{uc}}$ - total electricity consumption of supercapacitors (batteries) in the mode of acceleration [kWh].

When the E-bus is in braking mode, total braking power is shown in the following equation:

$$P_{ki} + P_{kj} + P_{rkj} = \sum_{i=1}^{2} M_{ki} \cdot \omega_{ki} + \sum_{j=3}^{4} M_{kj} \cdot \omega_{kj} + \eta_t \sum_{j=3}^{4} M_{rkj} \cdot \omega_{kj} \quad (1.11)$$

P_{ki} - power of braking wheels on the front axle of the pneumatic system [W]

P_{kj} - power of braking wheels on drive axle from the pneumatic system [W]

P_{rk} - power of braking wheels on drive axle from regenerative braking [W]

M_{ki} - torque of braking wheels of the front axle of the pneumatic system [Nm]

M_{kj} - torque of braking wheels of the drive axle of the pneumatic system [Nm]

M_{rkj} - torque of braking wheels of the drive axle by regenerative braking [Nm]

ω_{ki} - angular velocity of the front axle wheels [rad/s]

ω_{kj} - angular velocity of the drive axle wheels [rad/s]

$i = 1,2$ - wheels of the front axle.

When the E-bus brakes only with regenerative braking ($P_{ki} = P_{kj} = 0$) the mechanical power of the E-bus, which is transmitted to the drive electric motors via drive wheels and transmission, is represented by the equation:

$$\eta_t \sum_{j=3}^{4} \frac{M_{rkj} \cdot v_{ebus} \cdot i_t}{r_d} = P_{rk} \tag{1.12}$$

The electrical power generated by the drive motor is equal to:

$$P_{emg} = \frac{M_{emr} \cdot v_{ebus} \cdot i_t}{r_d} \tag{1.13}$$

So the equation is:

$$\eta_t \sum_{j=3}^{4} \frac{M_{rkj} \cdot v_{ebus} \cdot i_t}{r_d} = \frac{M_{emr} \cdot v_{ebus} \cdot i_t}{r_d} \tag{1.14}$$

P_{emg} - power of electric drive motor in regenerative braking mode (recuperation, generator mode) [W];

M_{emr} - torque of the drive electric motor in regenerative braking mode [Nm].

The power of the electric motor in generator mode represented by the current and voltage has the form:

$$P_{emg} = U_t \cdot I_{tr} \tag{1.15}$$

U_t - current value of electric motor voltage [V];

I_{tr} - current value of electric motor regeneration current [A].

The power of electrical losses in the electric motor and inverter in generator mode can be represented by the equation:

$$P_{gemr} = P_{emg} \cdot \left(1 - \eta_{emr} \cdot \eta_i\right) \tag{1.16}$$

P_{gemr} - power losses in the electric motor and inverter in generator mode [W];

η_{emr} - coefficient of efficiency of the driving electric motor in the regenerative braking mode (recuperation).

The output electric power (recuperation power) from the drive electric motor and inverter in the generator mode expressed in terms of current values of current and voltage and losses is shown by the equation:

$$P_{emr} = U_t \cdot I_{tr} \cdot \eta_{emr} \cdot \eta_i \tag{1.17}$$

P_{emr} - output electric power from the drive electric motor and inverter in the generator mode [W].

During regenerative braking in a time interval, the electricity that is generated and that can be stored in the source of electricity storage (supercapacitor, battery) expressed in kWh, is represented by the integral:

$$E_{r_{uc}} = \frac{\eta_{uc}}{3600000}\int_{t_1}^{t_2}\left(P_{emg} - P_{gemr} - P_{pu} - P_{ac} - P_h\right)\cdot dt \tag{1.18}$$

$E_{r_{uc}}$ - recuperation electricity stored in a supercapacitor (battery) [kWh].

The difference between the electricity consumed from the supercapacitor and the energy returned to the supercapacitor in the observation period represents the total electricity consumption of E-bus has the form:

$$\Delta E_{uc} = E_{P_{uc}} - E_{r_{uc}} \tag{1.19}$$

$$\Delta E_{uc} = E_{ebus} \tag{1.20}$$

ΔE_{uc} - difference between the electricity consumed from the supercapacitor and the energy returned to the supercapacitor in the observation period [kWh]

E_{ebus} - total electricity consumption of E-bus in the observation period [kWh].

The efficiency of regenerative braking of electric buses can be expressed as the ratio of electricity generated in the recovery phase to the consumed electricity in the phase of acceleration and driving at a constant speed using the expression.

$$\lambda_{uc} = \frac{E_{r_{uc}}}{E_{p_{uc}}}\cdot 100 \tag{1.21}$$

λ_{uc} - coefficient of efficiency of recovery [%].

If divide the difference between the electricity consumed from the supercapacitor and the energy returned to the supercapacitor in the observation period by the distance travelled by the E-bus, which is usually taken as the length of the route in the direction "A" and the direction "B", the average electricity consumption of the E-bus has the form:

$$\Delta E_{uc_A} = E_{P_{uc_A}} - E_{r_{uc_A}} \tag{1.22}$$

$$\lambda_{uc_A} = \frac{E_{r_{uc_A}}}{E_{p_{uc_A}}} \cdot 100 \qquad (1.23)$$

$$\Delta E_{uc_A} = E_{ebus_A} \qquad (1.24)$$

$$E_{ebusL_A} = \frac{\Delta E_{uc_A}}{L_A} \qquad (1.25)$$

2. METHODOLOGY AND RESULTS OF MEASUREMENT

The research of electricity recovered on the line EKO 1 (Vuk's monument-Belvil) in real operating conditions on a larger sample of measurements in both directions was performed on 25.06.2018, 28.06.2018, 27.09.2018, 08.10. 2019 and 09.10.2019 [2]. The average length of the EKO 1 line is 7995 m. Depending on directions, the length of the route in the direction "A" is 7477 m, where there are 15 stations with an average inter-station distance of 534 m. In the direction "B", the length of the route is 8513 m, where 17 stations are positioned with an average inter-station distance of 532 m. Figure 2, shows the topography of the terrain with the elevations of the stations [3].

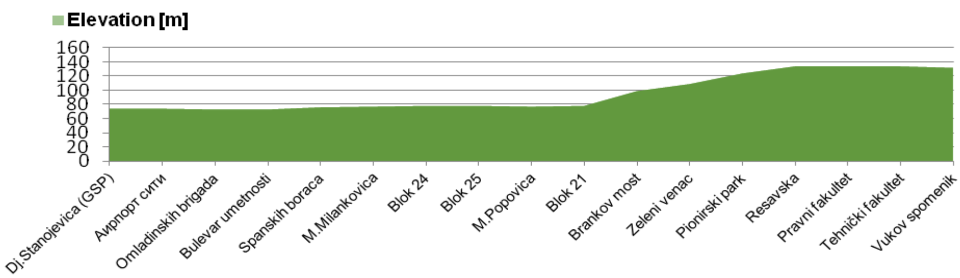

Figure 2 Characteristic of the route line EKO 1

The geometric characteristics of the route of the EKO 1 line are characterized by a distinctly flat terrain configuration in New Belgrade and the distance from the Faculty of Law to Vuk's Monument and a slight ascent of the terrain from Block 21- Branko's Bridge - Brankova-King Alexander Boulevard to Resavska Street. Time of year has been chosen when the heating and air conditioning systems were not used or were used minimally only in some periods of the day when the outside temperatures were higher than 23 ℃ or less than 12 ℃, in order to see as realistically as possible the coefficient of achieved recovery. The measured values of the supercapacitor voltage, current the discharge, the recuperation current of the supercapacitor, and the SOC (State of Charge), values were taken from the SD memory card BMS (Battery Management System) of the control unit that performs data acquisition from the V-CAN bus. The BMS control unit is shown in Figure 3.

Figure 3 BMS control unit

Results of energy consumed from the supercapacitor $E_{p_{ucA}}$, recuperation energy $E_{r_{ucA}}$ returned to the supercapacitor, recuperation coefficient λ_{uc_A}, for the direction "A" (Vuk's Monument – Belvil) is shown in Table 1.

Table 1 *Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction ''A'' (Vuk's monument-Belvil)*

Date [d-m-y]	E-bus	T_{spo} [°C]	Departure time [hh:mm.ss]	Arrival time [hh:mm.ss]
25-06-18	2104	14	7:15:00	7:43:15
25-06-18	2104	16	8:49:04	9:19:32
25-06-18	2104	17	10:23:33	10:50:35
25-06-18	2104	22	13:29:35	13:59:13
28-06-18	2104	17	7:38:08	8:09:40
28-06-18	2104	19	9:12:35	9:40:13
28-06-18	2104	20	10:45:58	11:13:07
28-06-18	2104	22	17:09:20	17:37:42
27-09-18	2105	13	10:22:21	10:50:31
27-09-18	2105	16	13:31:14	14:02:21
27-09-18	2105	18	15:05:21	15:39:43

08-10-19	2103	16	16:12:49	16:45:09
08-10-19	2103	11	19:29:29	20:02:39
09-10-19	2103	21	11:37:36	12:10:30
09-10-19	2103	26	14:39:11	15:12:01
09-10-19	2103	25	16:12:56	16:46:21
09-10-19	2103	13	22:26:16	23:00:31

***Table 1** Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction ''A'' (Vuk's monument-Belvil)(continued)*

Driving time [hh:mm.ss]	$E_{p_{uc_A}}$ [kWh]	$E_{r_{uc_A}}$ [kWh]	λ_{uc_A} [%]	ΔE_{uc_A} [kWh]	$E_{ebus_{L_A}}$ [kWh/km]
0:28:15	9.150	2.040	22.30	7.110	0.952
0:30:28	8.220	1.780	21.65	6.440	0.862
0:27:02	7.948	1.915	24.09	6.033	0.808
0:29:38	10.075	2.066	20.51	8.009	1.072
0:31:32	9.716	2.255	23.21	7.461	0.999
0:27:41	9.433	2.693	28.55	6.740	0.902
0:27:09	8.925	2.435	27.28	6.490	0.869
0:28:22	11.302	2.285	20.22	9.017	1.207
0:28:10	9.163	2.593	28.30	6.570	0.880
0:31:07	8.956	2.387	26.65	6.569	0.879
0:34:22	9.889	2.466	24.94	7.423	0.994
0:32:20	11.817	2.642	22.36	9.175	1.228
0:33:10	10.073	1.893	18.79	8.180	1.095
0:32:54	9.236	2.273	24.61	6.963	0.932
0:32:50	12.522	2.098	16.75	10.424	1.395

0:33:25	11.882	2.309	19.43	9.573	1.282
0:34:15	9.504	2.352	24.75	7.152	0.957

The highest value of recuperation energy achieved by the E-bus in the direction "A" is 2.693 kWh (28.06.2018, period from 9:12:35 to 9:40:13), the lowest value is 1.780 kWh (25.06.2018, period from 8:49:04 to 9:19:32), while the average value for all shown measurements of the realized recovery energy returned to the supercapacitor is 2.264 kWh. Analyse the ratio of realized energy recovery and the total electricity consumed by coefficients supercapacitor recovery λ_{uc_A} it can be concluded that its maximum value is 28.55%, a minimum of 16.75% and the average value realized in the direction "A" 23.20%. Graphic of measured values of supercapacitor voltage, supercapacitor charging/discharging current and SOC when the maximum recovery energy of 2.693 kWh was achieved, on the E-bus v.n. 2104 (28.06.2018, from 9:12:35 to 9:40:13), is shown in Figure 4.

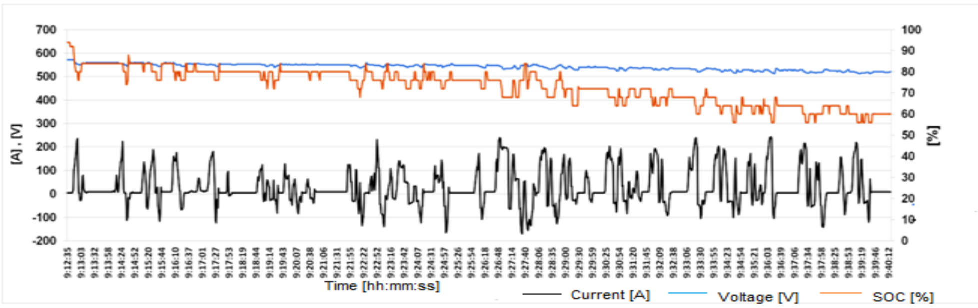

Figure 4 Values the voltage, current and SOC of supercapacitors in the period 9:12:35 to 9:40:13, direction "A", 28.06.2018

At the time of braking the E-bus, the maximum recovery current was 171.1 A at 9:27:29, at an E-bus speed of 46.9 km/h. Driving cycles that E-bus v.n. 2104 is achieved in the period from 9:12:35 to 9:40:13, is shown in Figure 5.

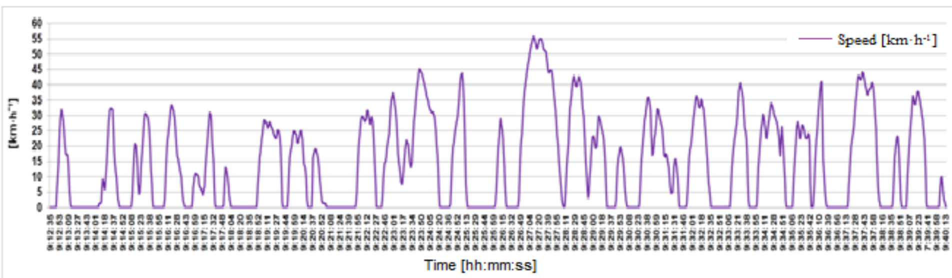

Figure 5 Values the speed of E-bus in the period 9:12:35 to 9:40:13, direction ''A'', 28.06.2018

From Figure 5, the driving time in the direction of "A" in the specified time period was 27 minutes and 40 seconds (00:27:40), which indicates the optimal traffic conditions, without traffic jams and delays, which was a prerequisite that E-bus reaches several times over 40 km/h, on Branko's bridge maximum speed was 55.2 km/h, which gave the E-bus great kinetic energy in the braking phase and the ability to generate a recovery current from 150 A to 171.1 A. For direction "B" (Belvil-Vuk's monument), the results of the energy consumed from the supercapacitor $E_{p_{ucB}}$, energy recovery $E_{r_{ucB}}$ which is returned to the supercapacitor, the recovery coefficient λ_{uc_B}, is shown in Table 2. In the direction "B" the highest value of recuperation energy generated by the E-bus is 2.510 kWh (28.06.2018, in the period from 6:47:21 to 7:18:46), the lowest value is 1.311 kWh (09.10.2019, period from 5:56:01 to 6:30:16), while the average value of the displayed results of the recovered energy returned to the supercapacitor is 1.863 kWh. The ratio of the recovered energy and the total electricity consumed by the supercapacitor is expressed in terms of the λ_{uc_B} is the maximum 19.57%, minimal 9.73% and the average value λ_{uc_B}, which is realized in the direction "B" is 14.06%.

Table 2 *Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction "B" (Belvile-Vuk's monument)*

Date [d-m-y]	E-bus	T_{spo} [°C]	Departure time [hh:mm.ss]	Arrival time [hh:mm.ss]
25-06-18	2104	13	6:22:10	6:56:59
25-06-18	2104	14	8:01:30	8:36:03
25-06-18	2104	17	9:35:30	10:09:42
25-06-18	2104	23	15:52:02	16:31:57
28-06-18	2104	16	6:47:21	7:18:40
28-06-18	2104	19	9:58:44	10:29:00
28-06-18	2104	26	16:18:40	16:59:01
27-09-18	2105	14	11:09:59	11:43:06
27-09-18	2105	16	12:44:19	13:17:55
27-09-18	2105	17	14:18:07	14:54:39
27-09-18	2105	18	15:51:33	16:28:50
08-10-19	2103	16	16:56:59	17:44:19
09-10-19	2103	8	5:56:01	6:30:16
09-10-19	2103	15	9:12:26	9:55:11
09-10-19	2103	25	13:53:21	14:32:16
09-10-19	2103	24	17:00:11	17:46:15

***Table 2** Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction "B" (Belvile-Vuk's monument)(continued)*

Driving time [hh:mm.ss]	$E_{p_{uc_A}}$ [kWh]	$E_{r_{uc_A}}$ [kWh]	λ_{uc_A} [%]	ΔE_{uc_A} [kWh]	$E_{ebus_{L_A}}$ [kWh/km]
0:34:49	11.828	1.702	14.39	10.126	10.126
0:34:33	12.372	1.844	14.90	10.528	10.528
0:34:12	10.974	1.371	12.49	9.603	9.603
0:39:55	14.434	1.866	12.93	12.568	12.568
0:31:19	13.439	2.510	18.68	10.929	10.929
0:30:16	12.806	2.506	19.57	10.300	10.300
0:40:21	17.415	2.480	14.24	14.935	14.935
0:33:07	12.736	2.333	18.32	10.403	10.403
0:33:36	11.264	1.732	15.38	9.532	9.532
0:36:32	12.497	1.931	15.45	10.566	10.566
0:37:17	12.677	1.909	15.06	10.768	10.768
0:47:20	13.877	1.567	11.29	12.310	12.310
0:34:15	13.477	1.311	9.73	12.166	12.166
0:42:45	13.764	1.355	9.84	12.409	12.409
0:38:55	14.649	1.809	12.35	12.840	12.840
0:46:04	15.225	1.576	10.35	13.649	13.649
0:34:49	11.828	1.702	14.39	10.126	10.126

An even greater degree of recuperation in direction "A", was achieved in the ''Study of the impact of driving style on the energy efficiency of the E-bus'' [4], when the driver strictly applied the manufacturer's recommendations and the recommendations from the polygon test [4]. In a real drive conducted on 22.01.2020, in the period of intermediate load and optimal traffic conditions, the maximum recuperation coefficient was achieved of $\lambda_{uc_A} = 29.18$ %, ($E_{p_{uc_A}} = 9.559$ kWh, $E_{r_{uc_A}} = 2.789$ kWh). The ride lasted 27.5 minutes. In order to better understand the values of λ_{uc}, we will list the results of measurements performed on the city line No.29 (Dorćol-Medaković III). In the test conducted with the E-bus (Higer KLQ6125GEV3) on the line No.29 (Dorćol-Medaković III) the degree of recovery expressed through the ratio of the regenerated and total electricity consumed achieved in the direction "B" is 33.77% [5]. If compare the obtained values of the recuperation coefficient on line EKO 1 and line No.29, where the direction "B" is declining for most of the route (about 70% of the line) and where is the maximum a drop of the road section 5.5%, E-bus has a significantly higher recovery rate achieved.

3. CONCLUSIONS

Based on the presented measurement methodology the acquisition of current values of current and voltage via BMS control unit E-bus (Higer KLQ6125GEV3) in real operating conditions on the line EKO 1, it was concluded that the highest degree of recovery is expressed through the ratio of recovered energy to supercapacitor and total consumption electricity from the supercapacitor, achieved in the direction "A" is 28.55%, while the maximum value in the direction "B" is 19.57%.

From the point of view of the impact on the achieved degree of recuperation and electricity consumption, it is important to point out that in the direction "A", from stations Zeleni venac-Block 21, has a constant drop of about 2.1% on a section of about 1.9 km. In the direction "A", the number of transported passengers is smaller, on the section in decline there are fewer resistance forces that occur in the phase of the movement which has an impact on less consumed electricity in the direction of "A".

In the mentioned section over Branko's bridge, the E-bus achieves the maximum speed of movement so that the maximum utilization of the kinetic energy of the E-bus during regenerative braking is possible, which is reflected in the amount of regenerated electricity returned to the supercapacitor. In the direction "B", the load of the E-bus is higher on the mentioned section, as well as the resistance forces of the movement, which affects the higher required electricity for movement. The ascending route and the lower maximum speed that is reached on the section over Branko's bridge affect the lower possibility of electricity recovery compared to the movement in the direction "A". It is obvious that the size of the recovery coefficient under the assumption that the regenerative braking system is used correctly is mostly influenced by the terrain configuration i.e. the presence of a road sections with decline.

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