MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2019.45.01.02
UDC: 629.41:629.342

TWO-YEAR SUCCESSFUL EXPLOITATION OF THE ELECTRIC BUSES IN BELGRADE

Slobodan Mišanović [1], Predrag Živanović [2], Dušan Savković [3], Pavle Krstić [4], Slobodan Ivanov [5], Slobodan Stević [6]*

Received in June 2018 Revised in August 2018 Accepted in October 2018

RESEARCH ARTICLE

ABSTRACT: Since, September 1, 2016, new line EKO 1 is established in Belgrade, where are five E-buses in operation. What are the experiences in exploitation in terms of realized transport, maintenance, electric consumption, environmental benefits as well as the satisfaction of passengers, who use the line EKO 1, are the subjects of this paper. In paper will also present future plans for further expansion of the network line in Belgrade, where the electric buses will operate.

KEY WORDS: e-bus, exploitation, development

[1]*Slobodan Mišanović, PhD candidate, University of Kragujevac, Faculty of Engineering Project manager, City Public Transport Company "Belgrade", Kneginje Ljubice 29, 11000 Belgrade, slobodan.misanovic@gsp.co.rs (*Corresponding author)*
[2]*Predrag Živanović, PhD, prof.assist., University of Belgarde, Faculty of Transport and Traffic Engineering, p.zivanovic@sf.bg.ac.rs*
[3]*Dušan Savković, Msc.M.E, Coordinator for tehnical jobs, City Public Transport Company "Belgrade", Kneginje Ljubice 29, 11000 Belgrade, dusan.savkovic@gsp.co.rs*
[4]*Pavle Krstić, Msc.E.E, City Public Transport Company "Belgrade", Kneginje Ljubice 29, 11000 Belgrade, pavle.krstic@gsp.co.rs*
[5]*Slobodan Ivanov, Msc.E.E, City Public Transport Company "Belgrade", Kneginje Ljubice 29, 11000 Belgrade, slobodan.ivanov@gsp.co.rs*
[6]*Slobodan Stević, Msc.E.E, City Public Transport Company "Belgrade", Kneginje Ljubice 29, 11000 Belgrade, s.stevic@gsp.co.rs*

DVOGODIŠNJA USPEŠNA EKSPLOATACIJA ELEKTRIČNIH AUTOBUSA U BEOGRADU

REZIME: Od 1. septembra 2016. godine u Beogradu je osnovana nova linija EKO 1, u kojoj radi pet električnih autobusa. Kakva su iskustva u eksploataciji u smislu realizovanog transporta, održavanja, potrošnje električne energije, ekoloških efekata kao i zadovoljstva putnika koji koriste liniju EKO 1, su predmet ovog rada. U radu će se takođe predstaviti i budući planovi za dalje proširenje mrežne linije u Beogradu, u kojoj će raditi električni autobusi.

KLJUČNE REČI: e-bus, eksploatacija, razvoj

TWO-YEAR SUCCESSFUL EXPLOITATION OF THE ELECTRIC BUSES IN BELGRADE

Slobodan Mišanović, Predrag Živanović, Dušan Savković, Pavle Krstić, Slobodan Ivanov, Slobodan Stević

1. INTRODUCTION

City Transport Company "Belgrade" (JKP GSP "Beograd"), is the bearer of public transport in Belgrade and one of the largest public transport companies in South East Europe. Every day in the operation is: 609 buses, 150 trams and 94 trolleybuses and 5 buses electrically powered. From 1st September 2016, introduced a new line of EKO 1 where operate buses exclusively on electric power. In this way, Belgrade is included in the map of cities in Europe and the world that have begun using electric buses as a long-term strategy for using this concept of drives, which will be the main alternative to diesel-powered buses.

The choice of the electric bus concept came after several years of activity in monitoring the development and application of these buses in many cities in Europe and the world, as well as successful cooperation with many bus manufacturers (Higer, BYD, Solaris, Siemens-Rampini). Also, City Transport Company "Belgrade" has been active in many EU projects related to electric buses (ZEEUS, Hybrid user forum, Civitas, UITP bus committee ...). Specificity of using electrically powered buses can be seen in terms of line on which they work, vehicle concept, charging systems, maintenance, exploitation indicators and environmental suitability.

2. CITY LINE EKO 1 (VUK'S MONUMENT – BELVIL)

The choice of a new line (Figure 1) on which electric buses operate, comes after a detailed analysis of the fulfilment of the following criteria [1]:

- A central city line, so that the environmental impact of the "0" emission is the biggest
- The high attractiveness of line from the aspect of passenger requirements
- Suitability of the line or terminal from the aspect of providing energy requirements for chargers
- Line length, such that at the end of the journey there is a minimum of 20% of the available power in the supercapacitors.

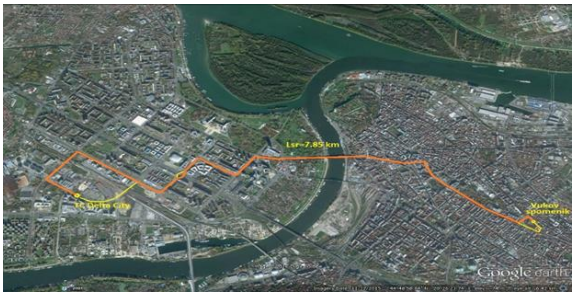

Figure 1. Route of line EKO

Figure 2. E-bus HIGER KLQ6 at the "Vuk's monument'' charging station

The mean length of the EKO 1 line is 8 km. The line is with a flat configuration with a slight climb. On the line work 4 buses "Higer KQL6" City E-bus bus, with an average interval of 20 minutes.

"Higer KQL6" (Figure 2), City E-bus bus has the capacity of minimum 80 passengers. E-bus is equipped with two traction asynchronous motors “Siemens IPV5135’’, 2x67 kW nominal power, 2x90 kW peak power. System for storing electricity realized by supercapacitor “Aowei“, 20 kWh capacity [2]. Chargers for fast charging have the power of 150 kW. The charging station on “Vuk’s Monument” terminus is connected to the DC voltage (DC) from the tram contact grid and the charging station on “Belvil’’, to the three-phase AC voltage from the public power grid. The charging time at the terminals is 5-10 minutes.

3. EXPLOITATION INDICATORS ON THE LINE EKO 1

Analysing the period of operation of buses on electric power from 01/09/2016 to 1/9/2018, E-buses have had the following results [3]:

- Working hours per vehicle per day: 16÷18 h
- Average daily mileage per vehicle: 190÷215 km
- Exploitation speed: 14.8 $km \cdot h^{-1}$
- Daily number of passengers transported per vehicle: 900÷1200 passengers
- Reliability of work on the line: 97.5%
- Depending on operating mode, number of passengers, traffic conditions, driving style, impact of the system for heating and air conditioning of the vehicle), electric consumption may vary
- In the spring/autumn period, direction "A" 0.82÷1.15 $kWh \cdot km^{-1}$, direction "B" 1.2÷1.45 $kWh \cdot km^{-1}$
- In the summer period average consumption is higher by 23.3%, than the transition period
- In the winter period average consumption is higher by 45.4%, compared with transition period
- Loss of electricity in the charging phase (network, charger, pantograph, super capacitor): about 5%
- E-bus realized recovery of electricity in the braking phase of about 25-30% compared to the energy consumed to drive.

An example of the exploitation indicators of the operation of the E-bus (garage number 2103) on the line EKO 1, for the day 18 April 2018, is presented in Tables 1 and 2. The outside temperature was min 12 ˚C, max 18 ˚C [4].

Table 1. Direction''A" (Vuk's-Belvil)-Expoloitation indicators, 18 April 2018

Timetable [hh:mm:ss] start	Timetable [hh:mm:ss] end	Electric energy-charging [kWh]	Loss in the charging phase [kWh]	*SOC [Vuk] [%]	SOC [Belvil] [%]	ΔSOC [%]	Electric consumption (ΔSOC+loss) [kWh]	Electric consumption [kWh·km^{-1}]	Driving time [hh:mm:ss]	Exploatation speed [km·h^{-1}]
5:14:00	5:45:00	5.00	0.25	98.00	62.00	36.00	7.38	1.02	0:31:00	14.46
7:13:00	7:45:00	10.87	0.54	99.00	62.20	36.80	7.54	1.08	0:32:00	14.01
8:46:00	9:21:00	10.17	0.51	99.60	55.20	44.40	9.10	1.29	0:35:00	12.81
10:20:00	10:49:00	9.86	0.49	99.00	69.00	30.00	6.15	0.89	0:29:00	15.46
11:55:00	12:27:00	10.70	0.54	100.00	66.00	34.00	6.97	1.00	0:32:00	14.01
13:31:00	14:05:00	9.75	0.49	94.75	55.00	39.75	8.15	1.16	0:34:00	13.18
15:04:00	15:40:00	11.30	0.56	99.00	62.60	36.40	7.46	1.07	0:36:00	12.45
16:39:00	17:14:00	10.21	0.51	88.00	49.70	38.30	7.85	1.12	0:35:00	12.81
18:12:00	18:42:00	11.34	0.57	94.00	55.00	39.00	8.00	1.15	0:30:00	14.94
19:46:00	20:18:00	11.69	0.58	98.00	70.00	28.00	5.74	0.85	0:32:00	14.01
21:19:00	21:46:00	10.25	0.51	98.00	65.00	33.00	6.77	0.97	0:27:00	16.60

*SOC (State of charge supercapacitor)

Table 2. Direction"B" (Belvil-Vuk's)- Expoloitation indicators,18 April 2018

Timetable [hh:mm:ss]		Electric energy-charging	Loss in the charging phase	*SOC [Belvil]	SOC [Vuk]	ΔSOC	Electric consumption (ΔSOC+loss)	Electric consumption	Driving time	Exploatation speed
start	end	[kWh]	[kWh]	[%]	[%]	[%]	[kWh]	[kWh·km^{-1}]	[hh:mm:ss]	[km·h^{-1}]
6:22:00	6:53:00	8.18	0.41	101.90	48.00	53.90	11.05	1.35	0:31:00	16.45
8:01:00	8:37:00	7.79	0.39	100.00	46.00	54.00	11.07	1.35	0:36:00	14.17
9:34:00	10:06:00	7.54	0.38	99.00	50.00	49.00	10.05	1.23	0:32:00	15.94
11:09:00	11:42:00	9.39	0.47	101.00	50.90	50.10	10.27	1.26	0:33:00	15.45
12:44:00	13:20:00	6.36	0.32	100.00	47.80	52.20	10.70	1.30	0:36:00	14.17
14:18:00	14:52:00	7.18	0.36	101.00	47.20	53.80	11.03	1.34	0:34:00	15.00
15:52:00	16:28:00	9.43	0.47	101.00	43.90	57.10	11.71	1.43	0:36:00	14.17
17:26:00	18:05:00	7.67	0.38	100.00	38.20	61.80	12.67	1.54	0:39:00	13.08
18:59:00	19:37:00	10.31	0.52	100.00	38.70	61.30	12.57	1.54	0:38:00	13.42
20:33:00	21:07:00	9.23	0.46	100.00	41.00	59.00	12.10	1.48	0:34:00	15.00
22:08:00	22:37:00	6.15	0.31	100.00	48.00	52.00	10.66	1.29	0:29:00	17.59

*SOC (State of charge supercapacitor)

Realized mileage per vehicle a given period is presented in table 3.

Table 3. Mileage per vehicle

E-bus	Period [1/9/2016 - 1/9/2018]* Mileage [km]
2101	104.400
2102	106.320
2103	109.050
2104	100.350
2105	103.100

* In the period 14/8-6/10/2017, E-buses not in operation because of the works in Roosvelt's street.

4. MAINTENANCE OF E-BUSES

Buses on an electric drive as a relatively new concept of buses used in public transport are characterized by certain specifics when maintenance is concerned [3]. Some of these specificities compared to diesel buses are:

- Simpler maintenance compared to the diesel bus
- Vital parts of the electrical components (inverters, converters, air compressors, steering pump, supercapacitor) are a modular type (Figure 3,4)
- Lower maintenance costs (compared to a diesel bus about 3 times, E-bus 3000 Euros per year, Diesel 9000 Euros per year)
- Diagnosis of defects are identified on the instrument panel
- Short replacement time.

Figure 3. Traction inverters

Figure 4. Compressor, steering pump

In Table 4, shows the components and systems on the buses with a diesel-powered and electric-powered bus.

The electrically powered bus has a significantly smaller number of components and systems, which makes it more efficient and cheaper in terms of regular and corrective maintenance. In E-buses, regular servicing is performed according to the defined checklist at every 20,000 km.

5. ECOLOGICAL EFFECTS ON THE LINE EKO

One of the main reasons for introducing E-buses on the line EKO 1 is the environmental effects compared to diesel buses [3]. This relates primarily to:

- The smaller the level of noise, compared to a diesel bus lower by 13 dB(A) [3]
- "0" emission of harmful gases. Comparison of the emissions of harmful gases of one E-bus and diesel buses on the line ECO 1 for annual mileage 60,000 km, consumption 44 L/100 km, present in Table 5.

Analyzing the period of operation of buses on electric power from 01/09/2016 to 15/5/2018, E-buses have had the following results [3].

Table 4. Components and systems on the buses with a diesel-powered and electric-powered bus

Component	Diesel bus	E-bus
Motor IC (internal combustion)	Yes	No
Engine lubrication system	Yes	No
Oil motor	Yes	No
Oil filter	Yes	No
Air filter	Yes	No
Belts	Yes	No
Engine cooler	Yes	No
Antifreeze	Yes	No
Intercooler	Yes	No
Starter	Yes	No
Turbocharger	Yes	No
Fuel injection system	Yes	No
Fuel tank, installation	Yes	No
Fuel filter, separator	Yes	No
Exhaust system	Yes	No
SCRT system	Yes	No
AD-blue,	Yes	No
Ad-blue reservoir tank, installation	Yes	No
Gearbox / Retarder	Yes	No
Front axle / Suspension / Steering system	Yes	Yes
Chassis	Yes	Yes
Rear axle	Yes	Yes
Brake system	Yes	Yes
Wheels and tires	Yes	Yes
Air conditioning, Heating	Yes	Yes
The door	Yes	Yes
Signalization, Display	Yes	Yes
CAN, On-Board	Yes	Yes
Power steering pump, compressor	Yes	Yes
Differential, Kardan	Yes	Yes/No
Drive Electric Motor /Reducer	No	Yes
Inverter	No	Yes
High-voltage installation DC / AC	No	Yes
Low voltage equipment DC / DC	No	Yes
Batteries for power supply	No	Yes
Pantograph / Plug inn	No	Yes
Cooling system for super capacitors / batteries	No	Yes

Table 5. Comparison of the emissions of harmful gases from one E-bus and diesel buses on the line ECO 1

Pollutant	E-bus	Emissions of diesel buses [Euro 3]	Emissions of diesel buses [Euro 4]	Emissions of diesel buses [Euro 5-EEV]	Emissions of diesel buses [Euro 6]
	[kg/year]	[kg/year]	[kg/year]	[kg/year]	[kg/year]
CO	0	206	147	147	147
CxHy	0	64.7	45.2	24.3	12.75
NOx	0	490.4	342.1	195.7	39.2
PM 10	0	9.8	1.96	1.95	0.95

6. E-BUS LINE- USERS SATISFACTON

Three months after the EKO1 line started its operation; a survey of the route's passengers was conducted in order to get acquainted with their opinions and first impressions. The survey was conducted in November 2016, during vehicles operation and lasted for three days [5]. The largest group of the EKO1 line passengers composed of employed users and the largest percentage of the passengers have been using the line daily.

Questions from the survey related to the satisfaction of passengers from the EKO1 line included the following:

- line route
- arrival interval of vehicles
- features of e-buses
- comfort and e-bus equipment

(interior and exterior design, noise and safety and other information in a vehicle, wi-fi ...).

Around 80% of the passengers are satisfied with the line route, and 2% of the passengers are completely dissatisfied with it.

The vehicles interior and exterior design, air conditioning and heating system and the noise level in them got a similarly high score. Even 99% of the passengers feel completely safe in the vehicles with purely electric drive and over 90% of the passengers are satisfied with the information system.

The EKO1 line passengers give it the highest grades. Even 73% of the passengers give it to grade 5, and 25% of them give it a high grade 4. Thus, the average grade for the EKO1 line in the opinion of its users is 4.7.

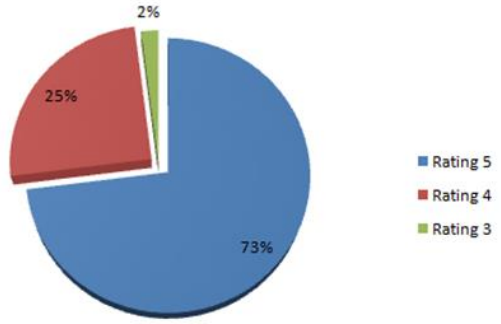

Figure 5. The total grade score for the EKO1line

7. FUTURE PLANS

After two years of successful exploitation of E-buses in Belgrade and satisfactory results, JKP GSP ''Beograd'' and the City of Belgrade are planning to develop the concept of the city electric bus drive on city lines [6].

The plan is to purchase of 80 E-buses in the next 3-4 years, which will replace trolleybuses that work on lines: 19,21,21,29. These lines pass through the city centre and the idea is to dismantle the contact network, due to the high costs of maintenance and frequent failures

that initiate large congestion and crowds in the centre of the city. For the realization of this project, it is necessary to complete the construction of the new central city terminal in Dunavska Street (work in progress), ensuring sufficient capacity of the electric network for the operation of chargers than 360 kW. The spatial position of the lines: 19, 21, 22, 29 on which electric buses will operate as well as the required number of chargers at the terminals is presented in Figure 6.

Figure 6. New E-bus lines in Belgrade

It is planned that E-buses will replace diesel buses on line 77 (Zvezdara-Bezanijska Kosa) that passes through the city center in order to reduce the emissions of harmful gases in the city center, as well as the introduction of new E-bus line will be connected the airport ‘’Nikola Tesla’’ with the central city zone.

8. CONCLUSIONS

The introduction of buses with electric drive in the regular operation is a significant step in the development of public transport system in Belgrade. The concept of E-buses with the pantograph charging system on the termini completely meets the conditions of exploitation in terms of electricity supply, the daily autonomy, and the passengers’ transport demands.

The new EKO 1 bus line with E-buses will enable the full effect of the use of this concept in terms of environmental requirements. Tracking the results of the use of electric buses on the EKO 1 line will serve as the best argument for defining future strategies of public transport in Belgrade, regarding this concept of buses and its mass application.

The introduction of electric buses on lines: 19, 21, 22, 29, 77 is compliance with the EU transport policy, which determines that participation of "clean" buses in the cities of Europe will be 50% by 2025 (amendment of the directive EC/33/2009) or 30% for cities from EU countries with less economic power.

REFERENCES

[1] Mišanović S., Tica S., Milković Ž., Krstić P., Milovanović B.: "Ecology and energy aspects of exploitation fully electrical buses on the new line in public transportation Belgrade", International Congress Motor Vehicles & Motors 2016, Kragujevac, 6-7 October 2016, pp 33-40, ISBN 978-86-6335-037-37.

[1] Higer Electric bus – Tehnička dokumentacija, 2016.

[2] Mišanović, S., Milković, Ž., Savković, D., Krstić, P., Stević, S.: "Specificity of exploitation and maintenance of electric bus in Belgrade", 3rd Maintenance Forum 2018- Maintenance and Industry 4.0, Belgrade 24-26th May 2018, Proceedings, ISBN 978-86-84231-43-9, COBISS.SR-ID 264166668, pp 119-127.

[3] ЈКП ГСП "Београд", Baza podataka potrošnje električne enegije E-busa, interni dokument, 2017- 2018.

[4] ЈКП ГСП "Београд", Истраживање задовољства путника на линији ЕКО 1 у Београду, интерни документ, 2016.

[5] Fabula Konsultant, Beoconex Beograd, Studija opravdanosti nabavke 80 elektroautobusa u Beogradu, 2018.