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DYNAMIC CHARGING OF ELECTRICAL VEHICLES

Night charging and fast charging are currently the two most common systems for charging electric buses. Despite the fact that numerous trial installations were started, neither of these two systems has obtained unqualified approval of the users. The alternative is to charge vehicles in motion - dynamic charging which combines the advantages of trolleybus transport and of electric buses: the main supply source are traction batteries; however, the charging is performed in motion, without the necessity of stopping the vehicle.
Ключові слова: Electric bus, trolleybus, traction batteries, dynamic charging, in motion charging

Introduction. Despite the continuous development of electrochemical batteries technology and the multitude of electric buses on offer, it is still not possible to exploit electric buses in urban transport on all-day basis without the necessity of charging them. Therefore it is necessary to build point-to-point contact charging stations or induction charging stations at the terminals. This results in substantial financial outlays connected with the construction of charging stations, and in the necessity to extend the stopping time at the terminals; there are also problems which arise in the situation where the route is changes [1 - 6]. The alternative solution is the so-called Dynamic Charging, also called In Motion Charging (IMC). It consists in building an infrastructure allowing for charging vehicles in motion, most often with the use of overhead contact line (Fig. 1) [7 - 9]. What is more, in the cities where tram network is already exploited, there is a possibility to use the elements of the tram infrastructure when constructing the catenary for the Dynamich Charging system.

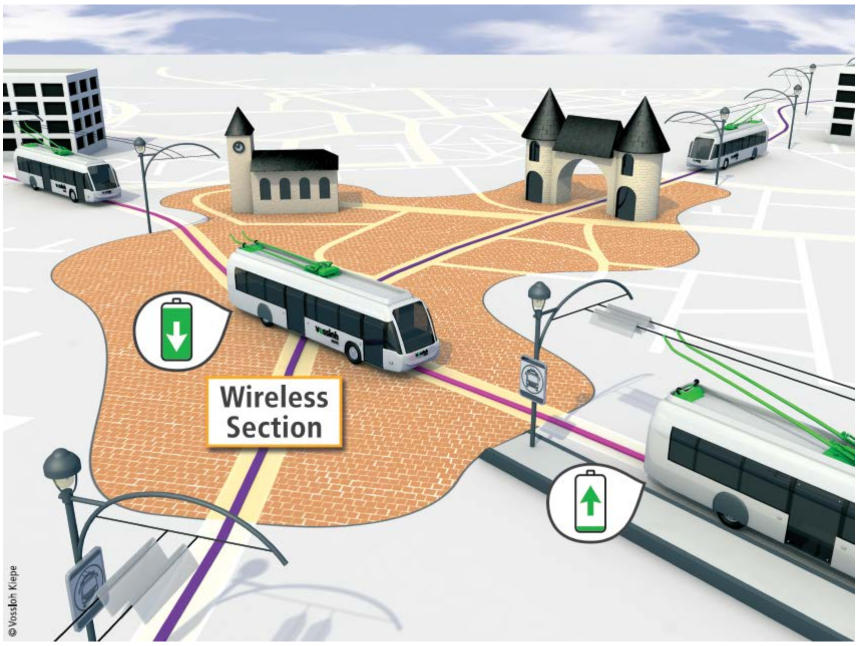

Fig.1. The idea of In Motion Charging system (IMC) [© Vossloh Kiepe]

The benefits of dynamic charging. The benefits of using dynamic electric bus charging will be illustrated by an example of line with a length 10 km, which is operated by standard length electrical buses. Maximal energy consumption at the level 3 kWh/km is assumed.

There are analyzed 3 alternative systems of line electrification (fig. 2):

- operation by standard electrical bus with one charging station and Terminus 1. The charging power is 400 kW,

- operation by dynamic charged battery bus with one 3 km wired section (variant 1),

- operation by dynamic charged battery bus with two wired sections: 1 km and 2 km (variant 2).

The average charging power of dynamic charging system is 140 kW, the average velocity in wired section is 20 km/h. The minimal charge level is assumpted at 50%. It table 1 there are shown the energy balances of analyzed variants. In case of standard battery bus the maximal discharge level is 60 kWh. With a minimal discharging rate 50%, this requires a **120 kWh** traction battery. In fist variant of dynamic charged bus the battery is discharged with energy 42 kW, what allows the required battery capacitance to **84 kWh.** In the second variant battery is maximally discharged with power 15 kWh. As a result of that, the traction battery with capacitance **30 kWh** will be enough to fulfill transportation route conditions. The fig. 3 presents the graph of battery charge level of analyzed variants.

Covering part of transportation route allows to reduce the required traction battery. The capacitance reduction is bigger in case of using more than one wired sections. This allows to alternate work in mode charging - discharging - charging - discharging. Thanks to this, the depth of discharge is significantly reduced.

Considering that the price of the battery is 1000 to 1500 euro for 1 kWh of capacity, the use of overhead contact line saves **90 000 euro** on one vehicle. In addition, the IMC system does not require stops for charging the vehicle, therefore the number of vehicles necessary to operate the line is smaller than in the classic electric bus.

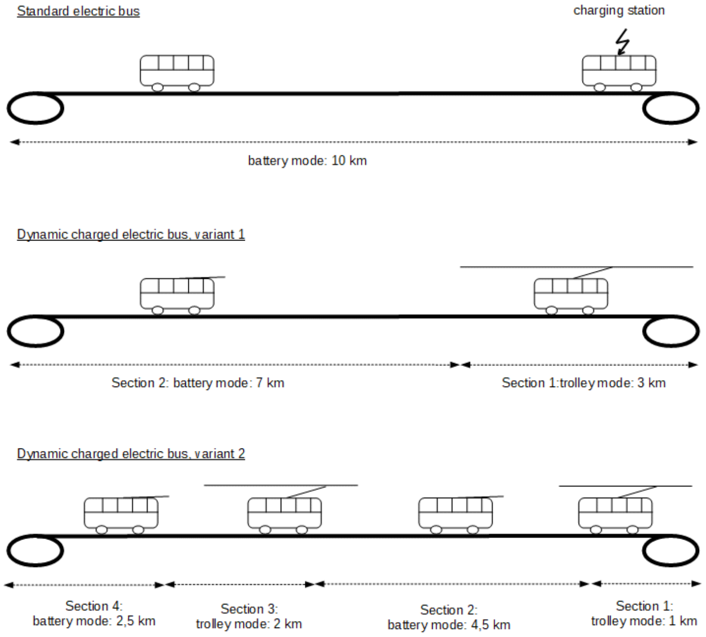

Fig. 2: The scheme of an example of route operated by standard electrical bus and two variants of dynamic charged buses

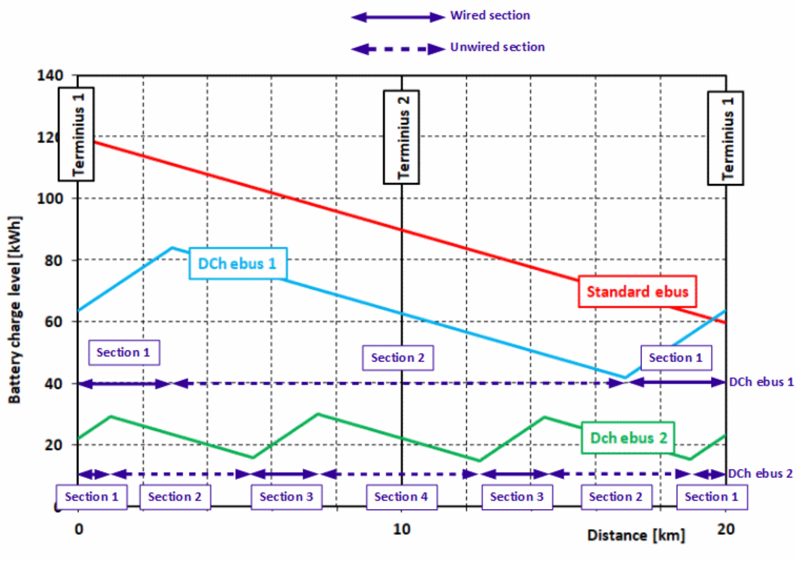

Fig. 3: Diagram of battery charge level during operation of route by standard electrical bus and two variants of dynamic charged buses

Prague case study. Prague can become an example of a slightly transformation of standard electric buttery bus into trolleybus. The experiences gained during the operation of stationary charged electric battery buses DP Praha (a public transport company in Prague) were reason to undertake tests with a dynamic vehicle charging system using a trolleybus overhead contact system.

Since 2012, Prague has been conducting a trial operation of electric buses of various systems and manufacturers. One of the noticed limitations was the impact of traffic congestion, i.e. reduction of bus charging time on the final stop in the case of delayed arrival. In addition, articulated vehicles play the main role in the Prague bus transport system, which significantly limits the market of available electric buses. However, the biggest concern was the difficult vertical profile of many routes. Prague is a city with large differences in elevation and, consequently, many street with high slopes. This creates high demands on the parameters of the propulsion system, which also results in an increase in the weight of the battery. One of the ways of solving this problem is a dynamic system of electric vehicle. The use of various power supply methods was considered, including vehicles with two pantograph (similar to trams) collectors and bipolar traction network. However, the most developed, simple and proven solution turned out to be a trolleybus traction network.

On 22 February 2016, the management of DP Praha approved the project "E-Bus s dynamickým nabíjením", meaning "E-bus with dynamic charging". It consisted in the construction of a test section of a "trolley-type line" for charging electric buses during traffic. A bus line 140 has been chosen for test installation. This route is characterized by a large difference in the height of the area between the Palmovka start stop and the Prosek settlement, with a road gradient of up to 10%.

In the first stage, a trial line of 140 electric buses of the IMC system is implemented on the shortened route of Palmovka - Letňany, with a length of 5 km. The trolleybus overhead cathenary is build on a steep section of Prosecka Street, a kilometer section between Kundratka - Kelerka stops, which is 20% of the entire length of test route. After more than a year of technical project design works, all necessary permits were obtained in July 2017 and the construction of the test section began on August 10, 2017. The construction was finalized one and a half month later. The process of official technical approval took place from 11 - 13 October 2017.

The constructed route consists of a two-way section of a trolleybus overhead contact line. In the "top" direction, that is from the Kundratka stop to the Kelerka stop, it has a length of 993 meters. In the opposite direction it is slightly shorter and measures 613 meters. At both beginnings of the route, there are installed "roofs" for semi-automatic connection of trolleybus collectors. A prefabricated, container tram substation equipped with one rectifier unit is used to supply of the route. It was previously used as a temporary power source during the reconstruction of tram traction substations in Prague. The built-up section, approximately 1 km long, is too short to fully charge the traction batteries. For this reason, a short section of the trolleybus traction contact wires was built on the Palmovka final stop with "roofs" for semi-automatic connection, for charging the vehicle during stopping. It is supplied by 750 V from the tramway traction network using supply station named "Dobudka." It is a container converter station, providing galvanic separation and increasing the voltage value from the tram network. It was produced by the Czech company Cegelec.

The SOR TNB 12 Acumario trolleybus is currently being tested (Fig. 12, 13). In the first half of 2018, the next vehicle, the Electron 12T trolley bus manufactured by Ekova (Ostrava), equipped with LTO batteries with a capacity of 47 kWh, is planned for testing. Škoda Electric also declares his vehicle for testing. It is also planned to test the articulated trolleybus, but currently a vehicle with appropriate parameters (mainly for auxiliary drive) is not available in the Czech Republic.

Fig. 4. Trolleybus SOR TNB 12 goes uphill on Prosecka street in Prague powered from the traction network

Fig. 5. Trolleybus SOR TNB 12 on Letňany terminous in autonomous drive mode

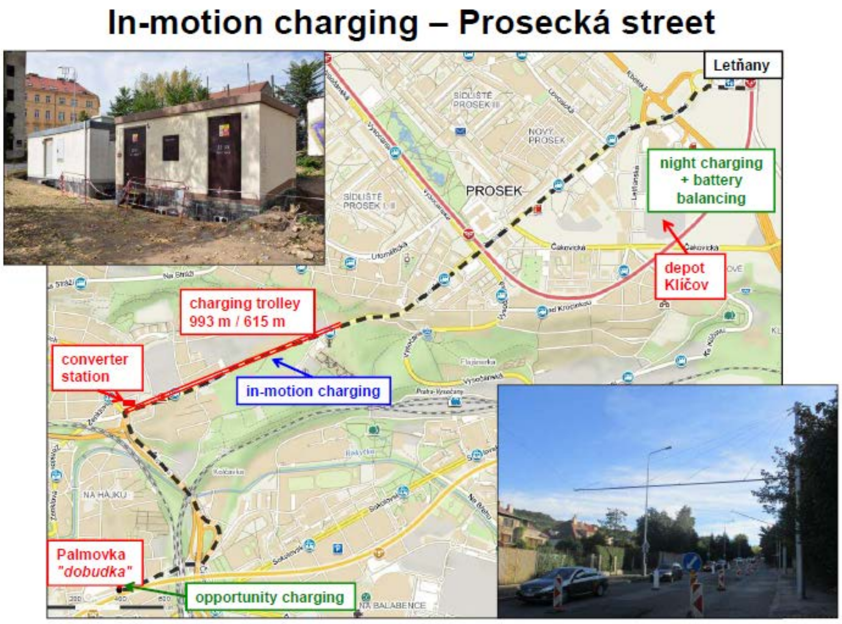

Fig. 6. The scheme of test route in Praha [© DP Praha, Jan Barchánek]

Marrakech case study. The BRT system in Marrakech (Morocco) is an example of a urban transport system that uses dynamic charging and the traction network has been simplified to the necessary minimum. Initially, the construction of a tram line was considered as in other Moroccan cities (Casablanca, Rabat), however, due to the high costs, the electrified Bus Rapid Transit system was chosen. The BRT line was opener in September 2017 and connects the centre of city with the western suburbs thought Hassan II Avenue. The total length of line is 8 km, the length of cathenary covered section is 2,5 km. Line is supplied with 750 V voltage from one traction substation, located at the west end of the route. The line along the whole route is run through separate bus-paths.

Line is operated by 10 standard, two doors Chinese YANGTSE trolleybuses. Each vehicle is equipment with 5 battery pack. Each battery pack has capacitance 200 Ah nominal voltage 115,2 V. Total energy capacitance of the batteries is 115,2 kWh. The trolleybus overhead line will be supplied from a 1 MWh photovoltaic plant and a 3 ha area. The energy generated from photovoltaic panels will be transferred to the 750 V DC power system. Unused surpluses will be sold to the power system operator.

Fig.7. The eastern end of the cathenary section of Marrakech's BRT system

Fig. 8. Vehicle in off-wire section of Marrakech's BRT system

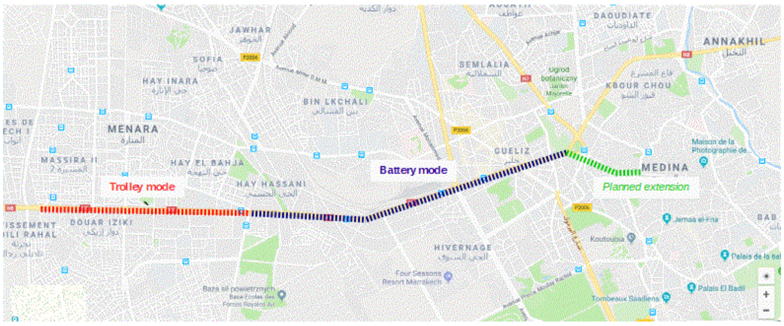

Fig. 9. The scheme of Marrakech's BRT system

Conclusions. Despite the fact that the number of cities exploiting electric buses in urban transport is increasing, the existing systems are test systems, and there is still no agreement among the users with regard to optimal and universal solution for electric buses. The issue of charging is one of the biggest problems. On the other hand, trolleybus transport in numerous cities is considered to be outdated. The Dynamic Charging system makes it possible to combine the advantages of trolleybuses and electric buses. The BRT system with Dynamic Charging can be potentially a much cheaper alternative to tram transport with identical transportation capacity.

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Бартломєйчик М. **Динамічне заряджання елетричних транспортних засобів**

Нічне заряджання та швидка зарядка в даний час є двома найбільш поширеними системами зарядки електричних автобусів. Незважаючи на те, що було запущено численні пробні інсталяції, жодна з цих двох систем не отримала безумовне схвалення користувачів. Альтернативою є заряджання рухомого складу - динамічне заряджання, яке поєднує в собі переваги тролейбусного транспорту та електричних автобусів: головним джерелом живлення є тягові батареї; однак, заряджання виконується рухом, без необхідності зупинки транспортного засобу.

Ключові слова: електричний автобус, тролейбус, тягові акумулятори, динамічне заряджання, заряджання в русі.

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