ECONOMIC BENEFITS OF DYNAMIC CHARGING OF ELECTRIC BUSES

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Abstract – **Diesel engines buses are still the most used type of buses. Electric buses provide promising green alternatives and a lot of advantages, but their main disadvantages are limited travel range and long charging time. This article is a presentation of innovative solution for charging of electric busses - Dynamic Charging (IMC). The modern IMC system in Solingen was presented. At the end of the article, a proposal was made to introduce a similar solution in Skopje, which would allow the electric vehicles operation on bus line no 9. This, in turn, would create score of electric Bus Rapid Transit system.**

Keywords – **electric buses, trolley busses, electromobility, dynamic charging.**

I. INTRODUCTION

In order for the traction batteries to be charged during vehicle's movement (Fig.1), the dynamic charging system (In Motion Charging – IMC) allows part of the route to be secured by trolleybus traction network (overhead line – OHL). The power accumulated in the traction batteries allow the vehicle to cover the rest of the course with no overhead line. Flexibility and functionality of the system are increased by withdrawal of the necessity to stop the vehicle while charging. Also, in the volume of the traction batteries may be reduced if a part of the route consists of the overhead line, because the distance covered in in battery propelling mode is shortened.

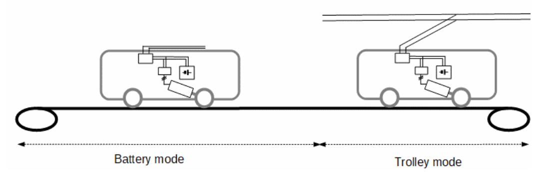

FIG.1. IDEA OF DYNAMIC CHARGING SYSTEM (IN MOTION CHARGING)

The most expensive part of the dynamic charging system is the overhead line. Hence, it is desired to minimize the length of the route that is fitted with the overhead line. However, the electrified part of the route has to be long enough to charge the traction batteries with an amount of energy that is at least equal to the energy required to cover the remaining battery-mode part. For the present state of technology, the lowest electrified-to-total route length ratio is at a minimum 40% to 50%. By increasing the charging power by 25%, the catenary coverage can be decreased [8, 9]. Consequently, in the case of the supply system of 750 V DC the possibility is to be reduced to 20% rate, while in the case of reduction in the heating power of the vehicle or use of thermal pumps, in this case that the coverage should go even below 20%. Fig. 2 presents an approximation of minimal coverage rate in function of charging power. Assuming that the energy intake for normal vehicle is 3 kWh/km (in the winter) then for an articulated vehicle it is 3,9 kWh/km [1,7].

The main aim of the article is to present the concept of using the dynamic charging system to electrify urban bus transport in Skopje. Chapter II describes the advantages of the IMC system, Chapter III presents the modern IMC system operating in Solingen (Germany) and proposes a similar solution for Skopje.

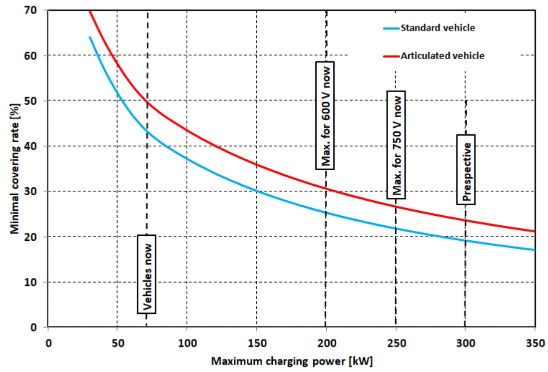

FIG. 2. MINIMUM CATENARY COVERAGE IN FUNCTION OF MAXIMAL CHARGING POWER [1, 7]

II. ADVANTAGE OF DYNAMIC CHARGING

Electric buses are fairly new ways of transport, so it should be clearly stated that there is not enough experience gained from operating them. Consequently, it is very hard to determine tendencies toward changes of the purchase prices of the electric vehicles in the future due to the dynamic nature of development of this market. However, what is even more obscure is that there is fairly much experience in the field of operating traction batteries with big capacities. Battery life is a key determinant which makes a problem and difficulty assessing it. Inasmuch the risk of entering this kind of transport is very high. There is a difference between them in the main element of the risk:

- Purchasing price and purchasing power of the vehicles,
- Cost of replacing the battery,
- Risk of traffic crowding and its effect on charging.

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A. Purchasing price and cost of replacing the battery

At this time, 50% of the price of the electric vehicle is the price of the battery [7]. However, in a lifetime of a vehicle a battery needs to be replaced at least once. Consequently, the drop of the price of the battery is very difficult to evaluate, but it is to be anticipated. Inasmuch, as what can be predicted is that while the electromobility industry increases in progress as well as increases in demand for energy storage a negative effect in battery cost can be expected.

B) Risk of traffic crowding and its effect on charging process

In order to deliver a right time backup for vehicle charging a stationary charging is required to increase number of vehicles servicing a line. However this makes a growth in the number of services and the drivers. Because of organizational difference of driver services, an additional cost can't be assessed. However 50% of maintenance costs of the transport system are the cost of driver's accounts [7]. A significant increase in cost can be noticed even at the smallest increase in the number of rolling stock. Due to this factor it can be noticed that this is also a part of the charging element. Thus it is a primary importance to also notice that when the vehicle stops for charging there is traffic disturbance and traffic congestion. Moreover this means that there is a lateness of scheduled arrival time to the final stop, which is another cause for less time left for recharging the vehicle batteries [8]. Fig. 3 shows a situation where the stationary charging causes an occurrence where there is not enough stop time to charge the vehicle which is needed to be used as a backup [7].

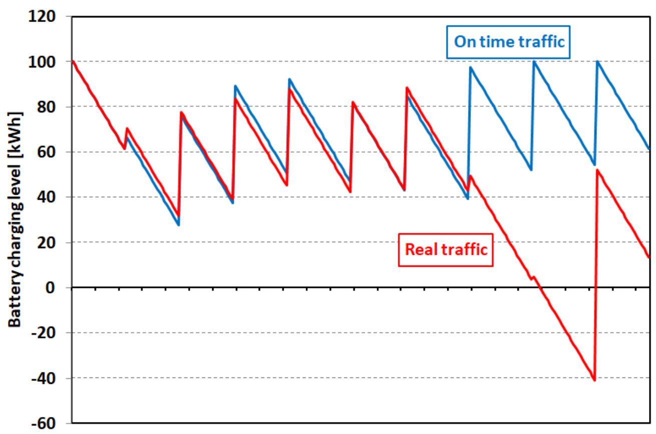

FIG.3. INFLUENCE OF TRAFFIC DELAYS ON BATTERY BUS OPERATION - DURING PEAK HOURS DELAYS CAN CAUSE REDUCTION OF STOPPING TIME, WHICH CAN BE TOO SHORT FOR FULLY CHARGING

C) Comparison of risk related with electrification of the bus routes

From economic point of view there is a difference in stationary charged and dynamic charged electrical buses and that difference is in the cost structure meaning that there are bigger fixed costs and lower level of variable costs. A financial analysis was made in terms of comparing the costs of stationary versus dynamic charged buses meaning analyses of costs like maintenance as well as cost of assets. These analyses of cost or financial analyses include discounted life cycle cost analyses or LCC. Sole purpose of these analyses is to find extreme life cost values for different inputs: the price of purchasing the vehicle, battery replacement price as well as the influence of traffic circumstances on the charging process. Two different types of scenarios were taken into consideration (optimistic and pessimistic approaches made by LCC calculator) to see the price of an individual cost element.

Life cost value analyses as well as risk value of life cost for the exposure of 20% by catenary and movement interval of 8 minutes is shown in Fig. 4, while Fig. 5 presents the structure of the cost [7]. The variance of maximum and minimum value of LCC cost is called risk value. Inasmuch it all defines that the investment in the traction network is available to lower the risk that is related to operating costs.

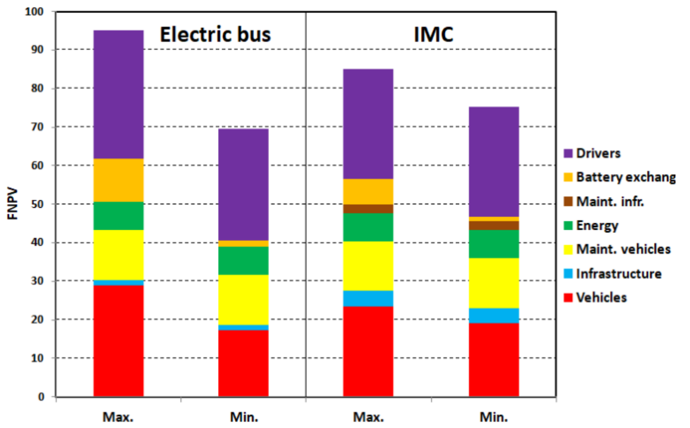

FIG. 4. LIFE COST ANALYSIS WITH ASSUMPTION OF 20% COVERAGE OF TRANSPORTATION ROUTE BY OVERHEAD WIRES (IN CASE OF IMC)

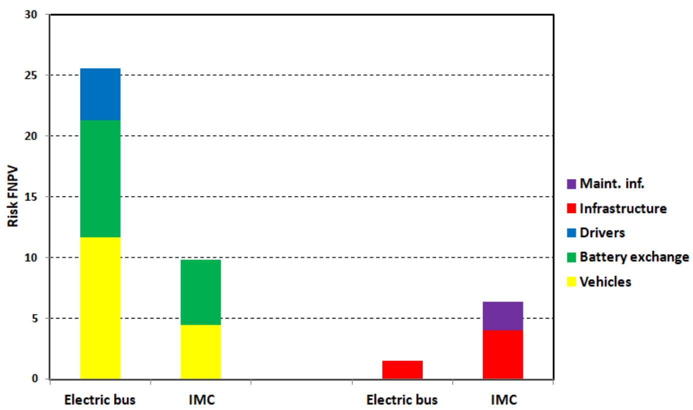

FIG. 5. ANALYSIS OF LIFE COST RISK WITH ASSUMPTION OF 20% COVERAGE OF TRANSPORTATION ROUTE BY OVERHEAD WIRES

III. PRACTICAL IMPLEMENTATION OF DYNAMIC CHARGING

A) BOB system in Solingen

In Germany, Solingen, the public transportation company SWS has a progressive dynamic charged system, their diesel buses route 695 are transformed to IMC electrical buses. As a charging infrastructure the Solingen trolleybus system will use around 2 km linear dynamic charging track which are the current overhead catenary wires. BOB system (Battery Overhead wire Buses) which will be the innovative system in Solingen practice vehicles with LTO traction batteries. These vehicles were a collaboration work between Solaris and Kiepe Electric (Table I, Fig. 6). The catenary wires that are 2x2.1 km long "IMC charging road" help BOB to function in a route that is 18 km long in both ways (Fig.7). Without the overhead wires the vehicles can function 75% of the route in battery mode [6, 9].

FIG. 6. THE BOB SOLARIS TROLLINO KIEPE ELECTRIC IN SOLINGEN (PHOTO JÜRGEN LEHMANN)

TABLE I

TECHNICAL DATA OF BOB VEHICLES IN SOLINGEN [6]

Vehicle type	Articulated low-floor trolleybus of the type "Trollino 18.75" (Solaris / Kiepe Electric)
Vehicle size	18.75 length m x 2.55 m width x 3.5 m height
Electric motor	2 x 160 kW asynchronous motors on the 2nd and 3rd axles (4 powered wheels)
Energy of battery	Lithium-titanate-oxide (LTO); 48 kWh usable energy / 60 kWh installed energy; 200 kW continuous power / 300 kW peak power
Charging concept	IMC® (in motion charging) up to 240 kW and opportunity charging (standing)

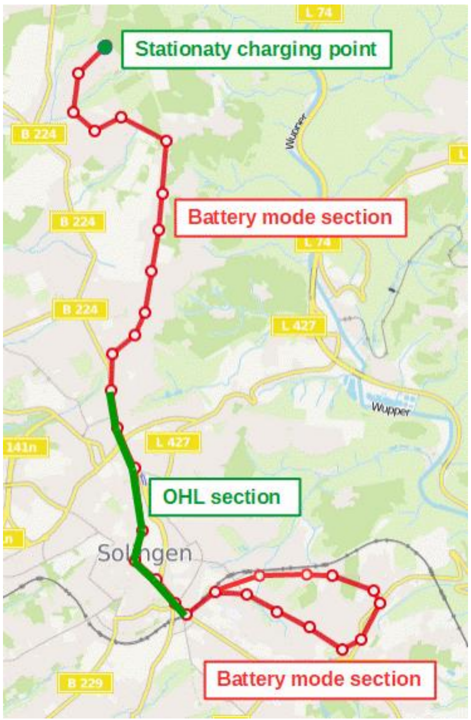

FIG. 7. THE SCHEME OF BOB SYSTEM (LINE 695) IN SOLINGEN, OHL - OVERHEAD TROLLEYBUS CATENARY LINE (BASED ON HTTPS://MOOVITAPP.COM/)

B) Conception of dynamic charging system in Skopje

Republic of North Macedonia has a Public Transport Company Skopje (Javno soobrakajno pretprijatie Skopje) that maneuvers over 50 urban and 50 suburban bus lines which makes it the largest passenger carrier in the country. The company has a park that is mostly double decker Yutong Chinese buses as well as LAZ models from Ukraine which are in number way lower than Yutong. Consequently many time the City of Skopje tried to plan a tram transport but without a successes. With global warming and the problem with emission that the whole world is dealing with the most reasonable solution as well as a cheaper solution to the emission problem is the form of dynamic charged electric busses. Moreover there are few boulevards the city has that are crowded during the rush hour but the most crowded with high intensity of traffic during the whole day is Boulevard Partizanski Odredi. This boulevard has 14 bus lines at all hours that connect the heart of the city with all parts urban and suburban. Electric charged buses in the IMC system are a possibility for this boulevard since there are multiple lines to operate with if a construction of an overhead contact line along the boulevard is taken into consideration. This infrastructure that would be build can be used by many vehicles while reducing the unit cost (per vehicle or per transport work) for construction as well as maintenance. Moreover the suggested route for the trolleybus network for charging vehicles in the IMC system is shown in Fig. 8. Also in Table II existing bus lines that use dynamic charging are listed. The mentioned trolleybus overhead traction line is 3.5 km long.

TABLE II

JSP BUS ROUTE PREDESTINATED BY IMC OPERATION

Bus route	*Route length [km]*	*Length of route under OHL [km]*	*Covering of route by OHL*
2	13,5	3,5	0,26
2A	14,6	3,5	0,24
4	9,1	3,5	0,38
12	14	3,5	0,25
15	10	2,5	0,25
21	12,5	3,5	0,28
22	12	3,5	0,29
22A	11	3,5	0,32
26	8	2,5	0,31

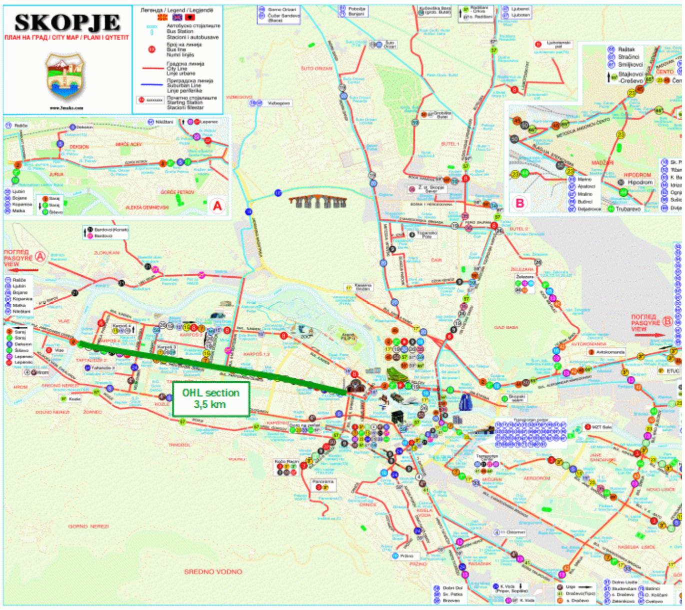

FIG. 8. THE IDEA OF IMC SYSTEM IN SKOPJE, BASED ON WWW.JSP.COM.MK

FIG.9. MARRAKECH'S IMC BRT SYSTEM

CONCLUSION

Using linear structure of the bus routes in the Karposh district is due to the use of the IMC system which makes it potential by using a separate bus lane that has and overhead contact line (Fig. 9). Unlike building a tram system this way is much cheaper solution. Rather than building a standard electric bus charger stationary this is more flexible solution while traction network will be used by many buses making it justifiable building the needed infrastructure.

The use of OHL infrastructure for dynamic charging allows reducing the capacity of traction batteries. This is especially important in terms of long-term running costs, as lower battery capacity brings lower replacement cost.

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