CONTRIBUTION TO THE CONSIDERATION OF SIGNIFICANCE OF HYBRID BUSES IMPLEMENTATION IN CITY TRAFFIC COMPANIES

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1. INTRODUCTION

Today's hybrid buses are important part of the improvement of catalytic vehicle safety [8]. Because of their specific work principle, which allows many benefits such as: reducing of exhaust emissions gases (which satisfy ecological aspect), economy (cost effectiveness regarding to the reducing of fuel consumption) and noise reduction, accent to their presence in urban and suburban traffic is increasing. Because of greenhouse effect which is, between other, consequence of increased exhaust emissions gases, exist continuously efforts to use as much as possible hybrid vehicles, especially in vehicle fleets of city transportation companies. Policy of "green vehicles", regardless to concisely defined and improved positive effects, still it is not fully accept. In accepting of this policy significant role play hybrid vehicles while different factors influence on development of their implementation. Traffic companies still partly are accepting mentioned tendencies and with reserve. This paper briefly presents basic work principle and classification of hybrid buses, interpretation of several experiences regarding to their exploitation and reasons of their accepting or denied. Also paper presents review presence of hybrid buses in Europe as well as one example of comparison analysis of fuel consumption within conventional bus with diesel engine and hybrid bus in aim to participate in answer to the question: Does increasing of hybrid buses implementation in city traffic companies is justified?

2. HYBRID DRIVE IN BUSES – WORK PRINCIPLE AND CLASSIFICATION

Hybrid drive in buses is composed of combination of electric motor and smaller than normal conventional internal combustion engine. The main components of hybrid drive are internal combustion engine, generator, a battery pack, and an electric motor. There are three types of hybrid drive systems. One is a parallel hybrid (Figure 1) bus where the combustion engine and the electric motor are connected to the transmission independently and where the power from the electric motor is using for "stop-and-go" traffic conditions, which are the most affected to the increasing of fuel consumption, while the power from the internal combustion engine is using at highway. Second type is hybrid bus with serial configuration, where internal combustion engine is connected to an electric generator which

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converts the energy produced by internal combustion engine into electric power (Figure 2). Thus, the main power for drive produces electric motor [3].

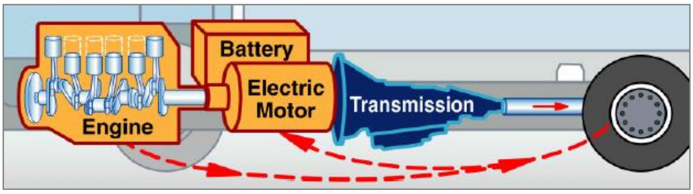

Figure 1: Parallel hybrid configuration on hybrid buses [3]

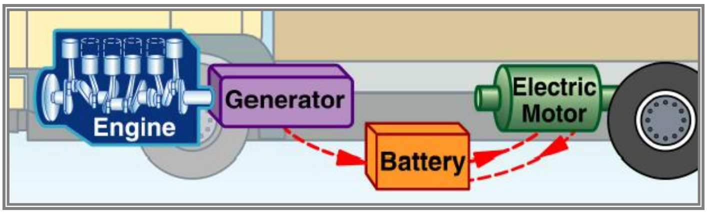

Figure 2 Serial hybrid configuration on hybrid buses [3]

The third type is combination of parallel and serial configuration of hybrid drive. In serial configuration, since the ICE is not connected to the wheels; it can operate at an optimum rate and can even be switched off for short periods of time for a temporary all-electric operation of the bus. Buses with parallel configuration in comparison with buses with serial hybrid configuration can provide high percent of fuel consumption efficiency on highway at high constant speeds, while serial configuration is better solution for city traffic environment, which is characterized with “stop-and-go” traffic [3].

3. SOME EXPERIENCE IN IMPLEMENTATION OF HYBRID BUSES

Regarding to the configuration of hybrid buses, for city traffic companies, beside mentioned fact (reducing of exhaust emission gases) it is particularly important element which is refers to possibility of reducing fuel consumption. However, uncertainty in their accepting is related to insufficiently improvement of reduced fuel consumption in real exploitation conditions, particularly in city traffic environment. Experiences in their using in such conditions are different. Beside, insufficiently practical improvement of reducing fuel consumption, problems of their higher participation in city traffic companies, can be dedicate to possible complexity of their maintenance, maintenance costs and cost price of hybrid buses. Complexity of their maintenance is related to the batteries which are using for energy storage for power of electro motors, while other components are suitable for maintenance. Many maintenance experts in city traffic companies have opinion that with failure of batteries, it can be expected serious downtime of vehicles with hybrid drive, which is regarding to the necessary exploitation frequency of vehicle fleet extremely unwanted. Their experience told that battery in hybrid buses is a component that is non-reparable and that the only way to repair failure and to get hybrid vehicle in fully function is to replace old batteries with new, which price is relative high in comparison with average price of components with similar functional characteristic and purposes. This indicates increasing of maintenance costs. Average price of batteries for hybrid vehicles is about 700 $ and more

[1], while frequency of their failures is high. For example, city traffic in London was equipped with 500 hybrid buses, which are from Irish bus factory “Wright bus”. After relative short period in exploitation, 80 buses worked only in the mode where using diesel internal combustion engine is. Reason for that were failures of batteries. Also 200 buses demands replacing of previous batteries with new [2]. Besides that, significant role in their higher participation in city traffic companies is related to the cost price. Average price of one contemporary hybrid bus is about 250.000-270.000 euros, while price of the conventional contemporary bus with engine emission class 5 and 6 is about 220.000 euros. [5, 6] If the topic is total maintenance costs, estimation of manufacturers is that total maintenance costs for conventional buses is approximately 0.10-0.15 euro cent/km, while total maintenance costs for hybrid buses is approximately 0.12-0.17 euro cent/km [5].

4. REVIEW THE PRESENCE OF HYBRID BUSES IN EUROPE

First hybrid buses in Europe were put into operation in year 2006. Period from year 2006-2010 was marked by small number of hybrid buses in exploitation in public transportation. It was the pilot testing a hybrid concept in cities: Paris, Barcelona, Dresden, Strasbourg, Nuremberg, Wallonia and Flanders region in Belgium, Luxemburg. London was exception where from 2006 in regular exploitation included 56 "double-decker’’ Wright-bus, which can be considered the beginning of the "mass" of introducing this kind of buses in Europe [9]. The EU has been in service 178 buses with hybrid drive but the mid-2012, in service is 1191 buses with hybrid drive.

Cities and regions with the highest number of hybrid buses currently in service are: London (260), Manchester (162); Flanders Region-Belgium (136), Dresden (57), Oxford (43); Birmingham (33), Dordrecht (27), Barcelona (25), Region South Holland (24), Luxembourg (21), Hamburg (20), Oslo (18), Bochum (13) [09]. (Figure 3)

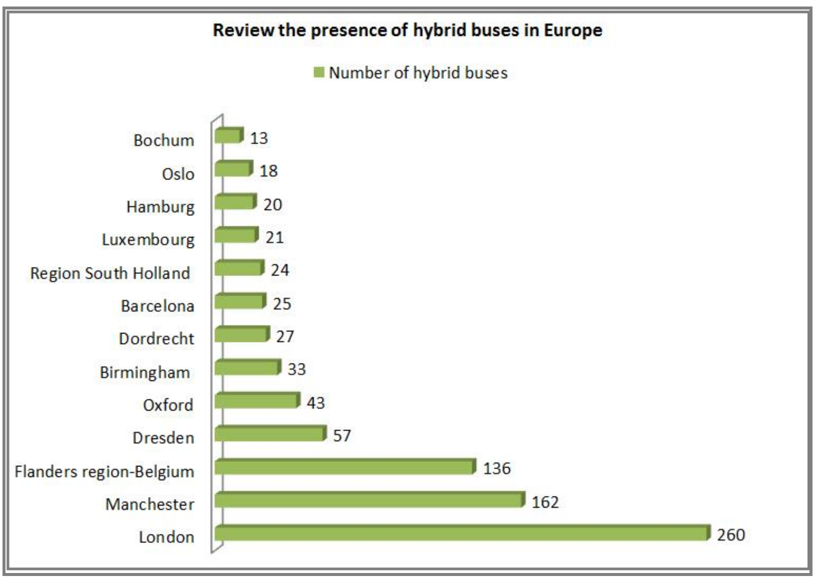

Figure 3 Presence of hybrid buses in Europe cities

5. COMPARISON OF FUEL CONSUMPTION BETWEEN HYBRID AND BUS WITH CONVENTIONAL DIESEL DRIVE – A CASE STUDY

Beside interpretation and analysis of different actualities regarding to the hybrid buses, in this paper particularly accent was placed to the lower fuel consumption within hybrid buses. [10, 12] In that purposes, it was performed comparison analysis of fuel consumption between hybrid bus and bus with conventional diesel engine. For monitoring of fuel consumption, it was selected two contemporary buses with diesel engine and hybrid drive. Both of them were in the same exploitation conditions. It is the city line, where the buses daily passing in average from 150-320 kilometers. The monitoring of fuel consumption for mentioned buses was performed during the 11 days driving. Both vehicles which were participated in analysis were without functional defects and during the monitoring there was no performing of maintenance. Also failures were not identified. Fuel in vehicles was on the same quality level for all 11 days of monitoring. For both buses tires were checked every day of monitoring, where was identified proper air pressure in tires. Bus drivers were with experience in driving both, buses with conventional diesel engine and hybrid buses, with similar driving behavior. Some of technical characteristic of compared buses, which are significant for the analysis are:

1. Conventional bus with diesel engine [04]:
   - length: 12.000 mm;
   - width: 2.550 mm;
   - height: 3.076 mm, including air condition system;
   - Tire size: 275/70 R 22.5;
   - Fuel tank capacity: 280 l;
   - Gross vehicle weight: 18.000 kg;
   - Engine: diesel 7.700 cm3, power Pmax = 210 KW na 2200 rpm, max. torque Tmax = 1.120 Nm at 1.200-1.600 rpm , emission class Euro 5;
   - Transmission: 6-speed, automatic transmission

2. Hybrid bus [11]:
   - length: 12.000 mm;
   - width: 2.550 mm;
   - height: 3.200 mm;
   - Tire size: 275/70 R 22.5;
   - Gross vehicle weight: 18.600 kg;
   - Hybrid system: Parallel hybrid configuration;
   - Diesel engine: 5.000 cm3, Pmax = 210 KW, Tmax = 800 Nm;
   - Electro motor: Pmax = 210 KW, Tmax = 800 Nm;
   - Power battery: 600 V;
   - Transmission: 12-speed, automatic transmission
   - Fuel efficiency: 35 % more fuel-efficiency than a conventional bus of the same category.

From above listed technical characteristics, it can be concluded that these buses are with very similar performance. This is particularly related to engines that using vehicle which were subject of monitoring of fuel consumption as well as dimensions and transmission. With this it is eliminated potential criticism to the possible structural and functional diversity of vehicles that are subject of monitoring. Measurement of fuel consumption, carried out with a probe (electronic float), which is designed for measuring the level of fuel and other liquids in tanks, pools, etc., which in this case sets in the tanks of vehicles that are subject of monitoring of fuel consumption (Figure 4). Length of probe is adjustable, and all sealing and mounting elements. Fuel level is recorded every 3 seconds. The measurement results are recorded in the independent electronic unit where they are processed, filtered and stored in memory. Measurement accuracy depends on several factors such as the cross-section of the tank, or the height and width, the position in which a measurement is performing etc. During this measurement, it was used probe capacitance-meter, which has a temperature gauge and G-sensor for detection of angles and fluid turbulence, which can guarantee the accuracy of the measurements [7].

Figure 4 The probe – electronic float [7]

Monitoring of fuel consumption was performed by Traffic Company “Mariborski potniski promet-Marprom” in year 2015 while comments and conclusions are results of author’s analysis.

Table 1 presents data about fuel consumption in l/100 kilometers for each day and kilometers which conventional bus with diesel engine have passed during that day. Also, in Table 1 is present average fuel consumption for all 11 days.

Table 1 Fuel consumption for each day of monitoring for conventional bus with diesel engine and average consumption

Day	Bus type	Passed km	L/100 km	Average consumption
1st day	Conventional bus with diesel engine	317	24.92114	34,16951389
2nd day	Conventional bus with diesel engine	325	28.30769	
3rd day	Conventional bus with diesel engine	315	29.84127	
4th day	Conventional bus with diesel engine	314	36.94268	
5th day	Conventional bus with diesel engine	318	42.45283	
6th day	Conventional bus with diesel engine	300	36.66667	
7th day	Conventional bus with diesel engine	314	35.35032	
8th day	Conventional bus with diesel engine	315	35.2381	
9th day	Conventional bus with diesel engine	314	35.35032	
10th day	Conventional bus with diesel engine	315	35.55556	
11th day	Conventional bus with diesel engine	315	35.2381	

Figure 5 shows graph of fuel consumption of bus with standard diesel engine.

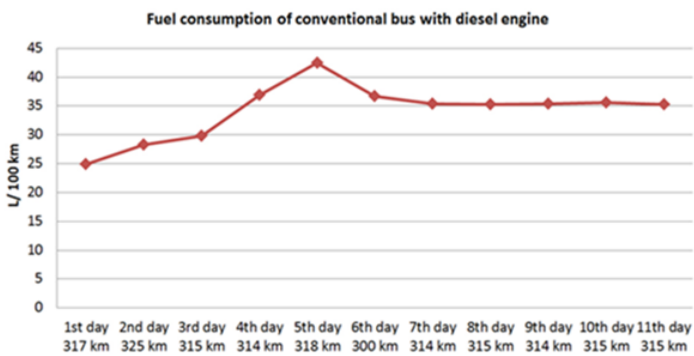

Figure 5 Graph of fuel consumption of conventional bus with diesel engine

In monitoring of fuel consumption of conventional bus with diesel engine, it can be notice different varieties. From the Figure 5, it can be seen that the lowest fuel consumption was on the first day of driving, when fuel consumption was 25l/100 km for 317 passed kilometers. The larger fuel consumption was recorded at fourth, fifth and sixth day, with fuel consumption of 37 l/100 km, 43 l/100 km and 36 l/100 km. These large varieties in fuel consumption can be prescribed to different driving regimes in relation to the traffic conditions. Besides that, it can be notice that on seventh, eighth, ninth, tenth and eleventh day fuel consumption was nearly the same. Total average consumption of conventional bus with diesel engine was about 35 l/100 km.

Table 2 presents data about fuel consumption in l/100 kilometers for each day and kilometers which hybrid bus with have passed during that day. Also, in Table 2 is present average fuel consumption for all 11 days.

Table 2 Fuel consumption for each day of monitoring for hybrid bus and average consumption

Day	Bus type	Passed km	L/100 km	Average consumption
1st day	Hybrid bus	381	18.3727	29,77267279
2nd day	Hybrid bus	242	42.56198	
3rd day	Hybrid bus	311	28.93891	
4th day	Hybrid bus	310	17.09677	
5th day	Hybrid bus	310	28.06452	
6th day	Hybrid bus	224	33.03571	
7th day	Hybrid bus	311	26.6881	
8th day	Hybrid bus	307	42.34528	
9th day	Hybrid bus	293	27.30375	
10th day	Hybrid bus	232	30.17241	
11th day	Hybrid bus	161	32.91925	

Figure 6 shows graph of fuel consumption of hybrid bus.

In monitoring of fuel consumption of hybrid bus, it can be also notice different varieties. From the Figure 6, it can be seen that the lowest fuel consumption was on the fourth day of driving, when fuel consumption was 17 l/100 km for 310 passed kilometres. The larger fuel consumption was recorded at second, sixth and eighth day, with fuel consumption of 42 l/100 km, 33 l/100 km and 42 l/100 km. These large varieties in fuel consumption can be also prescribed to different driving regimes in relation to the traffic conditions. Besides that, it can be notice that on the other days, unlike bus with diesel engine, there is a significant more variety. Total average consumption of hybrid bus with diesel was about 29 l/100 km.

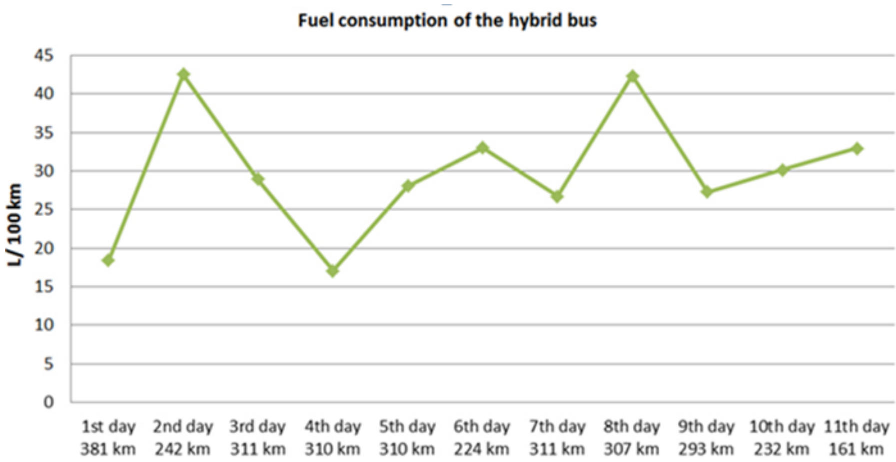

Figure 6 Graph of fuel consumption of conventional bus with diesel engine

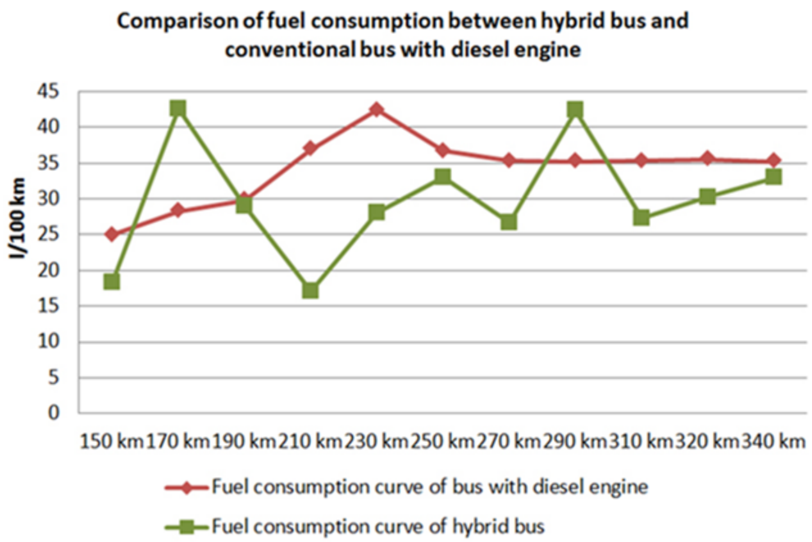

Figure 7 Comparison of fuel consumption between hybrid and conventional bus with diesel engine

In direct comparison of fuel consumption graphs of hybrid and bus with diesel engine, it can be seen that hybrid bus has moments with larger fuel consumption versus bus with conventional diesel engine. However, certainly there are more days when hybrid bus has significant lower fuel consumption unlike bus with diesel engine. This particular refers to first, fourth, fifth, sixth, seventh, ninth, tenth and eleventh day. Total average fuel consumption is on the side of the hybrid bus, with average consumption of nearly 29 l/100 km. Thus, hybrid bus made up about 4l/100 km lower fuel consumption versus conventional bus with diesel engine. Manufacturer of hybrid bus which was participating in comparison analysis estimate about 35% more fuel-efficiency than a conventional bus of the same category. Considered obtain results of comparative analysis, it can be concluded that hybrid bus, in the same exploitation conditions was achieved about 13% savings in fuel consumption relative to conventional bus with diesel engine.

6. CONCLUSIONS

Hybrid buses should certainly, from the standpoint of reducing exhaust emissions gases and environmental pollution, took an important place in large vehicle fleets, especially in the city traffic companies. However, their higher presence undoubtedly depends of higher level of improvement in lower fuel consumption in comparison with conventional buses with diesel engine. Example of the comparison analysis of monitoring fuel consumption, which is present in this paper, show that fuel consumption efficiency is significant lower than estimation of hybrid buses manufactures. This case show that is 22% lower saving in fuel consumption versus commercial data about fuel consumption efficiency of hybrid bus which was participate in comparison analysis. Besides that, factors such as price of the hybrid buses, maintenance costs, as well as problems related to the powering and failures of batteries for electro motors, also exists. For all this potential problems, better answer gives development countries, which can be seen in preview of presence of hybrid buses in cities in Europe, while in middle and poor countries it cannot be seen larger participation of hybrid vehicles in city transportation companies. Although in this example was identified lower savings in fuel consumption versus commercial data about fuel consumption efficiency of hybrid bus, if fuel savings considered on the level of the whole vehicle fleet, savings in fuel consumption is much larger. Thus, it can be said that implementation of hybrid vehicles in city transportation companies is more than justified, together with reducing of exhaust emissions gases. Further research should be performed through longer time period, with consideration of heterogeneity of test vehicle fleet, from the aspect of vehicle age and diversity of their constructional characteristics.

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