Using electromagnetic induction in the vehicles of public transport, as a good practice in the development of urban transport policy

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ABSTRACT
Using inductive powered batteries in public transportation vehicles delivers a lot of benefits. The most important advantage is contribution to environmental protection by reducing exhaust emission. The special construction of inductive buses, results more quite engine running, so among benefits there are also noise limitations (about 7dB comparing with diesel engines). Although the cost of inductive buses is almost twice bigger, the whole investment returns fourfold faster by low exploitation cost of such vehicles. Unfortunately implementing this technology requires road infrastructure adjustments, such as mounting inductive charging station into the road surface. It is worth mentioning that nowadays, when pro-ecological projects play a key role in transportation development strategies, the inductive vehicles can be an answer to all of necessary demands.

KEYWORDS: buses, electricbuses, induction charging, urban policy, electromagnetic induction, vehicles

1. Introduction
Modern cities increasingly attach the necessary importance to ecological aspect of development, so called urban ecology. Present trends identifies new idea of sustainability planning, named the urban culture. Development strategies defines city as "smart" and "green". The spatial planning includes urban agriculture and environmental technologies investments, such as renewable energy. One of the most important elements of those strategic goals is redefining the idea of urban transport. Also emphasis is placed on excluding private vehicular transport form the strict city centre and providing a reliable, comfortable, safe and environmentally friendly public transport. The growth of mass transit share in generality of urban travels is primary point to be made. Greater automobile traffic from the growing number of cities residents and constantly increasing motorization might lead to further deterioration in traffic conditions. That mater can influence also the public mass transit causing longer travel times and encourage the passengers to no longer choosing municipal transportation. Modern approach to eco-city politics establishes not only public transport promotion, but also reducing energy consumption and air pollution limitations [1,2].

According to “Urban Ecology” study, urban planning framework must be applied create “ecologically ideal city”. Special attention was paid to reduction of energy input in transport area. The framework was defined as follows [3]:
- decreasing the energy usage and demand for production, heating and transportation,
- percentage reduction for traffic energy,
- unnecessary energy use avoidance (including local public and bicycle transport promotion,
- avoiding empty means of transport running,
- reduction of motor vehicle traffic congestion,
- air pollution reduction.
It is possible to observe that operations in field of transportation, are crucial for decreasing energy input in urban areas. All those elements should be taken into consideration while planning the urban transport development strategy. In addition to this, another meaningful aspect is that development priorities should comply with the national industrial strategy and local specifics. The actions should include promoting the role of science and new technology in public transportation development. At the same time, it is important to remember that in terms of pollution emissions per one passenger, the automobile is the least efficient mean of transportation. So the primary technology branch in this area must be the research, concerning new vehicles construction solutions used in mass transit. Main purpose of the development should be increasing urban transport efficiency regarding the economy, time, society lifestyle and the environment. Substantial issue is adequate management and financing the public transport. The owners must perform an effective supervision of enterprises as well as implement standards for public transportation services. The formulation of each city key technology choices needs to fit not only the national and city development policies, but also city individual traffic pattern, structure of the road system, urban layout, economics, available science and technology ideas and ecological aspects. Those strategy components are essential to achieve urban mass transit healthy development and should be identified as the priorities [4].

The European Union backed a policy of obtaining energy using technologies that ensure low CO2 emissions. The ecological strategy for Europe was defined, one of the action taken was creating the “Energy Roadmap 2050” European Commission Energy Strategy for 2050. The study long-term goal for 2050 is the reduction of at least 60 % of carbon emissions. Medium-term targets that should be achieved by 2020, points out the transport sector as one of the key factors to achieve lasting reduction of energy consumption and CO2-emissions. The perfect solution to this issue seems to be electric buses implementation. The technological progress enabled to use the inductance phenomenon in vehicular movement. Inductive charging is not latest way of obtaining energy, but it is definitely a new way of energy wireless transmission from source to vehicle. It is very comfortable approach to power supply mode [5,6].

Mass transit seems to be a suitable place to start implementing electric induction for propulsion, since the location of the mentioned vehicles is more predictable than those of individual means of transport. A key benefit to inductive charging system is the wireless technology. It is not responsive to water or the weather. Solution allows to perform continuous electric bus operation due to high-power charging equipment embedded within existing bus road infrastructure. Another advantage are smaller electric vehicle batteries that make more room for passengers and battery life extension caused by with intermediary inductive charging. Also the financial and time costs get lower as induction charging allows to charge the battery by simply driving on the streets with embedded chargers [7,8].

In Germany, since the “National Strategy Conference on Electric Mobility” in 2008, many policies and electromobility promotion programs have been introduced. Because of this actions the German government supports different projects and programs concerning electromobility. These innovative projects enable to conduct an effective cooperation between industry, science, and the government. Many of those projects programs target especially electric buses. The electric bus research and implementations in Germany mainly apply to issues such as [9]:

- workability studies for electromobility everyday use in public transport,
- different charging strategies optimization,
- route optimization,
- inductive solutions and fast charging.

2. Buses with combustion engines and electricbuses

The main drive sources used in public transport are diesel oil, more and more often natural gas (CNG or LNG) and to a small extent, alternative fuels. Currently in buses, due to an apparent efficiency, the main power unit are engines with compression-ignition. This process is progresses by burning a mixture of previously prepared fuel and air in a closed combustion chamber. As a result of combustion, high temperature increases the pressure which is converted into mechanical work in the form of torque on the crankshaft of the engine, which, in turn, is transferred to the wheels of the car [10]. Figure 1 shows a diagram of the compression ignition engine.

![Fig. 1. Construction of a diesel engine](image)

Another, more ecological and more common solutions used in public transport vehicles are the engines that run on natural gas CNG (compressed) or LNG (liquid). In this case, the compressed gas is stored in a cylinder under pressure of 20 MPa. Such cylinders are most commonly mounted, just like in the conventional case of LPG, in the rear end of a vehicle. The gas, after opening the shut-off valve in conduit, flows under high pressure into the shut-off...
valve which is electrically controlled. In the absence of engine operation, the valve is closed, and after it is opened, gas flows through a conduit to an evaporator pressure regulator (heated fluid being supplied to the engine cooling system), where the gas pressure is lowered to a value close to atmospheric pressure, or about 0.2 MPa. Gas, after the pressure has been reduced, is sucked through the mixer into the intake system [11].

An intermediate solution with higher environmental performance than traditional motors are hybrid engines, which in the case of public transport are found in combination: diesel engine combined with electric or engine powered by natural gas CNG in conjunction with the electric drive. As a definite plus these solutions should indicate lower emissions and reduce fuel consumption, but this solution has considerable disadvantage in the form of higher costs of purchase of the vehicle, which, according to the company Solaris Bus & Coach SA are higher by 20 to 80% of the conventionally powered vehicle [12]. Diesel-electric drive makes it possible to drive in urban centers without harmful emissions and move outside cities with a conventional drive. When vehicle is braking, this drive makes it possible to recover a part of the kinetic energy (starting power, bus using diesel drive and braking power) [13].

Nowadays, in the transport sector, emphasis is put on environmentally friendly solutions that reduce emissions and costs of rolling stock. The latest development in this area are completely electric drive motors vehicles (electrobuses), which are considered the future of public transport in the city. The buses are equipped with lithium-ion batteries with high power, in which the stored energy is transferred to the electric motor driving the wheels of the car directly or through a gear assembly. Car batteries are charged by an external power source:

- charging from the socket,
- charging through pantograph,
- induction charging.

An important advantage of buses powered by electric motors is the lack of emissions, no noise emissions and lower operating costs (electrical energy, is cheaper than diesel or natural gas). As disadvantages should be noted: higher purchase price of vehicles, the need for installation of additional infrastructure (charging stations) and a limited range of vehicle operation on a single battery charge - there is a possibility of installing batteries for extended range, but these batteries are limited in the cabin of the vehicle (battery size). Figure 2 shows the distribution of elements on the bus with electric drive.

According to data from Miejskie Zakłady Autobusowe in Warsaw, after two months of operation of electric Solaris Urbino 12 electric (data collected in 2015 during the operation of the said bus line No. 222), it has been calculated that the costs of its operation are four times lower than the costs of traditional combustion vehicles [15]. The chart below shows the % of energy supplied in the fuel or electricity - the balance to 100 kilometers driven each of the three types of vehicles, research conducted by Solaris Bus & Coach SA, in cooperation with Poznan University of Technology:

The difference in fuel costs between buses with electric drive and combustion is significant and over the years, according to studies, is between 688 thousand to 1200 thousand PLN. The difference is mainly due to different consumption of electricity needed to proceed through 100 km [17].

3. The phenomenon of magnetic induction and use of it for vehicle charging

Electromagnetic induction depends on the formation of electrical current in the circuit due to changes in the magnetic field of the male through the circuit. As the first induction, in 1831, he described the English physics Michael Faraday. This phenomenon is used to change the magnetic flux, which can result from movement of a guide or source of the field. In the case of a bus or another vehicle, the two coils are used, one mounted in the vehicle and a second landing site, the coils are coupled magnetically together and form a transformer. Typical wireless charging system of the vehicle shown in Figure 3.

Charging the vehicle starts when parking on a specially prepared site parking (stop or depot), which is mounted transformer primary winding. The coil is supplied with alternating current at high frequencies generated by the inverter energoelektrycznej powered from the network EE. AC power is transmitted to the winding, and
then processed in a converter vehicle DC, which is powered by the battery of the vehicle. The amount of energy transferred from said primary winding depends on the size of the coil, and the frequency and amplitude of the voltage supply. The size of the coil, in this case, are limited in the size of the chassis of the vehicle, therefore, it gives the greatest potential for increasing the operating frequency of the coil. The greatest potential to increase system operation, provides the use of plates of silicon carbide SiC, which allow operation at frequencies up to a few hundred kHz [18].

An important part of the electrical power drive systems is the safety and the impact on living organisms. The main element of which may have an impact on living organisms is the effect of high-frequency electromagnetic field. Institute ICIRP defined standard values in this range. For frequencies that fall within the scope of the charging system, the permissible value is 6.25 microT. The metal chassis of the vehicle and the shape of the core coils provide no radiation inside the vehicle closest to the magnetic field occurs at the moment of exit from the vehicle, but the most common coil is within the threshold of the vehicle, which provides at this point the condition of safety. Additional protection can be an addiction and start charging from the presence of the driver in the vehicle or its vicinity [18].

4. Public transportation in Brunswick and Berlin as an example of harnessing electromagnetic induction phenomenon

Along with technology development, there is a question rising: „what about environment protection?“. The board of Braunschweiger Verkehr AG started cooperation with University of Technology in Brunswick, Bombardier and Solaris Busch and Coach S.A. companies to build efficient and ecological vehicles. That is how “Electromobility through induction charging” idea was created. Work on the project started on 31st of May 2012. The project interfered in bus stops architecture and expected purchase of new vehicles. Charging stations found in depot and on bus stops has been created in Brunswick. Buses operating there were produced in Bolechów near Poznań (Poland) by Solaris Bus and Coach S.A. company and equipped with PRIMOVE system by Bombardier company. It is estimated that electric buses are twice as expensive than buses with Diesel engines, however power consumption is about 35% lower.

“Emil” project is in implementation phase and its completion is planned for middle of 2016. Charging stations are located in depot and on bus station near train station. Induction vehicles consist of: one Solaris Urbino 12 electric (12 meters long) with 60 kWh battery and four articulated buses Solaris Urbino 18 (18 meters long) with 90 kWh battery. Two more buses have been ordered and are expected to appear on Brunswick roads soon. Li-ion batteries used in buses can be charged with either direct (450 V) or alternating current (750 V) on charging stations with 200 kW power [19]. Induction buses run as part of 419 line located in central points of the city. Six thousand passengers commute this line daily. This line is 12 km long, has 25 bus stops and runs in 10 minutes interval from Monday to Friday and in 15 minutes interval on Saturdays and in 30 minutes interval on Sundays. Total run time takes 39 minutes. At the beginning of the shift, driver retrieves a bus from service employee and drives to bus stop near train station. There he recharges the batteries and begins his route. Energy accumulated in the batteries last for duration of the whole route. After completing the loop the driver has 20 minutes long break. During this time he has to recharge the batteries, which
takes 11 minutes. If any delays, caused by traffic congestion or other random events, should occur and the bus driver will not be able to recharge the batteries in time, the bus stops and it has to be towed to the nearest charging station. Today, charging stations are operating in bus depot and main train station. In the near future two new stations are expected to be available on Hamburger Street and Amelien Square, where buses can be charged for 30s [20].

Fig. 6. Route of bus line 419 in Brunswick [20]

Project implementation met with obstacles, such as: problems with control settings, with cooling system and air-conditional. Currently the vehicles are operating impeccable, however engine upgrade has to be consider due to the low power.

Transport policy in Brunswick conducted in such way to attract drivers to alternative solutions. This brings lots of benefits to natural environment. Electric vehicles characterized by low energy consumption, lack of fumes emission and noise level lower by 7dB than vehicles with Diesel engine [21]. Unfortunately they are much more expensive, but according to unofficial data, cost of purchase is returned four times faster than internal combustion vehicles.

Alongside „Emil” project arise another project „Emilia”, what means “Electromobility through induction charging in a car”. The main goal of “Emilia” project is an electric taxis implementation. First induction cars should appear on the German market until 2017. e-Golfs research has been last by a middle of 2016. Firstly cars will be power with 3,7 kW current, than with between 10 and 20 kW current [22]. Induction charging system has encourage users because of its simplicity. Induction charging cars have not plants and are equipped with automatic positioning systems and are much more productive and health safety in contrast to electric cars with plug-in power [23].

Another project with usage of electromagnetic induction phenomenon is “E-Bus Berlin”. Since 15th of September 2015 on line 204, which is 6 kilometres long and has 18 bus stops, are trialling four buses Solaris Urbino 12 electric with PRIMOVE system by Bombardier company. This project and Brunswick’s are similar. Berliner buses are charging only on two bus stops and in depot. The trials will be continue by September of 2016. Thanks to induction buses, carbon dioxide emission will lessen about 260 tons yearly. Berliner buses are equipped with GPS systems. Mobile map was make available, thanks to this every user can perceive actual bus position [24,25].

Fig. 7. Route of bus line 204 in Berlin [26]

Electromobility expand in really dynamic way. Modern, economic and environmental friendly solutions are used in more and more cities. Induction charging system PRIMOVE has been used not only in Brunswick and Berlin, also in Mannheim and Belgian Brügge. PRIMOVE batteries powers city railways in Nanjing in China. Induction system has been used also in London and Turin [25].

Bibliography

[7] LAURSEN L.: Another Transit System Tests Inductive-Charging Buses, online access: http://tiny.pl/g/7tf [date of access: 15.11.2015]
USING ELECTROMAGNETIC INDUCTION IN THE VEHICLES OF PUBLIC TRANSPORT, AS A GOOD PRACTICE IN THE DEVELOPMENT OF URBAN TRANSPORT POLICY

[8] LOOMANS T., Germany Testing Wireless Induction Charging for Electric Buses, online access: http://tiny.pl/g7tt5 [date of access: 15.11.2015].


