Photo Arkadiusz Ławrywianiec

Tychy Trolleybuses Electromobility Since 1982

Text **ARTUR CYWIŃSKI, ZBIGNIEW BRUD**

Poland is a country, in which trolleybuses are very seldom used in the urban public transport. Now only three cities have a trolleybus traction in the country with anearly forty-million population: Tychy, Gdynia, and Lublin. What is interesting, the history of this means of public transport started in Poland in ... 1930.

Till 1999 trolleybuses were running in 12 cities: Dębica (1988-1993), Gdynia (from 1943), Legnica (1943-1956), Lublin (from 1953), Olsztyn (1939-1971), Poznań (1930-1970), Słupsk (1985-1999), Tychy (from 1982), Wałbrzych (1944-1973), Warsaw (1946-1973), and Piaseczno (1983-1995) [1]. Unfortunately, high costs of the traction network operation, the lack of modern vehicles and the lack of ecological awareness and responsibility for the natural environment confronted with the cheaper and more available bus transport, operating based on oil-derivative fuels, resulted in gradual liquidation of this means of urban transport in most of 12 cities, where it was operating. Three centres remained, in which trolleybuses won the fight for survival. Now, when people talk louder and louder about the necessity to reduce pollution and the CO2 emission, and also due to the support under projects co-financed by the European Union, they have found their opportunity for further development.

Tychy is an example of a city, where the fate of the trolleybus network and the ecological public transport is inseparably related to the latest history

Streszczenie

Przedstawiony poniżej tekst opisuje historię powstania, rozbudowę oraz modernizację sieci trakcyjnej tyskich linii trolejbusowych. W artykule opisano też doświadczenia eksploatacyjne związane z wykorzystaniem trolejbusów wyposażonych w baterie trakcyjne, a także analizę możliwości ograniczenia strat sieciowych, poprzez ograniczenie udarów prądowych za pomocą buforowego zasilania bateryjnego.

Słowa kluczowe: trolejbus, transport zintegrowany, sieć trakcyjna

Summary

Tychy trolleybuses – electric vehicle network since 1982
The paper presents the history, development and modernization of the trolley traction grid in Tychy as well as the operational experience with trolleybuses fitted with a battery pack and the analysis of possibility to minimize power losses in the transmission system using a buffer battery pack.

Keywords: trolleybus, integrated public transport, traction grid

Photo Marian Jamrozy

A trolleybus with installed STH600 x84 traction batteries

On the left
Presentation of new Solaris trolleybuses – November 2006. Vehicles were given names of Tysia and Tyszek

of Poland and the systemic transformation started in 1989. This is a particular city, because actually constructed from the beginning as a satellite city, dormitory town.

The decision, to turn a small town into an urban dormitory for the employees of existing and newly constructed plants of the Upper-Silesian Industrial Region, was made during the Presidium of the Government meeting on 4 October 1950. Twelve months later the construction of the first small estate (still according to the social realist style), and in 1952 the competition for the town planning design of the new city, intended for one hundred thousand inhabitants, was adjudicated. The population was growing very fast from less than 13,000 in 1950, through 26,000 in 1955, up to approx. 130,000 now [2].

The residents of the new city originated both from the overcrowded conurbations of the Upper Silesia and Zagłębie, but also from the farming areas of Poland. It should be also added, that a substantial group of new residents comprised repatriates from former eastern areas of Poland and from the USSR.

From a dormitory town Tychy transformed into a conurbation with modern automotive industry – a Fiat factory, manufacturing a cult model 500 as the only in world, a General Motors factory and numerous plants from the automotive sector. So not without reason Tychy is referred to as the automotive capital city of Poland. The city has been developing not only via the residential housing, industry or the social-cultural facilities. The infrastructure, including the public transport, was an equally important area of development.

The history of Tychy trolleybuses started during the martial law and resulted from economic sanctions of the western world imposed on the then authorities. The embargo resulted inter alia in a very bad situation on the fuel market. Shortages in the supplies of the diesel oil caused the necessity to reduce the share of buses in the passenger transport. In 1982 the voivode of Silesia made the decision to prepare the start of an experimental trolleybus line. Tychy was chosen because of a favourable road system (wide streets), no intersections with trams and railways, and also due to appropriate passenger flows required by the trolleybus traction. The first line, No 1 - 4 km long, was started on 1 October 1982 and the fleet consisted of 12 Soviet ZIU9B vehicles, popularly named 'Ziuteks'.

It is noteworthy, that the investment process, from the moment of decision making, through the design preparation, selection of the contractor and the task implementation lasted 8 months. During the next years subsequent sections of the traction network were constructed and commissioned and at the end of 1985 the total length of the traction network was 22 km [3].

The fleet was increase by another 12 'Ziuteks', this time that were ZIU 682UP models. Despite huge plans and development visions during 17 years from 1985 no new section of the traction network was constructed, and the investment activities confined only to the current maintenance and breakdown removal. The vehicles were gradually replaced and in the years 1989-1998 the fleet comprised 25 Jelcz trolleybuses. In 2002 the next section of traction was started, 1.2 km long. The European Union pressure on the promotion of ecological means of public transport development, translating into sources of financing under the Infrastructure and Environment projects of the National Cohesion Strategy, allowed further expansion of the trolleybus network.

Modernisation and expansion of the traction

For more than four decades of the socialist era an own car was a luxury good, available only to few people. In addition, the rationing and restriction in the access to fuel resulted in the fact that the public transport was the most frequently selected means of transport. The period of systemic transformation in Poland marked a very dynamic development of motorisation. The number of registered cars in the years 1989-2013 increased a few times, where the largest increase in the number of cars occurred after Poland's accession to the European Union, mainly through imports of second hand cars.

According to statistics in 2013 there were 504 cars per 1000 residents [GUS], while in Japan –

463, in USA – 404, in South Korea – 300, and the EU average was 487 [ACEA – 2012]. Unfortunately 81.8% of cars in Poland are more than 10 years old, and only 8.8% have not exceeded 4 years. The increase in the number of cars, especially with obsolete engines, means also increased emissions of pollutants, including CO2. The possession of an own car by every second statistical resident of the country and widespread admiration of the society for this form of transport resulted in a decreased share of the public transport. The car continues to be a symbol of material status in Poland. The other reasons for the number of travels in the urban transport include de-urbanisation and suburbanisation leading to the formation of settlement structures – difficult or even impossible to service by the public transport; the reduction of the offer and the deterioration of the public transport operation resulting from financial issues; a conservative and poorly flexible way of the transport management by the organisers. For a few years the volume of transport in the urban transport has been maintaining on a similar level of less than 4 billion passengers a year, with a slight downward trend, while at the beginning of the systemic transformation this figure was nearly twice larger. In mid-1980-s this value was higher than 9 billion passengers a year [4].

It is not an easy job to stop the unfavourable process and to reverse the current trend. Apart from substantial financial expenditure related to the reconstruction of vehicles guaranteeing the expected quality and comfort of travelling, it is also indispensable to develop a comprehensive and consistent transport programme adapted to the residents expectations, and to start activities promoting the public transport as the most economic and ecological.

The pursuit to raise the public transport quality to such a level, to make it competitive with the individual cars, should be the overriding objective. The public transport must be competitive primarily in terms of the travel time and cost.

The European Union pressure on the promotion of ecological means of public transport development, translating into sources of financing under the Infrastructure and Environment projects of the National Cohesion Strategy, allowed among other things for further expansion of the trolleybus network in this city.

Because of the EU financing under the project implemented by the Tramwaje Śląskie 'Modernisation and expansion of the tram and trolleybus infrastructure in the Upper Silesian Conurbation together with the accompanying infrastructure', in which the city of Tychy is a partner, the authors of this paper have prepared the concept of the traction network development and of starting new lines, and on its basis the documentation for the trolleybus traction modernisation and expansion. Tychy is one of municipalities, which has noticed this increasing problem and made steps to create a consistent urban transport, which could be an alternative to private cars.

The task financed by the EU funds comprised also the part related directly to the traction network and

2012	kWh/km	2013	kWh/km	2014	kWh/km
1	2,932	1	2,954	1	2,306
2	3,016	2	2,834	2	1,956
3	2,510	3	2,631	3	1,766
4	2,328	4	2,036	4	1,641
5	2,050	5	1,689	5	1,551
6	2,026	6	1,502	6	1,469
7	1,900	7	1,439	7	1,369
8	1,893	8	1,426	8	1,398

Table 1. Specification of energy necessary to travel 1 km

	vehicles	traction	all
june	25,84%	2,20%	27,47%
july	24,26%	4,89%	27,96%
august	24,66%	1,98%	26,16%
mean	24,92%	3,02%	27,20%

Table 2. Obtained energy consumption savings

trolleybuses – the construction of two multi-storey car parks and of a modern bus station with two platforms intended just for trolleybuses, which are one of the integrated public transport links – connection of the trolleybus and bus lines with the fast city rail and the car transport within the 'park and ride' philosophy aimed at the reduction of bus and car transport – mainly between Tychy and Katowice, which is the capital city of the region and of the Katowice conurbation – the biggest urban organism in Poland.

Multi-storey car parks were situated in nodal points, where the fast rail, bus and trolleybus lines intersect. Because of the railway connection start, two out of four bus lines between Tychy and Katowice were cancelled, and the number of journeys went down from 220 to 172 per day (i.e. 22%). Through convenient connections, modern and comfortable vehicles as well as the adaptation of the trolleybus and fast city rail timetables in such a way that the waiting and transfer time would be optimal, a gradual but clear trend in the social behaviour has been observed. Residents more and more often choose the trolleybus – train connection than driving an own car and do that with full conscience, for own comfort and respect for environment, and not due to a lack of car or problems with the fuel, like it was in the past.

The undertaken actions have perfectly integrated with the idea of sustainable development in the field of transport and with the National Transport Development Strategy, which determined five main objectives to be accomplished by 2030. These include: creation of modern and consistent transport infrastructure and reduction of adverse environmental impact of the transport. Moreover, the increase in the number and share of passengers using the public transport in big cities and their functional areas by 2020 was considered the most important objective in the field of urban transport, which is aimed at the reduction of congestion. Also the European Commission indicated the most important guidelines for the urban transport systems formation. They include: special care of the natural environment, the use of intelligent urban transport to improve the ef-

Photo Arkadiusz Ławrywianiec

Modern trolleybus on the streets of Tychy - June 2017. Photo - the intersection of kard. S. Wyszyńskiego and al. Niepodległości streets

ficiency of transport activities (creation of conditions for various modes of transport integration through the intermodal systems implementation – transfer nodes, 'park and ride' systems) [5].

The design of the performed modernisation comprised the replacement of the trolley wire together with the whole network accessories, including the wire switches, and also a change of the traction network configuration and operation mode. The aforementioned network components were constructed in the years 1982-1983, i.e. they were more than 30 years old. The applied technical measures were aimed at the reduction of network losses, of noise emission, and also at the improvement to the passengers travel comfort. The scope of modernisation covered a traction section approx. 6.5 km long, that is approx. 28% of the entire network. The Solaris Trollino 12MB trolleybuses purchased within the EU project were equipped with two STH600 x 84 nickel-cadmium traction batteries of 60 Ah capacity and the voltage rating in total of 202 V DC. The batteries were installed in the rear part of vehicles, without limitation of the passenger space. The batteries enable the trolleybuses to move without the trolleybus traction. The application of nickel-cadmium batteries may raise concerns, especially in so ecological means of transport as the trolleybus. The applied batteries are manufactured in accordance with the LCA and after the end of life the batteries are returned to the manufacturer in accordance with the carried out bring-back programme and cadmium from electrodes is processed in a pyrometallurgical process (SNAM-SAVAM) into cadmium oxide and installed again in the form of an electrode as a part of a new battery. In the initial period the use of batteries was planned only in emergency situations, e.g. leaving an intersection after the supply voltage failure or during the service. The operational experience, the measurements and analyses performed allowed to determine the route possible to drive by a trolleybus without the traction, assuming the optimum conditions of the battery operation (charging-discharging), which enabled starting alternative routes for the time of road works and traction modernisation, and the trolleybus transport became more flexible.

Also the experience, gained by the other two urban transport companies operating trolleybuses – in Lublin and Gdynia, was used [6]. A route possible to drive at a passenger load typical of the analysed route (50%) and lay of the land amounts to approx. 2.5 km. The time of quick charging from the level of 25% to 100% is 98 minutes. Unfortunately the carried out studies and measurements have shown that the battery capacity does not allow to start permanent routes on the streets not equipped with traction. The control system, apart from the drive and lighting, disconnects the other energy receivers including heating and air conditioning, which is especially troublesome in frosty winters and in hot summers. During braking the power transmission system of new trolleybuses switches from the engine work to the generation. The recovery of mechanical energy during the vehicle braking is the issue widely used in electric and hybrid drives. The energy gained during braking is used to very small extent to charge own batteries and the majority is transferred to the network. However, the network capacity to receive energy is limited and in fact it depends on the number of specific line vehicles, which can receive the generated energy and on the instantaneous state of their work. The lack of possibilities to return the energy to the distributor power network results from the traction supply system via rectifier stations. The measurements of the power transmission system operation have shown that the braking – generation time is approx. 11% and this is much more than in the case of railways or metro, due to the nature of the street transport, entirely different from the rail transport. Also the transmission losses between the trolleybuses generating and receiving the energy are difficult to estimate. The following table presents a specification of the average value of energy necessary to travel one kilometre between January and August in the years 2012-2014.

The number of kilometres travelled monthly slightly exceeds 100,000 km. New vehicles were introduced from April 2013, while the replacement of one trolley wire was completed in April 2014.

The analysis of the performed modernisation energy efficiency has shown a reduction of electricity consumption as a result of vehicles replacement at around 24%, while in the case of carried out traction modernisation at approx. 3%.

The energy consumption savings in the case of vehicles replacement result mainly from the systems of energy recovery during braking (92%) and the installation of asynchronous a.c. motors supplied via inverter systems, having very good regulation capabilities (8%). Similar values of the energy consumption reduction with the use of recuperation systems have been achieved in the public transport companies in Rotterdam, Zurich, Vienna, Stockholm and Bremen (*Clean bus procurement* – EU Workshop 11-

12 December 2013). The traction modernisation limited the network losses resulting from the electricity transmission (mainly the Joule losses). Table 2 presents percentage values of the obtained energy consumption savings.

Taking into account the entire annual energy consumption in 2012 equal to 3038 MWh, the estimated annual energy savings are as follows: 90 MWh (traction modernisation) and 760 MWh (vehicle replacement), while the obtained ecological effect (reduced annual emission) is as follows: 34 kg - particulate matter, 538 kg - sulphur dioxide, 670,650 kg - carbon oxide, and 338 kg - nitrogen oxides. The emission reduction was calculated based on the information on the electricity generation environmental impact in the field of emission volume for individual fuels and other primary energy carriers used to generate electricity sold by the supplier.

Although the savings of approx. 3%, obtained as a result of the traction network modernisation, were on the expected level, but they also became an impulse for the next analyses aimed at further reduction of network losses. During the first stage the course of a network rectifier load was measured for two configurations of the vehicles traffic. In the first case the course of current was registered for the line on which two trolleybuses were moving (during a normal journey on a holiday), in the second case one vehicle was moving (without passengers during the night hours). The registered courses illustrate the traction network load featuring very high unevenness and significant current surges related to the vehicle start and its acceleration.

Based on the obtained measurement results it was justified to estimate the achievable energy consumption savings consisting in the limitation of current surges and to develop a method for those surges minimisation, and also to apply solutions enabling a more effective use of the energy generated during braking.

Also a significant reduction of energy losses originating in the drive supply circuits is an advantage of the reduction of the peak value of the current received and returned to the network. The application of an ultra-capacitor energy-storage device may be one of possibilities [7-9].

Final conclusions

The modernisation and expansion of the trolleybus network in Tychy is a good example of a pro-ecological investment in the field of public transport and perfectly refers to the regional project 'Trolley' promoting trolleybuses as a solution for intelligent transport in Europe [10-11]. The application of novel solutions in the field of traction construction and the use of modern trolleybuses equipped with traction batteries and generation systems allowed to achieve the intended effects related to the environmental protection – the energy savings and the reduction of emission – in particular of CO2. The positive experience gave the green light to the next investment, planned for 2018 – the construction of a new section of the trolleybus traction together with a rectifier station and the purchase of three new trolleybuses with a battery, enabling to service a new line 'G' - partly without the traction.

The purchase of two electric buses and the construction of three points for charging from the trolleybus tractions will enable replacing buses on line No 291 with electric vehicles.

The carried out measurements and the analysis of the traction network load nature and also the estimation of the network losses originating from the current surges resulted in making the decision to undertake further studies on the possibility to use an ultra-capacitor energy-storage device in the trolleybus power transmission system. This will allow to improve the conditions of the traction network operation through the limitation of peak currents; the reduction of energy consumption, which will result from the applied solutions, is estimated at approx. 3%. ■

Artur Cywiński | *Design Office omega-projekt sp.j., Ph.D. Student at the Faculty of Electrical Engineering, Częstochowa University of Technology*

Zbigniew Brud | *President of the Management Board, Tyskie Linie Trolejbusowe Sp. z o.o.*

References

1. Załuski K., *Lubelskie Trolejbusy (Trolleybuses in Lublin – in Polish)*, print from the City Communication Company in Lublin.
2. Kaczmarek R., *Tychy – monografia Miasta* 2010.
3. Jackiewicz J., *Trolejbusy w Tychach 1982-2003,* materials of Tyskie Linie Trolejbusowe.
4. Borowik, L. Cywiński A., *Modernization of a trolleybus line system in Tychy as an example of eco-efficient initiative towards a sustainable transport system.* „Journal of Cleaner Production", No 03/1016, pp. 188-198.
5. Cywiński A., *Projekt modernizacji sieci trakcyjnej w Tychach,* report of TLT Sp. z o.o.
6. Hamacek S., Bartłomiejczyk M., Hrbač R., Mišak S., Stýskala V., *Energy recovery effectiveness in trolleybus transport.* „Electric Power Systems Research" 112, 2014, pp. 1-11.
7. Chlodnicki Z., Koczara W., *Superkapacitor storage application for reduction drive negative impact on supply grid,* in Proc. Compat. Power Electron. 2005, pp. 78-84.
8. Grbovic P.J., Delarue P., Le Moigne P., Bartholomeus P., *The Ultracapacitor-Based Regenerative Controlled Electtic Drives With Power-Smoothing Capability,* „IEEE Transactions of Industrial Electronics", 59 (2012) No 12, pp. 4511-4522.
9. Giziński Z., Gąsieski M., Giziński P., Żuławik M., *Zasobnikowe układy zasilania w pojazdach trakcyjnych, Pojazdy Szynowe,* 3(2011), 125-133.
10. *Rulaff M., Projekt trolley jako przykład promowania ekologicznego transportu publicznego, „Zeszyty Naukowe Politechniki Poznańskiej" No 60/2016.*
11. *www.trolley-project.eu*