Transactions on the Built Environment vol 16, © 1995 WIT Press, www.witpress.com, ISSN 1743-3509

Supply system of Warsaw Tram Company – present state and outlook for a new century

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Abstract

The main means of mass transport in Warsaw are trams. Warsaw Tram Company operates the largest urban electric transport network in Poland. Six hundred fifty street cars are on service every day (from nine hundred being on stock) on one hundred sixty kilometres of lines. A commercial speed reaches 20 km/h and maximum traffic capacity of a single route in rush hours is ninety cars per hour.

Fortunately in Warsaw tram lines were intensively used in sixties and seventies, even so it was an opposite to a general trend in the world, where trams were abandoned and changed by buses or cars. So nowadays it is easier to revitalize its role in the city mass transport system.

The paper presents the present state of the supply system of the Warsaw Tram Company and the perspectives, as changes in economic system in Poland creates new demands for electric transport system in Warsaw. Problems with financing new projects to expand the tram lines, buy new cars and equip the substations with new devices (low-current fault detectors, remote control etc.) become evident. But, from the other way now it is an easy access to new high more efficient technology from different foreign companies. The outlook for the supply system improvement, with taking into account the results of study work which were carried out with co-operation of Warsaw University of Technology Electric Traction Group is enclosed. Some results of the study works (measurements, simulation experiments) are presented [1-8]. The modification of the system is treated as a long term investment in Warsaw, where strong needs for better, safe and environment friendly service of electric urban transport has to be fulfilled by a widely spread network of trams, one line of trolley-buses, suburban railway and the first line of underground. The last one will be put into service from the beginning of 1995.

1. Warsaw trams supply system history and the present

In 1905 year Warsaw Tram Construction Committee was established, which decided to build their own power station for supplying energy to the constructed new lines of trams. The decision was undertaken after taking into considerations an alternative:
- supplying energy from Warsaw Power Station (owned by Electrical Society) and then converting a.c. voltage to 0.6kV DC in tram traction substation using rotary converters (mercuric rectifiers weren't known yet);
- building new power station for straight supply of DC 0.6kV energy (its rated power by 1939 year reached 10,5 MW).

Quite apart from this power station between the First and the Second World War there were three mercuric rectifier traction substations built (with total rated power of 16,7 MW) supplied from Warsaw power station. First trams were energized from the power station 26th of March 1908. After the destruction during the Second World War the supply system of Warsaw Tram Company have been being intensively reconstructed, developed and used for increasing number of street cars and traffic. It was rather against the general trend in the world, where tram lines were liquidated.
Nowadays it is opposite, due to revitalisation of trams as environmental friendly means of transport, interest in street cars is world-wide increasing.

The present electric transport system in Warsaw, the capital city of Poland with the population over 2 millions consists of (Fig. 1):
- tram lines,
- trolley-buses (one 14km long line, 3 traction substations),
- suburban tram (EKD),
- first line of underground (in construction),
- suburban railway lines.

However, the main means of electric transport in town is street-car, which overhead catenary supplying energy to trams is spread through Warsaw and is characterised as follow:
- 81 km of flat and 192 km of multiple contact line,
- 7000 overhead catenary posts,
- 41 traction substations equipped with 151 (3-4 at each substation) 6- and 12-pulse diode rectifiers have total rated power of 120.8 MW, which makes 75% of tram cars' rated power during rush hours,
- 432 km of feeder cables, total number of feeders - 320, usually 8 feeders in each substation, an average section of the catenary supplied by one feeder has 1.2km, the feeder cables are connected to the overhead catenary in 324 points (typical feeding scheme: an unipolar supply),
- 360 km of return cables, which are connected to running rails in 214 points.

A failure frequency of different supply system equipment in 1994 is set in Table 1.

Transactions on the Built Environment vol 16, © 1995 WIT Press, www.witpress.com, ISSN 1743-3509

Figure 1: A scheme of electric transport system in Warsaw.

tram lines

first line of underground (operating from 1995)

underground line under construction

suburban tram (EKD)

suburban railway

Table 1 Failure frequency of the tram supply system.

	overhead catenary	supply system			
	on line	crossings, switches, insulators	cables	substation a.c. equipment	high speed circuit breakers
number of failures	40	27	5	24	11
time of failures [minutes]	1672	1472	214	1750	263

It should be pointed out, that the tram track in 80% is separated from the streets. But the fact, that running rails, used as a return conductor, have low resistance to the ground, creates problems with the stray current protection.. The problem was profoundly examined in the project [5], where stress was put on decreasing voltage drops in running rails by uniform reconstruction of the return cables network and the points of connection the return cables to the running rails, and proper maintenance of rails and their parallel bonding. The specialized software, allowing simulation of the whole supply system with taking into account the rail-earth resistance was used.

The feeders are equipped with high speed breakers Wse and BWs (nominal current 3kA and braking current 40 kA) with asbestos-free extinguishing chambers manufactured by Apena (Poland).

Due to the fact, that the feeding sections and the feeder cables are not very long, the short-circuit resistance for long-distance faults in overhead catenary is low enough to allow high speed breakers to identify properly short-circuits currents from loads (Fig. 2- two short-circuit currents recorded in the traction substation feeder). Electric Traction Group invented a short-circuit detector [2], but as a result from the analysis of supply system parameters and load of feeders it appeared that there is now no need for installing that kind of device.

Power to the traction substations is supplied via 15 kV AC (mainly cable) lines with an average short-circuit power at the point of common coupling 100 MVA. It is well enough not to influence any other energy receivers connected to the same AC busbars by harmonics and quick current changes produced by substations' rectifiers.

In order to keep the supply system functioning there are 11 tower wagons and one fitting wagon in service with the total number of 240 staff working on power supply system operation.

The technical parameters of the supply system of Warsaw Trams were analyzed in the project [5]. The objective of the study was to check operating conditions of the supply system, the load of substations, voltage drops and energy losses in the contact line, the level of the stray currents impedance, breaking short-circuits and finding weak points in the supply system, which could limit the traffic capacity of lines. The results of the project were used to upgrade the supply the system and improve its reliability and efficiency.

2. Rolling stock

The rolling stock operating in streets in Warsaw is rather old-fashioned and a typical street-car is in service for over eighteen years, while the normative age is about seventeen. There are three models used: 13N (the oldest), 105N and 106N cars (manufactured by Konstal, Poland) connected in two-car trains. Body of all wagons are based on PCC type construction, with doors on one side. Further technical data of 105N car are as follow:

arrangement of axles:	4 motored axles on two boogies, BoBo
length:	13500mm
floor height	890mm
tare weight	16,5 t
seated capacity:	20
standing capacity	63 (4 persons/1 m2)
motor power	4 x 40 kW
maximum speed	72 km/h
maximum acceleration	1,4 m/s2
noise inside (outside)	75 (85) dB

Type 13N cars (with a barrel starter) and 105N (with a switching starter) are equipped with rheostatic control during starting and a switch-over of motors' groups while 106N car has chopper control unit and ability to regenerate energy during a deceleration. A typical recorded regenerate cycle of 106N wagon is presented in Fig.3. During the research project undertaken by Electric Traction Group of Warsaw University of Technology [1,5,6] quite apart from measurements on board of trams, energy consumption of tram cars for different traffic conditions were analyzed with simulation methods. Exemplary results of the study - a curve of unitary energy consumption as a function of distance between tram stops, with taking into account street lights, are shown in Fig. 4.

3. Energy consumption

The present technical status of the supply system fulfils all the requirements for energy supply to the trams. The voltage drops don't exceed 10% (equivalent) and the loads of the substations are below their load capacity. The ordered histograms of the instantaneous load of the traction substations according to their load capacity are shown in Fig. 5.

The traction substations are a great energy consumer and in 1994 they used 129 GWh energy with tg fi 0.15 to 0.38. An average cost of 1 kWh of energy in 1994 was 0.04 $. The receipts from tickets covered 65% of expenses for functioning of the Company. Energy losses in the each of the traction substation supply section didn't exceed 5% (in the case with the largest supply sections). The total traffic service supplied by the trams was 42,3 Mln car km. These figures spread into the months are shown in Fig. 6. An average unitary energy consumption (calculated from the global energy consumption and the traffic service) for 13N cars was 2,8 kWh/car km while 3,45 kWh/car km for 105N wagons.

4. Outlook for the new century

From the beginning of the 1995 there is a revolution in mass transport in Warsaw expected as the first part of the first line of the underground is to be put into service with the whole line finished by 2000. Next line of underground will cross the Vistula river (planned to operate by 2010) and will be oriented parallel to existing suburban railway lines. So in next 5-15 years in the city centre, in main transport routes, trams will still be used as main means of transport. In the outskirts of the city the trams will be used as well as the buses, trolley-buses and suburban railway. Strategic plans to extend the role of trams in the peripheral parts of the town exists, while in the city centre the underground will take over the role of mass transit leader from the trams.

Modernization of trams in Warsaw will include firstly the rolling stock, among them ordering new articulated and low-floor wagons with DC motors and choppers, AC drive or modernization of existing wagons will be reviewed. The price of a new articulated low floor tram manufactured in Poland is several times cheaper then the price of wagons built by the leading manufacturers in Europe. The new trams should be equipped with a high speed circuit breaker on board, as some failures were caused by short-circuits originated in the rolling stock main circuit. The use of cars with regenerative energy equipment will give significant energy savings, but the efficiency of the regenerative braking will be higher when inverters are installed in traction substations. As it is known from the experience in other traction systems, it is a very costly solution and its effectiveness strictly depends on the crossection of the overhead catenary and the feeder cables. The introduction of bilateral feeding, examined during the project [8], will give in some sections another energy saving due to lower losses and longer sections for regenerative energy between the trams. In the traction substations 6-pulse diode rectifiers will be gradually changed by 12-pulse ones. 20 traction substations are now equipped with an old type remote control system and there was warding contract by tenders undertaken in 1994 for supplying equipment to build a new load-dispatching unit with monitoring and remote control of power supply to the all traction substations. The introducing this project will give significant economic results (all the substations will operate without staff) and improve the reliability of the supply system. Due to the high costs of this investment it will take about ten years to finish the project. For purposes of proper maintenance of the overhead catenary specialized equipment (diagnostic and measurement wagons etc.) is needed and using new catenary fittings and insulators will lower the failures in this, nowadays the most vulnerable to damages part of the supply system.

All above mentioned aspects, undertaken very difficult circumstances of an economic transformation era, will warrant that Warsaw trams will be revitalized to the role of main means of mass transport in the twenty first century.

Acknowledgements

The authors wish to thank the Warsaw Tram Company for supplying information used in this paper.

Bibliography

1. Mierzejewski L., et al, Reliability, availability and energy saving in electric traction systems for urban agglomerations. *Grant KBN 8S 502 03005,* 1993-95
2. Analysis of short-circuits in supply system of Warsaw Tram Company *Research work (not published)*, Warsaw, 1994.
3. Analysis of proposed solutions of remote control and monitoring of tram power supply system of Warsaw Tram Company. (not published),Warsaw 1994.
4. Mierzejewski L., Szeląg A., Strawiński W. - Implementation of simulation for calculations of trams supply system. (in Polish), *Transport Miejski,* 8/1987.
5. Mierzejewski L., Szeląg A., Drążek Z.-.Analysis of functioning and recommendations for modernization of DC tram supply system of the Warsaw City Transport Company. *(work for the Warsaw Tram Company).* 1985-1987.
6. Mierzejewski L., Szeląg A., Drążek Z.-New methods of DC tram supply system design.(not published). *Research work of Electric Traction Group,* Warsaw University of Technology. 1986-1990.
7. Mierzejewski L., Szeląg A., Drążek Z.- Analysis of functioning and recommendations for modernization of DC tram supply system of the Elblag City Transport Company ,*(work for the Elblag City Transport Company),* 1987.
8. Mierzejewski L., Szeląg A., Drążek Z. -Principles of bilateral DC supplying network for trams and trolley buses in Poland. *Research work of Electric Traction Group, Warsaw University of Technology,* (not published), Warsaw, 1989.

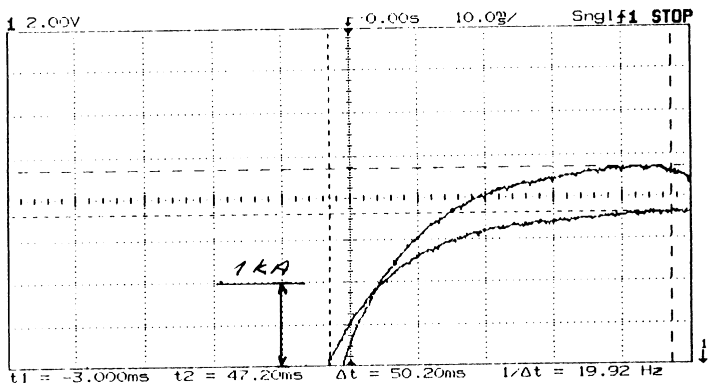

Figure 2: Two short-circuit currents of a feeder
(two different positions of a fault point).

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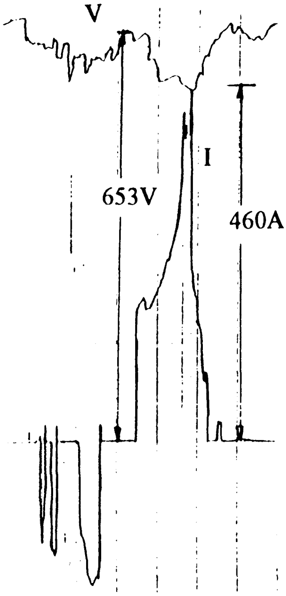

Figure 3: Regenerative braking current I and voltage V of a 106N car.

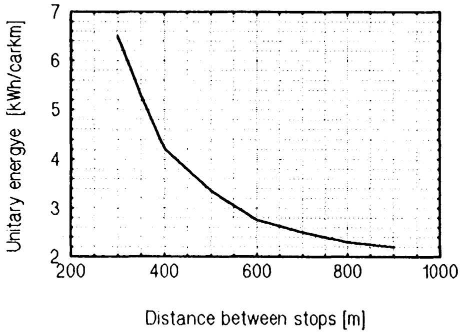

Figure 4: Unitary energy consumption of a tram car as a function of distance between stops.

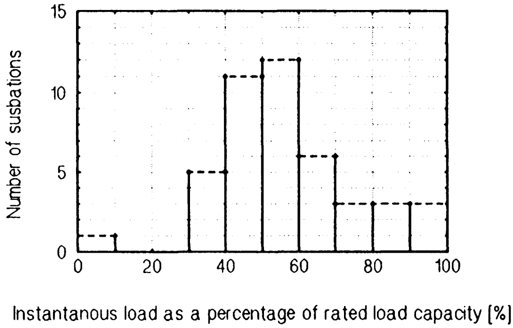

Figure 5: Ordered histogram of a number of substations according to their instantaneous load.

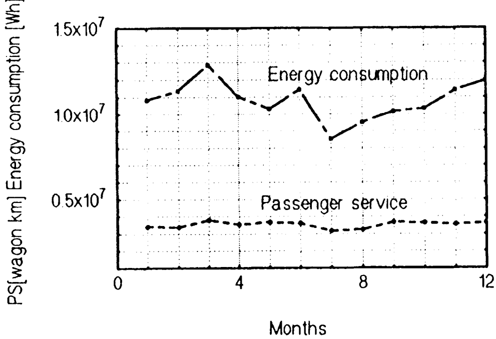

Figure 6. Tram passenger traffic service and energy consumption in 1994.