Output 3.3.6: Reference Guide on Trolleybus-Tram Network Use

Examination, Assessment and Documentation of Synergetic Effects between an Electric Urban Bus System and a Tramway System

Study for LVB, Leipzig: Erection of New Electric Bus Systems or Retrofit to Electric Bus Systems

on behalf of

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TABLE OF CONTENTS

I Objective of the Examination

As the energy costs, especially for fossil fuels like diesel, petrol and gas, increase and as the operating costs have to be reduced, the operators increasingly focus on alternative drive concepts. Moreover, they have to set trends in view of the present and growing environmental problems – keywords: fine dust, climate change, greenhouse effect.

Transport companies, which have much experience in procuring, servicing and maintaining tramways and tramway facilities (vehicles, workshops, overhead contact lines, power supply installations), already have broad expertise in handling electric components, which is also relevant to the operation of electric buses. Therefore, the Leipziger Verkehrsbetriebe GmbH (LVB) is well placed to introduce the operation of electric urban buses.

Electricity can be generated in many different ways. In the ideal case it is generated from regenerative sources of energy, but even if fossil sources of energy are used, pollutants can be filtered better centrally in the power station than decentralised in many internal combustion engines. Thanks to state-of-the-art power electronics braking energy can be recuperated from electric buses as well as from light rail vehicles and tramcars. Moreover, there are synergetic effects in Leipzig as the power supply for the tram lines and the lines of electric buses is combined, which also means that the braking energy of electric buses can be used for the tramcars and vice versa.

It is the objective of this EU project to compile a “compendium”, in which all possible synergies between an electric urban bus system and a tramway system are examined, assessed and documented – with reference to the actual situation in Leipzig, but also to other transport companies in a generalising way.

II Initial Situation / Task

In Leipzig there are good conditions for retrofitting the present bus lines to the operation of electric urban buses. As the present public transport network is a combination of bus and tram lines, the Leipziger Verkehrsbetriebe GmbH (LVB) has extensive knowledge with the procurement, operation, servicing and maintenance of electric components (of the vehicles, power supply installations, overhead contact lines, workshop equipment etc.). There will probably be additional synergetic effects with the present tramway network because it will be possible to combine the power supply systems of the bus system and the tramway system. The keyword is recuperation.

The LVB has initiated a thorough examination of the (re-)introduction of trolleybuses in Leipzig. In this connection it has applied successfully for participation in the “TROLLEY” project of the EU.

This project is divided into five activity packages (AP):

AP1 Market Overview

In this activity package the present state of development of the world’s electric urban bus systems and their components is described – particularly with a view to the supply of energy and the storage of energy in the vehicle. Moreover, the operational quality and the future development are assessed. A special aspect is the combination of different, electrically operated transport systems and the resulting synergies.

- Development of electric bus systems worldwide
- Overview of combined systems (electric bus + electric rail)
- Technical solutions for the supply of traction power
  - … from the public energy network (AC)
  - … from substations (DC)
- Supply to charging points
- Technical solutions for the transfer of energy into the vehicle
  - Overhead contact line/pole
  - Charging point
  - Induction
- Technical solutions for storage of energy in the vehicle
  - Battery

- Supercap
- Flywheel

AP2 Theoretical Requirements / Comparison of Technologies (Infrastructure)

In this activity package electric urban bus systems are described comparatively and it is explained how they differ in respect of the supply and storage of energy.

An important aspect is the examination of the possibilities of combining different electric power supply systems in a city.

Finally, the measures are assessed in respect of their sustainability.

- Dimensioning and capacity of the infrastructure
  - Overhead contact line (continuous, in sections)
  - Charging points at stops
  - Charging points in the depot
  - Substations
- Combining the urban system with the public transport system
  - Rivals or partners
  - Double networks
  - Competitors for the available space
  - Future requirements
  - Uniformity / peak loads
- Operation management and incident concepts
  - Redundancy
  - Accessibility
  - Safety
- Sustainability
  - Future proof
  - Available resources
  - Environmental compatibility
  - Acceptance

AP3 Economic Efficiency

In this activity package the relationship between the necessary investments and the expected benefit is examined. This benefit mainly results from the energy and operating costs, which are lower for electric urban bus systems than for the bus systems operated at present.

- Minimum requirements for the economic efficiency
  - Vehicle capacity
  - Demand
  - Operating procedure (cycle)
- Investments
  - Power supply installations
  - Networks
- Operating/maintenance costs (LCC)

AP4 Practical Application Exemplified by Leipzig (Line 70)

On the basis of the ascertained theoretical requirements the existing infrastructure for the supply of an electrically operated urban bus line (line 70) with power is examined in this work package in respect of the possibilities of adaptation and the necessity of expansion as well as in respect of the possible synergies with the tramway operation.

For this purpose the requirements for an electric urban bus system are drawn up using the example of line 70 in Leipzig. Moreover, the feasibility is assessed and the costs and savings of energy costs are estimated.

Finally, the possibilities of financial support for the procurement of vehicles and for erection of the infrastructure are assessed.

- Operational requirements
  - Demand
  - Cycle
  - Operation of vehicles
- Scenarios for comparisons
- Analysis of status quo
  - Existing infrastructure
- Need for adaptation

  - Reconstruction of substations / construction of new substations
  - Line routes
- Simulation of the current consumption per scenario
- Investment
- Effects
  - Maintenance
  - Staff
  - Operating costs

AP5 Summary / Result

When the above mentioned issues have been dealt with in detail and assessed monetarily, the results are summed up by Rail&Bus to a consistent recommendation with a high degree of details.

- Recommendation for Leipzig
- Transferability to other cities in Germany / Europe

III Work Packages

III-1 AP1: Market Overview

III-1-1 General

The offer of electrically operated urban bus systems develops dynamically at present. The below market overview aims at describing the situation in the summer of 2012. It seems that no fundamentally new systems are being developed at present. Instead the existing systems described below are improved and developed constantly.

In the below chapters names of manufacturers are also mentioned, but no claim to be absolutely complete is made as a certain degree of fluctuation, i.e. establishment of new companies, changes of name of companies and mergers of companies, does not allow a final compilation. Thus, the mention or non-mention of a company does not have an evaluative character at all.

III-1-2 Description of the Technologies

As regards the development of urban bus systems with components for electric energy supply and electric vehicle drives distinction can be made between the following basic types at present:

1. Hybrid bus
2. Battery bus or supercap bus . . .
    a. . . . being recharged when parked (plug-in)
    b. . . . being recharged inductively in the non-operating time
    c. . . . being recharged conductively when staying at stops
    d. . . . with exchange of batteries in the non-operating time
3. Trolleybus . . .
    a. . . . with a continuous overhead contact line
    b. . . . with an overhead contact line in some sections (hybrid electric)
4. Fuel cell bus
5. Inductive current transfer during the operation

6. Flywheel

Nearly all vehicle types have to be able to store energy on board, either by way of a battery, which can provide much energy for quite a long time, but has a long charging time, or by way of ultracaps (= supercaps), which can be charged extremely fast, but have to supply the stored energy as fast as possible. Therefore, it is important by the introduction of electric urban buses to harmonise the energy storage unit (size, weight, capacity) to the basic technology and the intended operating schedule. For optimisation an energy storage management system is needed, which controls the charging and discharging of the energy storage unit as well as the supply of the consumers so far that it even switches off selected secondary consumers to ensure that the next charging point is reached (incident management).

III-1-3 Hybrid Buses

Hybrid buses are designed as parallel or serial hybrids. Nearly each and every manufacturer of urban buses now sells vehicles with hybrid drive concepts and in several sizes (midi, solo, articulated and partly even double-articulated). The internal combustion engine can be either a diesel engine or a gas engine. Besides the electric motor the hybrid bus has an energy storage unit so that it can store the braking energy.

Volvo has announced a plug-in hybrid bus with a fuel consumption that is as much as 60 to 65 % lower than that of the diesel bus. The idea of plug-in is that the bus can go onto the line with a charged battery, which is recharged during the journey by way of recuperation and for several minutes at the terminal stops.

Volvo states that this plug-in hybrid bus can be operated fully electrically for 10 – 20 km as the capacity of the batteries has also been increased to about 40 – 45 kWh. The diesel engine then only performs subsidiary activities within the power train. In November 2012 a field test with three vehicles is to begin in Gothenburg. Volvo intends to build the plug-in hybrid bus in a modular design and even to equip it with double battery capacity, if desired by the customer. An articulated hybrid bus is also being planned on this basis.

The operation of hybrid buses does not differ fundamentally from the operation of standard diesel buses. The workshops have to be adapted to the maintenance of electric components and the staffs have to be trained for this kind of maintenance. Meanwhile, hybrid buses are often the introduction to bus technologies with electric components, but most often the expected fuel economy is not achieved. They are probably a bridging technology on the way to the electric urban bus and will be replaced as soon as useful drive technologies without diesel engines are ready for series production. Hybrid buses are not of further relevance to this study.

III-1-4 Battery Buses

As regards **battery buses** distinction has to be made between several types of operation:

- Battery buses without interim charging (only charging in the depot in the non-operating time)
- Battery buses with interim charging at terminal stops and perhaps also at some stops along the line
- Battery buses with interim charging at every second/third stop
- Battery buses with exchange of the batteries

The main problem of all battery buses is the capacity of the energy storage unit. The interaction between size, weight, thermal behaviour and capacity has to be optimised. According to the state of the art a battery bus can only drive up to 250 km without being recharged. This range is much shorter that of diesel buses. Therefore, this technology is no good for heavy urban bus transport, and at present nothing indicates that the battery technology can be improved decisively.

This problem can only be overcome by interim charging of the battery. There are various technologies ranging from plug-in (plug/cable) to inductive charging (e.g. Turin) via trolley poles (e.g. Vienna). Usually, there is enough time and space for the interim charging at a terminal stop. At a new installation in Brunswick inductive interim charging is provided at some stops with relatively long halts for the boarding and alighting.

In China (Shanghai) electric urban buses are operated that are being charged at every second or third stop. However, in most cases such a procedure would prolong the journey times in Europe as the buses would have to stay longer at many stops than necessary for the ordinary boarding and alighting.

The more often interim charging is possible, the smaller the energy storage unit can be dimensioned. However, it also has to be considered that the life of the energy storage unit depends on the frequency of the charging cycles and the degree of charging and discharging. If an energy storage unit is operated constantly between 100 % and nearly 0 %, its capacity is going decrease considerably after approx. 3,000 charging cycles. If the charging condition mainly ranges between e.g. 70 % and 90 %, the life and the number of partial charging cycles increase significantly.

At present, mini/midi buses (less than 9 m long) and urban buses of standard sizes are operated as battery buses.

Whereas mini/midi buses are being manufactured in small series by several manufacturers for inner city areas, urban buses with a length of 12 metres are still seldom and are mainly being operated for test purposes. Articulated buses with battery-electric drives are not available yet.

At present, the following manufacturers offer minibuses:

Allied Vehicles	Reconstruction on the basis of Peugeot
Breda Menarini	“Zeus” minibus
EcoPower Technology	Minibus with inductive recharging (Turin, Genoa, Lörrach)
Group Gruau	Microbus Electrique
Spijkstaal	Electric bus
Tecnobus	“Gulliver”, also as a fuel cell bus
Véhixel	Aptinéo Electric (reconstruction of Iveco Daily)
Xenova	“Terryman”
ZEV	Reconstruction of Mercedes “Sprinter” and Renault “Master”

Vehicles with the character of urban buses are offered by:

BYD	eBUS12 – the only real urban bus with battery operation on the busworld 2011 in Kortrijk
Contrac Cobus	e2500 – test vehicle for Porto / Offenbach / Wiesbaden

Dongfeng Motor Co	Tianyin All Electric Bus
Krystal	EVolution KK38 – test vehicle for the US market
Opbrid	“Arctic Whisperer” – electric bus on the basis of Volvo with a trolley pole for interim charging (Umea, Sweden)
Optare PLC	Solo EV
Sinautec	Ultracap bus with 42 seats for Shanghai
Solaris	Urbino Electric – 12 m long test vehicle
SOR	EBN 10.5 – test vehicle for Ostrava
Viseon	12 m long bus for Brunswick (Primove)
Yutong	PURE Electric Bus – In Kortrijk a coach with this technology was shown, but it can probably also be operated as an urban bus

At present, it applies to all battery bus systems that the battery increases the weight to be carried by the bus relatively much. Moreover, it is problematic that the secondary consumers (e.g. door drives, passenger information systems, lighting and especially ventilation/heating/air conditioning) reduce the capacity of the battery for the traction considerably as they also consume power. Moreover, it is still an open question whether it will be possible to supply sufficient chemical-mineral components of the energy storage units for relatively big bus fleets and, in return, whether they can be disposed of or recycled in an environment-friendly way.

III-1-5 Trolleybuses

The above mentioned problems can be reduced by way of a continuous external power supply. **Trolleybuses** are the most conventional kind of buses operated electrically for the most part. However, they need a suitable infrastructure in the form of overhead contact line systems and power supply installations (substations, cabling), which also have to be maintained. Usually, they are equipped with diesel engines as supplementary drives for the bridging of sections without current.

Classic trolleybuses with diesel engines as the supplementary/auxiliary drives are not discussed below. However, vehicles with electric supplementary drive systems allowing driving in sections without overhead contact line, but nevertheless electric are considered to be interesting in the sense of this study.

At present, such trolleybuses are being operated regularly in Rome on line 90. Moreover, Zurich is now procuring lighTrams with additional battery drives instead of the usual diesel generator sets.

The necessary overhead contact line infrastructure puts off many potentially interested transport companies from the restructuring to trolleybus operation. However, it can be proved that the investments amortize within 20 to 25 years. The optical spoiling is usually a subjective feeling, and alternative power supplies are expensive both in respect of investment and in respect of operating and maintenance costs.

In Europe 27 new trolleybus systems have emerged since 1990 (worldwide 45 systems). Leeds (United Kingdom) and Montreal (Canada) have published plans recently. Up to 14 lines are to be electrified in the Canadian metropolis in the next few years.

III-1-6 Hybrid Electric Buses

Hybrid electric buses can be regarded as a cross between trolleybuses with an additional generator set and battery buses with interim charging as they can charge their energy storage units under the overhead contact line during the journey and thus drive both on line sections with an overhead contact line and on line sections without an overhead contact line. In that way the disadvantages of the trolleybus (i.e. overhead contact line needed) and of the battery bus (i.e. low range) can be overcome by the hybrid electric bus, and an electric urban bus system with overhead contact lines over only about 30 to 50 % of the line emerges. Thus, it is particularly possible to avoid line sections with overhead contact lines …

- in sensitive urban areas in which the overhead contact line itself, but also its suspension at poles or outside walls is regarded as extremely disturbing.
- in areas in which very complicated and cost-intensive crossings and switches would be needed for the overhead contact line.

- in areas with less intensive cycles due to a lower demand, i.e. in areas in which an overhead contact line system would not amortize itself within a foreseeable future.
- in areas in which an overhead contact line system would have to be cut off in case of an emergency because space is very restricted.
- in areas only needed for turning or in case of service interruptions. If necessary, wire engagement devices also have to be provided along the overhead contact lines and not only at the beginning of the overhead contact lines.

It is important to optimise the overhead contact line share to operate the energy storage unit in the optimum range as far as at all possible and to be able to “skip” a charging section now and again.

The following trolleybus manufacturers offer trolleybuses that can be further developed as described above:

Hess	Trolleybus “Swisstrolley” with an additional battery drive for Zurich (test)
	“lighTram” as a platform for a modular electric bus system
Solaris	Trolleybus with an additional battery drive (Trollino 18 for Rome, as test for Eberswalde)
	Urbino Metro Style as a platform for a modular electric bus system
Van Hool	“ExquiCity 12 / 18” as a platform for a modular electric bus system
VDL	“Phileas” as a platform for a modular electric bus system
Viseon	“Elektroliner” - trolleybus with an additional diesel drive, which can be developed to a platform for a modular electric bus system

Some manufacturers are already open to platform solutions that are based on an electric drive concept, i.e. to modular solutions with an internal combustion engine (= hybrid), a trolley pole (= trolleybus), an energy storage unit (= battery bus) or fuel cells.

Furthermore, Siemens announced in May/June 2012 that it is going to develop an overhead contact line system for trucks. The automatic wire engagement during the journey is particularly interesting.

III-1-7 Fuel Cell Buses

At present, **fuel cell buses** are peripheral phenomena as drive concepts. Particularly the FuelCELL Citaro manufactured by EvoBus is well-known. This fuel cell bus has been tested in several European cities and is now mainly being operated in Hamburg and Luxembourg. The Hamburger Hochbahn already tests the third generation of fuel cell buses within the scope of its "SauberBus" (clean bus) project. Further tests, e.g. by the Rheinbahn, Düsseldorf, or the "Vestische Straßenbahn", Herne, with the minibus "Gulliver" from Tecnobus have been stopped by now.

Fuel cell buses on the basis of the "Phileas" from VDL are now being tested in Cologne and Amsterdam.

On the one hand, these vehicles do not need a special infrastructure along the line. On the other hand, the special facilities for filling up the buses with hydrogen and for storage of hydrogen in the depot are relatively complicated. Moreover, these vehicles can also only cover a much shorter range than state-of-the-art diesel buses.

The "AutoTram" project of the Fraunhofer Institute for Transportation and Infrastructure Systems is a special case in this category as the fuel cell drive is combined with guidance and interim charging at stops.

The data of the systems of particular interest to this study are listed in the annex.

Vehicles with hydrogen internal combustion engines are not being operated any more. It does not seem that this technology will be revived in the foreseeable future. However, the electric bus platforms described below under "Trolleybus" are also open to the fitting of this kind of components.

III-1-8 Inductive Current Transfer

In the middle of the 1980s the renaissance of the tramway began in France and several new networks have emerged and are emerging worldwide as a consequence. This development was combined with the wish to be able to do without the overhead contact line at least in some sections. This wish is not as much a technical necessity as a subjective and politically motivated wish. The dislike of “cabling the heaven” is often reasoned by impairment of the townscape, especially in case of historical buildings. In return, technically complicated solutions with much higher investment and maintenance costs are often accepted.

Whereas the current was transferred mechanically in the first systems (Bordeaux, APS), energy storage units are now also being used to bridge sections without overhead contact lines (Nice). At present, Bombardier tests a system with inductive, i.e. contact-free, transfer of energy, both at standstill and during the journey. Unfortunately, it has not yet been possible to present sound statements on the reliability of the system in the long term.

As rail vehicles are guided, it is relatively easy for them to pick up the current with small tolerances between the overhead contact line and the pantograph. In case of bus-based systems the buses would either have to be guided or their batteries would primarily have to be recharged at standstill. As from 2013 the latter alternative will be tested in continuous operation on a line in Brunswick. There are test facilities for the operation with buses in Lommel (Belgium) and Augsburg.

According to the manufacturers (source: stadtverkehr 7-8/2012) these test operations have shown that

- the efficiency is only slightly below the efficiency achieved with overhead contact lines (91% instead of 93%) despite multiple conversion of direct current into alternating current and vice versa and despite inductive transfer,

- the system is insensitive to climatic influences (temperature, snow, sand),

- the load of the passengers with electromagnetic waves etc. is far below the permissible limit values.

Nevertheless, questions still remain:

- Would it be possible to install an inverter (DC -> AC) in normal roads every 8 to 9 metres to supply the induction coils?
- Does a 6 cm thick cover of the induction coils suffice to permanently bear the load of trucks and buses?

Bombardier also tends to only equip some sections with “Primove” and to overcome the sections in between with batteries.

Up to now, other methods of supplying the vehicles continuously with external power via infrastructure fitted in the road instead of supplying them via the overhead contact line have not got beyond the experimental stage.

Example: “Stream” (Ansaldo) in Trieste, the rail fitted in the road should guide buses and supply them with power.

Fig.: Conductor rail for the “Stream” system in Trieste (source: wikipedia)

III-1-9 Flywheel

The idea of storing electrical energy in the form of a rotating disc (**flywheel**) dates from the 1950s, but so far this technology has not really been able to catch on. Two application cases are possible: The flywheel is fitted either in the vehicle or in the substation. It is operated by way of the recuperated current. However, in any case a rotating mass, which has a weight of at least one ton and which moves at speeds up to 900 km/h at the outer edge, has to be controlled.

The technology was revived in stationary applications for the tramways in Zwickau, Dessau, Bremen and Fribourg with systems from Rosseta Technik GmbH. The light rail and metro systems in Hanover and Hamburg also use the flywheel as the energy storage unit in substations. Here the devices are from Piller.

In the annex overviews in tabular form with technical data of the following exemplary systems are found:

No.	Manufacturer	Designation	Town / Operation
1	**Diesel hybrid bus**		
1.01	EvoBus	Citaro G BlueTec Hybrid	Leipzig
1.02	MAN	Lyons City Hybrid	Munich
1.03	Volvo	7900 Plug-in Hybrid	Gothenburg (S)
2	**Fuel cell hybrid bus**		
2.01	EvoBus Mercedes	FuelCell Citaro	Hamburg
2.02	VDL	Phileas	Cologne RVK
2.03	Skoda	TriHyBus	Neratovice (CS)
2.04	Fraunhofer Institute	AutoTram	Test facility
3	**Battery/ultracap bus**		
3.0	**Plug-in in the depot / no interim charging**		
3.01	BYD	eBus 12 (K9)	Frankfurt/M
3.02	Euracom	Eurabus 600	Pinneberg
3.03	SOR	EBN 10.5	Ostrava
3.04	VDL	e-Busz	Rotterdam
3.05	Contrac Cobus	e2500	Porto / Offenbach
3.1	**Plug-in in the depot + interim charging at the terminal stop**		
3.11	Solaris	Urbino Electric	Prototype
3.12	Hyundai	Namsan Tour	Seoul
3.2	**Plug-in in the depot + inductive interim charging at the terminal stop**		
3.21	EcoPower Technology	Elfo	Torino
3.3	**Plug-in in the depot + conductive interim charging at the terminal stop**		
3.31	Rampini / Siemens	ElectriCitybus	Vienna
3.4	**Plug-in in the depot + change of batteries at the terminal stop**		
3.41	Wallner	Change it	

3.5	**Conductive interim charging at the stop**		
3.51	Sinautec	Ultracap Bus	Shanghai
3.52	Proterra		
3.53	Opbrid	Arctic Whisperer	Umea
3.54	Siemens	e-BRT	
3.6	**Inductive interim charging at the stop**		
3.61	Bombardier / Viseon	Primove	Brunswick
4	**Linear energy supply**		
4.0	**Trolleybus**		
4.01	Viseon	LT20	Riyadh
4.02	Solaris	Trollino 18	Rome
4.03	Hess	Swisstrolley / lighTram	Zurich
4.1	**Induction**		
4.11	Bombardier Mitrac	Primove	Lommel
5	**Vehicle platforms**		
5.01	Solaris	Urbino Electric	
5.02	Solaris	Trollino Metro Style	Salzburg
5.03	Van Hool	Exquicity	Parma
5.04	Fraunhofer Institute	AutoTram XG	

III-1-10 Complete Systems

As only a few complex electric bus systems exist at present, focus is usually either on the vehicle or on the power supply installations. Contrary to traction systems, the system concept, which offers a solution from single source and includes e.g. stops, bus lanes and Park&Ride facilities, is not very widespread in the bus sector. However, the more complicated the power supply installations get, e.g. charging points at stops, the more important it gets to adapt the components to one another and to ensure that the design is uniform and complementary. Only then is it possible to call for tenders for a complete system and to award a contract for a complete system to a company or a consortium. Besides the investments the operation of such a system can also be included in the call for tenders.

Moreover, the concentration on vehicles and infrastructure/power supply makes it problematic to convince political institutions and potential providers of finance as the focus is restricted to a purely economic consideration of the costs arising and the amortization of these costs. However, the approach of introducing electric mobility goes far beyond these technical details towards questions of overall urban development, environmental protection and break with fossil fuels, which are rather to be considered in view of the overall national economy. In this context an electric urban bus would be a natural component of an overall concept instead of a 1:1 replacement of an existing line.

III-1-11 Summary

As a whole, the market for systems with electrically operated buses is still characterised by a very strong development of the technical components. Nevertheless, trends are emerging for a future development:

In Germany **hybrid buses** have only been procured within the scope of special support programmes up to now as these vehicles are about 60 to 70 % more expensive than comparable diesel buses. In May 2012 204 hybrid buses were being operated in Germany, of which 18 were operated in Dresden and 15 in Bochum. Many other transport companies often only operate one or two vehicles for test purposes. Although the savings in energy consumption amount to 15 to 25 %, the additional costs for the procurement are not outweighed. Especially towns and cities with demanding topographies also complain about a higher consumption of the heavy vehicles on uphill line sections without adequate savings on downhill line sections as the capacity of the energy storage units is limited. Nevertheless, much development engineering is being made in this field and it seems that a hybrid bus will be ready for series production soon or within a foreseeable future.

A bus with an energy storage unit on board (**battery bus**) not requiring interim charging would the ideal solution. However, the present maximum ranges of about 200 km are too short for the operation during a complete day. Moreover, no articulated buses are being operated as pure battery buses at present, and there is only little experience with the influence of temperatures and secondary consumers on the range.

There are several concepts for a bus system with the energy storage unit on-board the bus, which allow interim charging, but they are either not fully developed or not going to be available as 18 m long articulated buses in the short or medium term. Especially systems with fast charging at stops raise many questions on the galvanic process as well as on a time requirement clearly exceeding the duration of a mean halt at a stop.

The classic **trolleybus** with continuous overhead contact line represents a fully developed technology, which has even been applied recently in some cities (e.g. in Saudi Arabia). However, opinions are diverted on two aspects: The overhead contact line is often considered to be a disturbing element in the town planning and it binds the bus to its route and restricts the planning freedom considerably. The importance of these two arguments also depends on the political will. Therefore, concepts with at least sections without firmly installed power supply installations (**hybrid electric**) would increase the acceptance from a political and planning point of view.

For a long time hydrogen was found to be an ideal replacement for fossil fuels. This applied particularly to the **fuel cell**, which also seemed to be suited for the propulsion of buses. However, up to now it has not been possible to convincingly overcome the disadvantages with the handling of hydrogen, e.g. its generation, storage, temperature development and short range. Therefore, the hydrogen technology is still at the stage of development.

Finally, electric buses with **inductive power supply** are on the market. They are either interim charged at (terminal) stops or supplied continuously with power, at least in some sections. Neither system has been developed for articulated buses up to now. Moreover, the continuous power supply is still at the experimental stage, i.e. there is no experience with the realisation and the long-term suitability in daily operation.

In the below table III-1.1 the systems are compared from market aspects:

System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Marketability	available and fully developed	fully developed just for special operational cases, no articulated buses available			available and fully developed	all components are available and approved	mainly experimental	still experimental
Market Restraint	partly electric only	need for development (range)	need for development (charging procedure)		continouos overhead contact	partial overhead wire, need for development (autom. Connecting)	need for development at a lot of components	need for development at a lot of components
Market Participants	many competitors	increasing no. of suppliers	individual solutions depending on supplier (low level of standardisation)		several competitors	feasible by several competitors	less no. of suppliers	monopoly

Tabel III-1.1: Conclusion of Market Overview

III-2 AP2: Theoretical Requirements

III-2-1 General

An electric urban bus is defined as ideal if

- it offers all the advantages given for electrical operation:
  - locally zero-emission operation, inclusive of extremely low-emission operation from a global point of view
  - low noise, both outside and inside the vehicle
  - no vibrations from the vehicle, especially not inside the vehicle
  - fast acceleration
  - little maintenance and long life of the electrical components
  - low operating costs (energy consumption) / higher independence of energy suppliers

- it compensates all the disadvantages given for electrical operation:
  - deviation from the route by way of an auxiliary drive
  - sufficient energy reserves in the event of a power failure
  - less impairment of the townscape due to adapted materials / special design of the overhead contact line, the poles, charging points etc.

- its investment costs and depreciations do no differ significantly from the investment costs and depreciations for the existing systems – at least in the long-term:
  - for the vehicle and all its components
  - on and along the route / at the stops
  - in the depot / in the workshop
  - existence of a market with competition for vehicles and other system components
  - guarantee of future support and development of the system inclusive of supply of spare parts

- its operating procedure differs as little as at all possible from that of diesel buses, i.e.:
  - availability of different bus sizes depending on the operation purpose and the demand

- kilometric performance up to 20 hours per day (from the early morning to about midnight)
- range of more than 400 km without (full) refuelling or recharging
- simple and fast refuelling or recharging procedure
- unproblematic participation in the traffic (no section with technically conditioned speed restrictions and no technically conditioned halts, especially if the traffic lanes are used together with the other traffic)
- turnaround times at stops decided by the passenger volume and not by technical necessities
- sufficient supply of all secondary consumers like doors, lighting, ventilation/air conditioning systems and passenger information systems
- easy handling by the crew enabling it to mainly concentrate on the traffic and not on the vehicle and not requiring special knowledge of the electrical and electronic equipment of the vehicle

➢ its operating and maintenance costs are lower than the operating and maintenance costs of the diesel bus:

- lower energy costs
- independent of fluctuations of the price for energy on the world market
- less wear of the electrical components
- longer life of the vehicle and the components

It must be assumed that none of the present technologies can achieve good to very good values in all fields. Only a weighting and an overall assessment lead to a recommendation on the respective operation purpose.

III-2-2 Dimensioning and Capacity of the Infrastructure

All kinds of electric transport systems inevitably require installations for the power supply of the vehicles, either at points as a charging point or a hydrogen filling station or linearly as a suspended overhead contact line or a contact zone in the road. Moreover, substations and cable routes are needed. Therefore, the required costs and efforts as well as the system-immanent advantages and disadvantages are to be assessed individually in consideration of the respective local requirements when a decision on an electric bus system is to be taken.

III.2.2.1 Overhead Contact Line (Continuous or in Sections)

State-of-the-art overhead contact line systems are dimensioned for continuous operation provided they are maintained suitably. The requirements result from the:

- safety standards
- power demand inclusive of recuperation
- course of the lines (radii, gradients)
- maximum permissible speed
- climatic conditions

In detail, the catalogue of requirements consists of technical, operational and design aspects:

- Technical aspects:
  - Adequate cross section of the overhead contact line so that continuous power transfer is also possible in areas in which the demand is higher, e.g. when the vehicle starts driving, when it accelerates or when it drives in gradients or in line sections with short distances between vehicles (> 100 mm²)
  - Resistance to mechanical loads (pressure of trolley pole, wind, rain and ice)
  - High availability, also in case of climatic influence like temperature and humidity, which can lead to variations of the length of the overhead contact line and of its current-carrying capacity
  - Even contact with the trolleys and constant pressure of the trolleys irrespective of the speed to avoid uncontrolled wire disengagement or fire damage on the contact wire
  - Possibility of reliable automatic wire engagement (at standstill) at the beginning of a line section with overhead contact line (and at regular intervals for re-engagement after deviations from the route due to operational disorder)
  - Insulation to ensure safety and avoid leakage current and its corroding effect on the environment, often combined with sound absorption and vibration damping (especially in case of suspension on outside walls)
  - No restrictions for other road users as the overhead contact lines hang sufficiently high (5.5 – 6.0 m)

- Operational aspects:
    - Possible to operate the trolleybus at the maximum speed permitted irrespective of the thermal influence
    - No restrictions when points or crossings (trolleybus/trolleybus and trolleybus/ tramway) and section insulators are passed
    - More or less automated wire engagement with only little crew activity
    - Minimisation of incidents caused by defects on sliding contacts and the overhead contact line

- Design aspects:
    - Little conspicuousness of the wires and poles in the townscape
    - Poles combined with street lighting or suspension on buildings

As long as a trolleybus is operated under the overhead contact line, its range is more or less “infinite”, i.e. it does not depend on the filling degree of an energy storage unit (tank or battery). If the overhead contact line only exists in some line sections, an energy storage unit also has to be fitted. Its dimensioning depends on how much energy is consumed and how much energy can be recharged under the overhead contact line. If the quantity of rechargeable energy is bigger than the quantity of energy consumed, the range is also more or less “infinite”. If, on the other hand, the quantity of energy consumed exceeds the quantity of energy recharged, the filling degree tends to decrease and thus to limit the range.

It is technically easy to recharge from a classic overhead contact line of a trolleybus system, and such recharging takes place regularly in Rome on line 90. Whereas it is possible to change from operation under the overhead contact line to operation without overhead contact line (wire disengagement) when the bus is driving, wire (re-)engagement is only possible at present with the classic trolley pole when the bus stands still.[1]

Other, rather tramway-like designs of the overhead contact line and the trolley / pantograph usually require guidance of the bus to ensure clear allocation of the electrically

[1] The mine transport systems in South Africa and Canada have freight vehicles that can perform wire engagement when they drive. However, the required wire engagement facilities are so big and their appearance so impressive that they are not imaginable in townscape. Other solutions, e.g. optical localisation, are still at the experimental stage.

separated pantograph to the two-pole overhead contact line. However, guidance usually also requires a separate right of way.

In the past crossings and points in the overhead contact line usually had to be passed at reduced speed to avoid uncontrolled wire disengagement. Modern systems allow speeds of 50 to 70 km/h so that the permissible speeds in towns and cities can be kept.

Experience from cities with active trolleybus systems (Salzburg, Solingen) has shown that the contact wire reaches a life of approx. 10 to 15 years.

III.2.2.2 Power Supply in the Road (Continuous or in Sections)

A few years ago alternatives to continuous power supply without overhead contact lines were developed especially for tramway systems in France. So far, a corresponding application has not been developed for a (non-guided) bus system. It seems that the APS system from Alstom with a conductor rail in the road and sliders under the vehicle cannot be applied to bus systems. There are test facilities for the inductive, i.e. contact-free, system “Primove” from Bombardier in Lommel (Belgium) and Augsburg, and such a system has also been planned for Brunswick. The operation or at least the recharging of the energy storage units of buses and even cars is being tested at these test facilities.

All the bus systems with power supply via the road are still at the planning or experimental stage. Thus, experience with continuous passenger operation has not been gained yet. However, the requirements for such systems are comparable with the requirements for a “classic” overhead contact line system. Therefore, especially the differences are described below.

- Technical aspects:
  - Instead of an adequate cross section of the overhead contact line reliable power transfer is to be ensured in another way and by way of suitable materials and material thickness
  - Resistance to mechanical loads (pressure of current collector, rain and ice, passing of heavy trucks)
  - Few settlements / lane grooves in the road surfaces
  - High availability, also in case of climatic influence like temperature and humidity
  - Possibility of reliable, automatic contact making at the beginning of a line section with contact line

- The zone supplying the vehicle with power shall be identical with the zone occupied by the vehicle at the most to avoid hazardous situations to people caused by flowing current or excited magnetic fields
- Insulation to ensure safety and avoid leakage current and its corroding effect on the environment
- No restrictions for other road users by way of a sufficiently stable road superstructure

- Operational aspects:
  - Possible to operate the bus at the maximum speed permitted irrespective of the thermal influence
  - More or less automated contact making with only little crew activity
  - Minimisation of incidents caused by defects on the contact line

- Design aspects:
  - Little conspicuousness of the contact line / power supply in the townscape

III.2.2.3 Charging Points at Stops

Charging points also have to be so designed that they are suited for continuous operation provided they are maintained suitably. The requirements result from the:

- safety standards
- power demand
- duration of stay at the stop
- available space
- climatic conditions

In detail, the catalogue of requirements consists of technical, operational and design aspects:

- Technical aspects:
  - Automatic and technically safe connection and disconnection of the electrical current transfer within a short period (< 5 sec)

- Use of adequate materials with suitable cable cross sections/resistance values for continuous transfer of power within a short period
- High availability, also in case of climatic influence like temperature and humidity, which can lead to variations of the expansion of the material and to variations of the current-carrying capacity
- Insulation to ensure safety and avoid leakage current and its corroding effect on the environment
- No restrictions for other road users, e.g. heavy traffic, due to e.g. the trafficability of elements fitted in the road

➢ Operational aspects:

- Avoidance of longer journey times caused by charging times that take much longer than boarding and alighting
- Ensuring exact stop positions at the firmly installed components for the charging
- High degree of automation, i.e. only little crew activity
- Minimisation of incidents caused by defects on the contacts

➢ Design aspects:

- Little conspicuousness or deliberately striking design of the charging points in the townscape
- Combination with charging points for other types of electric vehicles (electric cars, electric bikes, Segways)

The vehicle always needs an energy storage unit (battery), the dimension of which depends on the quantities of energy that can be consumed or recharged. If the quantity of rechargeable energy is bigger than the quantity of energy consumed, the range is also more or less “infinite”. If, on the other hand, the quantity of energy consumed exceeds the quantity of energy recharged, the filling degree tends to decrease and thus to limit the range.

III.2.2.4 Charging Points in the Depot

Charging points also have to be so designed that they are suited for continuous operation provided they are maintained suitably. The requirements result from the:

- safety standards
- power demand
- available space
- size of the fleet (number of buses being charged simultaneously)
- climatic conditions

In detail, the catalogue of requirements consists of technical, operational and design aspects:

- Technical aspects:
  - Technically safe connection and disconnection of the electrical current transfer (automation and time needed are rather unimportant)
  - Use of adequate materials with suitable cable cross sections/resistance values for continuous transfer of power
  - High availability, also in case of climatic influence like temperature and humidity, which can lead to variations of the expansion of the material and to variations of the current-carrying capacity
  - Insulation to ensure safety and avoid leakage current and its corroding effect on the environment
  - No restrictions for other road users, e.g. heavy traffic, due to e.g. the trafficability of elements fitted in the road

- Operational aspects:
  - Arrangement has to optimise the work flows
  - Minimisation of incidents caused by defects on the contacts

- Design aspects:
  - Rather determined by safety at work aspects and ergonomics than by the townscape
  - Combination with charging points for other types of electric vehicles (auxiliary vehicles, other municipal vehicles)

III.2.2.5 Substations and Cable Routes

Usually, substations and cable routes are not really seen by the general public. It is a matter of course that they have to be so designed that they are suited for continuous operation provided they are maintained suitably. The requirements result from the:

- safety standards
- power demand
- available space
- climatic conditions

In detail, the catalogue of requirements consists of technical, operational and design aspects:

- Technical aspects:
  - Automatic and technically reliable functioning
  - Remote control possible from a central control room
  - Use of adequate materials
  - High availability, also in case of climatic influence like temperature and humidity, which can lead to variations of the expansion of the material and to variations of the current-carrying capacity
  - Insulation to ensure safety and avoid leakage current and its corroding effect on the environment

- Operational aspects:
  - Remote control possible from a central control room
  - Redundancy / ring feeder structures to ensure the power supply in case of technical faults
  - Fast accessibility for maintenance purposes and in case of incidents
  - No unauthorised access possible

- Design aspects:
  - Little conspicuousness of the substations in the townscape

- Used both by trolleybuses and tramcars

- Basically, substations for trolleybuses do not differ from substations for DC traction systems.
- A substation for a DC traction system can always also be used to feed trolleybus lines.
- A substation used exclusively for trolleybuses need not always be earthed. In this case the trolleybus substation cannot be used by a DC traction system.

III-2-3 Combining the Urban System with the Public Transport System

III.2.3.1 Rivals or Partners

The supply of electric modes of transport with power does not only require lines and cables directly at the location at which the vehicles are fed, but also an additional system of feeders from the substations to the supply sections, as return cables or as a redundant supply system in case of incidents. Therefore, many cities have two networks: The network of the power supply utility and the network of the public transport company. These two networks differ considerably as regards the kind of current and voltage and thus also as regards the necessary technical components.

If charging points are to be used increasingly for other modes of transport (electric cars, electric bikes) in future, further supply networks might be needed. It should be considered at an early stage whether the present infrastructure has such a capacity that it can take over the additional tasks. Moreover, the space available underground has already now reached its capacitive limits.

III.2.3.2 Double Networks

In German towns and cities the wide-area supply of electricity usually happens via a primary distribution system with 10 / 20 kV. Thereafter, the households are supplied with 230 / 400 V AC in the fine distribution.

The contact lines and the charging points can also be supplied by the primary distribution system if the current needed (600 / 750 V DC for trolleybus / light rail / tramway systems) is generated by way of transformers in rectifier substations. If an electrically operated public transport system, i.e. usually a light rail or tramway system, exists already, existing substations can also be used by an electric urban bus system. Depending on the capacity the system might have to be expanded.

In that case a cable has to be led from the rectifier substation to the contact line or charging point as the feeder and another cable has to return the current to the substation. These cables are relatively short within the contact line system and are fed at points as the contact line itself distributes the power over the line. A rectifier substation can supply an approx. 2 to 3 km long line section.

Charging points need cabling in parallel to the line for their power supply unless each charging point is supplied directly by the primary distribution system via a small substation. It has to be borne in mind that power is often needed at very peripheral locations if the charging points are set up at terminal stops, which can result in long cable runs if it is not possible to easily connect the charging points with the primary distribution system or if no agreement can be made with the power supply utility in this respect. Moreover, it has to be borne in mind that a charging point mostly needs high current within a short time. Usually, the primary distribution system is not dimensioned for such a demand.

Inductive power supply systems along the line also require parallel cabling as the power supply is divided into sections and as the system is only energised exactly at the positions of the vehicles. Therefore, it has to be possible to feed these sections separately.

III.2.3.3 Competitors for the Available Space

Most cables runnning parallel to lines are buried. Mostly, the available space is used for many different purposes in the towns and cities and additional cable runs are therefore increasingly regarded as problematic. Moreover, these spaces have to be opened up when cables are to be laid and maintained, which impairs the traffic and always means that neighbouring cables can be impaired by mistake.

III.2.3.4 Future Requirements

In future, an electric urban bus or tramway system and its appertaining network might also make up the extensive basis for the supply of other electric modes of transport (electric bike, electric car) as well as the charging points needed for these modes of transport. However, at present there are still legal obstacles if transport companies move onto the market as suppliers of electric energy.

In some towns and cities there is also a trend to perform other municipal services, e.g. the refuse collection, with electrically operated vehicles. Their range of action could also be extended if becomes possible to combine the charging points or connect special charging points to the electric bus system.

III.2.3.5 Uniformity / Peak Loads

The total power consumption of an electric bus consists of the power for

- the traction (drive motor),
- the secondary consumers (lighting, ventilation/heating, passenger information system etc.),
- the charging of the energy storage unit.

If the vehicle is supplied linearly with power, a relatively constant quantity of power from the upstream network is consumed continuously. The phases of acceleration and braking, perhaps with recuperation, result in a little amplitude. If, on the other hand, the power is supplied at points, there is a clear change between phases with high power consumption from the upstream network (vehicle connected to the charging point) and phases without power consumption (vehicle uses the on-board energy storage unit).

The variations / peak loads arising in that way can be balanced by interconnected energy storage units. These energy storage units are either fitted in the vehicle – preferably by systems supplied linearly – or in the substations. Technologically, both battery-based and flywheel-based systems can be applied. However, it has to be considered that the single elements might be heated up considerably during the charging so that they might have to be insulated or cooled or protected from fire.

III.2.3.6 Operation Management and Incident Concepts

The electrical infrastructure has to be so planned that the operation can continue as undisturbed as at all possible if one (or several) supply sections fail for a certain time. Thanks to the energy storage unit the vehicle can continue its journey without external power supply for a while.

Generally, it should be avoided that the charging condition of the energy storage unit gets below 60 % frequently to avoid that its life is shortened, but there is a buffer for incident situations. Nevertheless, it is advisable to dimension the supply sections and the charging points so that the desired optimum charging level of the energy storage unit is achieved during each cycle.

State-of-the-art public transport systems are monitored continuously, i.e. they have central control rooms, which can also regulate the situation in the event of an incident to keep the negative effects of the incident as negligible as possible. However, an electric urban bus system also requires knowledge about the interaction between the power supply and the vehicles. It has to be avoided that the energy storage unit of a vehicle is discharged beyond a certain condition in case of alternative routeing, shortening of the route, reduction of the turning/non-operating time etc. so that more vehicles become “incidents”.

Moreover, the drivers have to be trained adequately so that they are able to observe the charging condition of the energy storage unit of the vehicle and, if necessary, e.g. in the event of irregularities, to report it to the control room.

III.2.3.7 Redundancy

There is always the risk with an electric mode of transport with external power supply that the power supply is interrupted through external influence, e.g. that a digger separates a supply cable when it is digging or that a truck with a too high load damages the overhead contact line. To at least limit the effects of such damage, a redundant supply system is helpful. For this purpose it has to be possible to switch some sections of the contact line to different feeder sections. It also has to be possible to jumper the disconnectors of adjacent supply sections. Different branch lines can also be connected across with one another via cables so that there are ringlike supply systems.

Basically, it is possible for vehicles with energy storage units to bypass sections for any reason. However, it has to be borne in mind that additional energy is drawn from the energy storage unit in that case. Therefore, it would be ideal if the recharging period is so calculated that there is always an energy reserve for such a case and that this energy reserve is also re-established during a cycle.

III.2.3.8 Accessibility

In principle, an overhead contact line is always accessed more easily for maintenance purposes than a system with underground cables.

It has to be borne in mind that systems with charging points at intermediate stops and/or terminal stops require suitable feeders. Thus, a system with more or less parallel cables emerges, which are usually buried, instead of the visible overhead contact line for trolleybuses.

Systems with linear power supply in the road (mechanical or inductive) require a suitable infrastructure in the earth and additional parallel feeders. Consequently, complicated site measures have to be taken in case of a fault, which also imply that the public transport line itself has to be interrupted.

III.2.3.9 Safety

The keyword "safety" always implies consideration of the

- safety of the system in case of intervention from the outside and
- safety of the environment if the system breaks down.

A high degree of safety has to be ensured for all systems in both respects taking all valid technical regulations into account. At present, there are no special standards in Germany for the inductive power supply system.

III-2-4 Equipment of the Vehicle

III.2.4.1 Electric Energy Storage Unit

No electric vehicle can do without an on-board energy storage unit, either as the only source of energy or as a supplementary source of energy to be able to drive in sections without any other kind of power supply. However, the size and the capacity of the energy storage unit can differ considerably depending on the task. The following technical criteria are to be considered:

- charging capacity (kWh)
- power (kW)
- range (km)
- weight (kg)
- dimensions

- thermal behaviour
- life (number of charging cycles)

Basically, two kinds of energy storage units are available: batteries and supercaps.

Supercaps can take up much energy within a short time, but also have to supply the energy again within a short time (maximum 1 to 2 km). Therefore, they are mainly used for the recuperation in the vehicle.

In comparison, a battery is charged relatively slowly over a long time and can provide energy for a long time (up to 200 km). Therefore, electric vehicles which are to be operated without external power supply within relatively long line sections need correspondingly powerful batteries as the energy storage units.

As the energy storage unit makes up a significant share of the purchase costs of the vehicle and as it also has to be replaced several times during the life of the vehicle, special attention has to be paid to the life of the energy storage unit. Its life is defined by the number of charging cycles, which now amount to 3,000 – 5,000 cycles. This figure can be increased considerably if the battery is not charged from 0 % to 100 % during each charging cycle, but merely from 60 % to 80 %. However, such a charging condition affects the distance between the charging points and their arrangement.

III.2.4.2 Energy Management System

If a bus is operated fully electrically, the capacity of the energy storage unit has to be so dimensioned that the energy does not only suffice for the actual drive, but also for the operation of the secondary consumers, e.g. lighting, ventilation, actuators or passenger information systems. Thus, seasonal peaks, e.g. high heat output in a cold winter or high cooling power of the air conditioning system in a hot summer, can affect the total power and thus the range of an energy storage unit significantly. The capacity of a battery should always be based on a worst-case scenario to ensure that the energy reserve is high enough.

However, to ensure that a bus always reaches the next charging point or the next depot, the on-board energy flow has to be monitored continuously. If the stored energy falls below a defined value, the energy to secondary consumers has to be reduced or switched off purposively and gradually, if necessary.

The on-board energy management system then has to decide which secondary consumers still have to be supplied, e.g. for safety reasons, and which consumers can have less energy or be switched off so that the passengers' comfort is affected as little as at all possible.

In this connection it has to be considered that the consumption of traction energy depends on the conditions of the line and on the speed (way-dependent), whereas the secondary consumers have to be supplied continuously and steadily, i.e. also at standstill (time-dependent).

III.2.4.3 Energy Supply Systems

The transfer of energy from the outside into the vehicle is a special problem as very high voltages sometimes have to be generated depending on the time required or available, which involve special requirements for the safety. The applied materials also have to be suitable for thermal loads.

Distinction is made between linear power supply and power supply at points:

Power supply at points:

Plug-in solutions

Usually, battery buses without interim charging are being connected to charging points in the depot in the non-operating time. Several manufacturers provide fully developed solutions ensuring adequate current transfer and thus full charging (> 95 %) within several hours. As the voltages are relatively low and as no passengers are nearby, the requirements for material and safety are at the standard level.

Charging points at stops

Contrary to charging points in the depots, charging points at stops have to transfer a high current within as short a period as at all possible. At present, the manufacturers test different solutions with pantographs and conductor rails. Alternatively, inductive elements can be fitted in the road. However, it seems that none of these systems is ready for series production yet. The frequent coupling and uncoupling also generates a high mechanical load on the pantographs and partly also on the conductor rails, which can be swivelled for safety reasons. Moreover, the requirements for the material are high as it has to transfer high currents within a short time.

Recharging with passengers in the vehicle also requires additional insulation measures on the vehicle as in case of trolleybuses.

A special problem, which is rather operational than technical, is that such charging usually takes a longer time than the boarding and alighting. Thus, it will probably prolong the journey times.

Linear power supply:

Overhead contact line (trolleybus)

Typically, trolleybuses are equipped with two trolley poles, which are fitted in parallel and draw the traction current from the two-pole overhead contact line. State-of-the-art systems allow automatic lowering of the trolley poles at any position. The wire engagement can also be automatic, but in this case the vehicle has to be at a certain position and there has to be a wiring guide in the contact line over the trolleybus. Usually, this procedure follows when the trolleybus stands still at a stop. At present, research is made with systems that can apply the trolleys without support and perhaps even during the operation. It is expected that they will be ready for series production in the short or medium term.

Basically, modern trolleys for trolleybuses and overhead contact lines enable safe operation. A system with sections without overhead contact lines and several wire engagements and disengagements per cycle would undoubtedly stress the trolleys more mechanically. Experience in Solingen and Rome, in which trolleybuses are operated by way of their auxiliary drives in some sections in ordinary line-service operation, has not revealed any problems worth mentioning.

Induction

In case of inductive current transfer, either through recharging at standstill or as a continuous power supply during the operation, the vehicle has to be positioned relatively exactly over the elements fitted in the floor/road. Moreover, relatively small distances are required between the vehicle and the elements in the floor/road. Current transfer at standstill is already being practised e.g. in Turin. At present, the transfer into a bus is being tested. No authoritative experience exists up to now. As, however, a bus uses the road very intensively, much maintenance will probably be necessary. The wear of the receivers fitted on the vehicle will probably be low due to the contact-free transfer.

III-2-5 Sustainability

III.2.5.1 Future Proof

The market for electric vehicles is changing extremely much at present. New developments are described at regular intervals. Nevertheless, three theses can be summed up:

1) Technologies based on overhead contact lines are fully developed and available at once. As there are more than 300 systems worldwide and as one or two new systems are erected each year, the situation is characterised by sufficient market development (competition) and reliability in respect of future availability of system elements inclusive of spare parts.
2) Systems based on energy storage units are the intended result of many manufacturers. These systems will probably also be further developed as they have still got major weaknesses, especially as regards their range.
3) All the other systems are “lone fighters” on the market with a very uncertain end. At present, such systems cannot be recommended as it cannot be guaranteed that all system components can be supplied at affordable prices (series production) in future. The TVR tramway in Nancy and the suspended railway in Wuppertal are examples of how complicated it is if e.g. vehicles or spare parts have to be procured for exotics.

III.2.5.2 Available Resources

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety has initiated a potential analysis on the two battery components lithium and cobalt under the title of “Resource Availability of Secondary Raw Materials”. In the final report of October 2011 the following is said:

“Even if the market penetration of electric vehicles is strong (optimistic scenario), the geological reserves of lithium suffice to cover the high demand for raw material. However, the situation is different for cobalt: the resources known at present do not suffice to cover the demand under the assumption of a strong market penetration. However, if the deposits that are known, but cannot be mined economically today, are also taken into consideration, the demand can be covered until 2050. Moreover, it is possible to find new cobalt deposits via exploration and thus to increase the geological reserves and identified resources."

III.2.5.3 Environmental Compatibility

Generally, electric vehicles are considered to be more environment-friendly than vehicles with internal combustion of fossil sources of energy (diesel, gas). The most important argument for this point of view is that electric vehicles do not emit any exhaust gases at all on the spot, i.e. on the roads and streets in which they drive, or when they stand still at stops and light signals. If, however, the real environmental balance is considered globally, it depends on the energy mix processed in the power stations that deliver the electric current. At least theoretically – and in the medium or long term the objective – it is possible to generate current exclusively from regenerative primary sources of energy not emitting CO_2 and thus to have the best possible emission balance also globally.

Most of the vehicle components are identical irrespective of the kind of drive. However, the design of the energy storage units has to be considered. Batteries can contain materials that are regarded as special waste by the recycling later on. However, there is a trend towards developing batteries with an extremely low share of such materials and towards recycling major parts. The same applies to the development of the components for charging points etc.

In Germany the share of fossil sources of energy amounted to 78.2 % in 2010, inclusive of 33.6 % crude oil. The non-fossil sources of energy already amount to more than 20 %, but nearly 11 % of these non-fossil sources of energy are nuclear energy. It has been forecast that Germany can do completely without fossil sources of energy as from 2050 and without nuclear energy already from 2020 (*Source: Working Group on Energy Balances (AGEB) / German Institute for Economic Research (DIW), Berlin*).

A further advantage of electrically powered vehicles is that the noise level is reduced as these vehicles drive nearly silently. Only the driving noise of the tyres is heard. Their noise level is especially much lower when they start driving or accelerate. Tests in Switzerland and Arnhem (Netherlands) revealed differences of 6 to 9 decibels (3 decibels are felt as a doubling of the noise). *Sources: Arnhem Report (Trolley 2000); Swiss Service for Transport Studies (GVF) 1997.*

III.2.5.4 Acceptance

In the towns and cities in which electric bus systems are already being offered to the passengers the systems are usually accepted to a high degree and also attract additional passengers. Line extensions or replacement for diesel buses with electric buses, e.g. in Arnhem or Salzburg, lead to clear increases in the passenger loads. Especially in the environs of Salzburg many municipalities want to be connected to the trolleybus system to "be included". This wish also comprises the overhead contact line as the visual symbol of affiliation and as a pointer to an offer of high quality.

From the point of view of the passengers an electric bus is rather an improvement than a change for the worse as against a diesel bus. The number of seats, the timetable / journey times and the layout of the line hardly differ, but the ride comfort advantages (ride quality, interior noise, no vibrations) are perceived by the passengers and the image of environment-friendliness enhances the acceptance of electric vehicles.

Systems with infrastructure facilities for the power supply along the route have to pay more attention to solutions agreeable to the townscape in future:

- Overhead contact lines should be harmoniously integrated into the environment, either as inconspicuously as at all possible or as deliberately accentuating elements. Poles can also be combined with the street lighting.
- Energy storage units can be used in very sensitive areas.
- Underground power supply systems (e.g. induction) also require a sensitive road surface design, particularly as special lanes are needed for such a system to ensure the best possible current transfer. This leads to strong wear of certain driving surfaces (lane grooves). At present, it is not clear whether it is possible to combine a thin cover of the current-carrying elements in the road with a stable road e.g. of concrete.
- Charging points at stops also have to so designed that they fit the surroundings. If necessary, some parts can also be installed underground.

III-3 AP3: Economic Efficiency

III-3-1 General

The highest obstacles for the introduction of an electric urban bus system are the high initial investments in the infrastructure for the power supply and the much higher prime cost for the vehicles. On the other hand, the operating costs and the energy costs are much lower and the asset depreciation range is much longer. From a business-economic point of view the question therefore is whether or from when an electric urban bus system is more economic than a diesel bus system.

The cost-benefit analysis is very important for projects with a high share of investment costs for infrastructure measures, not only as regards the direct effect, but also and especially as regards the enduring influence on the operator's result.

Not only the results on the business economics have to be considered, but also the effects on the national economy, particularly because electric mobility projects are significant environment-friendly measures, which always have to be included in a cost-benefit analysis.

III-3-2 Method

For the assessment of the business economics different investment and operating costs are compared. Concretely, the continuation of the operation with diesel buses, on the one hand, and the operation with electric urban buses, on the other hand, are compared. The prices in 2012 are taken as a basis, later increases in prices are not considered.

The inputs – especially the investments required for the electric bus systems – are current and carefully identified data.

For the assessment of the business economics all the expenses and the revenue are calculated at first. For clarity a statement of changes was prepared for the various systems, which only comprises the parameters that differ in each system. Valuations which are identical in both cases, e.g. for the driver or the cleaning of the vehicle, are not included in the calculation.

In the period in which the operation is changed from diesel to electric operation the efficiency has to be as high as at all possible. Therefore, it is only suitable to examine a bus line with a very strong demand to begin with. Alternatively, it is possible to examine a route on which several lines are operated and which is therefore highly loaded. During the day the line should be operated with articulated buses at least in a 10 minute cycle, which corresponds to a demand of at least 400 to 500 passengers per hour and direction (or about 4,000 to 5,000 passengers per day and direction) in the busy traffic period.

III-3-3 Inputs and Assumptions

For the assessment of the business economics many inputs are needed:

- Operational concept
- Necessary investments
  - Procurement of vehicles (inclusive of energy storage units)
  - Redesign of vehicles
  - Infrastructure
    - Overhead contact lines / charging points
    - Roads / stops
    - Depot / workshop
    - Control room / technical control desk
- Operating costs
  - Drivers (number / qualification)
  - Workshop staff (number / qualification)
  - Control room staff (number / qualification)
  - Energy consumption (drive + secondary consumers)
  - Maintenance
    - Vehicles
    - Infrastructure
- Administration
- Costs of financing
- Expected benefit
  - Revenue
    - Fares
    - Promotional funds
  - Benefits to the national economy
    - Avoidance of environmental pollution

Not all inputs can and have to be quantified, e.g. in the sense of the statement of changes. Therefore, the above list is commented as follows:

Operational concept: In the first phase electric buses should preferably be operated on lines with a high demand. Therefore, only lines / routes on which at least six articulated buses are operated per hour (workday, during the day) are suitable. It is assumed that the total time of operation amounts to 20 hours at workdays, i.e. that the operation begins between 04:00 h and 05:00 h and ends between 24:00 h and 01:00 h, and that the transport offer is about halved after 19:00 h or 20:00 h. The line is served each day. On Saturdays, Sundays and holidays the transport offer is modified, i.e. reduced as against the offer on workdays.

Procurement of vehicles: In the first phase electric buses should preferably be operated on lines with a high demand. Therefore, only lines on which at least six articulated buses are operated per hour (workday, during the day) are suitable, and therefore only the prices for articulated buses are considered or forecast, if no articulated vehicle has actually been realised up to now.

The prices for electric vehicles will probably fall as soon as a series production is started:

Diesel bus (Euro 5):	330,000 EUR
Battery bus:	660,000 EUR
Trolleybus:	700,000 EUR (with auxiliary diesel drive)[2]
	750,000 EUR (with auxiliary electric drive)
Hybrid-electric:	850,000 EUR (trolleybus + energy storage unit)
Fuel cell-hybrid:	> 1,000,000 EUR[3]
Induction-hybrid:	> 750,000 EUR

Basically, it is assumed that the number of necessary vehicles is identical irrespective of the system. As, however, the range of battery buses and fuel cell buses is limited to

[2] Source: Public transport company of Solingen (SWS)

[3] Recently, the public transport company of Stuttgart (SSB) purchased fuel cell solo buses at a price of 1.5 million euros per bus. It is unlikely that this price will be the market price when the series production has started.

about 200 km at present without recharging / refilling and as a daily kilometric performance of 350 km can be assumed for some of the vehicles, it is assumed that 20 – 25 % more battery buses and fuel cell buses will be needed.

Redesign of vehicles: Particularly electric urban buses with lives of at least 15 years will probably be redesigned. The redesign mainly consists of "cosmetic repairs" (new seats, interior lining etc.). These costs are assessed to 200,000 EUR per vehicle for all electric urban bus systems once after about eight years.

Redesign of electrical components: The component with the shortest life in the electric vehicle is the energy storage unit. Its life is measured in charging cycles. Although the charging condition is optimised to a large extent, it has to be assumed that its maximum life amounts to about three years. These costs are assessed to 100,000 – 200,000 EUR.[4]

Infrastructure – overhead contact lines / charging points: As there are no market prices for many systems and their components, the investments have to be assessed plausibly:

Overhead contact line: 925,000 EUR per km two-lane bus line

Charging point: 250,000 EUR per charging point; on average two charging points are needed per line kilometre (one for each direction of travel)

Primove: It is not possible to assess the costs seriously as too many factors are still unknown.

Rectifier substations are not considered → synergetic effect with existing DC traction system

Infrastructure – roads / stops: It is assumed that it is not necessary to modify an existing system, i.e. that no reconstructions or new constructions have to be carried out.

[4] Source: HOPPECKE Batterien GmbH & Co. KG, Brilon

Depot / workshop: It is assumed that the vehicles are parked in an existing depot and can be maintained in an existing workshop. Therefore, only reconstruction / adaptation measures (e.g. charging points, roof access platforms and diagnostic devices) are considered.

Furthermore, power supply has to be provided for all vehicles in the depot, either via overhead contact lines or via charging points.

Control room / technical control desk: Here, too, it is basically assumed that there is already appropriate monitoring equipment in the control room – especially if light rail or tramway systems are already operated – and that it is possible to supplement or adapt this equipment at low cost.

Drivers: As it is assumed that the operational concept (journey times / number of cycles) is not changed, the number of drivers remains constant. Therefore, only the initial training of the drivers is considered.

Workshop staff: Due to the new vehicle technology it might be necessary to vary the number of staff. Moreover, other / new qualifications are needed. Synergies with the workshops for the light rail vehicles / tramcars have to be considered.

Control room staff: No significant changes are expected. Further technical conditions (range, charging condition) have to be considered in the event of an interruption or alternative routeing.

Energy consumption: Basically, it is assumed that articulated buses with a length of maximum 18.75 metres are operated. Moreover, it is assessed that they consume 65 l diesel or 3.3 kWh current. It is also assumed that part of the consumed current is recuperated braking energy. The values assessed for the secondary consumers in the vehicle are the maximum values that can occur e.g. due to heating in a very cold winter or due to cooling with the air conditioning system in a hot summer. The prices are based on statistical data collected everywhere in Germany. The German Federal Statistical Office in Wiesbaden mentions a price of 1.16 EUR per litre for diesel fuel to large-scale consumers for May 2012 and a price of 0.114 EUR per kWh for current, which corresponds to approx. 0.76 EUR and 0.38 EUR per km, respectively.

It is disputed how the prices are going to develop in future: Whereas increases in the price for diesel of about 5 % annually are forecast generally, the energy turnaround and the implied reconstruction and development of the infrastructure (power stations, network) make it difficult to assess the development of the price for current – at least in Germany. On average, the increase also amounted to about 5 % in the last five years.

Maintenance of vehicles: There are different opinions on the maintenance costs for vehicles: some trolleybus manufacturers say that they are comparable with or lower than the maintenance costs for diesel buses, but experience from Swiss studies (Winterthur / Schaffhausen) has shown something else: The additional expenses for the trolleybus occur due to a higher share of maintenance-intensive electronic equipment (the fault diagnosis is much more complicated for electric motors than for diesel engines), the trolleys with wear parts, the emergency generator and the checks for insulation safety. Some of the additional expenses also result from the longer life of the vehicle, i.e. eventually from its age.

Maintenance of infrastructure: Only the maintenance of installed facilities is considered. Additional cost-intensive relocations or provisional arrangements etc. can be necessary in case of building measures.

Administration: Is not considered as a variation is unlikely.

Fare revenue: Operators of traction systems or bus systems operated in a similar way often point out that an improved image or a more attractive system also increases the passenger demand and thus the fare revenue. Such effects are not considered in this study as a high-quality and environment-friendly mode of transport already exists in the form of a light rail or tramway system and as the bus lines in question therefore only partly generate additional effects for an increase in attractiveness that can be assigned directly to these lines.

Promotional funds: As it is not clear how public transport projects will be supported in future and as the regulations differ within the European Union, promotional funds are not considered.

Benefit to the national economy: Even if it is generally accepted that the operation of electric vehicles reduces the exhaust emissions (CO_2, fine dust) and the noise emissions, it is difficult to assess the monetary value of the effects. Therefore, they are only acknowledged qualitatively (cf. chapter III-3-5).

	unit	Diesel	Diesel-Hybrid	Battery without charging	Battery with charging	Trolleybus (continuous overhead wire)	Trolleybus (sectional overhead wire)	
Invest								
Vehicle purchase (articulated bus 18 m)	€/vehicle	330.000	550.000	660.000	700.000	750.000	850.000	
lifetime	years	12	12	15	15	15	15	
Redesign Interieur (1x after 12 Y)	€/vehicle	./.	./.	100.000	100.000	100.000	100.000	A)
Reinvest Electric / Electronic (every 3 years)	€/vehicle	./.	./.	200.000	150.000	100.000	150.000	B)
Infrastructure								
overhead wire	€/km	./.	./.	./.	./.	860.000	725.000	
charging stations	€/item	./.	./.	./.	100.000	./.	./.	
right-of-way, stops	€/km	./.	./.	./.	./.	./.	./.	C)
Depot / workshop (Basic)		50.000	200.000	200.000	200.000	650.000	650.000	
power supply in Depot		./.	./.	500.000	400.000	400.000	400.000	
OCC / SCADA		./.	./.	./.	./.	./.	./.	
Operation cost								
workshop staff		included in vehicle maintenance						
OCC staff		./.	./.	./.	./.	./.	./.	
Energy consumption	Liter/km; kWh/km	0,650	0,520	3,300	3,300	3,300	3,300	
Energy price	€/unit	1,160	1,160	0,114	0,114	0,114	0,114	E)
Inflation	%	4,000	4,000	4,000	4,000	4,000	4,000	
Maintenance								
vehicles	€/vehicle-km	0,520	0,650	0,650	0,700	0,650	0,700	
Infrastructure	€/year	1 % of Invest						
Administration		./.	./.	./.	./.	./.	./.	

A) within an overall lifetime of 25 years per vehicle once for the last 12 years
B) several components with different lifetimes
main component: energy storage with a lifetime of 10.000 chargings
average value: within an overall lifetime of 25 years per vehicle 7 times for 3 years each
C) Might be required with charging stations at stops and with the primove system
E) source: Statistisches Bundesamt (federal office for statistics), Wiesbaden

Table III-3.1 Overview / summary of the inputs

III-3-4 Synergetic Effects with the Existing Tramway System

For the introduction of electric urban bus systems the basic question is where there are synergetic potentials. To be able to answer this question, the following has to be analysed:

If the town or city already operates a tramway system, how …

- … is the present power supply being used?
- … is the workshop know-how being used (as an economic advantage)?

If the town or city operated a tramway / trolleybus system earlier, how …

- … is the power supply, if still present, being used?
- … are the exploitation rights, if still existing, being used?

Due to the example in this study, i.e. Leipzig, this study mainly considers the introduction of electric urban bus systems in cities which already operate a tramway system.

It is assumed that the existing infrastructure and the know-how from the operation and maintenance of electric traction systems provide important synergies for the change from usual bus lines to electric operation. Therefore, the combination with an already existing network can influence the calculation / cost estimate of the following cost positions:

<u>Infrastructure – overhead contact lines / charging points</u>: In case of overhead contact lines it can be examined whether the existing supports and contact line systems can also be used for the bus system, but synergetic effects are especially likely by the use of the rectifier substations and the cable routes.

<u>Depot / workshop</u>: Even if the electric vehicles of both modes of transport, i.e. the existing tramcars and the future electric buses, are parked at the same place, certain facilities can only partly be used by both modes, e.g. the roof access platforms. However, joint

use of workshops (maintenance of the electrical and electronic equipment) and joint spare parts storage have to be strived for.

Usually, a tramway depot has its own substation, which can also be used for the supply of the electrical equipment of the bus system.

Workshop staff: State-of-the-art drive control systems and on-board power supply systems for traction systems and electric bus systems have many common design features. Basically, the staff of a tramway operator has been trained for the servicing and maintenance of tramcars. It depends on the total fleet size whether more staff has to be employed.

A tramway operator has already got functioning resources for the operation and maintenance of power supply installations, e.g. tower vehicles and cherry pickers. Usually, they can still or also be used.

The size of the respective operational branches, and thus the work load, decides whether the staff is to be grouped according to the operational branches. The main difference between working on a tramcar and working on an electric bus is that the overhead contact line of a tramcar always has to be deenergised and earthed, whereas these measures need not always be taken for a trolleybus due to the two-pole contact line. To rule out serious mistakes due to different procedures, some public transport companies prefer separate maintenance areas.

Energy consumption: Usually, the energy generated by a modern tramcar or light rail vehicle during braking is recuperated and available to another tramcar or light rail vehicle drawing energy in exactly that moment. If an electric bus system is integrated into the tramway or light rail operation and combined with the existing power supply system, there are further consumers to begin with so that the chance of using the braking energy meaningfully is increased significantly. This applies mainly to systems with overhead contact lines. In these systems buses can always draw current from the system and also feed it back to the system.

However, electric buses are usually so designed that they conduct the braking energy to their own energy storage units at first and also draw current from these energy storage units, if necessary, above all because many systems are not connected continuously to a network via overhead contact lines. Therefore, bus systems with power supply in some sections or at points can only use the recuperated energy of the tramway system if it is interim stored in the substation.

III-3-5 National Economy Aspects

The decision on introduction of an electric urban bus system also has some effects on the national economy. Above all, the environmental pollution caused by CO_2 is to be mentioned. Diesel buses emit 1.7 kg CO_2 per km, i.e. if the annual performance amounts to approx. 1,000,000 km per line (as in case of the exemplary line 70), approx. 1,700 tons are emitted each year. If the valuation rate of 231.00 euros per ton, which is usual in Germany for standardised assessment of traffic infrastructure investments, is taken as a basis, an annual effect of 393,000 euros results for the trolleybus as the saving to the national economy.

The trolleybus has further advantages from the point of view of the national economy:

- It emits less noise.
- It emits less fine dust, carbon monoxide and nitrogen.
- It increases the value of the real estate along the line as the development is stable due to the overhead contact line.
- It is covered strategically longer against competition (according to the Passenger Transport Act a contract period of up to 15 years is possible).

III-3-6 Comparison from a Business-Economic Point of View

For a basic comparison of different electric urban bus systems a comparative costing analysis was prepared on the basis of the above described assumptions and inputs.

In some cases there are no prices for vehicles and installations or the existing data are based on research and experiments. Therefore, fuel cell buses and systems with linear induction were not considered. Moreover, only costs differing significantly for the electric bus system and the diesel bus system are considered. Thus, e.g. the costs for drivers were not considered as the number of drivers is constant.

In compliance with the synergetic effects given by the operation together with the tramway costs for overhead contact lines or charging points, if relevant, are considered, whereas costs for substations are not considered as it is assumed that they already exist.

To be able to show the development of the costs (investments + operation) for a long period, the costs were considered for two life cycles of electric buses, i.e. for 50 years. It appears from Fig. III-3.2 that the annual costs for electric bus systems are lower than the costs for diesel bus systems after about 20 to 25 years and that they are also going to remain lower with regular maintenance investments under the assumptions mentioned above. The decisive factor is the energy costs. In this study it was assumed that the price inflation is identical. If, however, the price for diesel increases more than the price for electrical energy, the electric buses are going to amortise much earlier.

Basically, the same applies to the diesel hybrid bus as to the electric bus. Compared to the diesel bus the lower energy consumption is felt in the long term. Already after 15 years the electric hybrid bus is more favourable than the diesel hybrid bus from the cost aspect.

The jumps in the curves of the electric bus systems result from the depreciations for the redesign and for the replacement of the energy storage unit, which are not assumed to have the life of the bus, but individual lives (12 and 2 x 8 years, respectively).

For better recognisability of the curves during the first 25 years they are also shown separately in Fig. III-3.3.

All in all, the annual costs for systems like the electric hybrid system are reduced to values under 90 % of the costs for a comparable diesel bus system.

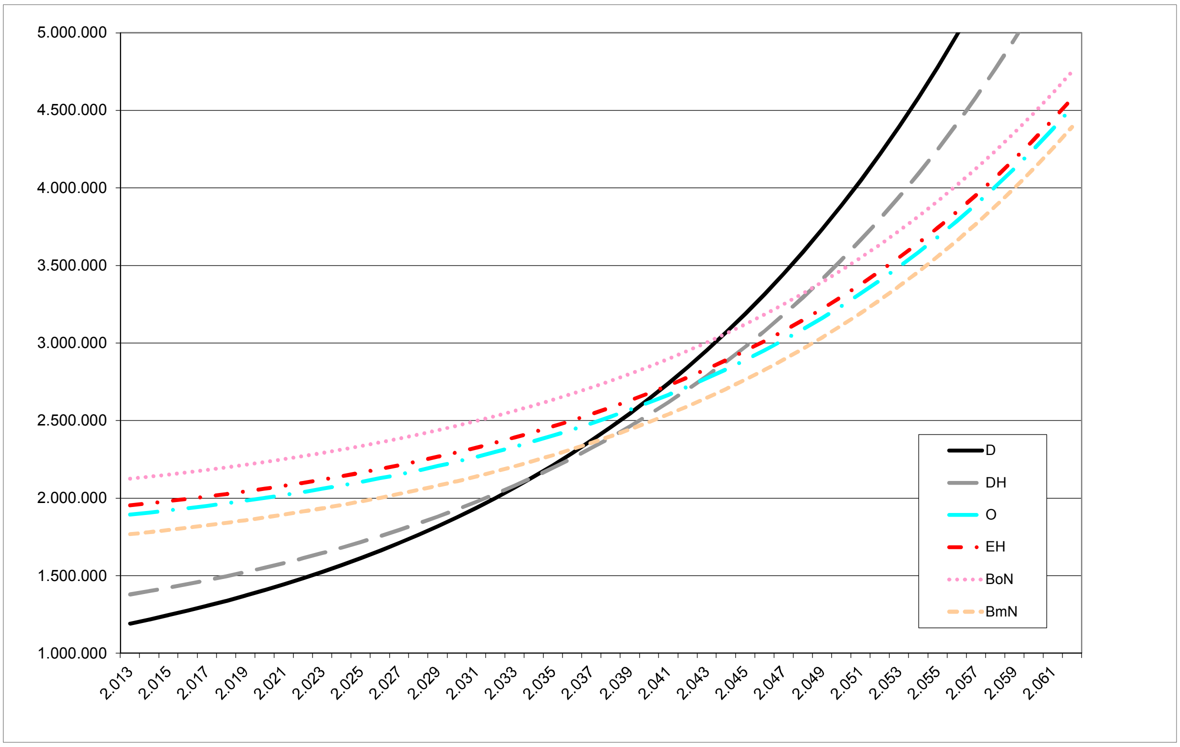


Fig. III-3.2: Development of costs of various bus systems during 50 years

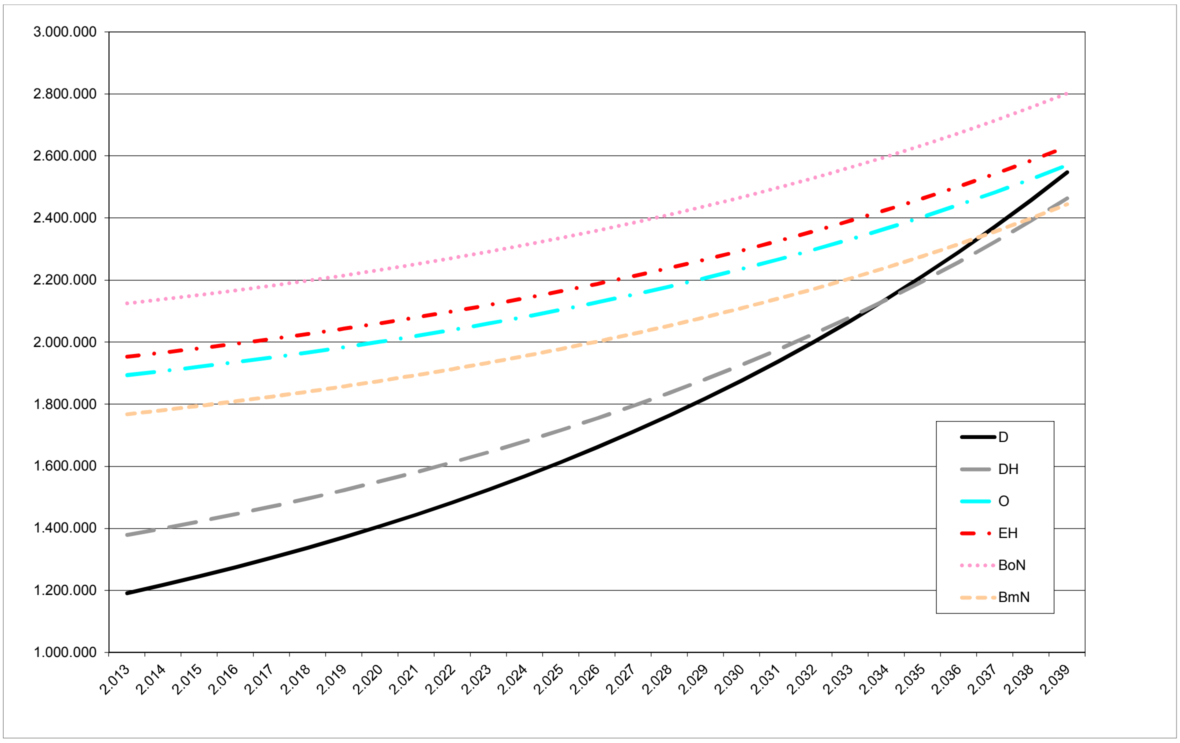


Fig. III-3.3: Development of costs of various bus systems during 25 years

Key:
D = Diesel bus
DH = Hybrid diesel bus
O = Trolleybus
EH = Hybrid electric bus
BmN = Battery bus with interim charging
BoN = Battery bus without interim charging

III-3-7 Promotional Funds

In Germany and other European countries measures to improve public transport are subsidized. The public authorities particularly pay part of the investment costs, e.g. for the construction of public transport ways or for procurement of vehicles, either at the municipal level or at the national level. As the rules for such involvement are managed very differently and also amended at regular intervals, such funds are not considered in this study. However, in the concrete individual case such funds can contribute decisively to the start of a project.

Most regulations on subsidies are intended for new constructions or new procurements. However, in Europe the public transport companies seem to focus less on the construction of new networks or extension of existing networks and more on improvement or development of the existing systems, e.g. by changing to more current operation management software systems or by equipping existing vehicles with new comfort features like air conditioning. Thus, in future it should also be possible to receive subsidies for qualitative improvements and not only for quantitative improvements.

III-3-8 Recommendation (Rough Choice)

A qualitative comparison of the different systems was made on the basis of the aspects discussed in chapters III-2 and III-3 (see tables III-3.4 to III-3.6). The diesel bus makes up the zero case (all fields blue). The electric bus systems are assessed as to whether they are equally good (also blue fields) or whether they are probably better (green) or a little worse (yellow) or much worse (orange) than the zero case.

First of all, the result shows that many more improvements than changes for the worse can be expected for all electric bus systems as against the diesel bus system. However, the real question is not: “diesel bus or electric bus?”, but: “which electric bus system is the best replacement for the diesel bus?”

When the electric bus systems are compared, it is seen that the trolleybus-based systems have fewer disadvantageous assessments.

The result can be summed up as follows:

As regards environment-friendliness and passenger comfort all electric bus systems seem to be better than the diesel bus system, but if the electric bus systems are compared with one another, they seem to be more or less equally good.

From an operational point of view there are hardly differences. There are nearly always technical solutions for the theoretical disadvantages of the electric bus systems. It seems to be most difficult to compensate the short range of the battery buses. Moreover, battery buses are not available as articulated buses (yet).

The most obvious disadvantage of all electric bus systems is the investment costs for the power supply and the vehicles, which have to be financed to start with and which are only balanced after 20 to 25 years by the operating and energy costs, which are much lower then.

Especially overhead contact line systems always lead to discussions. Supporters consider the “rails in the heaven” to be a visible pointer to a high-quality offer. Opponents rather believe that they spoil the street space, especially in sensitive areas, e.g. in front of historical buildings. However, it is a fact that all technologies for electric operation of bus and traction systems without overhead contact line lead to additional investments and are more expensive to maintain.

	System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Advantages of electric operation									
1	locally zero emission and the opportunity to do very low emission also on a global view		Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Low noise emissions, as well inside as outside of the bus		Yes	Yes	Yes	Yes	Yes	Compressors	Yes
3	No vibrations, specially inside the bus		Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Powerfull acceleration		Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Geringer Wartungsbedarf und lange Lebensdauer der elektrischen Komponenten		Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Geringe Betriebskosten (Energieverbrauch) / höhere Unabhängigkeit von Energielieferanten		Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Sichtbarkeit eines qualitativ hochwertigen Angebotes					Yes	sectional		Yes
Compensation of disadvantages of electric operation									
8	Abweichung vom Linienweg mittels Hilfsantrieb (möglichst auch elektrisch)		Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Ausreichende Energiereserven für den Fall von Störungen bei der Stromversorgung					It is assumed that there is - independend from the basic technology - an on-board energy storage unit. The performance of this unit may vary depending on the system			
10	Geringe Beeinträchtigung des Stadtbildes durch angepasste Materialien / spezielles Design für Fahrleitung / Masten / Ladestationen etc.		no such equipment needed	Charging stations	Charging stations	Poles along the whole route	Poles in sections without sensivity only	no such equipment needed	Installations in the lane / sealing

Table III-3.4: Qualitative comparison of various bus systems, part 1 of 3

	System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Operation similar to Dieselbuses									
11	Verfügbarkeit verschiedener Gefäßgrößen entsprechend dem Einsatzzweck / der Nachfrage		currently only 12-m	currently only Midibus	currently only 12-m	Yes	Yes	Yes	currently only trial vehicle
12	Performance up to 20 h per day (duty starting early in the morning, ending about midnight)		ca. 10 h	At Turin ca. 12 to 13 h (7:00 to 20:00)	target	Yes	Yes	ca. 12 h	target
13	Range more than 400 km/day without (complete) refueling or charging		ca. 200 km	ca. 60 km without / 200 km incl. Charging	target	Yes	Yes	ca. 250 km	target
14	simple and fast procedure of refueling or charging		Yes	Yes	target	Yes	Yes	Special Infrastructure	target
15	easy going with the flow of traffic (no speed reduction or stops by technical reasons, special when using lanes mixed with other car traffic)		Yes	Yes	Yes	Yes	Yes	Yes	separated Right-of-Way needed
16	Dwell times according to passenger demand, not extended by technical needs		Yes	Minimal break time -> no rest in blocks, adjustment of delay	charging > 30 sec, dwell time < 20 sec	Yes	Yes	Yes	Yes
17	sufficient supply to all auxiliary power consumers like doors, light, heating/AC and passenger information displays		target	target	target	Yes	Yes	Yes	target
18	simple handling by the driving staff (concentration on traffic, not on the vehicle and no special know-how for electric/electronic equipment needed)		Yes	Yes	continouosly supervision of level of charge	Yes	Yes	Yes	target

Table III.3-5: Qualitative comparison of various bus systems, part 2 of 3

	System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Investment cost similar to todays systems									
19	Vehicle and components					Cost 1,5x to 2x more than EURO5-Diesel		cannot be assumed	cannot be assumed
20	Competition in market when purchasing		assumed	assumed	currently only 1 supplier	Yes	Yes	currently only 2 supplier	Monopol (Patent protection!)
21	Infrastructure on the road / along the route / at the stops		no	charging station	charging station	overhead wire	overhead wire (sectional)	no	power supply system in lane surface / separated right-of-way
22	Infrastructure in depot / workshop		Electric components	Electric components	Electric components	Electric components + on-roof working installation	Electric components + on-roof working installation	Electric components + Hydrogen	Electric components
23	future development / long-time availability of spareparts		assumed	assumed	cannot be assumed	Yes	Yes	cannot be assumed	cannot be assumed
Cost for operation and maintenance									
24	lower cost for energy consumption		expected	expected	expected	expected	expected	expected	expected
25	Independency from fluctuation of prices on the worldwide energy market		expected	expected	expected	expected	expected	expected	expected
26	Less tear and wear by electrical components		expected	expected	expected	Yes	expected	expected	expected
27	longer life cycle of vehicle / components		expected	expected	expected	Yes	expected	expected	expected
	Conclusion of evaluation (number of criteria per evaluation level)								
	improvement in comparance to dieselbus operation	0	10	10	10	11	11	9	11
	equal level like dieselbus operation	27	13	10	9	12	12	11	8
	additional effort in comparance to dieselbus operation	0	2	5	6	4	4	2	4
	Significant degradation / no clear data (degradation expected)	0	2	2	2	0	0	5	4

Table III.3-6: Qualitative comparison of various bus systems, part 3 of 3

III-4 AP4: Practical Application for the Retrofit of a Bus Line from Diesel Bus Operation to Electric Bus Operation Exemplified by Leipzig

III-4-1 Introduction

On the basis of the ascertained theoretical requirements the existing infrastructure for the supply of an electrically operated urban bus line (line 70) with power is examined in this work package in respect of the possibilities of adaptation and the necessity of expansion as well as in respect of the possible synergies with the tramway operation.

For this purpose the requirements for an electric urban bus system are drawn up using the example of bus line 70 in Leipzig. Moreover, the feasibility is assessed.

The following criteria are considered for the selection of a suitable bus line in this study:

Operational concept?

- Timetable (cycle, intermediate terminals, …)
- Vehicles operated (capacity, line linking)
- Service output (vehicle kilometres per cycle)

Nearness to existing power supply installations?

- Contact line for the tramway system
- Substations
- Cable routes

III-4-2 Operational Requirements

III.4.2.1 Line Choice

According to the classic philosophy of the Leipziger Verkehrsbetriebe GmbH (LVB) the tramway is operated as the main mode of transport radially through the city of Leipzig. The bus lines are either urban cross connections between the tramway lines or connections into the environs (regional transport).

In Leipzig the LVB operates 61 bus lines in addition to the regional bus lines. In order to select a bus line suitable for the feasibility study the lines only operated in the periphery of the city are excluded as the first step because no synergetic effects with the traction power supply system of the tramway can be achieved with these bus lines.

Thereafter, the selection is limited to the lines on which 18 m long buses are operated according to the schedule (see chapter III-3.2). Line 60 is one of these lines, but it is also excluded from this study because it is already the focal point of another feasibility study on the retrofit to classic trolleybus operation.

Thus, there are five lines in the final round, which differ much in respect of the following criteria:

- vehicles operated
- scheduling
- passenger volume and
- nearness to existing power supply installations.

Concretely, the following lines are possible:

- Line 70 Mockau-West → Connewitz (Kreuz) and vice versa
- Line 72 Main station → Paunsdorf and vice versa
- Line 73 Main station → Sommerfeld and vice versa
- Line 80 Thekla → Lausen and vice versa
- Line 90 Wahren → Paunsdorf-Center and vice versa

Line 70 fulfils all the above mentioned criteria fully. It is operated in a cycle of 10 minutes, all buses are 18 m long, and the passenger volume is high.

Lines 72 and 73 also fulfil these criteria. Both lines are now operated with serial hybrid buses, but they leave the urban area, line 73 even rather much, which restricts the possibilities of using the traction power supply infrastructure severely.

Consequently, these two lines are out of the question.

Lines 80 and 90 are also operated with 18 m long buses. Both lines offer very good possibilities of connection to the traction power supply network of the LVB, but their moderate passenger volumes are a disadvantage to this study. Both lines are mainly operated in cycles of 20 minutes.

Consequently, these two lines are out of the question.

- Thus, only line 70 is suitable for this study.

Line 70 has many points of connection to the tramway network along its route as stops often serve both modes of transport. Therefore, there is a good basis for the intended examination of the synergetic effects of joint power supply for the tramway and an electric bus system.

III.4.2.2 Main Characteristics of Line 70

The examination of the requirements for an electric urban bus system in Leipzig is carried out on the basis of bus line 70 with a possible extension of this line to the Markkleeberg railway station. It is the intention that the line extension mainly follows line 9 of the tramway as from Connewitz Kreuz.

Bus line 70 runs from the north to the south between Mockau-West and Connewitz Kreuz. Its average length amounts to 16.1 km. The journey time amounts to 50 minutes for each direction of travel. 37 stops are served along the line in 12 cycles per day.

During the busy traffic period in the workdays (Monday to Friday between 06.00 h and 18.00 h) 18 m long articulated buses are operated in a 10 minute cycle. The layout of the line to the industrial estate East provides two alternative connections, i.e. either via "Abtnaundorf" or via the "Pleißenburgwerkstätten".

In the morning hours at weekends (Saturday from 05.00 h to 08.00 h and Sunday from 05.00 h to 09.00 h) the line is only operated between Mockau West and Thekla (bus turning point) (journey time: 8 min) and in the evening (from 23:36 h to 0:06 h) between Mockau West and the Thekla station (journey time: 14 min).

From Monday to Friday 12 buses and on Saturdays 8 buses of the type Mercedes Benz O 530G are operated on line 70. On Sundays the line is served by 8 12 m long standard line-service buses. The distances between the stops vary from 198 m to 981 m, and the average distance between stops amounts to approx. 450 m. The annual kilometric performance of line 70 amounts to 1,011,800 vehicle kilometres. The average transport speed, which is calculated as an average value of both directions of travel with both line variants (inclusive of the dwell time at stops), lies at 20.39 km/h.

Within the scope of this study line 70 is examined as an electric urban bus line extended to the Markkleeberg railway station.

The layout of this extension is identical with the present tramway line 9 from Connewitz Kreuz to the stop called “Markkleeberg, Forsthaus Raschwitz”. From this stop line 70 is to provide a new connection to the terminal stop at the Markkleeberg station via a new route.

According to the line data available at present the section between Connewitz Kreuz and the Markkleeberg railway station is 5.3 km long, which means that line 70 will have a total length of approx. 21.4 km from the new terminal stop called “Markkleeberg Bahnhof” (railway station) to Mockau West and that it will have a journey time of 64 minutes. The number of daily cycles would be increased to 16.

In Annex III-4.1 the line data of the four line variants of line 70 (Mockau-West → Connewitz Kreuz) are listed. These data include data about the

- journey time (inclusive of the dwell time at stops),
- average dwell time at stops / time for turning at the terminal
- distance to the previous stop as well as the total line length
- passenger turnaround (average figure per stop without reference to the journey)

In Fig. III-4.1 the course of the line is shown graphically.

Source: Leipziger Verkehrsbetriebe (LVB) GmbH

Fig. III-4.1: Course of line 70

As no elevation data can be recalled from the digital city map, the topography of the area of line 70 was recorded by collecting the GPS coordinates and representing them graphically (Fig. III-4.2).

The evaluation of the data showed that there is a difference in elevation of about 33 metres over the entire line route as the elevation varies from 110 m to 143 m. The highest spot is between the stops called “Naundorfer Straße” and “An der Tabaksmühle”.

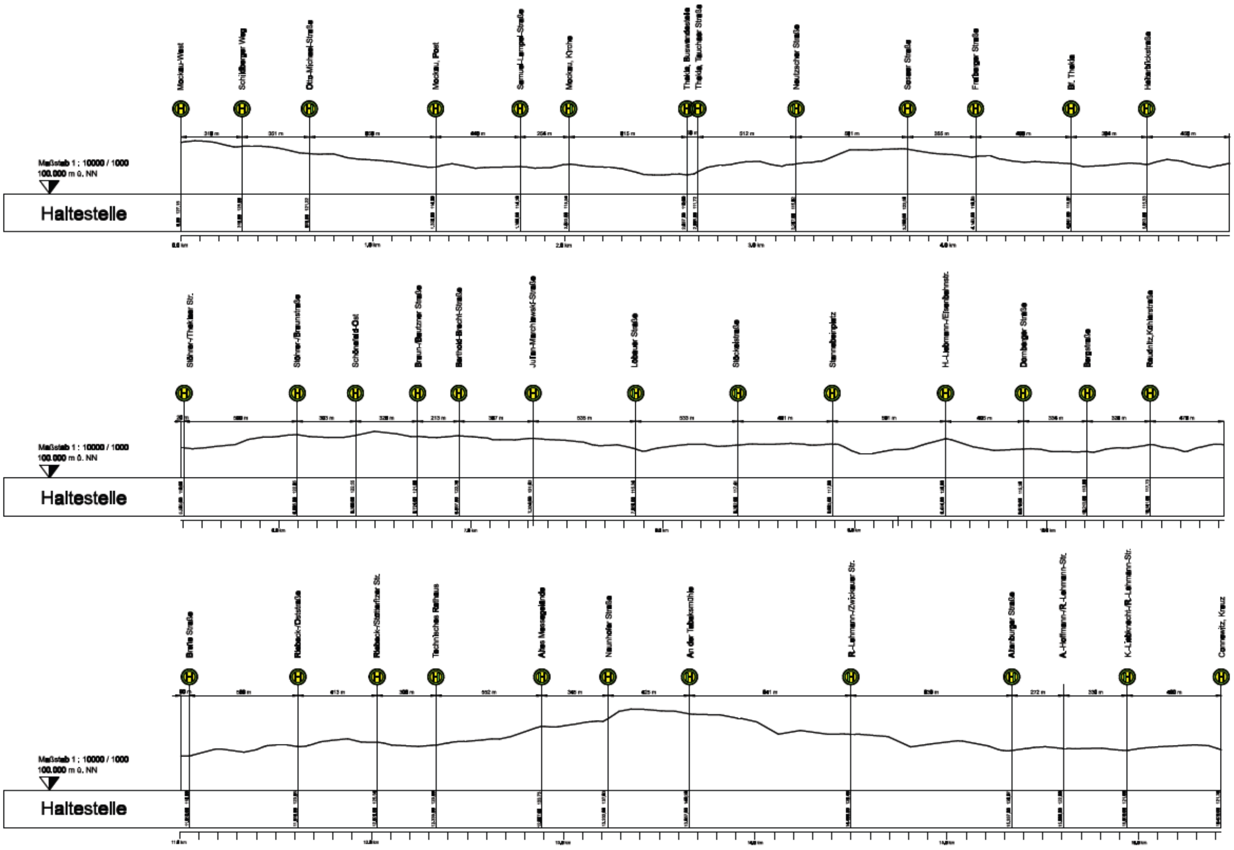


Fig. III-4.2: Topography of the area of line 70 (from Mockau West to Connewitz Kreuz)

III-4-3 Comparison of Scenarios

III.4.3.1 Choice of Scenarios

For the comparison it should not be the objective to compare as many variants as possible, but to compare as few scenarios as necessary.

This approach is not only reasoned by the understandable intention of keeping the examination effort at a reasonable level to the planning effort of a transport company, but also by the contemplation whether a higher quality of the findings can actually be achieved if the study does not only consider the realistic alternatives to the diesel bus, but as many alternatives as at all possible.

From that point of view the following scenarios are compared:

A Operation of diesel buses

B Operation of serial hybrid buses

C Operation of battery buses

D 1 Operation of electric buses needing continuous overhead contact lines (trolleybuses)

D 2 Operation of electric buses needing overhead contact lines in some sections ("hybrid electric buses")

It has been a deliberate choice not to include the options of "operation of fuel cell buses" and "operation of buses with linear, inductive power supply" in this study as – contrary to the above mentioned scenarios – none of the tested solutions for these modes of transport is ready for series production yet.

Scenario A "operation of diesel buses" is the point of origin of the consideration. It is the benchmark for the practical value features at least to be fulfilled by the alternative scenarios – both from the point of view of the transport company and from the point of view of the passenger.

III.4.3.1.1 Qualitative Assessment of the Scenarios

In tables III-3.4 to III-3.6 in chapter III-3.8 a comparative qualitative assessment is made in the form of a matrix.

In accordance with the task the below comments are mainly based on the example of the Leipzig bus line 70.

In this connection the following criteria are to be mentioned:

From the point of view of the transport company:

- Transport capacity
- Driving dynamics
- Operational flexibility
- Provision of traction energy
- Energy efficiency / ecological relevance
- Cost efficiency
- Reliability
- Servicing and maintenance efficiency

From the point of view of the passenger:

- Transport quality
    - ✓ Number of seats
    - ✓ Noise level
    - ✓ Jerk-free driving
- Punctuality
- Timetable cycle
- Schedule speed
- Environment-friendliness

In accordance with the operational requirements for this bus line only 18 m long buses are considered. If there is no experience with such a vehicle in a scenario, it is mentioned expressly.

It is obvious that some criteria of the various scenarios are to be assessed nearly equally or at least only a little differentiated.

Especially the following criteria are to be assessed as absolutely equally:

- Schedule speed
- Punctuality
- Number of seats

  In this connection the transport capacity is irrelevant to the passenger. He wants to know how much room there is for prams, wheelchairs etc. and he is interested in the subjective room ambience.

There are only minor differences between the scenarios as regards the following criteria:

- Transport capacity

  Generally, it may be expected from an 18 m long bus that it can transport at least approx. 140 – 150 passengers. It should have at least 40 seats. Minor differences can be ignored.

  The battery bus is assessed a little poorer because the battery takes up too much space at its present stage of development.

  This statement is only based on the assessment of the battery bus of the type EBN 10.5 from SOR. However, in the opinion of the authors of this study it is allowed to transfer this assessment to an 18 m long bus.

  It is regarded as unfounded to differentiate the scenario “operation of battery buses” further at the present stage, especially as regards the charging technology (plug-in, via pantographs like the eBRT system from Siemens or inductively via e.g. the IPT system from Conductix-Wampfler or the Primove system from Bombardier) because this differentiation cannot be verified on the basis of an 18 m long bus.

  Irrespective of the above statements, the efficiency of the energy transfer technology is commented in the discussion of the energy efficiency criterion.

- Jerk-free driving

  From an objective point of view all electrically powered vehicles are advantageous in this respect because the speed-torque characteristic is fully stepless.

- Accelerating power

  Usually, all comparable scenarios are so well motorised that this criterion is unimportant from the point of view of scheduling.

  Moreover, the passenger can hardly perceive any differences in this respect.

Below the assessments of the criteria are commented for those scenarios that differ more clearly from one another:

- Driving dynamics

  The classic trolleybus is assessed most positively as it has got the advantage of an electric drive – and especially the possibility of operating at overload for a short time – due to the provision of the electrical energy from the overhead contact line system.

  The other scenarios with electric drives (scenarios B, C and D 2) can only use this advantage to the degree that the necessary traction energy is provided by the traction generator and/or the energy storage unit (supercaps and/or battery). However, apart from that the statement on the classic trolleybus also applies to scenario D 2, i.e. operation with an overhead contact line in some sections.

  The diesel bus has the lowest elastic constant as regards the speed-torque behaviour because the diesel engine cannot be loaded beyond its nominal power.

  Thus, diesel buses only have power reserves for demanding operating situations if the diesel engine has been dimensioned sufficiently.

- Operational flexibility

  This term means the possibility of operating the vehicle on different lines of a transport company irrespective of the existence of stationary energy supply installations.

  The scenarios A, i.e. diesel bus, and B, i.e. serial hybrid bus, fulfil this criterion fully. The tank volume of these vehicles always allows operation during a complete day without refuelling – also in case of heavy urban transport.

  The classic trolleybus (scenario D 1) has got the lowest degree of operational flexibility as it needs the overhead contact line.

  Scenario C, i.e. battery bus, has also got a comparatively low operational flexibility as it cannot perform line service without interruptions at the present state of development of the energy storage unit. Moreover, it is dependent on a stationary charging infrastructure.

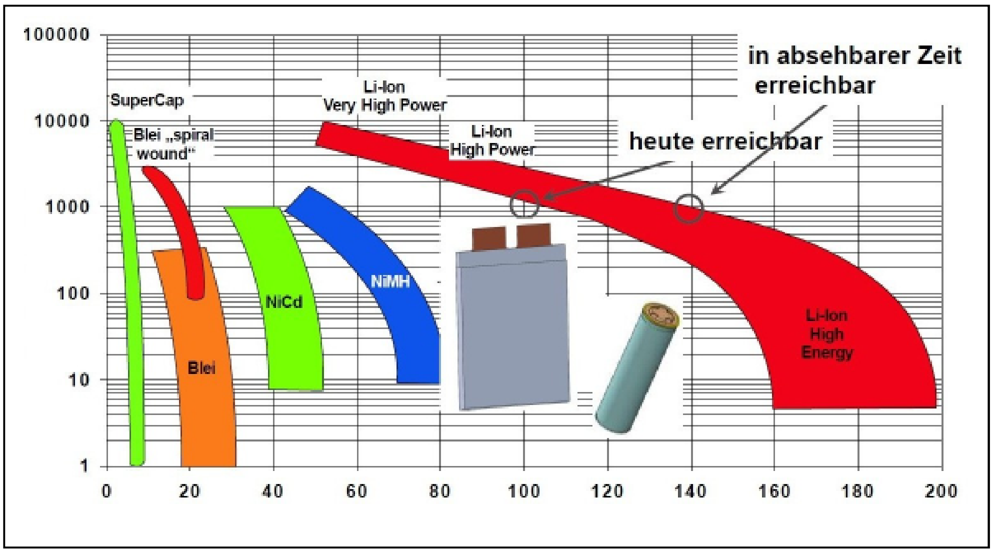


Fig. III-4.3: Mass/storage capacity relationship of energy storage units (source: Prof. Sauer, RTWH Aachen)

This assessment is particularly correct if the disadvantages of a too low capacity of the energy storage unit have to be compensated by recharging it during the dwell time at stops and terminals.

Fig. III-4.3 describes the present dilemma of the commercially available energy storage units for traction purposes and the resulting necessity of recharging them along suitable route sections or at stops at which the buses dwell sufficiently long.

From Fig. III-4.3 it appears that a quantity of energy of approx. 100 Wh/kg storage mass (of the cells) can be stored today, but it is assumed that it will be possible to store up to 140 Wh/kg in future – without statement of the period of time.

At present, a battery pack has an energy density of 50 Wh/kg to 95 Wh/kg (source: Prof. Sauer, RTWH Aachen). If the degree of discharge amounts to 50 %, a mass of 2.2 t has to be assumed for a battery of an 18 m long bus (scenario C) if it has to store the energy for a complete day of operation.

Such a weight cannot be realised practically and this approach is therefore turned down.

Thus, it is the objective to find an optimum between the following parameters:

- Energy demand of the bus
- Size (dimensions, mass, capacity) of the energy storage unit on board the vehicle
- Number and positions of the charging points at stops

The trolleybus operated without overhead contact line in some sections (scenario D 2) comes off a little better than the classic trolleybus (scenario D 1) because it cannot only be operated without overhead contact line according to schedule by way of the energy storage unit, but can also more flexibly in the event of interruptions of the operation (accidents, alternative routeing).

The criteria of optimisation mentioned above for the battery bus also apply to the hybrid electric bus (scenario D 2) as the line sections with overhead contact line are to be considered as charging sections in addition to the charging points at stops and terminals.

- Energy efficiency

The above mentioned scenarios differ clearly in respect of their energy efficiency. At first, it has to be mentioned that the assessment of the energy efficiency is made exclusively on the basis of the energy conversion in the vehicle. There is expressly no assessment of upstream processes, e.g. the way in which electrical energy is generated.

When the scenarios are compared, it is seen that the assessment on the basis of the energy efficiency criterion turns out in the same way as the assessment on the basis of the driving dynamics criterion. If the power installed in the vehicles is comparable, this fact is fully logical because the vehicle with the highest energy efficiency has most energy at its disposal for the actual traction.

The diesel bus (A) comes off worst in this comparison because the thermal engine is its only drive system.

Scenario B, i.e. the serial hybrid bus, is assessed to be only a little better. Although the recuperated energy is used for traction purposes so that up to 20 % fuel is saved, the basic disadvantages of the thermal engine cannot be compensated.

First of all, the scenarios with completely electric drives differ in the way in which they draw their traction energy, i.e. either from an overhead contact line or from a traction energy storage unit or from a combination of both systems.

Moreover, they differ in the way in which energy is led to the vehicle.

In consideration of these aspects the order of the scenarios C, D 1 and D 2 is seen as follows:

1. Scenario D 1: Classic trolleybus

   The classic trolleybus profits from the high transmission efficiency of the overhead contact line – current collection system of at least 98 %. It is independent of the storage efficiency in line-service operation.

2. Scenario D 2: Trolleybus operated in some sections without overhead contact line

   This kind of trolleybus is not quite as energy efficient as the classic trolleybus because the efficiency of the energy storage unit (which amounts to approx. 95 % for a lithium ion battery) has to be included in the assessment.

3. Scenario C: Battery bus

   The battery bus is only considered for the sake of completeness of the weighting. Basically, this scenario has to be rejected for the Leipzig line 70 as there are no 18 m long battery buses on the market at present.

   As it was mentioned in the comments on the operational flexibility criterion, a battery with a weight of approx. 2.2 t would have to be provided for an 18 m long battery bus if it cannot be recharged during a day of operation.

   Therefore, all manufacturers aim at making recharging of the batteries possible at several points of the route so that smaller battery packs suffice.

   The efficiency of the energy storage unit itself as well as the efficiency of the charging technology influence the energy efficiency of the battery bus considerably.

   By approximation, multiplication of the efficiency from the scenarios D 1 and D 2 can be assumed, which is only precise if the battery is recharged via a docking station (galvanic connection).

   If the energy is transferred inductively to the vehicle (e.g. via the IPT system from Conductix-Wampfler or via the Primove system from Bombardier), it has to be assumed that the efficiency is about 3 % lower than in case of recharging via a docking station.

The local energy costs per vehicle kilometre (table III-4.1) reflect the above comparison of the single scenarios.

Energiekosten

	Einheit	A Dieselbus	B Serieller Hybridbus	C Batteriebus	D 1 Klassischer O-Bus	D 2 Elektro-Hybrid
durchschnittlicher Kraftstoffverbrauch	l/100km	53,46	48,95			
durchschnittlicher Energieverbrauch	kWh/km	5,30	4,80	3,40	3,30	3,40
Energiepreis	€/kWh	0,14	0,14	0,11	0,11	0,11
Energiekosten pro km	**€/km**	**0,74**	**0,67**	**0,37**	**0,36**	**0,37**

Table III-4.1: Local energy costs per vehicle kilometre

- Cost efficiency of the vehicle

  The cost efficiency of the vehicle is a very complex criterion as it includes all factors influencing the vehicle-related costs. Thus, in the sense of this study the following factors are included:

  - Investments / capital cost
  - Energy costs
  - Staff costs

  If it is assumed that the single scenarios do not give rise to different staff costs due to the specific types of vehicles, the capital cost and the energy costs remain as the factors deciding on the order and ranking of the scenarios from the point of view of cost efficiency of the vehicle.

  From table III-4.2 it appears that the classic trolleybus has the lowest vehicle-specific costs.

  It is pointed out that the efficiency of the maintenance is not considered here, but examined as a separate criterion.

	Einheit	A Dieselbus	B Serieller Hybridbus	C Batteriebus	D 1 Klassischer O-Bus	D 2 Elektro-Hybrid
Kapitalkosten pro km	€/km	0,40	0,70	0,51	0,49	0,53
Energiekosten pro km	€/km	0,74	0,67	0,37	0,36	0,37
Kosten pro km	**€/km**	**1,14**	**1,38**	**0,89**	**0,86**	**0,90**

Table III-4.2: Cost efficiency of the vehicle

- Efficiency of the infrastructure

  This criterion is only relevant to scenario D 2 as infrastructure along the line is not needed for the scenarios A, B and C. Scenario D 1 requires erection of an overhead contact line along the entire line, i.e. variations are not possible here either. On the other hand, scenario D 2 requires that the overhead contact line system and/or the charging points are optimised in respect of the need for recharging.

Mainly the investment costs for the contact line sections and charging points to be erected are included in the assessment of the efficiency of the infrastructure. Moreover, the criterion of expected prolongation of the journey times caused by charging at stops or wire engagement at the stops at the beginning of contact line sections is considered.

The (non-scale) overview of the possible design variants of the infrastructure in the below table III-4.3 makes it easy to compare the possible infrastructure design variants.

After an initial examination of many technical solutions as far as the length and geographical position of the contact line sections and the arrangement of charging points at the terminals are concerned, two variants can be realised advantageously in compliance with the technical, urban and operational points of view.

An average expenditure of net 860.00 €/m is assessed as the cost for erection of the overhead contact line sections (in the sum both directions of travel are included).

Streckenabschnitte mit Fahrleitung	Variante 1	Variante 2
Haltestelle		
Mockau West		
Rosenowstraße		
Schildberger Weg		
Otto-Michael-Straße		
Essener- / Friedrichsh. Straße		
Mockau, Post		
Samuel-Lampel-Straße		
Mockau, Kirche		
Thekla, Tauchaer Straße		
Neutzscher Straße		
Sosaer Straße		
Freiberger Straße		
Bahnhof Thekla		
heiterblickstraße		
Stöhrer- / Theklaer Straße		
Stöhrer- / Braunstraße		
Schönefeld Ost / VNG AG		
Braun- / Bautzner Straße		
Bethold-Brecht-Straße		
Julian-Marchlewski-Straße		
Löbauer Straße		
Stöckelstraße		
Stannebeinplatz		
H.-Liebmann- / Eisenbahnstraße		
Dornberger Straße		
Bergstraße		
Reudnitz, Köhlerstraße		
Breite Straße		
Riebeck- / Oststraße		
Riebeck- / Stötteritzer Straße		
Technisches Rathaus		
Altes Messegelände		
Naunhofer Straße		
An der Tabaksmühle		
R.-Lehmann- / Zwickauer Straße		
Altenburger Straße		
A.-Hoffmann- / R.-Lehmannstraße		
Liebknecht- / R.-Lehmannstraße		
Connewitz, Kreuz		
Mathildenstraße		
Koburger Brücke		
Wildpark		
Forsthaus Raschwitz		
M'berg, Sonnensiedlung		
M'berg, Gautzscher Platz		
Markkleeberg West		
Markkleeberg, Ring		
S-Bf. Markkleeberg		
Anzahl Fahrleitungsabschnitte	4 / 5	4 / 4
Länge (gesamt) [m]	13.205 / 12.934	13.172 / 13.147

Fig. III-4.3: Overview of the design variants of the infrastructure

The variants only differ a little in respect of the investment costs (see below) and thus inevitably in respect of the costs for servicing and maintenance.

- **Variant 1**
  - Markkleeberg - Mockau-West net 5,561,620 €
  - Mockau-West - Markkleeberg net 5,678,150 €
- **Variant 2**
  - Markkleeberg - Mockau-West net 5,653,210 €
  - Mockau-West - Markkleeberg net 5,663,960 €

Both variants can be realised without additional charging points at the terminals. Here variant 2 especially benefits from the fact that the overhead contact line section fitted in the town is closer to the terminal.

In that way it is possible to keep the charging condition of the traction battery entirely above the value of 80 %, which increases the life of the battery.

In our opinion this criterion is so decisive that it is the crucial factor for choosing variant 2 as the solution.

In Annex III-4.2 the charging condition is shown as a function of the position and length of the contact line sections for both variants and both directions of travel.

Therefore, it is technically absolutely justified to do without charging points at both terminals and thus to save costs. Not only investment costs are saved, i.e. for the actual charging points and their integration into the terminal stop, but also expenses

- for the necessary expansion of a control panel in the rectifier substation and
- for the cable route between the rectifier substation and the charging point.

Due to the much longer cable route it would be much more expensive to erect a charging point at the Mockau West terminal than to erect one at Markkleeberg-West (railway station). Thus, the charging point at Mockau West would cost approx. 300,000 € net, whereas the charging point at Markkleeberg-West would cost approx.180,000 € net.

This means that investment costs of approx. 480,000 € are inapplicable without these two charging points.

Comments on the assessment of the infrastructure design variants

In both directions of travel **variant 1** has an additional contact line section approximately in the middle of the line. Nevertheless, the costs for the stationary infrastructure are only slightly higher than in case of variant 2.

Variant 2 only needs four contact line sections in each direction of travel.

The decisive advantage of variant 2 as against variant 1 is the optimised energetic operation of the line at the Mockau West terminal.

Variant 2 is the preferential solution.

- Efficiency of the maintenance

  Of course, all technical installations – and especially all electrical installations – have to be serviced and maintained at regular intervals, no matter which maintenance philosophy the operator of the installations prefers.

  In this case

  - approx. 26,000 m overhead contact line and
  - 7 switchgear cubicles in existing rectifier substations

  would have to be serviced and maintained for both directions of travel.

  The servicing and maintenance of the overhead contact line, which is calculated to approx. 2 €/m per year (i.e. approx. 52,000 €/year), only profits from a synergetic effect with the servicing and maintenance of the overhead contact line of the tramway in so far as technical resources and qualified staff are already at disposal and can take over the work on the additional installations.

  This also applies to the servicing and maintenance of the rectifier substations, but in this case there is the additional positive effect that the present concept can be realised without having to build new rectifier substations. Instead an additional switchgear cubicle is fitted in each existing rectifier substation.

  These switchgear cubicles are serviced and maintained together with the other traction power supply system components fitted in these rectifier substations.

According to a conservative estimate the maximum annual costs for the switchgear cubicles needed for the power supply of the electrically operated bus line amount to 1,400 € (200 €/year per cubicle).

The costs for the servicing and maintenance of the switchgear cubicles are estimated to be so low because they are part of the maintenance costs for the traction power supply system of the rectifier substations and are maintained within the scope of maintenance of these rectifier substations.

- Reliability

For the assessment of the reliability a simple breakdown was examined for both directions of travel.

As a precaution the failure of the power supply for a complete overhead contact line section – and not only for a feeding section – was examined as the simple breakdown.

Thus, a breakdown with a very low probability of occurrence was examined.

The calculations of the resulting charging condition of the traction battery appear from Annex III-4.3 in WP4 – AP4.

Such a consideration should always be carried out to examine or prove the reliability of the operation if part of the charging infrastructure fails. Just as in case of the traction power supply the following applies: It has to be possible to overcome the simple breakdown (failure of an incoming feeder) without impairment of the transport performance.

The results of these examinations are encouraging. In the most unfavourable case the vehicle would reach the next overhead contact line section with a charging condition of the traction battery of approx. 40 %.

Therefore, it is not uncertain whether the scheduled operation of the electric bus line can be kept up.

It is possible to cope with the simple breakdown without having to interrupt the operation.

- Noise level in the bus

  The noise level is higher in the diesel bus and the hybrid bus than in the electric bus because they have diesel engines as the drive units, which are perceived acoustically by the passenger during the journey. The noise is louder in the rear part of the bus because the diesel engine has been fitted here.

  The hybrid bus has a clear advantage within the stop zone because it can drive electrically, i.e. hardly audibly for the passenger, into this area. It can also leave the stop zone fully electrically as the diesel engine is only switched on when the energy management system of the vehicle initiates switching on due to the decreasing charging condition of the vehicle. The driver cannot influence this behaviour of the hybrid bus.

  The scenarios with fully electric drives (C, D 1, D 2) are assessed to be equally good because these buses are only powered electrically.

- Visible transport offer

  The scenarios D 1, i.e. the classic trolleybus, and D 2, i.e. the trolleybus operated in some sections without overhead contact line, fulfil this criterion fully as a visible line layout, i.e. the overhead contact line needed for the operation, is seen by the passenger and as this overhead contact line clearly shows that public transport is within reach.

  Neither the diesel bus nor the hybrid bus nor the battery bus has such a visible symbol as these types of buses do not need an overhead contact line and fit into the road traffic.

- Environment-friendliness

  The scenarios C (battery bus), D 1 (classic trolleybus) and D 2 (trolleybus operated in some sections without overhead contact line) are assessed most positively, both as regards the noise pollution and as regards the pollutant emission, as they are operated fully without emissions.

  As both hybrid buses and diesel buses are powered with diesel fuel, they are assessed to be less good than the above mentioned scenarios.

The pollutant emission of internal combustion engines has been thoroughly discussed, and this subject is not commented anew in this study.

The hybrid bus is assessed to be better than the diesel bus because it can store and recuperate the braking energy, whereas a diesel bus is only powered by diesel fuel.

III.4.3.1.2 Result of the Qualitative Assessment of the Scenarios

In the concrete case, i.e. line 70 in Leipzig, the tendency of the qualitative assessment corresponds to the general assessment: electric urban bus systems have many advantages and only few disadvantages as against the operation with diesel buses. Moreover, systems with batteries are inferior to systems with overhead contact lines at the present state of the art. The apparently higher degree of freedom without overhead contact lines is paid expensively with a much shorter range, i.e. operating time, or with an additional load due to the high weight of the battery.

A system with an overhead contact line only at positions at which it is really needed is the ideal combination, also for Leipzig, as it overcomes the disadvantages of a short range (battery bus) and of the restriction of an overhead contact line (trolleybus).

III.4.3.1.3 Determination of the Power Required per Scenario

The power required for each scenario is determined in three steps:

- **Step 1: Approximate determination by way of the graphical timetable**
  - Basis: a constant average traction power of 20 % of the nominal power per cycle => 2.5 kWh/km
  - Additionally: power required by the secondary consumers as summer/winter scenario

- **Step 2: Vehicle simulation of the scenarios**
  - Basis: test runs with a serial hybrid bus → Recording of the power from the intermediate circuit
  - Computer-based modelling of the data acquired

- **Step 3: Examination of the various cases of operation**
  - Basis: maximum demand for traction energy per km determined during the test runs
  - Calculation of the development of the charging condition of the traction battery, especially in the event of a simple breakdown as well as for the journeys from the parking facilities to the line and vice versa

The basis for step 1, i.e. for determination of an average traction power per cycle at a set schedule speed of 20 km/h, is the nominal power of the decisive secondary consumers given in the manuals on the hybrid buses operated in Leipzig.

The simultaneity factor g and the load factor a per day were applied for the calculation. The result of this calculation showed that the secondary consumers require a total power of 18 KW, which corresponds to a consumption of approx. 0.9 kWh/km. Accordingly, the specific total energy demand amounts to approx. 3.3 kWh/km. If the calculated data are compared with the data of the SWISSTROLLEY 3 project, they can be regarded as realistic for the further examination due to their accuracy.

Fig. III-4.4 presents the secondary consumers of the hybrid buses used for the calculation as well as the appertaining nominal powers.

Nebenverbraucher	P_{nenn} in W	a	g	P_{max} in W	Kommentar
Fahrer-Assistenzsysteme	100	0,66	1,00	66	
Fahrzeugbeleuchtung gemäß StVZ(	250	0,50	1,00	125	
Belüftung/Kühlung Energiespeicher	600	1,00	0,75	450	
Kühlsystem Fahrgastraum	36000	0,40	0,27	3.888	an 100 Tagen im Jahr
Heizsystem Fahrgastraum	76.000	0,40	0,27	8.208	an 100 Tagen im Jahr
Kühlsystem Fahrerarbeitsplatz	8.000	0,40	0,27	864	an 100 Tagen im Jahr
Heizsystem Fahrerarbeitsplatz	22.000	0,40	0,27	2.376	an 100 Tagen im Jahr
Defrosteranlage	22.000	1,00	0,05	1.100	an 100 Tagen im Jahr für 4 h
Innenraumbeleuchtung	360	1,00	0,33	119	2.920 Jahresbenutzungsstd.
Fahrgast-TV	50	1,00	1,00	50	
Entwerter	300	0,75	0,01	2	vernachlässigbar
Zielanzeigen	50	1,00	1,00	50	
Sonstige: z. B. E-Kompressor etc.	15.000	0,25	0,10	375	
Leistung Nebenverbraucher	**180.710**			**17.673**	entspricht ca. 0,9 kWh/km

Fig. III-4.4: Decisive secondary consumers in the hybrid bus

It appears from the graphical timetable of line 70 (see Fig. III-4.5) that 12 cycles are operated in the morning between 6 h and 9 h from Mockau West to Connewitz Kreuz and from the “Arno-Nitzsche-Straße” to Mockau West, respectively.

16 cycles are required for the entire line 70 when it has been extended to Markkleeberg.

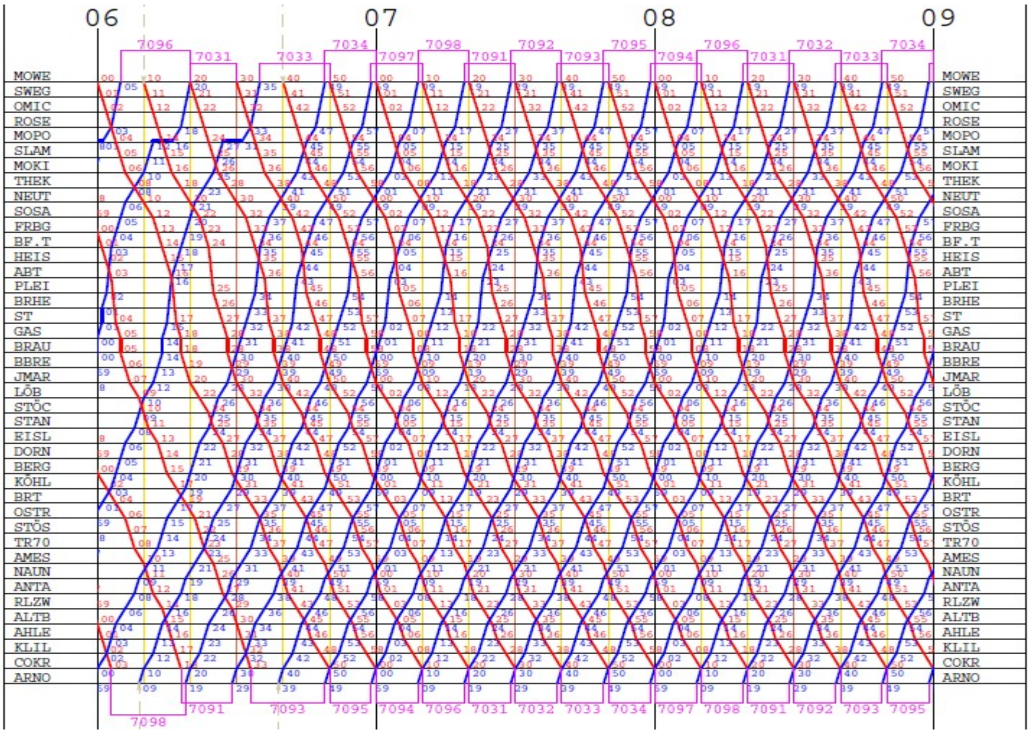


Fig. III-4.5: Graphical timetable of line 70

The Fraunhofer Institute for Transportation and Infrastructure Systems IVI in Dresden performed the vehicle simulation of the power demand and calculated the necessary charging power (step 2).

The power is recorded on the basis of test runs with a serial hybrid bus on line 70 in Leipzig. Thereafter, the acquired data are used for a computer-based modelling of the scenarios:

- Simulation of a classic trolleybus (scenario D 1)
- Simulation of a trolleybus operated without overhead contact line in some sections (scenario D 2)
- Simulation of a battery bus with interim charging at certain points (scenario C)

  + determination of the charging power

It was only possible to continue the calculations and examinations (step 3) in this simplified way due to the flat country character of the topographical line profile.

On an average, the bus consumes approx. 3.7 kWh per km from its energy storage unit when it is operated in sections without overhead contact line. When it is operated by way of the overhead contact line, its energy storage unit is recharged with approx. 3 kWh.

III.4.3.2 Interfaces between the Bus and the Tramway

The existing infrastructure along line 70 and possible interfaces to the tramway lines have to be analysed. It has to be examined whether it will be possible for the bus and the tramcar to use the same power supply system in future.

As regards the existing infrastructure any parallels concerning the

a) availability of the traction power supply installations (cable distributors, rectifier substations),
b) need for adaptation,
c) reconstruction of substations / construction of new substations,
d) arrangement of stops and/or charging points
e) coordination of protective provisions for people, infrastructure and rolling stock (coordination of protective devision)

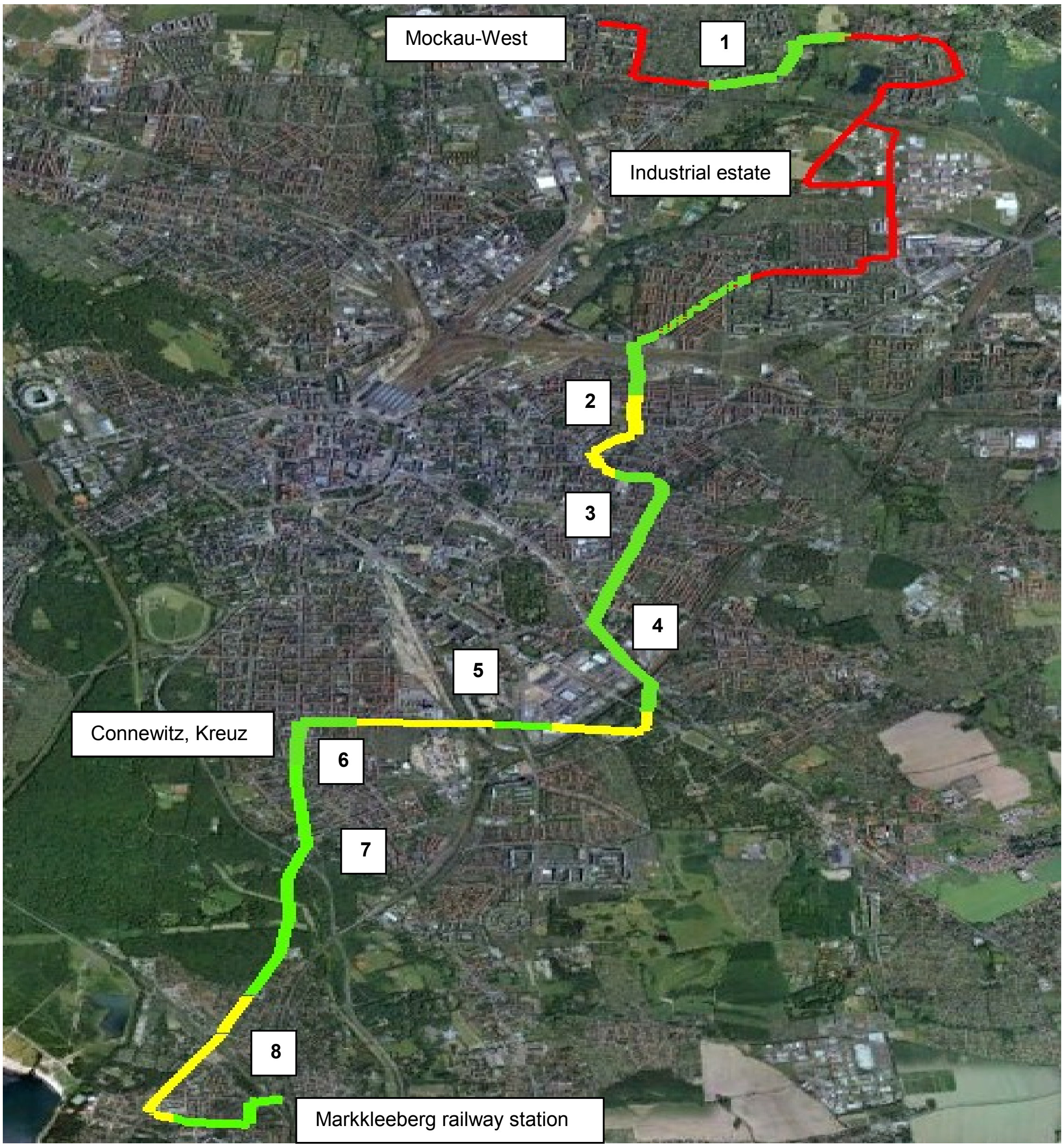
have to be examined.

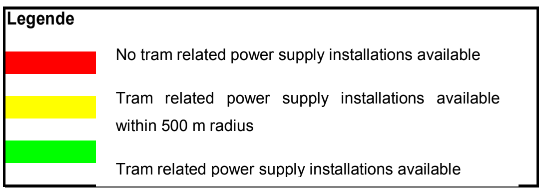
a) Availability of traction power supply installations (cable distributors / rectifier substations)

The below Fig. III-4.6 shows at which stops of line 70 (from Mockau West to Connewitz Kreuz) inclusive of the extension to the Markkleeberg railway station there are interfaces or parallels between the bus line and the tramway.

The graph of the line shows that many stops of the bus line are served in parallel by both modes of transport in the following sections:

- Mockau, Post - Thekla, Tauchaer Straße,
- Löbauer Straße - H.-Liebmann-/ Eisenbahnstraße,
- Reudnitz, Koehlerstraße - Naunhofer Straße,
- at the stop R.-Lehmann-/ Zwickauer Straße and between
- A.-Hoffmann-/ R.-Lehmann-Str. - Connewitz Kreuz





(Source: google earth)

Fig. III-4.6: Line 70 – interfaces to the tramway lines and rectifier substation locations

According to the key the line sections with traction power supply installations are shown in green. Due to the alternating line routes through the industrial estate Leipzig East line 70 is operated alternately via “Abtnaundorf” and the “Pleißenburgwerkstätten” on workdays. Just in this line section there is no connection to the tramway lines at present. The same applies to the Mockau West terminal. The line sections without traction power supply installations are shown in red. The yellow line sections are the sections with traction power supply installations within a radius < 500 m.

There are eight substations within the zone of line 70 (inclusive of the extension to the Markkleeberg railway station):

1. Mockau
2. Neuschönefeld
3. Reudnitz
4. Dauthestraße
5. Zwickauer Straße
6. Arthur-Hoffmann-Straße
7. Connewitz
8. Markkleeberg Mitte

The locations of the rectifier stations along line 70 (from Mockau West to the Markkleeberg railway station) are shown in Fig. III-4.6 in accordance with the above numbering.

The year of construction of the single substations is listed in the below table III-4.4.

Substation	Year of construction	New substation planned	Nominal power in MVA
Mockau	1977		2
Neuschönefeld	1973		4 (3.2 after reconstruction)
Reudnitz	1973	2013	4 (3.2 after reconstruction)
Dauthestraße	1978		3
Zwickauer Straße	1999	new	3.2
Arthur-Hoffmann-Straße	1988		4
Connewitz	1973	to be given up	3
Markkleeberg-Mitte	1993	new	3.2

Table III-4.4: Substations – Year of construction and nominal power

The examination of the condition of the overhead contact line system for the extended line section between “Connewitz Kreuz” and “Markkleeberg West” (which corresponds to the present tramway line 9) revealed that the poles of the overhead contact line system are in a critical condition. This line section can only be used for a trolleybus line if all poles are exchanged. As regards the entire extended line section this applies particularly to the section between “Connewitz Kreuz” and “Markkleeberg, Forsthaus Raschwitz” as well as to the section between “Markkleeberg West” and the Markkleeberg railway station.

The existing overhead contact line system is not suited for operation of electric buses in the classic sense of a trolley variant. It would be absolutely advisable to modernise the infrastructure or erect new infrastructure on the above mentioned line sections.

b) Need for adaptation

The following questions have to be answered:

1. Where are feeding points along the bus line needed according to the result of the simulation of the power required?

   Note: The exact positions of the feeding points are determined at a later planning stage. For this purpose the overhead contact line sections set out in the study have to be divided into feeding sections.

2. Are all traction power supply installations found within an economically reasonable distance?

   Note: Distances of 500 m (in justified cases up to 800 m) are considered to be economically reasonable.

3. Can the existing traction power supply installations (rectifier substations or at least cable distributors) provide the additional power needed for the operation of electric buses?

   Note: Basically, it is always possible to ensure the supply of an electric bus line in all new substations or all reconstructed substations.

4. Is it possible to fit additional cable outlet fields in the existing rectifier substations?

   Note: The necessary space for the expansion of the switching device is available.

5. If necessary: Which locations are suited for the construction of new additional rectifier substations?

Note: Up to now, it is only intended to build new rectifier substations or expand existing rectifier substations at their present locations.

c) Reconstruction of substations / construction of new substations

Since 2008 the LVB has been changing the nominal voltage of the contact wire from 600 V to 750 V within the scope of an extensive modernisation concept. The electrical installations and their equipment are examined and, if necessary, exchanged in this connection.

Although the rectifier substations are rather old (on average 30 – 35 years), it is preferred to reconstruct the substations instead of building new ones because the buildings are in a relatively good condition. The reconstruction programme of the LVB will probably end in 2015.

The following effects are achieved with the change to a nominal voltage of the contact wire of 750 V and with the building measures to be taken for this reason:

- better utilisation of the braking energy,
- less total demand for power,
- less conduction loss in the traction power cables and the overhead contact lines
- increase in the capacity of the power supply system – improvement of the security of supply
- less wear on the overhead contact lines and the trolleys for current reasons.

The modernisation of the substations is a good initial position for implementation of modern transport concepts and modes of transport, e.g. new electric bus systems or retrofit to an electric bus system.

The substations *Mockau* and *Arthur-Hoffmann-Straße* are to be (re-)constructed within the scope of the 750 V programme of the LVB sometime after 2013. It has not been finally decided yet whether the Mockau substation is to be reconstructed or replaced by a new substation at another place. Both substations have enough space for an extension.

It is the intention to reconstruct the substations *Neuschönefeld* und *Dauthestraße* next to the “Härtelstraße” within the scope of the 750 V programme when the existing Reudnitz substation has been replaced by a new substation. The exact schedule for this building activity depends on the available funds.

Here, too, space has been reserved for the extension in the form of an additional switch-gear cubicle for another line.

The substations *Markkleeberg-West* and *Zwickauer Straße* are still new as they were built after 1990. At present, all the existing routes are used for the tramway operation. As the buildings of these substations were dimensioned for this purpose, there is no room for an extension of the substations.

Next year the *Reudnitz* substation is to be replaced by a new substation in the same place.

The *Connewitz* substation is to be given up as this real estate is not owned by the LVB. One or several small substations next to the “Bornaische Straße” are to supply the areas of Connewitz and Lößnig in future. The exact positions have not been fixed yet.

If the tramway line 9 is extended from the Thekla terminal to the Thekla station, a new substation would have to be erected in this area. As line 70 also serves these two stops, this line should also be considered for the future.

Moreover, the *Volbedingtstraße* substation, which does not lie directly next to line 70, should also be examined as this substation has room for an extension after the reconstruction realised already.

d) Arrangement of stops and/or charging points

A basic requirement for the erection and operation of charging points along the line is that the dwell time at stops amounts to at least 15 – 20 seconds. This requirement is always fulfilled at the terminals as the average time for turning amounts to 9 – 10 minutes.

The below table III-4.5 shows at which stops the average dwell time at stops is ≥ 15s.

This restriction is necessary to be able to examine the variant of supplying the bus with power at points (charging). However, it is not enough that the dwell time is sufficiently long. In fact, it is decisive whether it is possible to supply the charging points with power.

Line 70 Mockau-West --> Connewitz Kreuz		Line 70 Connewitz Kreuz --> Mockau-West	
Name of stop	Ø dwell time [s]	Name of stop	Ø dwell time [s]
Mockau-West	600	Arno-Nitzsche-Straße	543
Mockau, Post	18	Connewitz, Kreuz	15
Thekla, Taucher Straße	17	Naunhofer Straße	21
Julian-Marchlewski-Straße	16	Altes Messegelände	16
Stöckelstraße	20	Riebeck-/Oststraße	15
Stannebeinplatz	16	Breite Straße	17
H.-Liebmann-/Eisenbahnstraße	19	Reudnitz, Koehlerstraße	24
Reudnitz, Koehlerstraße	24	H.-Liebmann-/Eisenbahnstraße	23
Breite Straße	20	Stannebeinplatz	16
Riebeck-/Oststraße	17	Löbauer Straße	18
Naunhofer Straße	17	Thekla, Tauchaer Straße	15
Connewitz, Kreuz	554	Mockau, Post	20
		Mockau-West	600

Table III-4.5: Line 70 – stops with an average dwell time > 15 s

It does not matter for this analysis which alternating route is followed through the industrial estate East as the dwell time at the stops in this estate are all under the set limit.

It is a premise for the possible operation in Leipzig that the mobile energy storage unit of the vehicle is exclusively charged at the charging points from the overhead contact line of the trolleybus by way of the standard trolley of the trolleybus. It is a deliberate choice within the scope of this study that no other technical solution is accepted for the charging than the one that has already proved its worth and is standard for the operation of buses in sections with overhead contact lines.

As another design solution for the power supply in the sections without overhead contact line charging points designed as a firmly installed contact line was considered as the trolleybus contact line within the area of the charging point.

A recommended design solution is the integration of the firmly installed contact line into a complete stop shelter construction, which is applied by Siemens within the scope of its e-BRT project (see Fig. III-4.7).

Fig. III-4.7: Charging point at a stop taking the e-BRT system from Siemens as an example

This solution is based exclusively on components that have already proved their worth in practice. The continuous current-carrying capacity of the system consisting of a contact wire or a firmly installed contact line and a trolley allows a charging current of approx. 150 A for several minutes without any problems. In that way the charging condition of the mobile energy storage unit can e.g. be improved by at least 15 kWh if the bus stays 9 minutes at the terminal.

Moreover, the system consisting of a contact wire or a firmly installed contact line and a trolley has a high degree of transmission efficiency. It should lie at 97 % under the usual contact conditions (no icing, not too much dirt).

An interesting alternative in the form of inductive transfer of energy is the PRIMOVE concept developed by Bombardier (see Fig. III-4.8). Due to the inductive transfer of energy the vehicle has to be modified technically as a socalled power pick-up unit has to be fitted under the vehicle. This unit acts as the secondary coil of a transformer.

According to information from Bombardier the costs for a PRIMOVE charging point amounts to approx. 125,000 €, but it is unlikely that this sum includes the costs for the installation or the costs for the feeding cables.

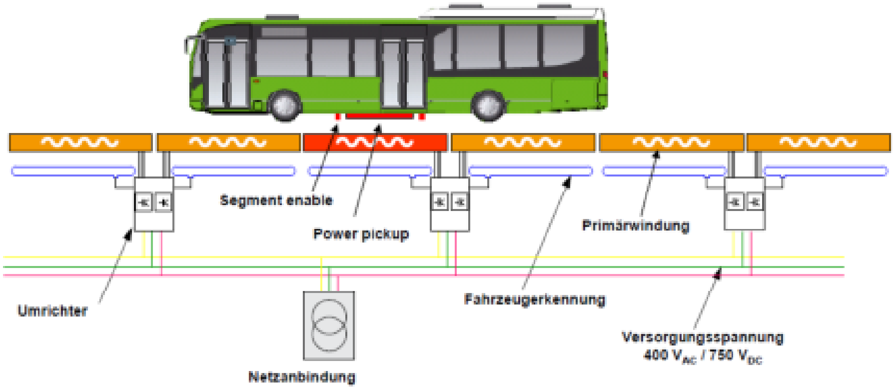


Fig. III-4.8: Charging point according to the PRIMOVE principle of Bombardier

On the basis of the available information it is assessed that the costs for a complete charging point amounts to approx. 150,000 €. Thus, the inductive charging point would be about 50,000 € more expensive than the conventional charging point (no consideration at all of the feeding cables from the next rectifier substation to the charging point and no consideration of the costs for expansion of the rectifier substation itself).

The transmission efficiency of about 95 %, which is mentioned by Bombardier, is also lower than that of the conventional charging point.

At the deadline of this study it was not possible to finally assess the two alternatives as the information about the PRIMOVE concept was incomplete.

e) Coordination of protective provisions for people, infrastructure and rolling stock (coordination of protective provisions)

Obviously there is an economic advantage to use the infrastructure of the existing tram power supply to provide energy for an electric bus on the one hand.

On the other hand the common use of the tram power supply by tram and by electric bus can lead to a link of the electrical hazards as well as of the operational risks.

For a better understanding a basic scheme of the energy supply infrastructure is shown in figure III-4.9.

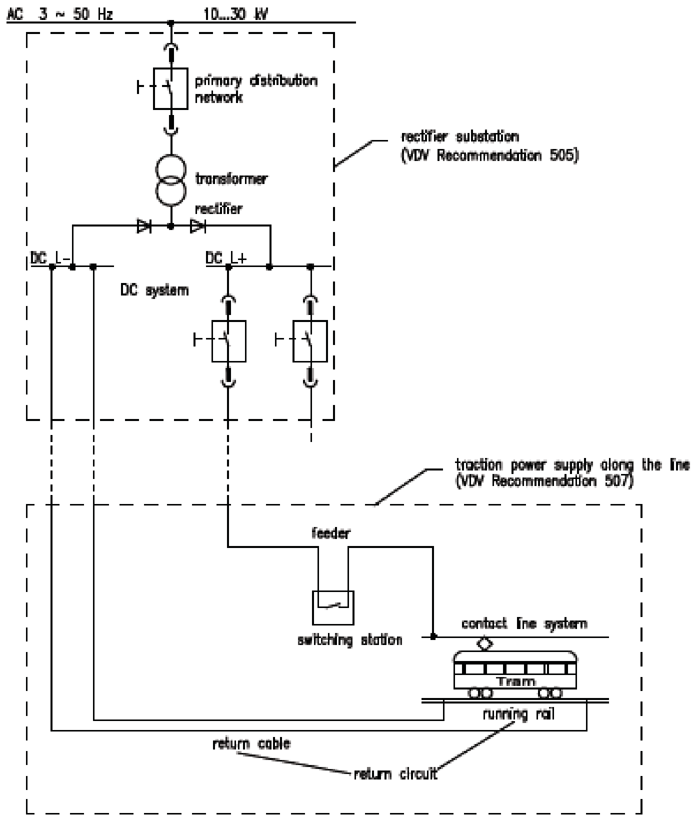


Figure III-4.9: Basic scheme of the energy supply
(Source: VDV recommendation 507)

Although Figure III-4.9 shows the structure and the facilities of a tram power supply network the situation of the energy supply for an electric bus is nearly the same.
This applies without any exception for all AC system components and the rectifier.

The fundamental difference is that the return current of the electric bus flows through the catenary system and not –like in the case of the tram – through the running rails.

This has consequences for the application of protective provisions of the DC system components for the tram on the one hand and for the electric bus on the other hand.

Table III-4.6 shows the possible scenarios of hazards for the common energy supply infrastructure for tram and electric bus.

Failure Serial Number	Plants to be protected	Characteristical Hazards	Affection of the power supply for tram / electric bus
1	Complete infrastructure	Surge (e. g. flash of lightning)	equally affected
2	Supplying AC power network	Power failure, Surge	equally affected; Equipment covered by third parties → Own precautions unpossible
3	Medium-voltage switchgear	Surge, Ground fault and short-circuit current	equally affected
4	Transformer	Internal failure (e. g. insulation damage), Overtemperature	equally affected
5	Rectifier	Surge, Eccessive current	equally affected
6	DC Switchgear	Surge, Ground fault and short-circuit current	Selective protection → Limitation of the impact
7	DC Cable network	Single-phase or two-phase fault	Selective protection → Limitation of the impact
8	Catenary system	Overload, Ground fault or short-circuit	Selective protection → Limitation of the impact

Table III-4.6: Possible hazards to the power supply

The energy supply for mass transit systems is usually provided by the local public AC-energy supply network at a voltage level of 10 kV or 20 kV. The area of responsibility of the public AC-power supply is coloured red in III-4.6.

Of course the operator of the public power supply network uses a wide range of protective provisions to deal with possible hazards to the network or malfunctions of single components or even complex parts of the network. Usually the operator of the public energy supply networks insures a high reliability of the energy supply.

This is an important prerequisite for a trouble-free energy supply of the mass transit system. The substations are supplied with 10-kV- or 20-kV-ring networks.

Only in the rare case of a failure in both feeding parts of the ring-network there will be no chance to avoid a failure of single substations of the mass transit.

In these cases the impact on the mass transit energy supply network depends particularly on those factors.

- Realisation of the energy supply of the substations of the mass transit by connecting the substations to different 10-kV- or 20-kV-ring networks (if possible)
- Connecting/Disconnecting the sectioning points to feed a section of the tram or electric bus energy supply by another substation

The rectifier (yellow-coloured in table III-4.6) is feeding the tram power supply as well as the the power supply of the electric bus. Therefore both means of transportation will be affected in the case of malfunction of the rectifier.

As it is shown in table III-4.6 only the green-coloured parts of the DC-power supply infrastructure provide a real selective protection from the viewpoint of the energy supply of the tram on the one hand or the electric bus on the other. This means if a failure happens in the tram power supply system the power supply of the electric bus network will not be affected and vice versa.

Looking for technical standards or safety regulations we find a comprehensive framework of regulations for DC mass transit systems in the form of the so called VDV-Regulations.

(VDV means “Association of German Transport Companies”.)

On closer examination this framework is made in detail for trams, electric light railways and so on but not for electric buses.

The “Passenger Transport Act” (PbefG) and the “German Federal Operating Regulations for Motor Vehicles” (BOKraft) are the only binding rules for electric buses in Germany.

Only the “Passenger Transport Act” is ruling basically the tram as well as the bus or the electric bus.

The “German Federal Regulations on the Construction and Operation of Light Rail Transit Systems”” (BOStrab) include a large number of protective provisions which must also be applied for electric buses.

In addition to the above mentioned protective provisions there is the German / European Standard DIN EN 50122 "Railway applications – Fixed installations – Electrical safety, earthing and the return circuit" which provides a lot of information concerning the protection of people and livestock.

This standard is specifically applicable to trolley bus systems. The generalized application of the relevant regulations on electric buses we consider as acceptable.

Protection of people and livestock

Of course the protection of people is a top priority. On the one hand the regulations concerning the tram as well as the electric bus are nearly identical on this field of action. These are above all the protective provisions concerning the direct or indirect contact with live parts (conductive parts of the infrastructure which are intended to be energized in normal use).

On the other hand one specific of the protective provisions for the tram infrastructure should be mentioned - the **rail potential**! (This is the voltage drop across the electrical resistance between the running rails and the earth (see DIN EN 50 122-2).

> This is the voltage occuring under operating conditions when the running rails are utilised to carry the traction return current. Under fault conditions it is the voltage between the running rails and the earth.
>
> Therefore special restrictions regarding the so called **accessible voltage** have to be observed. The accessible voltage is that part of the rail potential which can be bridged by persons under operating conditions.

The electric bus (only in the case of the energy supply by an overhead line or a by charging stations with electrical connection) also has a special feature. This is the double insulation of all parts of the vehicle which a person might touch when getting on or off. The reason is that the body of the electric bus does not have a electrical conductive connection (of practical importance) to the earth potential. Otherwise a dangerous voltage might occur on the body of the electric bus in the case of a fault.

Protection of the energy supply infrastructure

The existing VDV-Recommendations can be applied for the tram energy supply as well as for the power supply infrastructure of the electric bus.

Particularly noteworthy are the VDV-Recommendations

- Number 505: Design of and Protective Provisions for DC Rectifier Substations for DC Mass Transit Systems
- Number 506: Design of and Protective Provisions for Electrical Power Installations in Depots and Workshops for DC Mass Transit Systems
- Number 507: Design of and Protective Provisions for Electrical Power Installations Along DC Mass Transit Lines
- Number 525: Design of and Protective Provisions for Electrical Traction Power Installations for DC Mass Transit Systems in the case of flash of lightning

The VDV-Recommendations mentioned above give the persons responsible for such systems pointers and practical examples to make it easier for them to solve problems practically.

Protectition for the primary distribution network

The electrical power for DC traction systems is usually drawn from the public three phase primary distribution network to rectifier substations and converted there. All hazards which might occure to the primary distribution network and all failures which may be the result for the traction energy supply (tram and electric bus) are outside the responsibility and control of the transport company. Therefore such hazards or failures will not be considered in this report.

Protection for DC Rectifier Substations

In the case of the common use of the tram power supply for the tram as well as for the electric bus the protection of the rectifier substation has to be made in principle in the same way for tram and electric bus.

Basically a rectifier and a DC switchgear assembly are connected in series downstream of each rectifier transformer. Usually the share of the provided power of a DC rectifier substation for the energy supply of the electric bus will be significantly smaller than that for the tram.

From an economical point of view it does not make any sense to provide a transformer and a rectifier only for the energy supply of the electric bus.

Due to a different protective monitoring for the tram and the electric bus there should be used another DC switchgear for the outgoing feeders for the tram or the electric bus power supply each.

With respect to the protection of the rectifier transformer it does not matter whether the transformer feeds only a tram or electric bus power supply or a combination of both.

The only criterion is the type of the electrical insulation and the cooling of the transformer.

There are two ways.

- Dry-type transformer, resin capsulated with air cooling
  → Monitoring of the temperatures of the windings (of all limbs)
- Transformers with liquid cooling:
  → Buchholz protection and monitoring of the temperature of the coolant

The protection of the rectifier itself must be included in the protective provisions for the DC switchgear assembly. It has to be ensured that the rectifiers and the transformers are neither endangered in case of a short circuit nor in case of overloading or overvoltage.

Note that their protective equipment affects the medium-voltage switchgear assembly (in-coming cables from the primary distribution network)!

Under fault conditions the switchgear will be triggered via the protective monitoring of the connected infrastructure and the protective devices.

Protection for Power Installations Along DC Mass Transit Lines

These protective provisions cover the traction power supply installations along the lines which usually consist of the following components:

- Feeders
- Return circuits
- Switching stations
- Contact line systems

This report is not dealing with the protective provisions for the electrical equipment along the lines and at the stops which are not fed by the contact line but by the local AC network.

There are different **classes of protection of the equipment**:

Class I

The protection against electric shock of class I equipment is not only founded on the basic insulation. As an additional protective provision the parts of the equipment are connected to the protective conductor (PC) of the fixed installation. On this way no voltage can remain if the basic insulation fails.

Class II

The protection against electric shock of class II equipment is not only founded on the basic insulation. There additional safety precautions (e. g. double insulation). Class II equipment is totally insulated.

Despite of the different design and different mode of operation of some components of the power installation for the tram and the electric bus (e. g. contact line systems, return circuits) there is no fundamental difference in dealing with the protective provisions.

Protection and safety criteria for people who are inside the vehicles or hopping on or off

There are significant differences in dealing with this issue for the tram on the one hand and the electric bus on the other hand.

The origin of these differences is mainly the different design of the vehicle itself and of the return circuit.

The return circuit of the electric bus uses a return wire of the overhead line before connecting a return cable connecting point at first or finally the return cable bus bar.

The crucial point is: During normal operation there is no electrical connection possible between the body of the electric bus and the earth potential. The consequence is that the protective earthing is not available as a protective provison.

Therefore special protective provisions are to be considered in the design and manufacture of the electric buses.The aim of these precautions is to avoid all contact voltages and in particular to avoid a voltage between the body of the vehicle and the earth potential.

To cite examples there are in detail such protective provisions as

- Steps, handrails and access platforms

  All these components have to be insulated from the vehicle body or made of insulating material.

- Doors

  All components accessible to the passengers have to be insulated from the vehicle body or made of insulating material.

- Leakage detection

  Electric buses should be equipped with an automatic safety device – the so called leakage detector. This device gives an alarm signal to the driver if the insulating resistance between the circuits fed with the overhead line voltage and the body (mass) of the bus decreases down to unacceptable limits (look at EN 50153) or the vehicle body potential reaches the limits given in EN 50 122-1.

The tram shows a completely different situation because the return circuit is considered to have nearly earth potential.

So it is unpossible that a dangerous voltage could remain between the body of the tram and the earth potential even under fault conditions.

III.4.3.3 Urban Integration

The integration of overhead contact lines into the city is a very emotional subject. Often the town planners do not approve of the overhead contact lines and often the citizens find that they spoil the townscape.

It is admitted that optically suboptimal structures emerge at complicated crossings with the overhead contact line system of the tramway from straight and branching line sections and that it is also expensive to install and maintain such crossings.

Alternatives, like operation without overhead contact line in some sections, make it possible to avoid such conflicts in urban surroundings of high quality (e.g. in historical town or city centres) and to reduce the costs for the overhead contact line systems. However, it is a condition that the trolleybus is technically able to drive fully electrically or by way of an auxiliary generator set in some sections.

So far, the subject of urban integration of charging points into the townscape has not been discussed broadly. It is essential that the charging installations are integrated fully into the design of the stop.

Fig. III-4.7 presents a stop design into which the e-BRT system from Siemens is integrated. Here the bus is interim charged during its dwell time at the stop via the overhead contact line fitted in this section.

Generally, this aspect will be weighed differently by each municipality. It is hardly possible to generalise. The instincts of the experts involved in such a project are in demand.

III.4.3.4 Costs and Investments

Many inputs have to be considered when the economic effects of the scenarios mentioned in chapter III.4.3.1 are to be compared.

As regards scenarios A (operation of diesel buses) and B (operation of serial hybrid buses) the data gained from the operation of the fleet of the LVB are taken as a basis. Relevant cost elements concerning scenario D 1 (operation of electric buses needing continuous overhead contact lines (trolleybuses)) are found in the specialist literature and taken from practical examples in German cities with trolleybus operation.

However, as regards scenarios C (operation of battery buses) and D 2 (operation of electric buses needing overhead contact lines in some sections ("hybrid electric buses")) it has turned out to be difficult at the present stage of the study to mention typical values and reference values for the operation of 18 m long buses. At present, only 12 m long battery buses are operated by transport companies.

The following cost elements and criteria are to be analysed and assessed for an 18 m long articulated bus:

- Vehicle costs
- Workshop
- Charging points
- Overhead contact line
- Further costs

<u>Vehicle costs</u>

The costs for the procurement of one vehicle make up the basis for the further cost analysis. In table III-4.7 these costs are mentioned for each scenario.

	Procurement costs and service life of an 18 m long articulated bus				
	Diesel bus	Serial hybrid bus	Battery bus	Electric bus with continuous overhead contact line	Electric bus w. overhead contact line in sections
Purchase price	330,000 €	700,000 €	660,000 €	750,000 €	850,000 €
Service life	12 years	12 years	20 years	20 years	20 years

Table III-4.7: Procurement costs and service life of an 18 m long articulated bus

The comparison of the purchase prices shows that the diesel bus is the most inexpensive kind of bus, but also that it has got a shorter service life than a trolleybus, which has an average service life of 20 years.

There were no practical reference values for the battery bus. On the basis of the costs for procurement of a 12 m long battery bus (approx. 440,000 €) it was assessed that an 18 m long battery bus would cost approx. 660,000 €.

The high purchase price for an electric bus needing overhead contact line in some sections mainly arises due to the costs for procurement of the system components needed in the vehicle.

Moreover, the life of its energy storage unit is limited by the expected high number of charging cycles per bus and per year. Thus, the energy storage unit probably has to be replaced after maximum 60,000 charging cycles, i.e. after about 3.2 years in a bus operated on the exemplary line 70 (cf. variant 2). Therefore, these replacement investments in batteries to the amount of approx. 150,000 € per bus are an important cost factor in the cost-benefit analysis. This aspect will be discussed in detail further below in this chapter.

Workshop

The costs for servicing and maintenance of the various kinds of buses differ. All scenarios lead to costs for the provision of a necessary spare parts centre for material and tools. Moreover, costs emerge for the qualification of the workshop staff in the form of training if the staff is not already suitably qualified. The LVB has a cost advantage in this respect due to its experience with the hybrid bus fleet and the training already realised.

The following main items have to be procured for the servicing and maintenance of buses of all scenarios in a workshop, provided they are not already part of the workshop equipment:

- Working pit
- Roof access platform
- Test bay
- Feeding and charging installations
- Overhead contact line within the depot area (for scenarios D 1 und D 2)

It is not possible to do without a roof access platform because work has to be carried out on the roof of the buses, e.g. corrective and preventive maintenance of the air conditioning installations, the supercaps and the ancillary units, as well as on the trolleys and the electrical traction equipment.

The investment costs for an 18 m long roof access platform, which is equipped with swivelling railings and accessible from two sides and which is so high that articulated buses can pass unter it, amount to approx. 130,000 € nowadays.

The average maintenance costs per kilometre for the diesel buses of the LVB amount to 0.50 €/km at an annual average kilometric performance of approx. 61,000 km per bus.

This cost rate consists of 40 % labour expense and 60 % material costs.

At present, it is difficult to exactly state the reference values for the maintenance of the hybrid buses of the LVB. As these vehicles are still very young, the vehicle manufacturers are obliged to repair any damage occurring during the guarantee period and to maintain the special components. Therefore, the exact maintenance costs per kilometre cannot be mentioned before the guarantee period has expired.

As the operation of trolleybuses was stopped already in 1975, no current local price can be mentioned for this operating system.

The analysis of an electric bus system has to consider that new electrical components have to be serviced and maintained, whereas some other components like the diesel engine and the gear box fall away.

Consequently, it is assumed that there will only be minor differences as regards the servicing and maintenance of the various types of vehicles, which can be neglected for the further analysis.

However, the costs for the vehicle reserves needed to ensure reliable operation may not be neglected. They amount to approx. 21,500 € per bus annually.

Charging points

The scenarios D 2 (operation of electric buses needing overhead contact lines in some sections) and C (operation of battery buses) require that charging points are erected

- at the terminals and at the stops for the (fast) interim charging necessary during the line service (only relevant to scenario C) and
- within the depot for the normal recharging of the battery overnight or out of the line service period.

Further costs in addition to the pure investment costs for the charging points incur for the provision of the necessary infrastructure, e.g. for the connection to the power supply system. Moreover, the costs for the integration of a facility for interim charging into already existing stops and the reconstruction measures to be taken in this connection as well as the costs for the operation of the system have to be examined.

The analysis of the two line variants examined (cf. variant 1 and variant 2 mentioned in chapter III.4.3.1.1 under the point “Efficiency of the infrastructure”) showed that it is not meaningful to erect and operate charging points along the line due to the short dwell time at stops (< 15 s).

It was originally considered to erect charging points at the terminals to increase the charging condition of the energy storage units, but within the scope of the analysis and due to the positions of the line sections with overhead contact lines it has become clear that the energy storage units do not have to be charged at the terminals. As the batteries are recharged during the journey, such a high charging condition of the batteries can be ensured that charging points at the line terminals become superfluous.

However, this does not mean that it is possible to do completely without stationary charging points. The batteries of the vehicles always have to be recharged overnight, e.g. at the Lindenau bus station or in the "Technisches Zentrum Heiterblick", so that the vehicles are ready for operation at the beginning of the daily service.

It is assessed that the costs for all parking facilities amount to approx. 400,000 €.

The configuration of the charging points in the parking facilities is not specified within the scope of this project because a reasonable decision can only be made on the basis of a specification of the vehicles to be procured. A plug-in solution seems to be meaningful as it has proved its worth for the pure battery buses.

Overhead contact line

In connection with the erection of an overhead contact line system for trolleybuses costs incur for the:

- contact wire,
- poles,
- section insulators,
- points and
- crossings.

If the overhead contact line is only needed in some sections, the latter two items become superfluous or are at least reduced considerably, but the vehicle costs are increased. Moreover, costs arise for the servicing and maintenance of the overhead contact line system.

An average expenditure of net 860.00 €/m is assessed as the cost for erection of the overhead contact line sections (in this sum both directions of travel are included).

A comparison of the costs is found in the next chapter, in which the figures of the line variants are compared.

Further costs

Further costs are e.g. the consequential costs for the integration of the charging points into the townscape and the costs for adaptation of the road network, if any. This cost aspect is included in the costs for the power supply system.

III.4.3.5 Economic Comparison of the Line Variants

The economic efficiency of the line variants is explained by means of bus line 70.

Table III-4.7 (below) shows an economic comparison of the variants of line 70, the examined variants 1 and 2, i.e. operation of electric buses needing overhead contact lines in some sections, and the classic trolleybus variant with continuous overhead contact lines are compared.

The economic analysis is performed for a period of 20 years.

Due to the different lengths of the sections with overhead contact line the highest construction costs for the overhead contact line and the traction power supply arise for the classic trolleybus variant as its overhead contact line share amounts to 100 % along the line. Consequently, it is also expected that the highest costs for the servicing as well as the preventive and corrective maintenance of the overhead contact line system incur for this variant within the period under consideration.

The servicing and maintenance of the overhead contact line, which is calculated to approx. 2 €/m per year, only profits from a synergetic effect with the servicing and maintenance of the overhead contact line of the tramway in so far as technical resources and qualified staff are already at disposal and can take over the work on the additional installations.

This also applies to the servicing and maintenance of the rectifier substations, but in this case there is the additional positive effect that the present concept can be realised without having to build new rectifier substations. Instead an additional switchgear cubicle is fitted in each existing rectifier substation.

According to a conservative estimate the maximum annual costs for the switchgear cubicles needed for the power supply of the electrically operated bus line amount to 1,400 € (200 €/year per cubicle).

The costs for the servicing and maintenance of the switchgear cubicles are estimated to be so low because they are part of the maintenance costs for the traction power supply system of the rectifier substations and are maintained within the scope of maintenance of these rectifier substations.

These switchgear cubicles are serviced and maintained together with the other traction power supply system components fitted in these rectifier substations.

Position / Kriterium	I Variante 1 O-Bus partielle Fahrleitung	II Variante 2 O-Bus partielle Fahrleitung	III O-Bus mit durchgängiger Fahrleitung
Streckenlänge in m	43.874	43.874	43.874
Anzahl der Ladestationen	0	0	0
Anzahl der Fahrleitungsabschnitte	9	8	2
Länge der Fahrleitungsabschnitte in m	26.139	26.319	43.874
Anteil der Fahrleitungsstrecke in %	60	60	100
Baukosten Fahrleitung + Bahnstrom in €	11.239.770	11.317.170	18.865.820
Wartung/Instandhaltung/Reparatur Fahrleitung für 20 a (mit 2 € / m * a)	1.045.560	1.052.760	1.754.960
Ausbau von 7 GUW in €	420.000	420.000	420.000
anteilige Wartung/Instandhaltung/Reparatur GUW mit 200 €/GUW * a	28.000	28.000	28.000
Anzahl Ladezyklen je Bus p-a. (bei 330 Einsatztagen)	20.790	18.480	1.320
Lebensdauer der Batterie in Jahren (bei max. 60.000 Ladezyklen)	2,9	3,2	10,0
Fahrzeugbeschaffungskosten (I, II: 18* á 850.000€; III: 18* á 750.000€)	15.300.000	15.300.000	13.500.000
Ersatzinvestitionen für Batterie (I, II á 150.000€; III á 50.000 €) bei Nutzungsdauer der Busse von 20 Jahren	16.200.000	16.200.000	900.000
2 Ladestationen in den Abstellanlagen mit 200.000 € / Station	400.000	400.000	400.000
anteilige Wartung/Instandhaltung/Reparatur Ladestation mit 200 €/Station* a	8.000	8.000	8.000
Gesamtkosten über 20 Jahre in €	**44.641.330,00**	**44.725.930,00**	**35.876.780,00**
Kosten / a in €	**2.232.066,50**	**2.236.296,50**	**1.793.839,00**

Table III-4.7: Economic comparison of the variants of line 70

As already mentioned in chapter III.4.3.4, the costs for erection of two charging points in the parking facilities probably amount to altogether approx. 400,000 €.

If it is assumed that a bus is operated 330 days a year, the life of the battery will probably only amount to 2.9 or 3.2 years, respectively, due to the many charging cycles per bus according to the state of the art. To realise a conservative cost-benefit analysis, the possibility of a longer life is deliberately not considered. A longer life would be possible if the charging condition of the energy storage unit would amount to at least 80 % as calculated or only falls below 80 % in exceptional cases. Moreover, there is no long history of use as regards the increase in life in that way.

Therefore, the necessary replacement investments in batteries are a cost factor, which decisively explains the big differences in the overall cost analysis of the variants.

To avoid that other public transport companies get a wrong idea of the expenditure - revenue image, the revenues situation of bus line 70 is deliberately not included in the analysis.

Too many local factors, like

- line loading
- fares
- local politics decisions,

do not allow a general assessment of the revenue.

That variant 2 is favoured shows that the decision-making may not follow exclusively on the basis of the investment and life cycle costs. The technical reliability is extremely important.

One technical reliability parameter is the charging condition of the energy storage unit. In the concrete example it was regarded as very important that the charging condition does not fall below 80 % during normal operation, which naturally influences the positions of the overhead contact line sections along the line.

Moreover, the decision in favour of variant 2 clearly shows that the size of the investment and operation costs is an important, but not crucial decision criterion.

In the present case the charging condition of the energy storage unit during the journey is considered to be important

- because the expected life of the energy storage unit is extended when the energy storage unit is operated at a charging condition between 100 % and 80 % and
- because the positions and the lengths of the overhead contact line sections have to be able to cope with a simple breakdown.

III.4.3.6 Servicing and Maintenance

In Leipzig a concept for efficient servicing and maintenance of electric urban buses cannot be examined without also examining the servicing and maintenance of the hybrid buses.

At present, the diesel buses and the hybrid buses are serviced and maintained in the Lindenau bus station.

There is no depot along the route of the examined line 70. Thus, it is not necessary to discuss whether another site than the Lindenau bus station should also be equipped for the servicing and maintenance of electric buses.

The buses are now being parked in the Paunsdorf and Lindenau depots. When the "Technisches Zentrum Heiterblick" has been erected and put into service as the main workshop of the LVB and when the Paunsdorf depot has been closed as a consequence of the new workshop, some of the buses are going to be parked on the site of the new workshop.

III.4.3.7 Analysis of the Routes of Buses Coming onto or Leaving the Line

As mentioned already, buses will be parked in the Lindenau bus station as usual and in future also in the "Technisches Zentrum Heiterblick".

The possible routes of buses coming onto or leaving the line are examined for both destinations in consideration of the recharging facilities.

Fig. III-4.9: Route for vehicles to park in the Lindenau bus station

Source: google earth

It is recommended that vehicles that begin or end their journeys at the Markkleeberg railway station follow this route (see Fig. III-4.9):

- From the Lindenau bus station the route of line 60 is followed (direction of travel: Lindenau - Lipsiusstraße) via the “Kurt-Eisner-Straße” to “Connewitz Kreuz”.

It is not possible to recharge the energy storage unit on board the vehicle along this route, which means that it is always discharged during the journey from or to the bus station. If the batteries have been charged nearly 100 % in the bus station, e.g. overnight, it is unproblematic to pass this section, which is about 6.3 km long.

The overhead contact line can be used to recharge the energy storage unit as from the “Mathildenstraße” stop towards the Markkleeberg terminal.

In the other direction the complete overhead contact line section from “Markkleeberg, Gautzscher Platz” to “Mathildenstraße” can be used to recharge the energy storage unit to such a charging condition that it would be possible to drive the above mentioned route to Lindenau.

An examination of the route to the “Technisches Zentrum Heiterblick” as a possible parking location for the buses shows that in principle there are two possibilities of access to this site, which are differently long.

Fig. III-4.9: Route for vehicles to park in the “Technisches Zentrum Heiterblick”

Source: google earth

Merely the access to the “Technisches Zentrum Heiterblick” via the “Teslastraße” is being analysed because this way is shorter. If it is favoured to lead the vehicles via the “Wodanstraße” for operational reasons, this way is also unproblematic from the aspect of the charging condition of the energy storage unit.

In figure III-4.10 the recharging section is shown by way of green squares. It is about 1.9 km long. It begins at the junction “Essener-/Friedrichshafener Straße” and follows the line route to the stop called “Thekla, Tauchaer Straße”. From this stop the journey is continued without overhead contact line to the destination, i.e. to the “Technisches Zentrum Heiterblick”.

The situation is similar in the opposite direction. The recharging section begins at the “Thekla, Tauchaer Straße” stop and continues to the “Rosenowstraße”. This section is about 2.1 km long.

III.4.3.8 Diesel Bus and Trolleybus - Joint Servicing and Maintenance?

Diesel buses and trolleybuses can be and are being maintained in the same workshops. As many components are identical in the vehicles (e.g. axles) and as many procedures are identical (e.g. tyre management and corrective maintenance after accidents) (source: Annex to VDV Recommendation 881, 05/2006), it is not advisable to separate the maintenance of trolleybuses. Joint use of the workshop is advantageous to the public transport company not only in respect of the provision of the real estate (buildings) needed, but also in respect of the workshop staff (no additional staff needed).

It is not possible to do without a roof access platform because work has to be carried out on the roof of the buses, e.g. corrective and preventive maintenance of the air conditioning installations, the supercaps and the ancillary units, as well as on the trolleys and the electrical traction equipment.

If the workshop is used for diesel buses and trolleybuses, it is avoided to invest twice in the same equipment. If the maintenance of the diesel buses and the trolleybuses takes place on two different sites, this advantage is not given.

The more maintenance-intensive electronic equipment as well as the necessary exchange and maintenance of the carbon inserts and the trolleys of the trolleybuses lead to higher maintenance costs and a demand for higher qualification of the staff than required for diesel buses. If, however, it is taken into consideration that the LVB has been operating 14 articulated hybrid buses and 5 standard hybrid buses since 2010 and that the staff has already been trained to service and maintain hybrid buses, the workshop staff has a state of knowledge that is advantageous to the maintenance of trolleybuses in future.

Moreover, the LVB can fall back on many years of experience with tramway operation. Thus, the handling of the relevant workshop components and spare parts is no problem at all and this know how can also be used for the servicing and maintenance of trolleybuses.

The situation is more difficult in towns and cities in which neither a tramway nor a trolleybus system is operated. In this case each transport company has to examine which kind of maintenance and which real estate represent the most economic variant for the operation of such a mode of transport like the electric bus.

In such a case it should not be forgotten that staff with the necessary qualifications has to be trained or hired at first. Public transport companies already operating tramcars or trolleybuses employ persons who are skilled to handle electrical and electronic equipment and who can service and maintain electric buses. Employees who have exclusively worked on tramcars so far already fulfil the qualification requirements for performing servicing and maintenance work on electric buses. They merely have to be made acquainted with the specific features of the electric buses within the scope of introduction.

Annex III-4.1: Line data for line 70

Anlage III-4.1
Blatt-Nr.: 1

Liniennr.: 70
von: Mockau-West
nach: Connewitz, Kreuz

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur	Lage / Position der	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Höhenmeter		Gefällesituation		Fahrgastwechsel				Besonderheiten (z.B. längere
Epon / Kenn-Nr.	Haltestellenname	vorherigen Haltestelle	Haltestelle auf Linie	A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	verkehrsbedingte Halte)
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Mockau-West	319	0	1	1	1	1	600					7,5				
	Schildberger Weg	351	319	1	1	1	1	8	112	207	4,21	1,85	2,2	2,2	0	0	
	Otto-Michael-Straße	658	670	2	2	2	2	11	41	292	0,22	1,31	3,0	3,0	0	0	
	Mockau, Post	440	1.328	1	1	1	1	18	114	541	0,22	1,33	4,2	4,2	0	0	
	Samuel-Lampel-Straße	254	1.768	1	1	1	1	7	318	122	1,71	2,00	1,3	1,3	0	0	
	Mockau, Kirche	615	2.022	2	2	2	2	5	177	77	1,01	0,96	0,7	0,7	0	0	
	Thekla, Buswendestelle	58	2.637	0	0	0	0	0	100	497	0,57	1,38	0,0	0,0	0	0	
	Thekla, Tauchaer Straße	512	2.695	2	2	2	2	17	58	0	2,55	0,00	1,8	1,8	0	0	
	Neutzscher Straße	581	3.207	2	1	1	1	14	381	114	1,85	2,02	2,0	2,0	0	0	
	Sosaer Straße	355	3.788	1	1	1	1	4	432	149	1,61	0,46	0,3	0,3	0	0	
	Freiberger Straße	498	4.143	1	1	1	1	13	19	336	1,76	1,23	2,4	2,4	0	0	
	Bf. Thekla	394	4.641	1	1	1	1	3	100	497	0,93	1,57	0,8	0,8	0	0	
	Heiterblickstraße	470	5.035	1	1	1	1	3	248	146	0,77	1,55	0,4	0,4	0	0	
	Stöhrer-/Theklaer Straße	590	5.505	1	1	1	1	4	210	243	2,06	1,56	0,3	0,3	0	0	
	Stöhrer-/Braunstraße	303	6.095	1	1	1	1	5	548	42	1,33	1,19	1,4	1,4	0	0	
	Schönefeld-Ost	326	6.398	1	1	1	1	4	143	160	0,85	1,03	1,0	1,0	0	0	
	Braun-/Bautzner Straße	213	6.724	1	1	1	1	4	132	190	0,92	1,55	0,3	0,3	0	0	
	Bertolt-Brecht-Straße	387	6.937	1	1	1	1	12	114	92	0,70	0,78	2,2	2,2	0	0	
	Julian-Marchlewski-Straße	535	7.324	2	2	2	2	16	93	294	0,56	1,23	6,3	6,3	0	0	
	Löbauer Straße	533	7.859	2	1	1	1	14	87	448	0,60	1,74	4,3	4,3	0	0	
	Stöckelstraße	491	8.392	1	1	1	1	20	429	104	1,15	2,18	5,6	5,6	0	0	
	Stannebeinplatz	591	8.883	2	2	2	2	16	310	181	0,53	0,69	5,6	5,6	0	0	
	H.-Liebmann-/Eisenbahnstraße	405	9.474	1	1	1	1	19	377	131	2,34	3,55	7,4	7,4	0	0	
	Dornbergerstraße	334	9.879	1	1	1	1	13	151	254	0,75	1,84	1,8	1,8	0	0	
	Bergstraße	328	10.213	1	1	1	1	9	134	200	0,41	0,94	1,5	1,5	0	0	
	Reudnitz, Koehlerstraße	509	10.541	2	2	2	2	24	236	92	1,93	0,77	5,7	5,7	0	0	
	Breite Straße	566	11.050	2	2	2	2	20	293	216	1,29	2,03	6,8	6,8	0	0	
	Riebeck-/Oststraße	413	11.616	1	1	1	1	17	335	176	2,41	1,21	3,7	3,7	0	0	
	Riebeck-/Stötteritzer Straße	306	12.029	1	1	1	1	13	247	166	2,12	1,00	2,0	2,0	0	0	
	Technisches Rathaus	552	12.335	2	2	2	2	9	91	215	0,92	1,68	1,2	1,2	0	0	
	Altes Messegelände	345	12.887	1	1	1	1	11	503	49	1,60	0,15	1,2	1,2	0	0	
	Naunhofer Straße	425	13.232	1	1	1	1	17	247	98	1,66	0,59	2,9	2,9	0	0	
	An der Tabaksmühle	841	13.657	2	2	2	2	4	119	306	5,40	0,83	0,7	0,7	0	0	
	R.-Lehmann-/Zwickauer Straße	839	14.498	2	1	2	2	10	216	625	0,63	1,51	0,7	0,7	0	0	
	Altenburger Straße	272	15.337	1	1	1	1	9	308	531	0,85	2,04	0,7	0,7	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	330	15.609	2	1	1	1	7	174	92	1,01	1,07	0,4	0,4	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	490	15.939	2	1	2	2	11	139	177	0,24	0,57	0,2	0,2	0	0	
	Connewitz, Kreuz		16.429					554	347	143	1,08	1,83	9,5	9,5	0	0	
Summe		16.429		50	45	47	47	1543	8.086	8.200							
	durchschn. Haltestellenabst. (m)	444	Ø- SOLL Geschw.(km/h)	19,71	21,91	20,97	20,97										

Anlage III-4.1
Blatt-Nr.: 2

Liniennr.: **70**
von: **Connewitz,Kreuz**
nach: **Mockau-West**

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle: Epon / Kenn-Nr.	Haltestelle: Haltestellenname	Entfernung zur vorherigen Haltestelle (m)	Lage / Position der Haltestelle auf Linie (m)	Fahrzeit (incl. Haltezeit) A (min)	Fahrzeit B (min)	Fahrzeit C (min)	Fahrzeit F (min)	Ø Haltezeit / Wendezeit am Endpunkt A (s)	Steigungs- / Gefällelänge (+) steigend (m)	Steigungs- / Gefällelänge (-) fallend (m)	Gefällesituation Ø Steig. (%)	Gefällesituation Ø Gefälle (%)	Fahrgastwechsel (Mittelwert je Haltestelle ohne Bezug zum Fahrtverlauf) Ø Einsteiger (Pers.)	Ø Aus-steiger (Pers.)	Differenz (Pers.)	Änderung Zuladung (kg)	Bemerkungen
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Arno-Nitzsche-Straße	206	0	1	1	1	1	543					3,1				
	Connewitz, Kreuz	403	206	2	2	2	2	15	92	114	3,19	1,50	6,9	6,9	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	233	609	1	1	1	1	13	18	385	0,11	0,90	3,6	3,6	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	317	842	1	1	1	1	9	142	91	0,81	1,17	1,6	1,6	0	0	
	Altenburger Straße	794	1.159	2	1	1	1	10	204	113	0,62	0,99	1,7	1,7	0	0	
	R.-Lehmann-/Zwickauer Straße	981	1.953	2	2	2	2	12	441	353	2,01	1,35	2,0	2,0	0	0	
	An der Tabaksmühle	388	2.934	1	1	1	1	6	787	194	1,93	0,26	0,2	0,2	0	0	
	Naunhofer Straße	427	3.322	2	2	2	2	21	207	181	1,14	3,56	1,7	1,7	0	0	
	Altes Messegelände	470	3.749	2	1	2	2	16	78	349	0,27	2,88	3,4	3,4	0	0	
	Technisches Rathaus	198	4.219	1	1	1	1	5	66	404	0,51	2,17	2,2	2,2	0	0	
	Riebeck-/Stötteritzer Straße	439	4.417	1	1	1	1	12	21	177	0,85	0,91	2,4	2,4	0	0	
	Riebeck-/Oststraße	519	4.856	2	2	2	2	15	242	197	1,63	1,72	0,4	0,4	0	0	
	Breite Straße	641	5.375	2	2	2	2	17	248	271	0,80	1,84	11,0	11,0	0	0	
	Reudnitz, Koehlerstraße	258	6.016	1	1	1	1	24	290	351	1,05	2,97	5,8	5,8	0	0	
	Bergstraße	397	6.274	1	1	1	1	9	19	239	1,72	1,34	1,1	1,1	0	0	
	Dornbergerstraße	261	6.671	1	1	1	1	11	221	174	0,72	0,40	1,3	1,3	0	0	
	H.-Liebmann-/Eisenbahnstraße	716	6.932	2	2	2	2	23	152	109	3,56	0,40	3,6	3,6	0	0	
	Stannebeinplatz	474	7.648	1	1	1	1	16	216	500	3,39	1,51	3,5	3,5	0	0	
	Stöckelstraße	375	8.122	1	1	1	1	13	270	204	0,51	0,68	1,8	1,8	0	0	
	Löbauer Straße	662	8.497	2	2	2	2	18	113	262	1,01	0,97	3,9	3,9	0	0	
	Julian-Marchlewski-Straße	388	9.159	1	1	1	1	14	512	132	1,39	1,62	1,2	1,2	0	0	
	Bertolt-Brecht-Straße	228	9.547	1	1	1	1	8	281	107	1,13	1,08	0,4	0,4	0	0	
	Braun-/Bautzner Straße	307	9.775	1	0	0	0	2	81	97	0,39	0,93	0,2	0,2	0	0	
	Schönefeld-Ost	484	10.082	1	1	1	1	3	199	108	1,42	2,15	0,0	0,0	0	0	
	Stöhrer-/Braunstraße	442	10.566	1	1	1	1	4	146	338	0,97	0,78	0,1	0,1	0	0	
	Stöhrer-/Theklaer Straße	483	11.008	1	1	1	1	3	17	407	2,90	1,85	0,1	0,1	0	0	
	Heiterblickstraße	390	11.491	1	1	1	1	3	207	276	1,69	1,84	0,1	0,1	0	0	
	Bf. Thekla	531	11.881	1	1	1	1	3	199	191	1,51	0,83	0,3	0,3	0	0	
	Freiberger Straße	287	12.412	1	1	1	1	11	425	106	1,34	1,19	1,3	1,3	0	0	
	Sosaer Straße	586	12.699	2	1	2	2	3	227	60	1,77	0,73	0,2	0,2	0	0	
	Neutzscher Straße	498	13.285	2	2	2	2	10	80	506	1,68	1,33	1,0	1,0	0	0	
	Thekla, Tauchaer Straße	558	13.783	2	2	2	2	15	148	350	1,34	2,00	0,8	0,8	0	0	
	Mockau, Kirche	254	14.341	1	1	1	1	6	450	108	1,07	0,67	0,3	0,3	0	0	
	Samuel-Lampel-Straße	468	14.595	1	1	1	1	8	128	126	1,32	1,81	0,3	0,3	0	0	
	Mockau, Post	791	15.063	2	2	2	2	20	215	253	1,39	1,15	5,4	5,4	0	0	
	Rosenowstraße	445	15.854	2	2	2	2	10	732	59	1,43	0,15	0,4	0,4	0	0	
	Mockau-West		16.299					600	327	118	1,08	0,40	5,4		0	0	
Summe		16.299		50	46	48	48	1.533	8.199	8.014							
	durchschn. Haltestellenabst. (m)	453	Ø- SOLL Geschw.(km/h)	19,6	21,3	20,4	20,4										

Anlage III-4.1
Blatt-Nr.: 3

Liniennr.: 70
von: Mockau-West(Pleißenburgw)
nach: Connewitz, Kreuz

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur	Lage / Position der	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Steigungs- / Gefällelänge		Gefällesituation		Fahrgastwechsel (Mittelwert je Haltestelle ohne Bezug zum Fahrtverlauf)				Bemerkungen
Epon / Kenn-Nr.	Haltestellenname	vorherigen Haltestelle	Haltestelle auf Linie	A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Mockau-West	319	0	1	1	1	1	600					7,2				
	Schildberger Weg	351	319	1	1	1	1	8	112	207	1,05	1,85	2,2	2,2	0	0	
	Otto-Michael-Straße	658	670	2	2	2	2	11	41	292	0,22	1,31	3,1	3,1	0	0	
	Mockau, Post	440	1.328	1	1	1	1	18	114	541	0,22	1,33	3,9	3,9	0	0	
	Samuel-Lampel-Straße	254	1.768	1	1	1	1	7	318	122	1,71	2,00	1,3	1,3	0	0	
	Mockau, Kirche	615	2.022	2	2	2	2	5	177	77	1,01	0,96	0,6	0,6	0	0	
	Thekla, Buswendestelle	58	2.637	0	0	0	0	0	100	497	0,57	1,38	0,0	0,0	0	0	
	Thekla, Tauchaer Straße	512	2.695	2	2	2	2	17	58	0	2,55	0,00	2,3	2,3	0	0	
	Neutzscher Straße	581	3.207	2	1	1	1	14	381	114	1,85	2,02	2,9	2,9	0	0	
	Sosaer Straße	355	3.788	1	1	1	1	4	432	149	1,61	0,46	0,3	0,3	0	0	
	Freiberger Straße	498	4.143	1	1	1	1	13	19	336	1,76	1,23	2,7	2,7	0	0	
	Bf. Thekla	199	4.641	1	1	1	1	3	110	365	0,93	1,57	0,3	0,3	0	0	
	Pleißenburgwerkstätten	365	4.840	1	1	1	1	3	164	35	2,07	4,30	0,4	0,4	0	0	
	Braun-/Heiterblickstr.	350	5.205	1	0	1	1	4	281	54	1,12	0,52	0,6	0,6	0	0	
	Stöhrer-/Braunstraße	303	5.555	1	1	1	1	5	261	89	1,87	0,75	0,6	0,6	0	0	
	Schönefeld-Ost	326	5.858	1	1	1	1	4	143	160	0,85	1,03	1,3	1,3	0	0	
	Braun-/Bautzner Straße	213	6.184	1	1	1	1	4	132	190	0,92	1,55	0,3	0,3	0	0	
	Bertolt-Brecht-Straße	387	6.397	1	1	1	1	12	114	92	0,70	0,78	2,2	2,2	0	0	
	Julian-Marchlewski-Straße	535	6.784	2	2	2	2	16	93	294	0,56	1,23	6,3	6,3	0	0	
	Löbauer Straße	533	7.319	2	1	1	1	14	87	448	0,60	1,74	3,9	3,9	0	0	
	Stöckelstraße	491	7.852	1	1	1	1	20	429	104	1,15	2,18	5,8	5,8	0	0	
	Stannebeinplatz	591	8.343	2	2	2	2	16	310	181	0,53	0,69	5,6	5,6	0	0	
	H.-Liebmann-/Eisenbahnstraße	405	8.934	1	1	1	1	19	377	131	2,32	3,55	7,3	7,3	0	0	
	Dornbergerstraße	334	9.339	1	1	1	1	13	151	254	0,75	1,84	2,1	2,1	0	0	
	Bergstraße	328	9.673	1	1	1	1	9	134	200	0,41	0,94	1,3	1,3	0	0	
	Reudnitz, Koehlerstraße	509	10.001	2	2	2	2	24	236	92	1,93	0,77	5,8	5,8	0	0	
	Breite Straße	566	10.510	2	2	2	2	20	293	216	1,29	2,03	7,2	7,2	0	0	
	Riebeck-/Oststraße	413	11.076	1	1	1	1	17	335	176	2,41	1,21	3,5	3,5	0	0	
	Riebeck-/Stötteritzer Straße	306	11.489	1	1	1	1	13	247	166	2,12	1,00	2,1	2,1	0	0	
	Technisches Rathaus	552	11.795	2	2	2	2	9	91	215	0,92	1,68	1,3	1,3	0	0	
	Altes Messegelände	345	12.347	1	1	1	1	11	503	49	1,50	0,15	1,0	1,0	0	0	
	Naunhofer Straße	425	12.692	1	1	1	1	17	247	98	1,66	0,59	2,4	2,4	0	0	
	An der Tabaksmühle	841	13.117	2	2	2	2	4	119	306	5,40	0,83	0,9	0,9	0	0	
	R.-Lehmann-/Zwickauer Straße	839	13.958	2	1	2	2	10	216	625	0,63	1,51	0,6	0,6	0	0	
	Altenburger Straße	272	14.797	1	1	1	1	9	308	531	0,85	2,04	0,7	0,7	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	330	15.069	2	1	1	1	7	174	92	1,01	1,07	0,3	0,3	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	490	15.399	2	1	2	2	11	139	177	0,24	0,57	0,3	0,3	0	0	
	Connewitz, Kreuz		15.889					554	347	143	1,08	1,83	8,7		0	0	
Summe		15.889		50	44	47	47	1.544	7.796	7.815							
	durchschn. Haltestellenabst. (m)	429	Ø- SOLL Geschw.(km/h)	19,1	21,7	20,3	20,3										

Anlage III-4.1
Blatt-Nr.: 4

Liniennr.: 70
von: Connewitz,Kreuz
nach: Mockau-West(Pleißenburgw)

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur	Lage / Position der	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Steigungs- / Gefällelänge		Gefällesituation		Fahrgastwechsel (Mittelwert je Haltestelle ohne Bezug zum Fahrtverlauf)				Bemerkungen
	Haltestellenname	vorherigen Haltestelle	Haltestelle auf Linie	A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Arno-Nitzsche-Straße	206	0	1	1	1	1	543					3,3				
	Connewitz, Kreuz	403	206	2	2	2	2	15	92	114	3,19	1,50	7,2	7,2	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	233	609	1	1	1	1	13	18	385	0,11	0,90	4,3	4,3	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	317	842	1	1	1	1	9	142	91	0,81	1,17	1,8	1,8	0	0	
	Altenburger Straße	794	1.159	2	1	1	1	10	204	113	0,62	0,99	1,7	1,7	0	0	
	R.-Lehmann-/Zwickauer Straße	981	1.953	2	2	2	2	12	441	353	2,01	1,35	2,4	2,4	0	0	
	An der Tabaksmühle	388	2.934	1	1	1	1	6	787	194	1,93	0,26	0,4	0,4	0	0	
	Naunhofer Straße	427	3.322	2	2	2	2	21	207	181	1,14	3,56	2,0	2,0	0	0	
	Altes Messegelände	470	3.749	2	1	2	2	16	78	349	0,27	2,88	4,2	4,2	0	0	
	Technisches Rathaus	198	4.219	1	1	1	1	5	66	404	0,51	2,17	2,2	2,2	0	0	
	Riebeck-/Stötteritzer Straße	439	4.417	1	1	1	1	12	21	177	0,85	0,91	2,4	2,4	0	0	
	Riebeck-/Oststraße	519	4.856	2	2	2	2	15	242	197	1,63	1,72	0,4	0,4	0	0	
	Breite Straße	641	5.375	2	2	2	2	17	248	271	0,80	1,84	12,7	12,7	0	0	
	Reudnitz, Koehlerstraße	258	6.016	1	1	1	1	24	290	351	1,05	2,97	5,9	5,9	0	0	
	Bergstraße	397	6.274	1	1	1	1	9	19	239	1,72	1,34	1,1	1,1	0	0	
	Dornbergerstraße	261	6.671	1	1	1	1	11	221	174	0,72	0,40	1,3	1,3	0	0	
	H.-Liebmann-/Eisenbahnstraße	716	6.932	2	2	2	2	23	152	109	3,56	0,40	4,4	4,4	0	0	
	Stannebeinplatz	474	7.648	1	1	1	1	16	216	500	3,39	1,51	4,9	4,9	0	0	
	Stöckelstraße	375	8.122	1	1	1	1	13	270	204	0,51	0,68	2,8	2,8	0	0	
	Löbauer Straße	662	8.497	2	2	2	2	18	113	262	1,01	0,97	4,5	4,5	0	0	
	Julian-Marchlewski-Straße	388	9.159	1	1	1	1	14	512	132	1,39	1,62	1,3	1,3	0	0	
	Bertolt-Brecht-Straße	228	9.547	1	1	1	1	8	281	107	1,13	1,08	0,5	0,5	0	0	
	Braun-/Bautzner Straße	307	9.775	1	0	0	0	2	81	97	0,39	0,93	0,2	0,2	0	0	
	Schönefeld-Ost	450	10.082	1	1	1	1	3	199	108	1,42	2,24	0,0	0,0	0	0	
	Stöhrer-/Braunstraße	340	10.532	1	0	1	1	4	239	211	1,02	1,27	0,1	0,1	0	0	
	Braun-/Heiterblickstr.	299	10.872	1	1	1	1	3	142	198	0,47	1,14	0,2	0,2	0	0	
	Pleißenburgwerkstätten	208	11.171	1	1	1	1	3	63	222	0,26	0,90	0,3	0,3	0	0	
	Bf. Thekla	531	11.379	1	1	1	1	3	62	146	1,56	3,21	0,1	0,1	0	0	
	Freiberger Straße	287	11.910	1	1	1	1	11	425	106	1,34	1,19	1,6	1,6	0	0	
	Sosaer Straße	586	12.197	2	1	2	2	3	227	60	1,77	0,73	0,3	0,3	0	0	
	Neutzscher Straße	498	12.783	2	2	2	2	10	80	506	1,68	1,33	0,9	0,9	0	0	
	Thekla, Tauchaer Straße	558	13.281	2	2	2	2	15	148	350	1,34	2,00	0,8	0,8	0	0	
	Mockau, Kirche	254	13.839	1	1	1	1	6	450	108	1,07	0,67	0,3	0,3	0	0	
	Samuel-Lampel-Straße	468	14.093	1	1	1	1	8	128	126	1,32	1,81	0,4	0,4	0	0	
	Mockau, Post	791	14.561	2	2	2	2	20	215	253	1,39	1,15	5,6	5,6	0	0	
	Rosenowstraße	445	15.352	2	2	2	2	10	732	59	1,43	0,15	0,6	0,6	0	0	
	Mockau-West		15.797					600	327	118	1,08	0,40	6,0		0	0	
Summe		15.797		50	45	48	48	1.533	8.137	7.577							
	durchschn. Haltestellenabst. (m)	439	Ø- SOLL Geschw.(km/h)	19,0	21,1	19,7	19,7										

III-5 AP5: Summary / Result

III-5-1 Recommendation for Leipzig

It is recommended to retrofit line 70 (Mockau <-> Connewitz <-> Markkleeberg) for the operation of electric buses. Four line sections are equipped with overhead contact lines, whereas the remaining line sections are operated by way of energy storage units on board the vehicles. Additional charging points at the terminals are not needed.

It is recommended that the overhead contact line is a two-pole overhead contact line for trolleybuses as all other technologies for the transfer of current during the journey are not fully developed yet.

III-5-2 Transferability to Other Cities

The subject of “electric mobility” is one of the challenges of urban development in the short or medium term. Public transport can contribute considerably to meeting this challenge, also in the bus sector, as the appropriate technologies are already available. Although the present study goes into great detail with line 70 in Leipzig, this example can be transferred to any bus line

- that is operated with articulated buses in a cycle of 10 minutes at the most (at least in the busy traffic period). Other operating concepts might require other technical solutions.
- that has got several points of contact to the power supply system of a tramway or light rail system and
- that has got staff qualified to operate and maintain the infrastructure and the vehicle components.

The latter two items are especially important for the economic efficiency of the system.

Naturally, the positions and lengths of the sections with overhead contact line always have to be determined individually from town to town and from line to line, but generally about 50 % of the line have to be equipped with an overhead contact line to ensure sufficient power supply if charging points are undesirable at the terminals.

The following generally valid conclusions can reliably be drawn from the analyses carried out:

a. It is technically and economically advantageous to operate an electric urban bus line.

b. If a diesel bus line is retrofitted for the operation of electric buses, it is possible to do without the overhead contact line of the classic trolleybus in some sections if the energy storage unit of the vehicle is dimensioned sufficiently.

c. A very high degree of operational reliability is achieved with overhead contact lines only in some sections if the overhead contact line system is dimensioned correctly in respect of the positions and lengths of the contact lines. In that case a simple breakdown can be overcome without obstructing the operation.

d. The necessary vehicle and infrastructure components are available as desired from the series production of well-known manufacturers.

e. Basically, electric buses can be supplied with power from the power supply system of tramways. In practice, the same examinations and calculations as in case of an extension of the tramway network have to be carried out.

f. Public transport companies operating tramways have got sufficiently qualified staff for the servicing and maintenance of electric buses. Operators of hybrid buses are in a particular advantageous situation in this respect.

g. The assessment of the synergetic potentials mainly depends on the structure of the area and the capacity of the traction power supply system that is to supply the electric buses with power in addition to the tramcars or light rail vehicles. The topography of the area and the structure of the town or city are of minor importance.

h. The economic feasibility of such a measure cannot be described generally as not only knowledge of the expenditure, but also of the revenue is needed.

   However, the expenditure described in this study in the form of investments and life cycle costs should enable companies interested in taking up the ideas of this study to complete the economic calculation on the basis of their concrete revenues.

Basically, it can be stated that public transport companies that look into the subject of “erection of new electric bus systems or retrofit to electric bus systems” within existing tramway or light rail systems always have to analyse the operational requirements for the bus lines within their transport network, i.e. they have to analyse the actual situation to be able to make the correct decisions on the further procedure.

III-5-3 Good practice of the City of Szeged

In this chapter there is given good practice of Szeged Transport Company, where the tram service was introduced in 1908, the trolleybus in 1979. Szeged is a typical mid-size town with population of 170.000 people with still 40 % share of public transport in all mobility. Szeged is served with four tram and four trolleybus routes which count for half of the daily public transport passenger use.

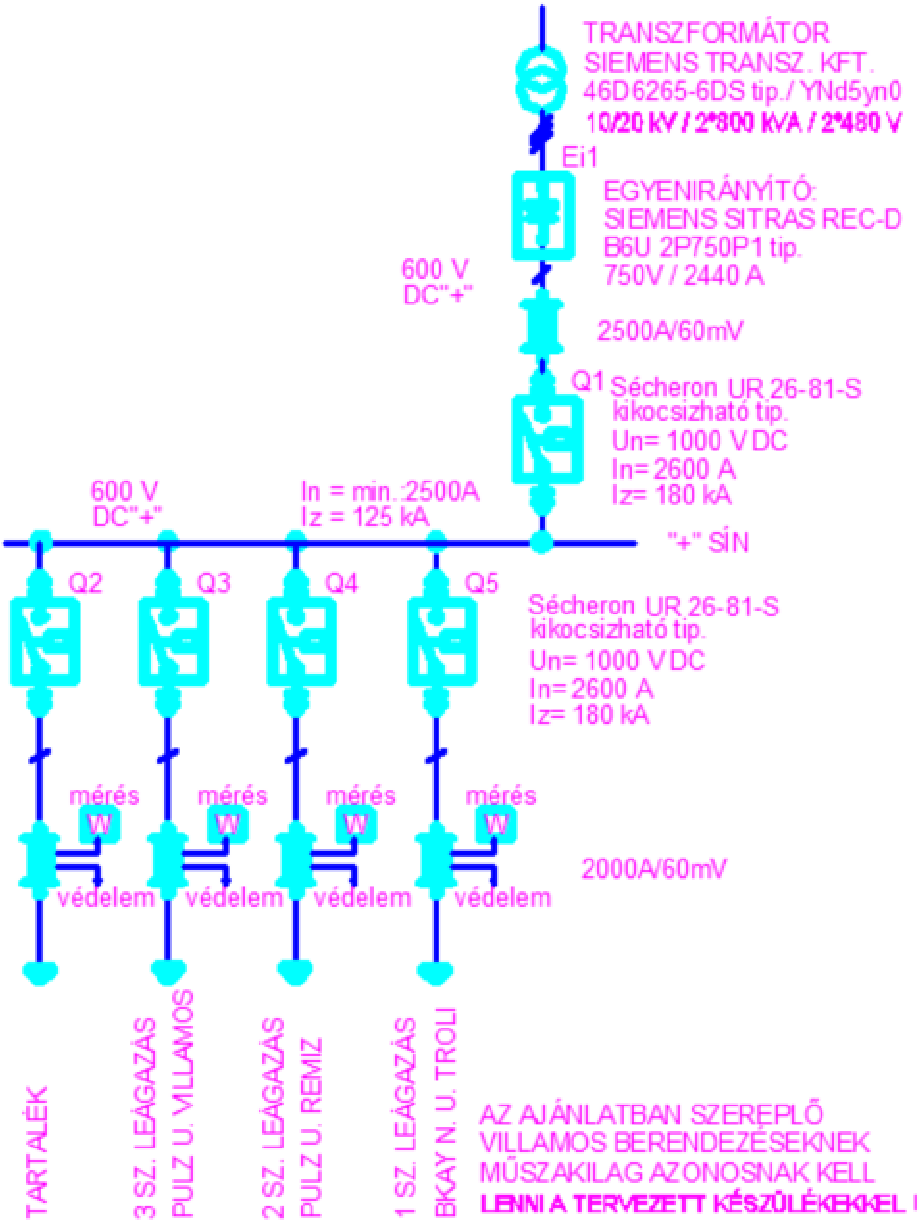
Nowadays trams and trolleybuses play almost to a percentage equal role, certain high-capacity corridors are served with trams, other with trolleybuses. In the recent years the municipality of Szeged made massive reconstruction of the tram and trolleybus network of 100 M Euros value with line extensions and new vehicles as well supported by EU Cohesion funds.

Common tram-trolleybus power supply

The most obvious synergy of the two modes is the common tram-trolleybus power supply, which is an economical solution for the two electric modes. The most common urban voltage both for trams and trolleybuses is traditionally 600 V DC. Even newer serial hybrid buses got battery packages which produce between 400-600 V DC (*see e.g. Mercedes-Benz Citaro G prototypes*), and both the tram and trolleybus traction technology in their newest forms still rely on 400-600 V traction motors even in their most sophisticated form (*see e.g. ZF's new wheel-hub motor drive solution for lowfloor hybrid buses*).

Thus the power supply is common for tram-trolleybus operators. Operators use common substations, which can feed both tram and trolleybus catenary.

An example is shown in the following figure, which shows the positive wiring of the 1500 kW output power substation in the Pulz utca depot of Szeged Transport Company.



One can notice the transformer and the rectifier in the top, which creates 600 V DC. There is a common “+”-rail from which four branches start: 1. Bakay Nándor utca trolleybus section, 2. Pulz utca tram depot section, 3. Pulz utca tram network section, 4. reserve. The positive feeder cables for the trolleybuses and trams are separate and diverge from this point.

For safety reasons there is always high-power switch between the tram and trolleybus side in order to get a perfect insulation between the two operation in case of detecting a short-circuit in the tram or trolleybus network. The positive cables are regularly join to the overhead wires of the trams and trolleybuses, the negative cables go partly to the trolleybus overhead wires, partly to the rails of the tram system. This makes the negative cable of the trolleybuses grounded.

A feature of this layout is that the recuperation current generated from a tram or trolleybus during braking can be fed to the common “+”-rail, thus there is a possibility that a recuperating tram can feed an accelerating trolleybus and vice versa.

By operating a trolleybus network one needs to be aware, that if there are sub-stations in the trolleybus network that solely used only for trolleybuses, than it is likely that the

“-”-side of this network part is not grounded. One needs to have attention at the meeting of the grounded and the non-grounded network parts (at section insulators or e.g. at tram-trolleybus overhead crossings).

For tram and trolleybus overhead crossings one can use a wide selection of geometry of overhead materials from the manufacturers (*e.g. Elektroline, Esko or Kummler & Matter*). Different solutions is shown in the above figure (crossing of Rókusi körút and Csáky utca), these strain overhead elements provide smooth and fail-safe crossing with tram-pantograph and trolleybus currentcollectors.

Tram and trolleybus overhead wires can co-exist without any major trouble, and many overhead elements (e.g. span wires, contact wires, insulations, hangings, anchors, etc...) are common. Overhead maintenance crew for trams and trolleybuses are also common by Szeged Transport Company.

Common tram-trolleybus maintenance

There is a significant difference between the bus and tram depots, although there are historic examples of common operations. For trolleybuses the daily maintenance cycles resembling more to conventional buses. Maintenance operations however became very different in the two sides of Europe. In Western Europe there are more examples of operations without major workshop activities, but in the former socialist states' operators almost all have a developed workshop area for major overhauls of the vehicles. These activities can be merged for trams and trolleybuses.

By the example of Szeged Transport Company:

there is a separate electrical workshop, mechanical workshop and painting workshop and final assembly workshop which all work both on trams and trolleybuses. Below is a picture about the common tram-trolleybus mechanical workshop showing the frame of a Skoda trolleybus.

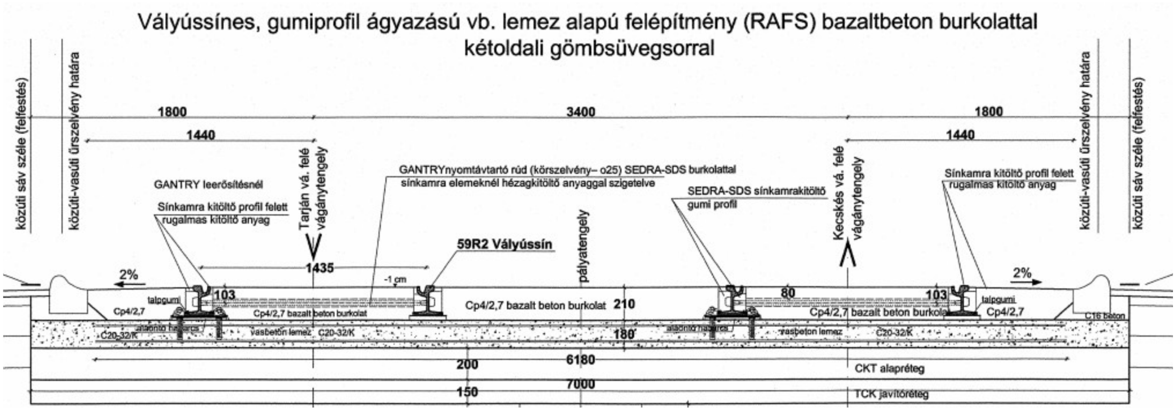
Common tram-trolleybus corridors

Many cities in Europe fight with the problems of the lack of space in their old city centers. The tram's major advantage thus became the possibility of a separate tram track which provides a visible high passenger capacity public transport route.

Often buses and hence trolleybuses use this opportunity: the surface of a tram-track is an ideal bus and trolleybus corridor: a common tram-bus-trolleybus lane – preferably with physical separation – can increase the speed of all traffic modes. It is an interesting psychology that the city's decision makers and inhabitants can also easier accept a separate tram lane than a separate bus lane – the latter is often seen as only taking away space for cars, while a separate tram track is more associated with a good public transport. In Szeged we have several examples of common tram-bus lanes and also a tram-bus-trolleybus corridor.

While in terms of traffic technology there are many advantages of these corridors: higher circulating speed, decreased accidents due to the physical separation, public transport advantage by traffic lights, etc..., however in terms of track maintenance common tram-bus operation is a bigger challenge. One can observe an increased wearing of the common asphalt surface, which are caused mainly at the insufficient technical solution at the meeting of the asphalt and the rail. Since often the rails are in a rubber cover in order to decrease noise and vibration, one has to keep a groove between the asphalt and the rail. Asphalt itself do not hold itself for long time without support from the side, thus often they start to brake near the rails. In Szeged after 7 years of operation one needed to renew the asphalt cover due to the intense bus usage. This was the case for several different type of asphalts built with different technologies and width.

In the recently reconstructed common tram-bus-trolleybus tracks special basalt-concrete was used for preparing the road surface between the rails. Due to the recent increase of petroleum-products using concrete became also cheaper. The obvious disadvantage however is the time the concrete needs in order to solidify, which is more than for asphalt.



The above figure shows the used cross section of the concrete covered section, notice the lack of asphalt at the top of the surface.

In terms of the overhead wires of the common tram-trolleybus lanes due to the flexibility of the trolleybuses the overhead of the trolleybuses were placed slightly on the side of the corridor. This means also, that the trolleybuses have the ability to use in case of any obstacle on the tram track the side road surface as well, and by-pass the obstacle. This is advantageous to think about also at tram stops: i.e. the trolleybuses should be able to get around the tram's loading island from the other side in case there is an obstacle or construction in the stop. For this purpose one should avoid higher than 4 m objects in the stops (e.g. lampposts, trees, etc...). This of course is not necessary, if all trolleybuses have the ability to run without overhead wire for a short section.