ACTUATE

Advanced training for safe and economic driving of electronically powered vehicles

TROLLEYBUS

Co-funded by the Intelligent Energy Europe Programme of the European Union

actuate

Site notice

Concept and editorial staff:
DI Christian Osterer, Ing. Markus Perberschlager, Richard Moltinger

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DI Christian Osterer; Archive: Salzburg AG

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Contact:

Rupprecht Consult - Forschung & Beratung GmbH
Dr. Wolfgang Backhaus

Clever Straße 13-15
50668 Köln / Germany
Tel.: +49 / 221 / 606055-19
Mail: w.backhaus@rupprecht-consult.eu
Web: www.rupprecht-consult.eu

Salzburg AG
for energy, transport and telecommunication
SALZBURGER Lokalbahnen
DI Christian Osterer

Plainstraße 70
5020 Salzburg / Austria
Tel.: +43 / 662 / 4480-1500
Mail: salzburger_lokalbahnen@salzburg-ag.at
Web: www.slb.at

ACTUATE

- a project for optimising the driving performance for reduced energy consumption

Training programmes and general training measures for the economic driving of electronically powered vehicles in the public transport sector (ÖPNV) were developed, tested and successfully introduced within the framework of the European-sponsored project, ACTUATE.

The introduction of advanced training for economic driving, the energy-saving potential of electronically powered vehicles such as trams, hybrid buses or trolleybuses can be further optimised and thus, the cost-effectiveness and wide distribution of this vehicle type can be promoted.

The project ACTUATE places particular focus on the driver as the pivotal element for economic driving. Accompanying motivational campaigns will also ensure that drivers apply what they have learned in the advanced training sessions in the long-term.

ACTUATE - a project to optimise driving behaviour...

- for safe economic driving of electronically powered vehicles in the public transport sector (ÖPNV)
- to increase the cost-effectiveness of electronically powered vehicles in the public transport sector through
- developing and testing trainings programmes for safe and economic driving
- motivational campaigns for drivers of trams, trolleybuses, hybrid buses

This training brochure has been developed for the trolleybus within the framework of ACTUATE.

Content

1. Introduction

1.1 Economic driving in the public transport sector

Economic driving means energy-efficient, low-wear and ecological driving. Three requirements can be established for economic driving in the public transport sector:

- **Safety requirement**
  All other requirements are subordinate to the safety requirement.
- **Punctuality requirement**
  Punctuality in the public transport sector is a requirement and means neither a premature, nor a delayed departure from a stop.
- **Cost-effectiveness requirement**
  Economic driving means minimising energy-consumption and protecting the vehicle by considering the requirements of safety and punctuality.

The following applies when driving a public transport vehicle: safety before punctuality and punctuality before cost-effectiveness. The laws, service regulations and rules which are to be followed in order to drive safely in public transport vehicles are assumed to be known in the following.

Economic driving equally contributes towards environmental protection and covering a travel itinerary in a stress-free manner for both the passengers and the driver, and it helps the company lower the vehicle and energy costs by reducing wear and tear.

Advantages for the driver	Advantages for the passenger	Environmental protection	Companies
stress-free driving	stress-free transport	active contribution to environmental protection	Reducing vehicle costs
Safeguarding jobs through cost savings			Reducing energy costs

Table 1: Advantages of economic driving

Factors for economic driving which can be influenced by the driver are presented in the following sections in green; factors that can generally not be influenced by the driver are presented in yellow.

1.2 Energy carrier

The electric drive of road vehicles gains significant importance through the high level of efficiency of electric motors. It not only accelerates electric public transport but the developments in the passenger car sector also indicate the increased use of alternative drives. In addition to the pure electric drive, such as how trolleybuses are operated, hybrid drives are also gaining importance. The strength of alternative drive systems using electrical energy is the possibility of recuperation in brake applications back into the overhead line and/or into mobile energy storage units such as batteries or supercaps. Furthermore, the advantage of the electrical drive lies in the use of primary energy. Combustion engines are largely operated with fossil fuels such as petrol, diesel or natural gas which must be converted and transported for consumption, which is a costly process.

Clean electrical energy can however be obtained in an emission-free hydroelectric power station and/or from solar or wind energy and - aside from low conduction losses - it can be directly converted into mechanical work in the vehicle. Locally, electrical energy is always emission-free. Advanced electric motors have a level of efficiency of between 90 and 99 percent, whereas diesel engines reach 35 percent in an ideal speed range.

1.3 Definitions

Firstly, the most important terms will be explained in order to better understand the technical procedures of converting secondary energy into effective energy, in other words, into mechanical work in order to move the vehicle:

Speed
Speed is the ratio of the number of rotations of a component and the time span required for it. The speed, for example, states how often the crankshaft of a combustion engine rotates in one minute. The unit for speed is 1/min (U/min).

Torque

The torque (rotating energy) is a physical quantity and causes a rotary movement in the event of a change. The torque is dependent on the force applied and the distance between the centre of rotation and force application point (torque = force * normal distance). The unit of the torque is a newton metre (unit symbol: Nm).

Power output

The torque level and the associated speed are decisive factors for power output of a combustion engine. This is because the power output is the product resulting from speed and torque. For electric motors, the power output is also calculated from the product of current and voltage (power output = current * voltage). The power output is stated in Watts (for bigger engines, even in kilowatts) (unit symbol: W and/or kW).

Offset output

The offset output P_{Offset} is the part of the total output which is not used for the drive. Ancillary components such as control, compressor, light etc. are supplied by it. The offset output determines the consumption of energy in standstill phases and is close to zero when rolling because the auxiliary equipment is supplied with energy through the self-excitation of the engine. The heat output is considered independent of the offset output.

1.4 Driving resistance

Driving resistances work enduringly while a vehicle is moving. The resultant force always shows the movement in the opposite direction and brakes the vehicle. The driving force of the engine required to overcome the driving resistances significantly affects the energy consumption. Economical operation of utility vehicles is only possible with knowledge of driving resistances and the parameters that influence it. It is for this reason that the driving resistances are explained as follows.

Resistances and forces while driving			
Rolling resistance	Climbing resistance	Aerodynamic resistance	Acceleration resistance

Table 2: Driving resistances

Rolling resistance

Rolling resistance is the resistance which occurs due to the rolling motion of the wheels on the road surface. It is dependent on the mass of the vehicle and the coefficient of rolling frictions, which take into account the properties of material combination (tyres and condition of the road) and the geometry of the tyres. This is warped when the tyres roll. The majority of the warping is elastic and loss-free, and returns to its original shape. Lossy procedures, which become evident in a development of heat, include the flexing work in the rubber of the tyre as well as the percentages of sliding friction when rolling the eccentric tyre parts and when driving a curved course.

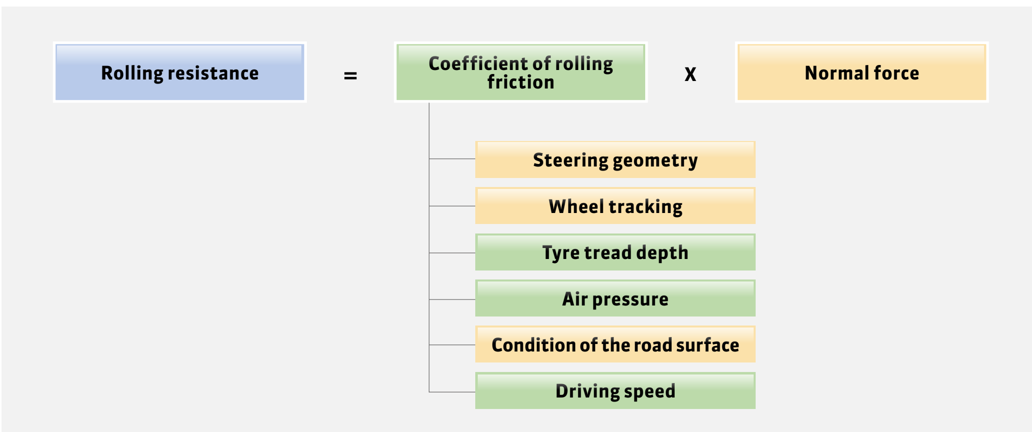
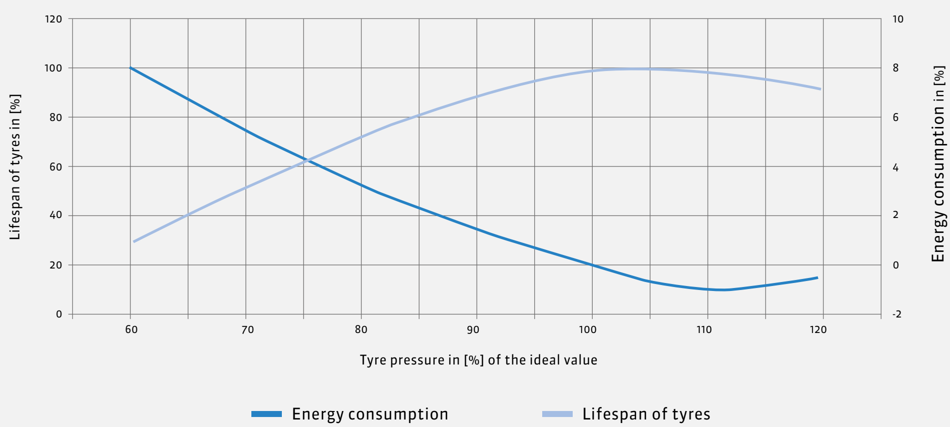


Fig. 1: Influences on the rolling resistance

The normal force stated in Figure 1 corresponds to the vehicle mass operating proportionally on one tyre.

Although an increased tyre pressure does reduce the rolling resistance by decreasing the flexing work in the rubber of the tyre and the contact surface between tyres and road (sliding friction), it also impacts negatively on the tyre's grip on the road and the driving comfort of the vehicle.

If the air pressure is too low, it can lead to greater energy consumption as a result of the greater rolling resistance through the effect of flexing work. Furthermore, tyre wear and the risk of burning tyres increases. At approximately 85 percent of ideal air pressure, the durability of the tyres falls by 20 percent.



Source: Eco-Training; Günter Meyer; Hubert Ebner Verlags GmbH

Fig. 2: Durability and energy consumption subject to air pressure

Increased energy consumption is the main difference between summer and winter tyres with regard to economic driving. Winter tyres have a greater rolling resistance due to their deeper profile and have a greater energy consumption of up to 10%.

Climbing resistance

The climbing resistance is the force which is necessary to be able to overcome an uphill difference in altitude. The climbing resistance is composed of the influences shown in Figure 3.

Climbing resistance = **Vehicle mass** x **Gravity (= 9,81 m/s^2)** x **Cosine of road gradient**

Fig. 3: Influences on the climbing resistance

Aerodynamic resistance

The force which must be expended for the displacement of air is referred to as aerodynamic resistance. The aerodynamic resistance is quadratically dependent on the driving speed; this means that a duplication of the driving speed would result in four times as much aerodynamic resistance.

Other influential factors include the cross-section surface of the vehicle, the air drag coefficient (aerodynamic form) and air density.

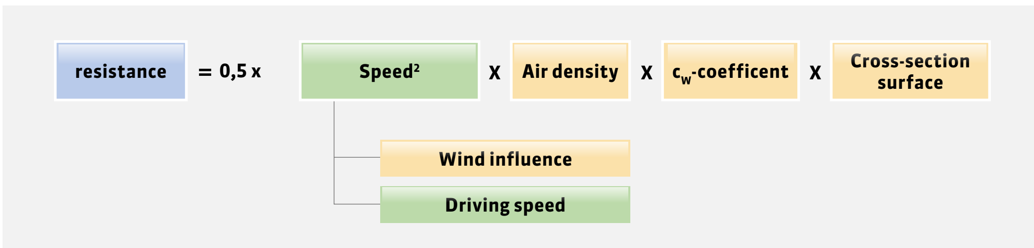


Fig. 4: Influences on the aerodynamic resistance

Acceleration resistance

The inertia of the vehicle and the moving components installed therein causes the acceleration resistance. The physical principle of inertia means that a body with a mass remains in the state of inertia until a force is applied to this body. In automotive engineering, this means using energy to change the speed. The following dependencies occur in acceleration resistance:

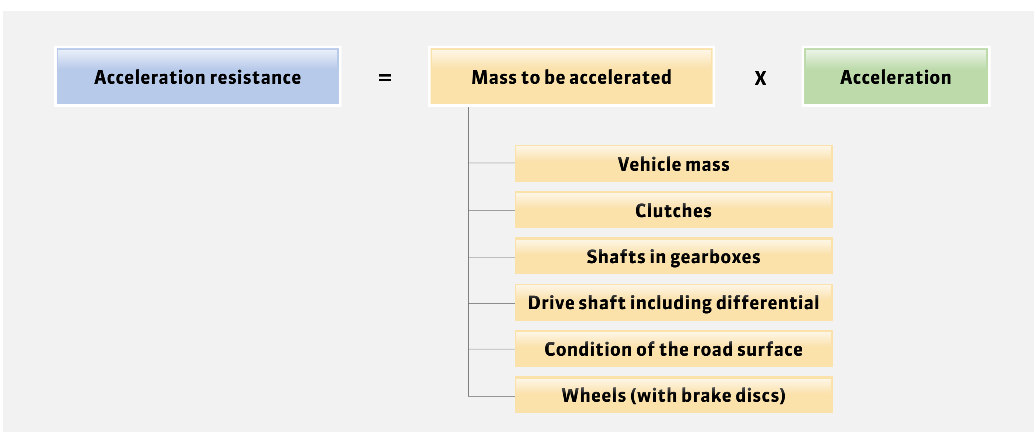


Fig. 5: Influences on the acceleration resistance

From the connections of the individual driving resistances, it can therefore be shown that two significant factors play an important role in the energy-saving operation of utility vehicles:

- **before starting the journey:**
  Inspection of the vehicle condition, especially the tyres
- **during the journey:**
  conscious choice of the driving speed

1.5 Driving conditions

Various driving conditions are possible during the movement of vehicles. It is precisely in public transport over short distances between stops that knowledge about driving conditions becomes more important because there is an immediate influence on energy consumption and this can be significantly influenced by the correct driving style choice. In the following, four achievable driving conditions of vehicles are described:

- **Acceleration**
  Acceleration means increasing the driving speed through energy input. The driving force of the vehicle must be greater than the driving resistances working against the direction of motion.
- **Steady state**
  Steady state means keeping the driving speed constant. Here, the precise amount of energy must be used which corresponds to the driving resistances working in opposition of the movement.
- **Rolling**
  The driving speed is lowered by rolling. Sometimes this is due to the driving resistances which work against the vehicle movement. Whilst rolling, no energy is expended for the forward motion of the vehicle.
- **Braking**
  Braking means reducing the driving speed. In a trolleybus this generally takes place through the electric brakes which can recover a portion of the energy. Braking with the mechanical brakes causes the total braking energy to be converted into heat through the friction between the brake disc and the brake pad and it is lost into the environment.

The driving conditions can be perfectly presented in a speed-time diagram. In doing so, a trapezoidal velocity curve is shown in the driving cycle with steady driving (see Figure 6).

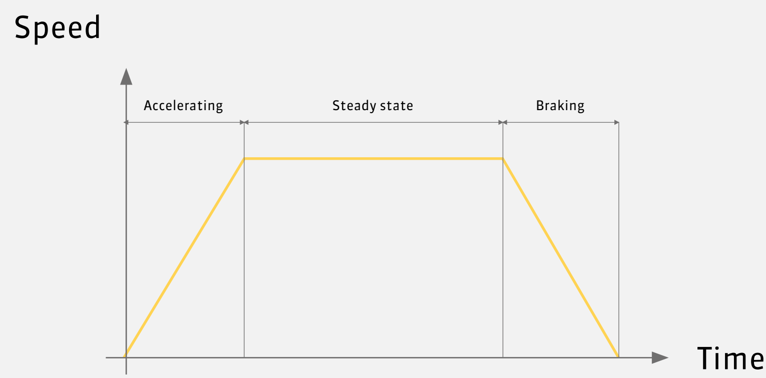


Fig. 6: perfect driving cycle with steady state Speed

Figure 7 shows the perfect driving cycle with maximum rolling ratio. Due to the fact that no energy needs to be expended to roll the vehicle, this driving cycle is considered to be the cycle with the minimum level of energy consumption. This driving cycle can be presented as a triangle in the speed-time diagram.

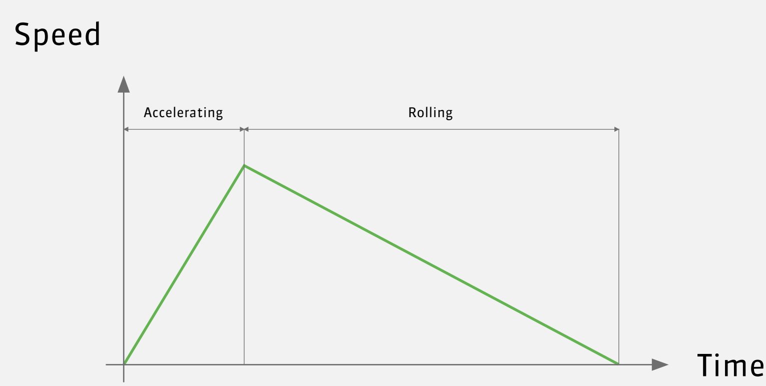


Fig. 7: perfect driving cycle with maximum rolling ratio

This shows that the driving cycles with a high rolling ratio are the most energy efficient. In reality, the form of the driving cycle is a square in most cases because it is usually necessary to brake at the next stop. The driving conditions known as steady state and braking should be reduced to a minimum if possible.

2. The "Trolleybus" system

The "Trolleybus" system is characterised by local emission-free and almost noiseless operation. The system and its characteristics will be presented in the following sections.

2.1 Power supply

The power supply for the propulsion of the vehicle and propulsion of the auxiliary equipment is ensured by the overhead line. The current supplied by the power supply company is converted into direct current in rectifier substations (RS) and fed into the overhead line network.

The different sections supplied by the rectifier substations are separated using isolated overhead line areas ("isolator"). Older isolators function using simple isolating distances, which is why no current can be obtained from the overhead line network from these areas, and the power controller of the trolleybus must be switched off. Advanced isolators are designed as diode separators where in principle, the power supply of the vehicle is guaranteed. In order to exclude comfort restrictions and to protect the use of technology available (both on part of the vehicle as well as overhead line), even these isolators must be driven with a switched off power controller if possible.

The overhead line however is not just used to supply trolleybuses with energy. It is also able to recover this during brake applications and use it to supply other vehicles with energy in the same supply section. This process, known as recuperation, enables an energy recovery of up to 25% of kinetic energy of the trolleybus when braking with the electric brake at the time of applying the brake. The recovered energy is firstly used for the own requirements of the auxiliary equipment of the trolleybus and surplus energy is supplied back into the overhead line network (see Figure 9). If this is no longer capable of recovering energy, the surplus brake energy in the roof-mounted resistors is converted into heat and lost into the environment.

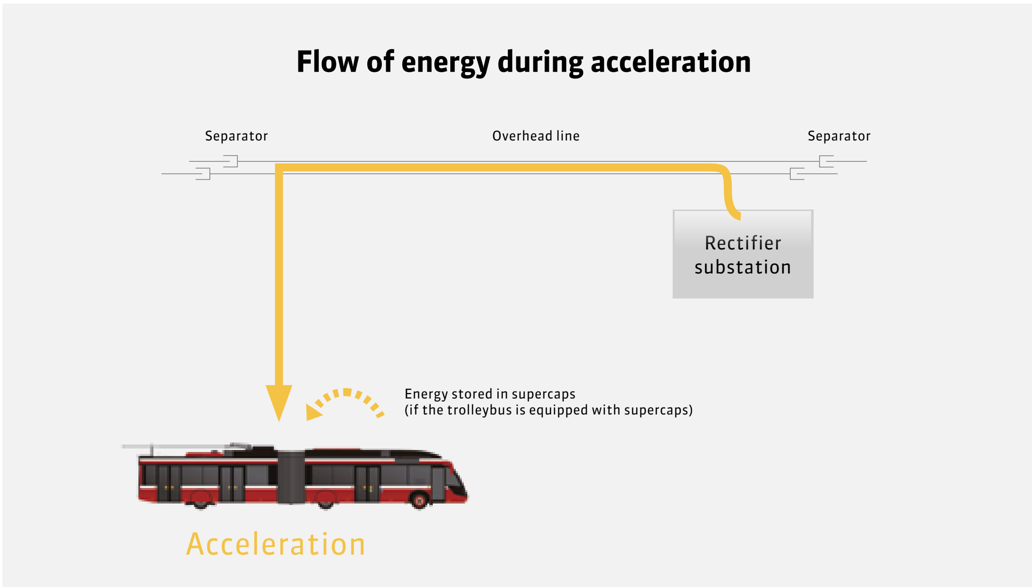


Fig. 8: Flow of energy during acceleration

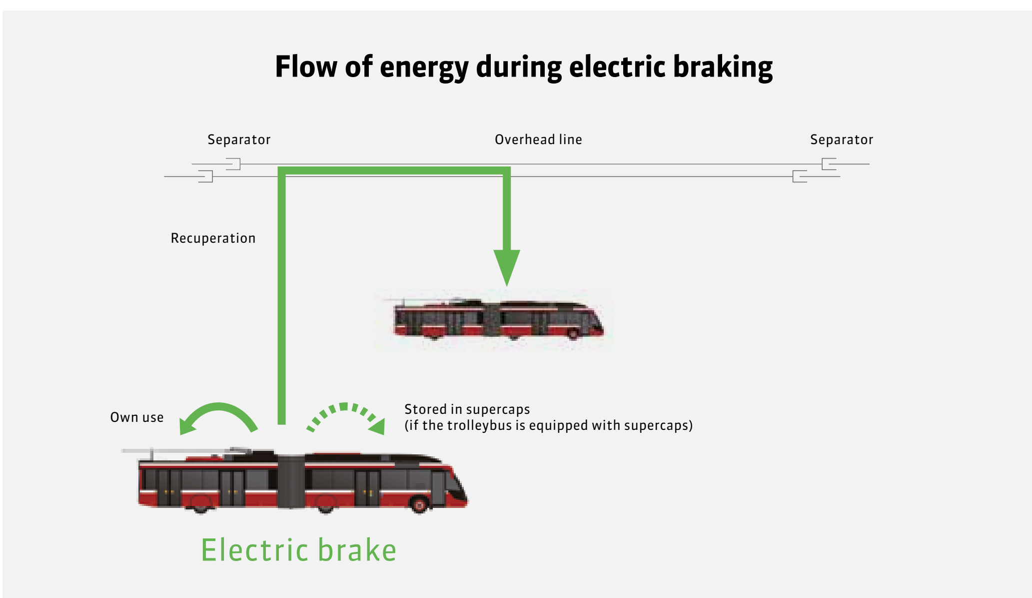


Fig. 9: Flow of energy during electric braking with surplus energy

As a result of the current demand, each acceleration of the trolleybus leads to a lowering the overhead line voltage and each braking process with the electric brake leads to an increase of the overhead line voltage on the trolleybus.

Trolleybuses with supercaps store a part of its recuperated energy during braking in their supercaps and use it for acceleration processes from a standing position or in low speed. This kind of energy management on-board helps to downsize overhead line infrastructure, because the effect of lowering and increasing of the overhead line voltage during acceleration and deceleration is reduced.

2.2 Automotive engineering

The current from the overhead line is extracted using a current collector and guided via the input filter, over-voltage arrestor and the main switch to the electronic control systems (see Figure 10). The input filter is used for smoothing the current, which can display irregularities in the voltage curve through different external influences.

The over-voltage arrestor (cathode drop arrestor) is used as an on-board shield compared to over-voltages in the overhead line, which to some extent have significant levels of energy and thus could destroy parts of the automotive engineering. Over-voltages are caused by direct or proximate lightning strikes, electro-magnetic impulses and switching procedures in the mains. The main switch is able to galvanically separate the trolleybus from the overhead line.

The components of the power and control electronics are housed in roof-mounted equipment containers in the advanced low-floor trolleybuses. This includes the direct pulse inverter (DPI) to control the traction engines and the static converters (SC) to supply the electric auxiliary systems of the trolleybus. Generally, the input filter and the electrical contactors are housed in the roof-mounted equipment container. The roof-mounted equipment container connected with the overhead line voltage on the input side presents a compact unit on the roof of the trolleybus. Passive accident protection is guaranteed through the positioning outside the bumper area. The double insulation of the high-voltage conducting parts which is important for the trolleybuses is integrated into the roof-mounted equipment container.

The direct pulse inverter (DPI) used for the electric control of the traction engine is directly supplied with power from the overhead line via the input filter and generates voltage blocks of variable widths used to supply the driving motor.

Through this process, which is characterised as pulse width modulation, it is possible to generate a three-phase system of variable current and frequency which can transport energy in both directions. The IGBTs (Insulated Gate Bipolar Transistor) - characterised by the high switching frequency and small losses - are used as switching elements. With this advanced technology, it is possible brake electrically almost up to a standstill with the appropriate controls and thus, maximum energy recovery can be achieved.

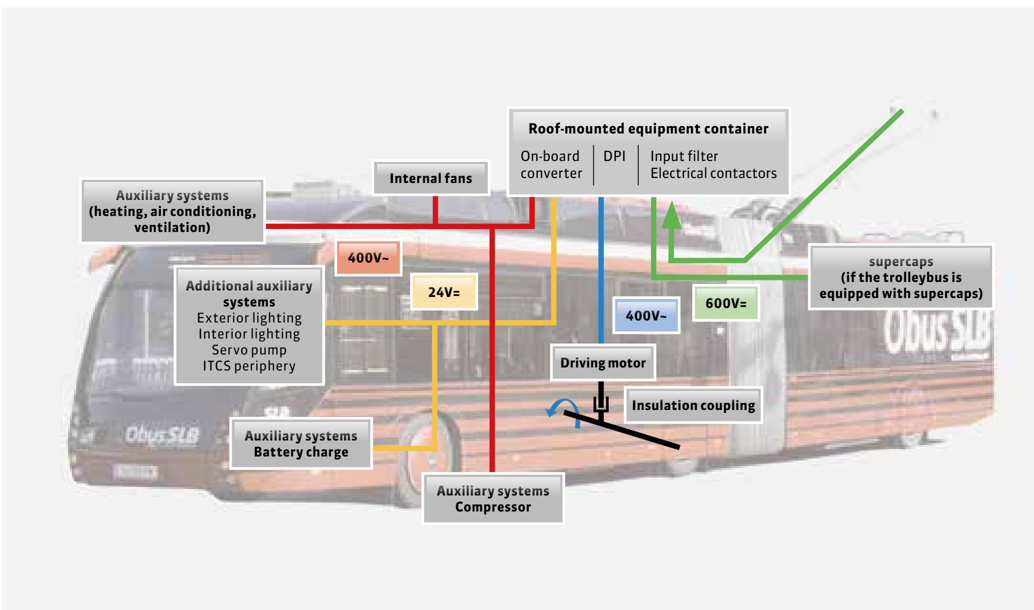


Fig. 10: Components for operating and controlling a trolleybus

The static inverter supplies the auxiliary equipment with power. In most of the trolleybuses it is a 24 volt direct voltage supply and a 400 volt three-phase supply. While the drive of the compressor is effected via the 400 volt three-phase supply, the battery charge as well as the supply for auxiliary equipment such as interior and exterior lighting, servo-pumps and the ITCS periphery is guaranteed by means of the 24 volt direct voltage supply (see also Figure 10). Due to safety reasons, all outputs are galvanically separated in duplicate from the overhead line voltage directly connected to the entrance.

From drivers station it is possible to switch the direction with D,N and R buttons however this may depend on the vehicle type.

Converting the electrical energy from the overhead line into mechanical kinetic energy is effected by magnetism in the electric motors. The electric motor works more simply and more effectively than a combustion engine. It consists of an (external) stator and an (internal) rotor. The rotor is moveable and equipped with permanent magnets which have a north and south pole. By electrically controlling the drive with the help of the direct pulse inverter, the trolleybus does not need a gear mechanism to transmit this rotation. From the driver's station it is possible to switch the direction with the D, N and R buttons; however, this may depend on the vehicle type.

Asynchronous motors are used in modern vehicles. The choice of the correct number of poles is particularly important during procurement as 6-pole motors are usually more expensive to procure; 4-pole motors, however, consume more power due to the continuous control current required to determine the motor armature's direction of rotation, but generally exhibit a smaller diameter with the same output.

The driving motor is connected to the drive shaft through a positive insulation coupling whereby, on the one hand, electrical insulation is achieved between the high-voltage components and the mechanical driving part and, on the other hand, the driving motor of the motor can be transferred almost without any losses.

Surplus energy from the brake applications with the electric brake, which is not required for the vehicle‘s own usage, and cannot be re-supplied into the overhead line for lack of consumers, must be converted into heat in electric brake resistances. Furthermore, the electric brake resistances together with the driving motor operated as a generator comply with the legal requirements of the permanent brake. The brake resistance is controlled by the brake chopper which is integrated in the DPI. The electric brake is maintenance-free.

Electric brakes can be applied until stopping is achieved. The travel motor is used as a generator. By doing so, the mechanical brake is rarely required and the wear and tear of the brake pad is significantly reduced. This also means a reduction of the holding times and thus increases the availability of the vehicle.

2.3 Vehicles with supercaps

Supercapacitors or supercaps, technically known as electric double-layer capacitors, are electrochemical capacitors with an energy density hundreds of times greater than electrolytic capacitors. Supercaps are used for energy storage in various applications such as vehicles, medical and low-power devices, alternative energy appliances and as complement for batteries. In the public transport sector this kind of energy storage has been installed on trolleybuses, hybrid and electric buses and light and heavy rail vehicles. The modules of trolleybuses are usually placed on the roof of the vehicle, but it may depend on the vehicle type.

Supercaps are made by two layers of the same material (usually activated carbon) connected with an electrode and divided by a thin seperator. The porosity of the material allows the storage of high quantities of charge in a small volume.

Operational advantages of trolleybuses with supercaps are a very high rate of recuperated energy (up to 90%) during decelerations while using the electric brake and an overall operational energy saving up to 25% depending on topography and overhead line network. Furthermore overloads in substations and the risk of electric arcs between overhead lines and current collectors can be reduced. On-board devices have an improved reliability.

To get a maximum of advantages a supercap system has to be sized according to the characteristics of the trolleybus network, in which the trolleybus is to be operated in. There is always a number of, modules that represents the most efficient solution. The number of modules with a maximum of advantages depends on curves, slopes and speed of each trolleybus route, because more modules mean more energy savings, but also more energy consumption caused by additional weight.

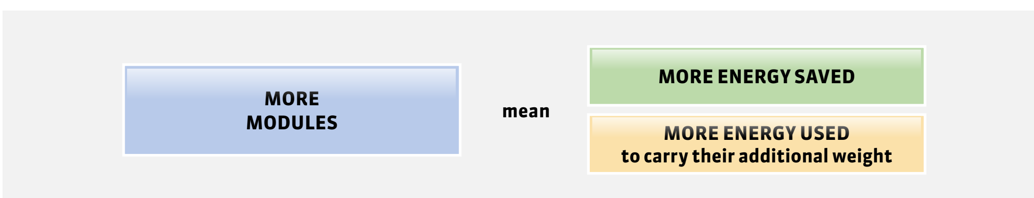


Fig. 11: Influence of number of supercap modules

3. Economic driving with trolleybuses

3.1 Fundamental aspects

Economic driving means energy-efficient, low-wear and ecological driving. It is essentially dependent on the following aspects:

- on the technical state of development of the trolleybus
- on the vehicle condition and the regular maintenance of the trolleybus
- on line management, traffic density and the utilization of the trolleybus
- on the driver's driving method, particularly anticipatory driving
- on the conscious use of the heating, air-conditioning and ventilation system

The traffic volume, routing (road condition and topography), utilization of the trolleybus and the vehicle type in the public transport system cannot be influenced at all by the driver (presented in yellow in Figure 13). Greater importance is placed on factors which can be influenced by the driver such as the style of driving, anticipatory driving and controlling the heating, air-conditioning and ventilation system.

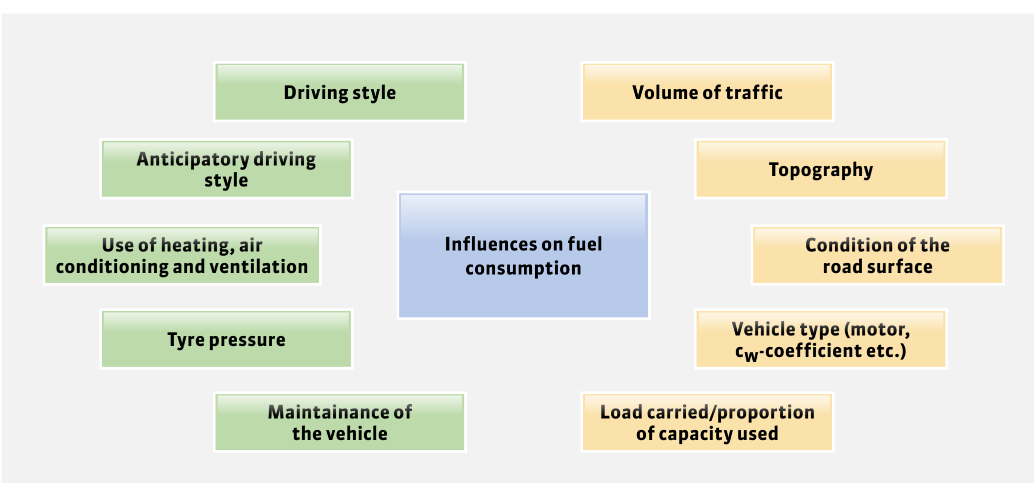


Fig. 12: Influences on the energy consumption

Furthermore, the driver (and/or the garages) can examine the tyre pressure and the vehicle's condition. Good cooperation with the control centre and the garage through the precise explanation of possible defects in the vehicle is just as important as observing the operating instructions.

3.2 Effects of the style of driving

Conscious choice of the style of driving and anticipatory driving come to the fore in saving energy in operation.

The cost-effectiveness of trolleybus operation greatly depends on the driver's style of driving. It is up to the driver to ensure that the passengers are transported not only safely and punctually but also using energy efficiently.

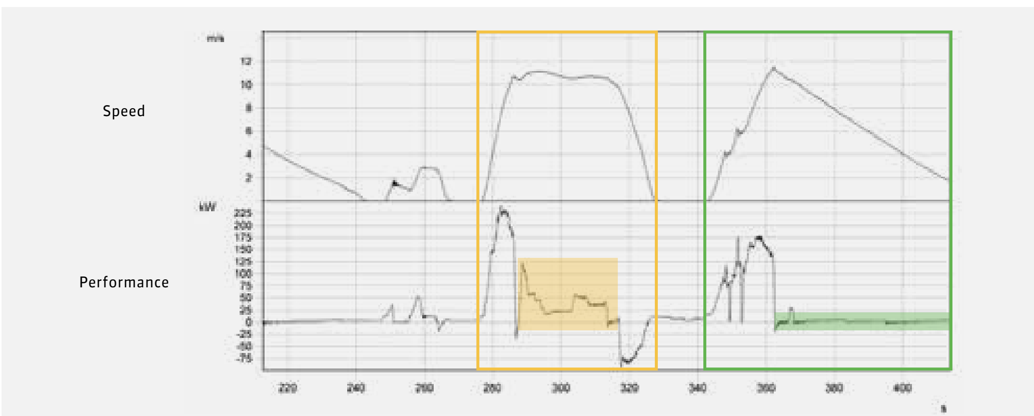
In the course of the test run, the influences of driving conditions (see also section 1.5) on energy consumption and the overhead line voltage were tried and tested. The measurement results from test drives are presented in Figure 14. Both of the upper graphs show the velocity curve and the acceleration over time. The current and the power proportional to it is then presented (power = voltage * current, see section 1.3).

On the basis of the different driving cycles of the test run, it was stated that:

- acceleration should be quick,
- the steady state should be completely avoided,
- the rolling ratio by complying with the schedule should be as high as possible,
- unnecessary braking should be avoided and ideally the energy recovery should only take place with the wear-free electric brakes.

Frequent and only low acceleration should be avoided because, while rolling, the auxiliary equipment is supplied through self-excitation with energy. Each operation of the driving switch causes the offset power to increase, leading to increased consumption of energy. In each acceleration process, the target should be pursued taking into account the maximum permissible driving speed in order to enable a long-lasting rolling phase.

High rolling ratios are only possible with an anticipatory driving style and a well-measured distance to the vehicle ahead, and not only save energy but also increase driving comfort. Driving with an anticipatory style means driving without unnecessary acceleration and braking processes. Unnecessary start-up procedures (for example, frequent moving up in traffic jams or against a light-signalling system indicating stop) could also be avoided by means of an anticipatory driving style.



Energy consumption corresponds to the surface below the performance curve

Fig. 13: real driving conditions with steady state (yellow) and rolling (green)

In order to be able to use as much rolling ratio as possible from the scheduled time available, the stop time must be kept as short as possible.

Although energy is recovered while braking with the electric brake, the driving speed should be selected through an anticipatory driving style in such a way that braking can be reduced to a minimum.

3.3 Energy-efficient braking with the electric brake

In braking applications in trolleybuses, after the aspect of safety, emphasis is placed on the most efficient recovery of braking energy. By operating the brake pedal, the traction motor acts as a generator, meaning that it is possible to recover braking energy. The electric brake system is regulated with the brake pedal into which the mechanical brake, operated with compressed air, is integrated.

In most of the trolleybuses in operation, when using the brake pedal, presented in Figure 15 as a red characteristic curve, only the electric brake is active. When the brake pedal is continuously operated, the brake torque (yellow characteristic curve) is increased to 100%. After about two-thirds of the path of the brake pedal (depending on the vehicle type), the electric brake remains constant with an effect of 100%; it also increases the effect of the mechanical brake by continuing to operate the brake pedal. The resulting effect of the brake pedal is therefore linear and quick without blows or brake torque changes.

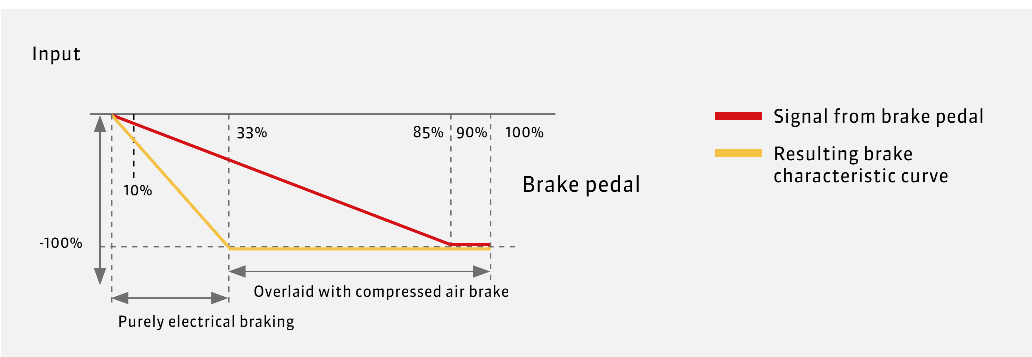
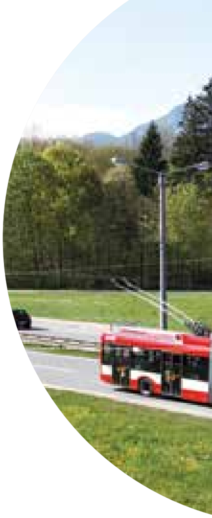


Fig. 14: Interaction of the electric brakes and the air brake

For the braking response it means that the brake pedal is never fully operated but to a maximum of two-thirds in order to recover as much braking energy as possible and to protect the mechanical brakes. Nevertheless, safety must be at the fore.

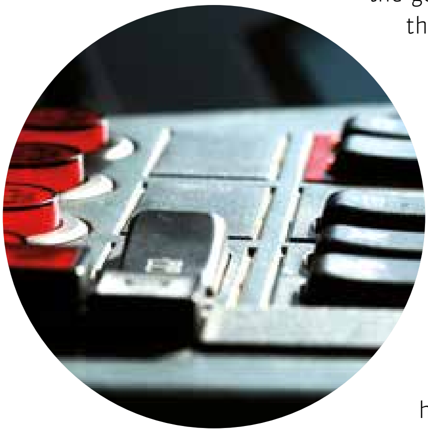


3.4 Conscious use of the heating, air-conditioning and ventilation system

If the driver manually controls the heating, air-conditioning and ventilation system, he can make an additional significant contribution towards reducing energy consumption through conscious utilization. Heating and/or cooling vehicles with open windows should be avoided.

3.5 Differences from economic driving with diesel-powered vehicles

Electrically operated vehicles and vehicles driven by a combustion engine differ significantly with regard to economic driving. Not least, even the gear mechanism required for the power transmission between the engine and the wheels is crucial for the vehicle's overall level of efficiency.



A gear mechanism in the drive chain between the engine and the drive axle is necessary because combustion engines only deliver sufficient torques in a limited speed range. This makes it possible vary the speed and/or torque ratio between the engine at the drive axle. A distinction is made between (manual) gearboxes and automatic gearboxes.

Due to the positive connection in gearboxes, these have higher degrees of efficiency than the non-positive automatic gearbox. However, buses used for local city transport usually have an automatic gearbox with four to six gears in order to increase driving comfort. Positive gearboxes require an interruption of the drive chain (decoupling) for the switching procedure, whereas automatic gearboxes do not need to be interrupted in the drive chain due to the hydraulic converter.

In order to drive at different speeds with the relatively favourable speed ranges, it is necessary to switch the different gears. This is possible with advanced gearboxes with front- and rear-mounted range change. In coaches, there are additional gear change aids such as automatic pre-selection shifting (SVS, AS Tronic) and electro-pneumatic switching (EPS).

The gear changes of the automatic gearbox can be influenced by the accelerator pedal. If the driver withdraws from the accelerator pedal on time, the gearbox switches to the next gear down.

To increase the degree of efficiency, the torque converter is bridged above a specific driving speed. This takes place depending on the speed and load and can be between 5 and 35 km/h. It should only be accelerated using partial gas up to this switching procedure in order to reduce the losses caused by slip.

Emissions also play an important role in combustion engines. On the one hand, these can be reduced through driving in a way that preserves fuel, and the associated reduction of fuel consumption; on the other hand, through different procedures for the post-treatment of exhaust gas, which gained in importance through the gradual introduction of the Euro emission standards from 1990. Since the introduction of the Euro 4 emission standard in 2006, the required maximum exhaust emissions can no longer be achieved without the post-treatment of exhaust gas.

The Euro 5 limit values allow a maximum nitrogen oxide emission (NOx) of only 2 g/kWh and a particle emission of maximum 0.02 g/kWh.

In the course of an exhaust gas recirculation (EGR), a part of the exhaust gas is re-supplied into the air intake via a valve in order to be mixed with fresh air. The mixture of fresh air and exhaust gas has a lower oxygen content (O2) and thus contributes to the reduction of combustion temperatures in the combustion chamber. Lower combustion temperatures lead to a reduction of poisonous nitrogen oxides (NOx). The increase of the development of soot and carbon monoxide (CO) is counteracted by a catalytic converter.

Only a SCR catalyst (selective catalytic reduction) can cause an additional reduction of the exhaust emissions. Ammonia (NH3) in the form of a 32.5% watery urea solution is injected into the exhaust gas in front of the SCR catalyst. This is known as AdBlue. Ammonia and water (H2O) are created through the chemical reaction (hydrolysis reactions). The ammonia reacts with the nitrogen oxides in the exhaust gas in the SCR catalyst which in turn reduces the NOx emissions. The advantage of the post-treatment of exhaust gas using the SCR catalyst is that it does not lead to any loss of performance or any extra fuel consumption.

4. Safety

The safety requirement is at the fore and all other factors are subordinate to the safety requirement. An anticipatory manner of driving contributes to safety and reduces the risks for the driver and the passengers to a minimum. The correct behaviour in the event of faults and accidents is essential nevertheless, and reminders of this are given in the following sections. The objective is to keep the damages to a minimum, to avoid further damage and to minimise risk to third parties.

4.1 Correct behaviour in the event of accidents

If the fault is caused by an accident, the driver must utilise all resources in a calm and reasoned manner in order to eliminate the fault, reduce damage and avoid further damages. If a risk cannot be eliminated immediately, the hazardous area must be secured.

To do so, the vehicle must be stopped, hazard warning lights switched on and the trolleybus must be secured against unauthorised start-up and rolling. The main switch must be turned off when exiting the trolleybus, and if required the current collectors must be removed.

For reasons of personal safety, the vehicle must only be exited whilst wearing a reflective vest. On country roads, highways and motorways, the drivers are legally obliged to wear a reflective vest upon leaving the vehicle.

If the vehicle is exited, the scene of the accident must be secured and the breakdown triangle which is kept in the vehicle must be set up according to national legislation.

Only then should the first-aider enter the area of danger and take the parties involved in the accident out of the area of danger..

The control centre is responsible for informing the necessary aid organisations for assistance after an accident and for hazard avoidance.

The trolleybus driver of the vehicle that was involved in the accident and/or the fault, or who was first prevented from continuing the journey, is responsible for informing the control centre.

Once the parties involved in the accident and the first-aider are no longer subject to risk due to third parties, First Aid must be provided and help requested. The common European emergency number is 112 (following Directive 2002/22/EC – Universal Service Directive) and also standard on GSM mobile phones. 112 is used in Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, the Republic of Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, the Republic of Macedonia, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine and the United Kingdom in addition to their other emergency numbers. In doing so, it is important to provide a summary of the accident situation that is as detailed as possible.

Eye-witnesses and parties involved in the accident must be stopped for an accident report and their personal details (name, address, contact details) must be noted down. An accident report and/or accident statement, including an outline of how the accident happened, must be completed; photos of the scene of the accident may be helpful for the preservation of evidence. The insurance data (company, insurance number, insurance card) of the parties involved in the accident must be exchanged.

4.2 Behaviour in the event of technical faults on the trolleybus

Faults on the trolleybus may have a variety of different causes and may require different responses. If a trolleybus has to be stopped on the route, the driver must secure and monitor the trolleybus. The switched-off trolleybus can be secured against rolling away by applying the hand brake and, in the event of a missing or damaged spring-loaded brake, it must be secured by placing stop blocks. Furthermore, the main switch must be switched off and, if required, the current collectors must be removed. The lock key must be removed and the driver must keep it.

In the event of insulation faults on the trolleybus, the main switch must be switched off while the doors are still closed. Finally the drive must remove the current collectors. If there is suspected damage to the electrical equipment after the accident, no attempts should be made to drive the vehicle. The control centre must be informed.

4.3 Towing

Particular precaution is required when towing a trolleybus. No passengers must be transported in a towed vehicle. The towing speed must not exceed the speed limit according to the national legislation. The general danger signal must be attached to the rear-end of the towed trolleybus (“in tow”).

4.4 Behaviour in the event of fire

If a fire is detected on board the trolleybus, the trolleybus must be stopped and secured at a suitable location (if possible not within a tunnel or subway). The main switch must be switched off; however, the trolleybus must on no account be shut down or the main power supply (battery voltage) be switched off because this would prevent the doors from opening automatically. It is possible to allow passengers to exit the vehicle by operating the door release. Injured persons must be identified and taken out of the area of danger. The emergency services are requested by informing the control centre.

The driver must remove the current collectors and can attempt to extinguish the fire with fire extinguishers, depending on the possibility and usefulness of this.

4.5 Behaviour if the trolley poles derail

If a derailment of the trolley poles has been detected, the vehicle must be stopped immediately, considering the passengers and the following traffic.

The trolley poles, trolley-heads and the overhead line at the derailment point are subject to a visual inspection. Touching the trolley poles while other trolley poles are still attached to the trolley system is prohibited. Removing the roof or touching the live vehicle and overhead line parts is also prohibited.

The main switch must be switched off before setting up and/or removing the trolley poles. In trolleybuses where the trigger bar is kept in the passenger compartment, the door release should not be operated, but the door is question must be opened using an emergency valve. By doing so, it is possible to avoid a premature release of the pre-selected door for quick boarding and alighting.

The reflective vest must be worn on public roads.

The trolley poles must only be connected to the overhead line using the current collector trigger bar provided for this purpose.

The control centre must be informed immediately of each trolley pole derailment, and these must be entered in the vehicle log book. If damage to the trolleybus, overhead line or third parties is detected, the control centre must be notified in writing as well as the initial notification. Current collectors with damaged current collector shoes must not be used. Instructions from the control centre must be waited for before continuing the journey.

4.6 Damage to the overhead line systems

Particular caution is requested if parts of the overhead line are dangling because the complete operating voltage can be applied between both overhead wires (plus and minus overhead wire). If there is a risk of the following motorists coming into contact with the dangling wires, the trolleybus driver of the trolleybus that arrives first is obliged to secure the hazard area appropriately. Approaching or touching the dangling overhead and feed lines, as well as other wires connected to these, without protective means, is prohibited.

If a vehicle is in contact with the dangling wires, it must be ensured that the passengers calmly remain in the vehicle until the fault clearing service has arrived. However, if a fire starts at the same time, an emergency shutdown of the overhead line must be carried out by the control centre. If this is not possible, the passengers must jump out of the trolleybus to avoid electric arcs (step voltage!) and it must be ensured that the road has been isolated with suitable means upon exiting (for example, dry clothing).

If a person is in contact with a live wire, the person can only be rescued by using non-conducting items. The person must be pulled away by gripping only the clothing. The person providing assistance must first stand on a sufficiently effective insulated layer, for example, an insulating mat, a board or thick dry material. Other possible aids and appliances for removing the live conductors include current collector trigger bars and, if available, rescue hooks made of non-conductive material.

If the continued journey is interrupted due to a failure of the power supply, the airspeed (momentum) should be exploited if possible and the trolleybus shut down so that the road traffic is not significantly impeded. Current collectors must be removed where appropriate. Trolleybuses with auxiliary drive continue their journey with an alternative system.

An overloading of the power supply must be assumed if there are repeated interruptions to the electricity supply within a short period. In this case, special care must be taken when driving with reduced speed, and the simultaneous start up of several vehicles should be avoided. Where required, the control centre can provide individual departure orders in order to avoid a simultaneous start up. Where possible, the heating, air-conditioning and ventilation system and all other auxiliary equipment must be switched off.

If a vehicle from the trolleybus fleet with yellow blinking lights is standing at a trolleybus system, the trolleybus must be stopped with sufficient distance to the maintenance vehicle. The driver of the trolleybus must establish visual contact with the trolleybus fleet and the continued journey must only be initiated once a signal has been received from the trolleybus fleet, any supervisors present, or through the instructions of the control centre. Extreme precaution must be practised when passing an area of danger. The speed can only be increased once the current collectors of the danger zone has been passed and the contact wire position allows it.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Obus SLB
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5. Execution of the training sessions

The training sessions are organised into five phases. The goal during the training sessions is to develop an economic driving style and to implement the skills acquired into every day public transport operations.

- **Introduction and operation of the "Trolleybus" system**
- **practical driving**
- **economic driving style with a trolleybus**
- **practical driving considering the knowledge relating to the economic driving style**
- **Safety aspects when driving trolleybuses**

The training takes place over 7 hours.

During the practical parts, energy consumption is measured with special software and finally presented in a journey log. In addition to the journey data (length, duration, average speed), the energy values can also be read in this journey log.

The values for the total energy applied per driven kilometre and the consumption from the drive operation per driven kilometre are crucial for economic driving with regards to energy consumption.

If the consumption decreased by 0.10 kWh due to the more effective driving style of the driver, at a driving performance of 5 million kilometres, it would result in an annual energy saving to the amount of 500,000 kWh.

Obus SLB

Name Muster
Vehicle no. 308
Date 01.06.2012

Parameters	Values	
measuring time	**0,22**	hrs.
distance	**5,83**	km
average speed (for time, the speed was not 0)	**30,74**	km/h
admitted energy (electrical work) from overhead powerlines	**10,74**	kWh
recuperated energy (electrical work) to overhead powerlines	**2,07**	kWh
admitted energy minus recuperated energy	**8,67**	kWh
energy consumed for powertrain	**10,07**	kWh
produced energy of powertrain	**3,58**	kWh
energy consumed for additional auxilliary systems	**1,18**	kWh
(servo pump, compressor, battery charge)		
energy consumed for heating system	**0,00**	kWh
admitted energy per kilometer	**1,84**	kWh/km
recuperated energy per kilometer	**0,36**	kWh/km
admitted energy per km minus recuperated energy per km	**1,49**	kWh/km
energy consumption per km	**1,11**	kWh/km

Unterschrift ____________

Drücken: 14.07.2014

Fig. 15: Test record template for energy consumption measurements during practical training part

ACTUATE partners

The ACTUATE consortium consists of five public transport companies from **Salzburg** (Salzburg AG, Austria), **Brno** (DPMB, Czech Republic, Parma (TEP S.p.A., Italy), **Leipzig** (LVB, Germany) and **Eberswalde** (BBG, Germany) which already operated electronically powered vehicles as well as the Leipziger Aus- und Weiterbildungsbetriebe [training and development operations] **(LAB)**, the Belgian bus manufacturer **Van Hool** and **trolley:motion**, the international association for the promotion of innovative, zero-emission e-bus systems (Austria). The project is coordinated by **Rupprecht Consult** GmbH (Germany).

Co-funded by the Intelligent Energy Europe
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Economic driving in the public transport sector

3 requirements for economic driving in the public transport sector:

Safety requirement

All other requirements are subordinate to the safety requirement.

Punctuality requirement

Punctuality in the public transport sector is a requirement and means neither a premature, nor a delayed departure from a stop.

Cost-effectiveness requirement

Economic driving means minimising energy-consumption and protecting the vehicle by taking the requirements of safety and punctuality into consideration.

The following applies when driving a public transport vehicle: safety before punctuality and punctuality before cost-effectiveness.

5 golden rules for energy efficient driving

- acceleration should be quick,
- the steady state should be completely avoided,
- the rolling ratio should be as high as possible, whilst ensuring compliance with the schedule
- unnecessary braking should be avoided and ideally energy recovery should only take place with the wear-free electric brakes
- conscious use of the heating, air-conditioning and ventilation system if this is not automatically controlled in an optimised way anyway

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Factsheet

Safety

Correct behaviour in the event of accidents

If the fault is caused by an accident, the driver must utilise all resources in a calm and reasoned manner in order to eliminate the fault, reduce damage and avoid further damage.

- Stop vehicle and switch on hazard warning lights
- Secure the vehicle against unauthorised start-up and use
- hand brake to secure against rolling away
- if required, the current collectors must be removed
- in the interest of personal safety, only leave vehicle
- wearing a reflective vest
- Secure accident point/point of fault
- Take the parties involved in the accident out of the area of danger
- Provide First Aid and request help
- Accident reports, stop witnesses and exchange data

The control centre is responsible for informing the necessary aid organisations for assistance after an accident and for hazard avoidance.

The trolleybus driver of the vehicle that was involved in the accident and/or the fault, or who was first prevented from continuing the journey, is responsible for informing the control centre.

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