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CACTUS

Models and Methods for the Evaluation and the Optimal Application of Battery Charging and Switching Technologies for Electric Busses

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Partners

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Content

1 Introduction

The global trend towards clean and energy-efficient vehicles is driven by concerns regarding the impacts of fossil-fuel-based road transport on energy security, climate change and public health. Electrification in particular is understood as providing a potential multitude of opportunities for the use of energy from renewable sources and for the reduction of local emissions and greenhouse gas emissions like no other. In 2009, the European Commission presented the Green Cars Initiative aimed at encouraging the development and market uptake of clean and energy-efficient vehicles. This strategy will enable the environmental impact of road transport to be reduced and will boost the competitiveness of the automobile industry.

1.1 Problem

The use of public transport is an environmentally friendly way to travel. If more and more passenger cars will be powered by electrical energy in the future, public transport companies will be forced to convert their diesel busses into electric busses in order not to lose this advantage.

The requirements of busses are different to those of passenger cars. A bus covers an average distance of 250 to 300 km each day. The bus itself has a weight of, for example, 14-17.5 t (Solaris Urbino 18), 28 t (MAN NG 313) or 26.6 t (Mercedes O 405 GN). A suitable battery that would enable the bus to run for such a long distance without having to be recharged would be far too big, heavy and expensive. In order to overcome this problem, several approaches are currently being investigated, for example switching the battery and the short inductive charging of super capacitors at bus stops. With these technical solutions, which combine vehicles and infrastructure, fully electric busses should be enabled for use in public transportation.

Assumptions:

1. In the near future, there will be no batteries for fully electric busses which provide the daily output of 300 km without needing to be recharged and which would be acceptable in terms of their size, weight and cost.
2. No technical approach that is currently being investigated will be equally suitable for all public transport companies.
3. In any case, investment costs for vehicles, in-vehicle components and infrastructures (e. g. battery charging or battery switching facilities) will be very high for public transport companies.

The following conclusion is drawn: The available technical approaches and solutions must be considered separately against the prerequisites and requirements of every single public transport company in terms of transportation, technical, economic and environmental aspects. Only on this basis can a decision for a technology that optimally meets the requirements of a public transport company be made.

1.2 Objectives

Technical solutions to enable fully electric busses should be evaluated so that they reflect the prerequisites and requirements of the participating public transport companies. The ultimate goal of the project is to find the best technical solution for the participating public transport companies HVB, MVB, PVGS and PKM depending on their real input data (timetable, vehicle operation plan, etc.), which in most cases may mean minimising the investment and operational costs. Of course, the best solution may vary between the participating public transport companies due to the strongly different prerequisites, assignments and aims. The best solution does not only involve a technology, but also its optimal application.

To achieve this aim, models of all relevant transportation, technical, economic and ecological values will be elaborated. Methods will be developed with which the question as to the most suitable technical solution (depending on the input values) can be answered and which help to apply the technical solution found in an optimal way. A software tool will be developed with which the different solutions can be easily compared. It should be possible to study the gradual integration of fully electric busses into existing fleets of diesel, natural gas and hybrid busses.

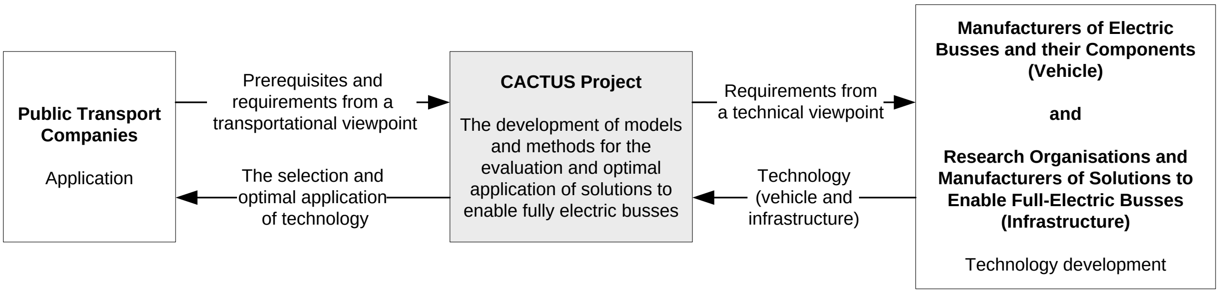

Figure 1: The role of the CACTUS project

The preliminary studies with the participating public transport companies will be lead into recommendations for the actors in the field of technology development, namely the manufactures and researchers of fully electric busses and the corresponding infrastructure. The role of the CACTUS project can be seen in Figure 1.

1.3 Concept

In the CACTUS project, considerations concerning techniques for fully electric busses will be made to decide which best fits a public transport company's needs. This requires a series of detailed questions to be answered. Some general questions are:

- Is it possible to keep to the timetable with a given configuration (all technical and strategic elements requiring the operation of fully electric busses), a given vehicle fleet (including those with mixed engines) and a given vehicle operation plan?

- How high are the investment and operational costs?

In this context, several optimisation issues arise, some of which are listed here:

- What should the operation plan look like so the timetable can be kept to?
- Where the charging or exchanging facilities have to be located?

In the CACTUS project, methods that can be used to answer these will be developed.

1.4 Scope of this Deliverable

In Deliverable 1.1 the questions have been collected which will be answered within the CACTUS project. The Deliverable 1.1 only mentioned ‘what is the problem’ not ‘how will the problem be solved’ (this is part of Deliverable 2.1 and moreover part of Deliverable 3.1). In general, aspects of transportation, technology, economy and ecology will be considered. In Deliverable 2.1 available technologies for fully electric busses will be collected. The central issue of the CACTUS project is: What is the best technical solution for a certain public transport company in the field of the four aspects transportation, technology, economy and ecology? This central issue is described in this document in detail by discussing the relevant topics and belonging questions. Although a lot of questions seem to be answered complete automatically, some questions remain for which this seem impossible in the frame of the CACTUS project because of the very complex linkage to other aspects outside of the scope of the CACTUS project. In these cases, solutions may be found by cleverly modifying some input parameters.

2 Transportation and Technical Questions

Transportation and technical questions are considered together because for most questions a clear assignment is hardly possible.

2.1 Energy Consumption

It is clear that the energy consumption of fully electric busses (resp. vehicles in general) depends on the mass of the bus, the speed profile (braking, stopping and accelerating) and the height profile (e.g. mountains). The outside temperature influences the energy consumption of the bus inventory (heating, cooling). It is to be answered how much is the influence of the mentioned parameters to the energy consumption and therefore on the range of the bus:

a) How the energy consumption depends on the mass of the whole bus (the bus itself, the battery and the passengers)?

b) How the speed profile influences the energy consumption of the electric bus?

c) How the energy consumption depends on the height profile?

d) How the energy consumption of the electric bus depends on the outside temperature through air conditioning?

e) How much is the influence of the energy recovery (e.g. when braking) on the energy consumption?

2.2 Battery Capacity

The operation plan for a certain bus for a certain day is given. The operation plan is thought for a diesel, natural-gas or hybrid powered bus. The bus now is powered with a certain technology for fully electric busses – this includes batteries on the bus and facilities for charging/exchanging within the network. Further, a charging/exchanging plan is given. Then the following questions will be answered:

a) Is the battery capacity sufficient to a given operation plan?

b) What battery capacity is needed so that the bus never runs into an empty battery fault?

There is a strong relationship to the location of the charging/exchanging stations and the charging/exchanging plan. By using given operation plans it is guaranteed that the timetable will be always kept.

2.3 Battery Charging and Battery Exchanging

The timetable and an operation plan (comprises all fully electric busses) is given. Also given is a technology for fully electric busses including several constrains like maximum and optimum charging current. The technology for fully electric busses usually comprises energy storage and energy transfer parts. The central issue of battery charging and battery exchanging topic is how charging/exchanging the batteries can be performed such that the number of charging/exchanging stations is optimal. The expected result includes a charging/exchanging plan as well as the locations of the charging/exchanging stations. The following questions will be answered:

a) Where the charging or exchanging stations have to be located?

a) How many charging or exchanging stations are required?

b) When the batteries have to be recharged and how long?

c) Where the batteries have to be recharged and how long? (It should be possible to preselect some candidates for charging and exchanging or for excluding certain locations.)

d) When the batteries have to be exchanged?

e) Where the batteries have to be exchanged? (It should be possible to preselect some candidates for charging and exchanging or for excluding certain locations.)

f) How can super-capacitors support the charging process?

It can be assumed that having a central bus station (e.g. a well-equipped depot or integrated multimodal public transport interchanges) may have the effect of reducing the number and nature of the intermediate (on route) battery charging/exchanging station. Integrated interchanges (multimodal public transport interchanges) should be considered in the category of potential locations of charging stations. An important advantage of these sites is the location of the interchange from many bus routes.

2.4 Battery Lifetime

Any battery has limits for its charging current and lower energy bound. The battery lifetime varies greatly depending on the number of charging cycles and profiles of charging and discharging. The charging current profile over time should be close to the recommendations given by the manufacturer. However, strongly following the recommendations of the batteries' manufacturer can lead to drawbacks during operation because of longer charging periods. The following questions will be answered:

a) How long a battery can be used depending on the charging plan?

b) How the current profile for charging and discharging influences the lifetime of the battery? Which current profile is acceptable for a long battery life?

Taking into account the period of battery life (depending on the charging strategy) is a very important issue from the perspective of the economic evaluation.

2.5 Operation Plan

Given is a timetable. An operation plan is not given. Further given are fully electric busses with batteries. Also given are charging/exchanging stations and a charging/exchanging plan. The following questions arise:

a) How many electric busses are required in order to keep the timetable?

b) How are the resulting operation plans and charging/exchanging plans?

Answering these questions is difficult, because it is not sufficient to consider the timetable only. Shift plans and numbers of employees have to be regarded as well. Therefore, these questions will not be answered complete automatically during the CACTUS project. However, the models and methods could support answering these questions.

2.6 Bus Fleet

Usually, public transport companies own vehicle fleets of diesel, natural gas and hybrid busses (or a subset of these bus types). As a new bus type, fully electric busses should be purchased and integrated into the existing vehicle fleet. It is supposed that there is no public transport company which switches its whole vehicle fleet of diesel busses into electric busses at once. Instead, the busses could be replaced step by step. The issue here is how the gradual integration of fully electric busses into the existing vehicle fleet with diesel, natural gas and hybrid busses can be achieved in the best way? This means for example, is it better firstly to buy a small bus with a higher range or to buy a standard bus with a lower range? The following questions will be answered:

a) Which are the most appropriate routes for introducing electric busses?

b) Which diesel busses should be replaced be electrically powered busses at first?

It might occur, that no bus route of the current timetable with a given operation plan will be able to be handled by electric buses, because of the very high energy demand (e.g. caused by high altitude differences or a significant drain on the battery for the air conditioning in summer and heating in winter). In such a case, the bus routes and the bus operations plans should be modified by the respective public transport company. After that, the examination can be performed again.

It seems to be beneficial to analyse the relationship between the characteristics of the public transport routes and the type of the bus. The result could be general recommendations for the bus type depending on the bus route.

3 Economic Questions

Of course, the costs are very important criterions for public transport companies to decide for or against pure electric busses. In any case, the investment costs for vehicles, in-vehicle components and infrastructure (e.g. battery charging or battery exchanging facilities) will be very high for public transport companies. Additionally, there are hardly experiences regarding the operational costs. How much is the economic drawback or benefit when pure electric busses would be used instead of diesel busses, natural gas busses or hybrid busses? Within the CACTUS project the mentioned economic issues will be examined.

3.1 Investment Costs

The following questions will be answered here:

a) What will it cost to purchase the required number of battery-powered busses?

b) What will be the investments in infrastructure and technical facilities for electric busses?

The investment costs of the vehicles and the infrastructure (e.g. buildings, service stations, battery charging/exchanging stations) depends on many variables e.g. government funding, interest on loan, runtime of the loan, discounts etc.

3.2 Operational Costs

The following questions will be answered here:

a) What are the operating costs of the electric busses to procure the electrical energy?

b) What are the maintenance costs for the electric busses and the infrastructure?

c) What is the difference to conventional busses if they are equipped with fuel saving systems (e.g. stop & go)?

4 Ecological Questions

Public transportation is an environmentally friendly way to travel. If more and more passenger cars will be powered by electrical energy in the future, public transport companies will be forced to convert their diesel busses into electric busses in order not to lose this advantage. The usage of electrical energy to power busses in public transportation promises a new level of environmental mobility. This is particularly the case when electrical energy from renewable sources is used. Within the CACTUS project several ecological issues will be examined which unites the overall question: How much is the ecological benefit when pure electric busses would be used instead of diesel busses, natural gas busses or hybrid busses? Herby, fuel saving systems of conventional busses like stop & go will be considered too.

4.1 Climate Gases, Air Pollution and Noise

Combustion engines (diesel, gas) cause air pollution and noise. Additionally they produce climate gases. When electric busses are used, all local emissions are omitted. But on the other hand global emissions are risen when the electrical energy is produced (e.g. by burning coal). Therefore, the ecological benefit of electric busses strongly depends on the mix of energy sources. The following questions will be answered:

a) How much CO2 and other climate gases are avoided compared to conventional busses (local and global, depending on the mix of energy sources)?

b) To what extent the air pollution (suspended solids, toxic particles) is decreased (local and global, depending on the mix of energy sources)?

c) How much is the local decrease of noise?

4.2 Battery Lifecycle

For a specific battery type special materials are used. Especially metals and electrolytic fluids can be harmful for the environment during the production process. The calculations depend on which technology will be used for batteries for electric Vehicles and electric busses in the future. The battery manufacturers have to be queried. It has to be examined whether an instrument like the GEMIS database can be used to calculate the ecological footprint for a specific material. At the end of the lifetime the battery must be scrapped or recycled. These processes leave some negative effects on the environment. They depend on the type of battery and on the process which is chosen. The following questions will be answered:

a) Are there poisonous metals, such as lead, mercury or cadmium used during the battery production process?

b) Which impacts are caused when the battery is scrapped or recycled at the end of their lifetime?

5 Glossary

Battery
A battery stores the electrical energy of a fully electric bus. It is part of the bus. It can be recharged at recharging locations or replaced at replacing locations.

Battery Capacity
This is the capacity of a battery.

Bus Empty Weight
This is the weight of a bus without passengers. It includes the weight of the battery.

Bus Inventory
This includes all electrical energy consuming devices like heating and air condition, lighting, ticket automat, doors, displays for passenger information (next stops). The energy consumption of the bus inventory influences the range of the bus.

Bus Type
Bus types are natural gas, fully electric, hybrid and diesel.

Charging Current
This is the current with which a battery is charged. There is a maximal, a minimal and an optimal charging current. The charging current is also constraint by the charging location.

Charging Plan
The charging plan includes all charging activities. The charging plan is a set of entries. Each entry includes the vehicle, the charging station, the charging power and the charging duration. See also Exchanging Plan.

Charging Station
This is a location where batteries of busses can be recharged. The methods of charging can be divided in charging at a point and charging at a line.

Height Profile
The height profile includes all height information of the way between two successive bus stops.

Operation Plan (Bus)
This includes all runs of a bus on a whole day.

Passenger Capacity
The passenger capacity describes the number of passengers that can be transported at maximum. Standing places will be considered too.

Passenger Profile

This means the number of passengers on a certain run. The profile is composed of a constant numbers of passengers between two succeeding stops. The number of passengers varies between different sections.

Exchanging Plan

The replacing plan includes all replacing activities. The replacing plan is a set of entries. Each entry includes the vehicle, the replacing location and the replacing duration. See also Charging Plan.

Exchanging Station

This is a location where batteries of busses can be replaced. The bus connects to such a station. A (discharged) battery is automatically taken out of the bus and a fully charged battery is put into the bus. The discharged battery now can be recharged within the replacing station.

Speed Profile

The speed profile describes all acceleration and braking processes of a bus during two successive bus stops.

Super-Capacitor

A super capacitor is a capacitor which can absorb a lot of electrical energy in a very short time. This is used to bring much electrical energy into the bus where only little time is available (too short for conventional charging).

Timetable

It is a set of runs of public transport vehicles within a certain time period. A run describes an ordered list of stops and times when the public transport vehicle arrives at and departs from each stop.