Advanced Driver Aid System for Energy Efficient Electric Bus Operation

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Abstract: Electric bus energy consumption is mainly due to the vehicle traction. Additionally, auxiliary systems such as cabin heating-cooling, air compressor, and power steering consume energy. One way to optimize the consumption is a Driver's Aid System (DAS). Based on the route information, DAS provides the driver the optimal driving suggestions, and simultaneously may optimise the energy use of auxiliary systems. These approaches are discussed in the paper. When the optimal air compressor operation was introduced, vehicle energy consumption was decreased 1.6 %. In addition to guiding the auxiliary devices and the driver, prospects of using DAS as a communication hub for managing buses, their charging and to share information for a bus operator are discussed.

1 INTRODUCTION

In the near future, hundreds of electric buses will be operating in a single city by different bus operators. A well planned system is needed to manage the re-charging of the fleets. Even the carefully planned system is vulnerable e.g. for issues in electricity distribution, which could lead into situation where charging demand exceeds the capacity. The most promising approach for electric city bus charging infrastructure is believed to be the opportunity charging concept, where the high power quick charging would take place during the bus stops and in the bus hubs. Buses designed for this concept have small capacity batteries to solve the issue of higher price of the high power batteries. With these small batteries, there is always a risk of running out of charge leading into stoppage.

As the Public Transport Authority (PTA) is responsible for management of the transport system and ensuring smooth operation, it should have a strategy also for abnormal operation situations. For this, data from in-service buses is needed for the charging management system to (automatically) identify e.g. buses in most urgent need for re-charging. Therefore, on-line data collection is needed for every electric bus. In addition, the driver should have an access to the required information related to the dynamic charging plan of the bus in hand. The driver's assistance system can therefore work as a central information system to guide the driver not just about the optimal driving style, but also inform about the charging need. The bus operator on the other hand is interested on remote fault diagnostics of the bus components, monitoring the performance of the drivers in sense of energy consumption, maintaining the speed limits and timetable.

Although originally developed for diesel buses, the driver's aid device can be used for electric buses also. The monitoring system collects the well performed driving sections which are used for learning the best driving profile for a specific bus route. The driver's assistance system will be even further developed to include optimal operation of the subsystems. In the normal conditions, the operation will follow the pre-defined optimal guidance. For abnormal conditions, the guidance should adapt and change into corresponding mode.

The energy efficient control of subsystems can be found either with simulations or using the same "learning during operation" principle as the original driver's aid. As an example of the subsystems, auxiliary components is chosen for the purpose. The potential of intelligent operation in this case is discussed in the paper.

2 FUTURE NEEDS FOR COMMUNICATION AND DATA SHARING WITH ELECTRIC BUSES

In quest of increasing the share of low-emission buses in the Metropolitan Helsinki area, Finland, the local PTA, Helsinki Region Transport (HSL), has announced that they are aiming at ramping up the share of fully electric busses to be 1 % in 2015, 10 % in 2020 and 30 % in 2025 (Figure 1), (HSL, 2014). In various other major European cities, similar actions are taken as well.

For fully electric operation, the two main alternatives for the charging strategy are an electric bus with a large battery (depot charging concept) and one with a small battery (opportunity charging concept). The choice between these two has significant impact on the designed infrastructure and cost of the system. Practical issues, such as charging standards when connecting the charger and the vehicle physically, but also protocols for the information exchange, are yet to be solved. The bus operators and other stakeholders being the end users and responsible of the costs are interested on the total cost of ownership if diesel buses are replaced with electric buses. As the best choice tends to be a case-specific, careful planning is needed. However, designing the system beforehand is extremely difficult, and therefore some flexibility should be available instead of hard coding the plan. The proposed driver's assistance system could work as a framework for the required communication platform enabling flexibility for the bus operation.

Currently the driver's aid systems are focusing on assisting the driver to survive in special situations or to add safety functions into driving. Using machine vision, pedestrian detection has been studied by Geronimo (2010). For preventing lane crossing, multi sensor approach was proposed in (Mcall and Trivedi, 2006). To perform better in
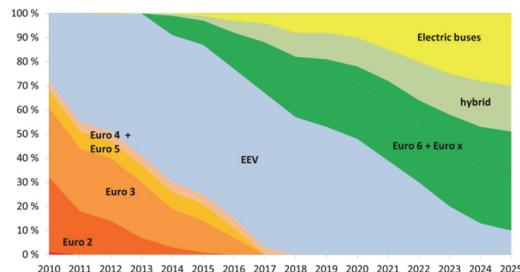
demanding tasks, such as parallel parking, driver's aid was researched (Ozkul et al., 2008, Vorobieva et al., 2015).

For fixed schedule applications where route is predetermined (e.g. buses) and the task is to minimise the energy consumption, there is not much research activity, although some general patents exist such as (Franchineau and De Verdalle, 2008). The closest research activity is related to active acceleration pedal (Várhelyi et al., 2004), which is effectively having similar target.

3 DRIVER ASSISTANCE

3.1 Optimal Driving Style for Electric City Buses

For studying the optimal driving style for electric city buses, measured data collected from real-world operation on actual bus line is used. The purpose of the study is to find out how the driving style affects electric bus energy consumption and to compare the identified optimal driving style with the optimal driving style of diesel buses. The basis of the study is the real-time driver assistant device, originally developed for use on diesel buses.

To identify the optimal driving style, the driving performances involving the lowest possible consumption are sought and their speed profiles are then analysed. The optimal driving style for electric busses is anticipated to differ from that of diesel buses. The main reason is the possibility for regenerative braking and differences in efficiency maps between an electric motor and a diesel engine.

An example of variation in energy consumption is seen in Figure 2 where two drivers have been driving the same fully electric city bus on Line 11 in Espoo, Finland.
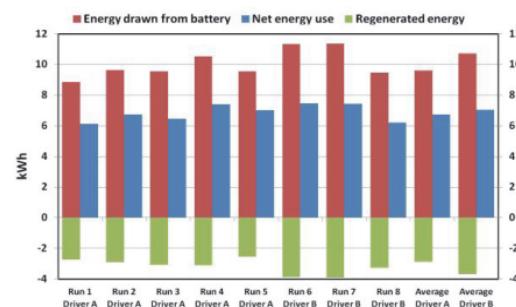
Figure 2: In-service electric energy consumption of a test bus running on Line 11, in city of Espoo.

Figure 1: Fleet strategy of Helsinki Region Transport for ramping up the share of fully electric busses (HSL, 2014).

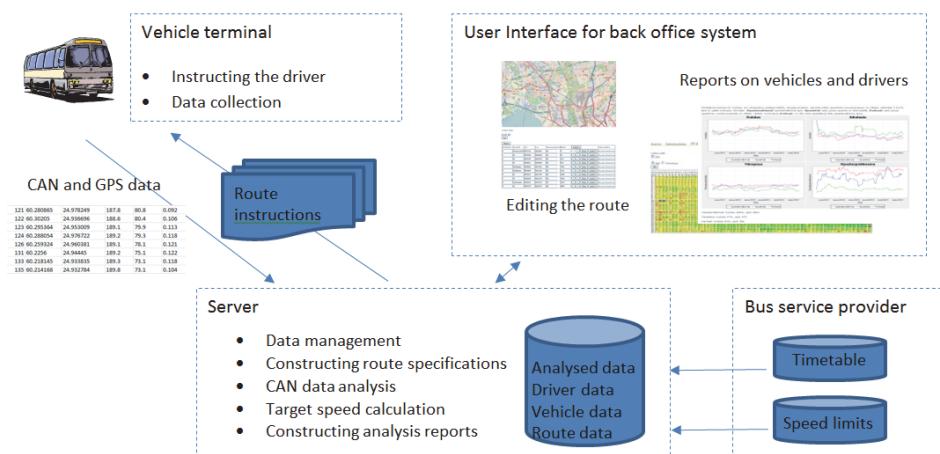## 3.2 Guiding towards Optimal Driving Style

When the optimal driving style for electric bus has been defined, the following procedure is identical to the diesel buses' data collection, back office calculation and other required operations to achieve the driver assistance system to guide the bus driver for energy efficient driving, maintaining the speed limits and timetable (Figure 3). With aid of driver assistance system, it is possible to affect the driver's manner of driving in real-time. In a diesel city bus, economical driving is achieved by quick acceleration and constant speed that is as low as possible. The system provides real-time guidance to drivers, taking into account vehicle position compared to scheduled position, speed limit and the travelling comfort of passengers using recommendations on the intensity of acceleration and feedback on current speed and its relation to the target speed. When determining the speed it dynamically takes into account the timetable: if the bus is ahead of schedule the constant speed can be lower.

On diesel buses, saving potential of 5-10 % has been realized when the driver assistant system has been demonstrated and tested. The better the driver follows guidance, the greater savings can be achieved.

The collected data during the operation is transferred wirelessly to a back office system consisting of a server software and browser-based user interface. The server software automatically processes and analyses data recorded on the bus line. The analysis reports can be viewed in the user interface. The on-board terminal device manages the measurement data collection and sending it to the server, and also the actual display of guides for the driver. To operate, the guidance needs route-based instructions. For this, the necessary data, such as timetables and speed limits, are collected from other systems by the server software. After a learning period, the target speeds for the bus route will be calculated using the data that is collected during the operation. The location information as Global Positioning System (GPS) coordinates and vehicle speed with energy consumption are the essential variables for the monitoring system to compare with timetable. Using this background data, location-based target speed profiles will be created to each bus line and departure. Initial target speeds for the route can be, schedule permitting, e.g. 5% lower than the respective speed limits. The system will then adjust these speed instructions according to the learned optimal driving style. The route can be edited in the user interface, if some of the background data cannot be collected automatically. The route is presented to the terminal device as a list of GPS coordinate points with their target speeds, having information about the bus stops, speed limit changes and other possible factors.

The most recent addition for the driving assistant system is the functionality that enables the partial comparison of driving performances, allowing the analysis to focus on optimally driven stretches between bus stops or on even shorter stretches in order to construct optimum overall speed profiles. If these driving stretches and corresponding partial speed profiles are categorised to form general results, they can be used for adaption to other bus lines as well. Categories can be based on e.g. speed limits, stops and slow downs (traffic lights, speed bumps, pedestrian crossings and intersections) or length and shape (turns and hills) of the stretch.

Figure 3: Communication between the components of the driver assistance system.

4 AUXILIARY DEVICE ENERGY CONSUMPTION

In diesel buses, auxiliary device energy consumption consists of engine cooling fan, air compressor, air conditioning, power steering and alternator to run the 24 V devices such as lightning. For fully electric buses, the engine cooling fan can be taken out from the list and separate alternators are not used, but the equivalent 24 V auxiliary device consumption does exist. In addition, the electric buses use this low voltage source for many low power auxiliaries e.g. fans and pumps of powertrain component cooling circuit. Instead of alternator, regenerative braking energy via drive motor is used to produce also the low voltage electricity.

As reported by Erkkilä et al. (2012), the energy consumption of auxiliary components in diesel powered city buses is only marginal. During summer time, the average consumption for power steering was under 1 % (in relation to energy available on crankshaft). In the same study, air compressor was consuming 2 % and air conditioning 3 %. During winter time, the auxiliary heater was responsible for 20 % of the total energy consumption.

Albeit the relative energy consumption of the auxiliary components is low in diesel buses, the same amount of energy in an electric bus means higher relative portion from the total energy consumption. In Figure 4 can be seen a measured example of how the auxiliary components are using energy during operation in an actual bus line.

In this example, Heating Ventilation and Air Conditioning (HVAC) consumption is minimal,
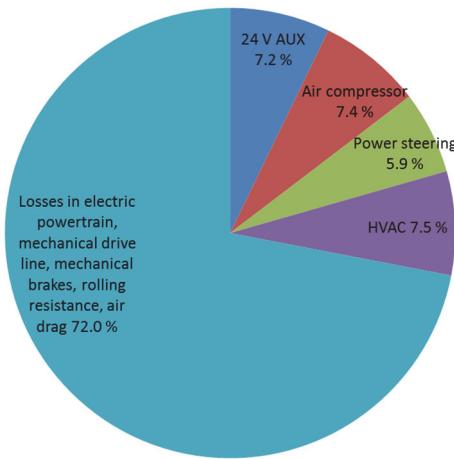

Figure 4: Measured share of auxiliary component energy consumption in electric city bus during real-life operation on Line 11 in Espoo, Finland at 15 °C ambient temperature.

because the outside temperature was 15 °C, which does not require much heating or cooling. Some of the energy required by the HVAC system is seen in the 24 V AUX consumption, as the fans of the HVAC system (air source heat pump) is connected there. In this particular case, the fans were responsible for half of the 24 V AUX energy consumption. To produce maximum heating or cooling power, the combined energy consumed by the fans and the actual HVAC will be at least four times as much. During a cold winter day, even additional heating would be needed to maintain the cabin in desired temperature. The need can be four times the maximum power of the air source pump, and therefore needs to be produced with a fuel operated heater.

5 SUBSYSTEMS' OPTIMAL OPERATION

The optimisation of the subsystems' operation adds further potential to energy savings. Even though the driving losses due to the vehicle-traction are responsible for a large part of the battery energy consumption, the subsystems waste most of the energy. The biggest driving losses in city buses are caused by the rolling resistances of the tyres. In the subsystems, powertrain components, such as mechanical driveline and electric motor with an inverter, produce losses during the operation due to the limited efficiency in power transmission. Using mechanical brakes for deceleration, significant losses are generated, which can be reduced with regenerative electric braking. Besides powertrain components, subsystems include also the auxiliary components. These are not mandatory for vehicle traction, but may in some cases consume a considerable amount of energy.

To study and optimize the power consumption of the auxiliary subsystems a MATLAB Simulink model was developed. The dynamics of the bus has been modelled with Simscape (Halmeaho et al. 2014). Main subsystems of the model are shown in Figure 5.

During the simulation, the bus is driven on an actual bus route, Line 11 in Espoo, Finland, with bus stops and other traffic, whose effect into simulation is included via measured speed profile and auxiliary component energy consumption. Stopping at bus stops and traffic lights and following the road with junctions and turnings require steering, braking and opening the bus doors. Auxiliary device consumption is thus dependent on the bus route and

also on the ambient conditions which demand using HVAC for passenger and driver comfort.

Power consumption of the auxiliary devices is modelled using a system identification approach. The electricity consumption of the power steering and air compressor has been measured. Based on the measurement data and the route of the bus, simple mathematical models of the energy consumption of the given auxiliary devices can be created.

The model of the power steering gives the consumption as a function of turnings based on GPS coordinates. The air compressor is used by brakes, suspension and doors. Usage of brakes has been measured and opening of doors can be estimated based on speed and locations of the bus stops. Based on that information, a model of the air compressor can be created.

Potential of utilizing optimal air compressor operation to reduce overall energy consumption was selected for closer examination. The potential for energy savings comes from the battery efficiency and limited charging current. The efficiency is usually around 96 %, hence using a battery to store energy will not waste much energy. However, the battery charging current limit is extremely sensitive for the battery temperature. During the winter time, the permitted current can decrease into at least one third of the maximum, which will limit the regenerative motor power. However, the regenerative power could be increased if there was alternative electric load available. For this purpose, the compressor was modified to activate only at long and hard enough decelerations, when it is normally activated based on air consumption. The cumulative energy consumption was equal in both strategies. The battery charging limit was set to 45 A, which represents the actual observed limit permitted by the Battery Management System (BMS) in +3 °C ambient condition.

Figures 6 and 7 compare the results of using the modified and normal compressor activation strategy. Figure 6 shows the used speed profile together with the cumulative battery energies separately for charging and discharging directions. In Figure 7 is visible a partial stretch of the cycle, where can be seen the differences for battery and motor operation when baseline or modified air compressor activation strategy is used. The energy savings are achieved because of the higher regenerative motor power and avoiding the unnecessary charging and recharging losses of the battery.

The realized cumulative savings during the whole cycle was 0.13 kWh, which means 1.6 % decrease for the overall vehicle energy consumption.
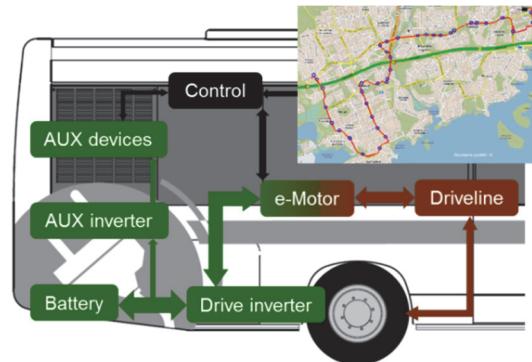

Figure 5: Subsystems of the auxiliary device energy consumption model. The coordinate data is included in the model, shown in a map at the top of the figure.
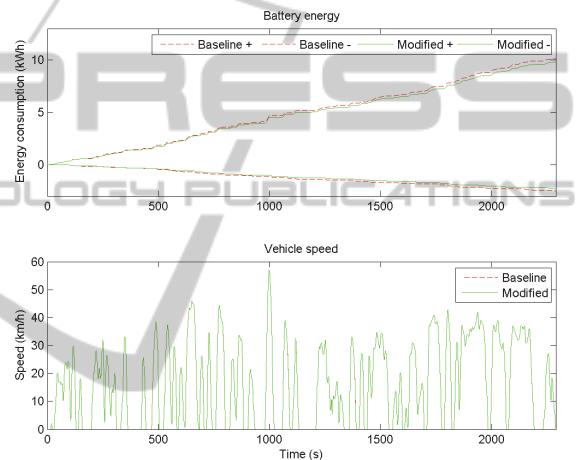

Figure 6: Simulated cumulative energy consumptions and realized speed profiles for baseline and optimal air compressor operation during the whole cycle length.
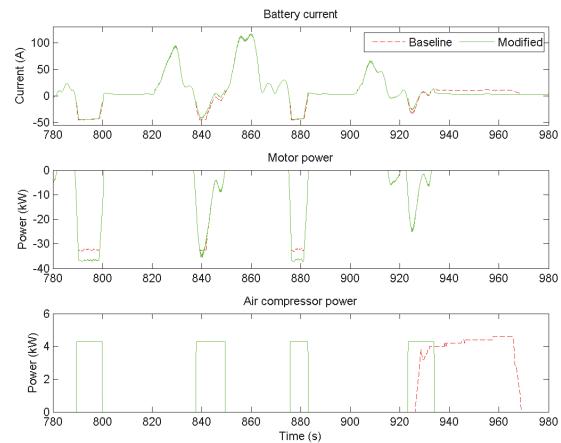

Figure 7: Simulated battery current, motor power and air compressor power for baseline and optimal air compressor operation during part of the cycle length.

The total consumption of the compressor was 0.56

kWh during the cycle. All of this potential is not available for recovery, because the system is already in baseline operation inherently feeding the energy for consumers during the regenerative braking. In addition, the timing of the compressor usage in the baseline is often occurred during the hardest decelerations, and on the other hand, many of the additional compressor activation in the modified strategy occur in low power regeneration and current limit is not met. Although the achieved energy saving was small on this particular case, higher savings can be anticipated when also the power steering and HVAC usage will be optimized. This could include switching off the power steering pump on straight driving sections and boosting HVAC power when slowing down. In addition, the speed profile of the cycle had only modest decelerations, and therefore the battery current limit was exceeded only few times.

6 CONCLUSIONS

Electric buses in comparison with conventional buses have potential for increased energy efficiency, zero tail pipe emissions and decreased noise caused by city transport. This paper described a driver assistant system to be used for guaranteeing optimal driving style for electric city buses. The system will be even further developed to include also intelligent control of various subsystems. Optimal operation of auxiliary components was discussed in the paper. Auxiliary components in electric buses are inherently controlled in more energy efficient manner than in diesel buses. Some improvements in efficiency using intelligent control can be still achieved. A simulation model that is used for studying the optimal operation of electric vehicle subsystems was described. Simulation results when using optimal air compressor activation was presented. Overall energy consumption of the vehicle was reduced 1.6 %. The savings can be further increased when other auxiliaries are also considered for optimization.

Based on the bus route information, the proposed advanced driver's aid system could combine the driver guidance and the optimal use of auxiliary components to achieve more energy efficient electric city bus driving. In the future, it could include also communication interface for bus fleet management.

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