EVS28
KINTEX, Korea, May 3-6, 2015

Electric city bus and infrastructure demonstration environment in Espoo, Finland

Juhani LAURIKKO[1], Mikko PIHLATIE[1], Nils-Olof NYLUND[1], Teemu HALMEAHO[1], Samu KUKKONEN[1], Annakaisa LEHTINEN[1],Veikko KARVONEN[1], Reijo MÄKINEN[2], Sinikka AHTIAINEN[3]

[1]VTT Technical Research Centre of Finland, Finland

[2]Helsinki Region Transport, Finland, [3]City of Espoo, Finland

Abstract

VTT has together with several partners created a multi-dimensional demonstration environment for electric busses and their supporting infrastructure. The on-going demonstration in the city of Espoo – part of the Helsinki Metropolitan area - is unique in many aspects. One of them is the weather: due to the local climate conditions, the ambient temperature can swing up to 60 ^{o}C between high summer and mid-winter. This certainly stresses the vehicles and their batteries to their limits at both ends of their operational range. Furthermore, maintaining comfortable riding conditions requires sufficient heating and cooling of the passenger compartment. Therefore, an energy efficient HVAC system that does not jeopardize the total energy balance of the bus is needed.

Another important feature of this demonstration and field-trial run is that several different commercially available busses are operated simultaneously on the same line. This approach gives an excellent opportunity to benchmarking. Furthermore, the service operations in real driving are supported with in-service data acquisition and chassis dynamometer measurements in a controlled laboratory environment at VTT. Lab measurements enable more accurate determination of the energy use profile in different duty-cycles, and make possible resolving of the contribution of the on-board sub-systems.

However, a battery-electric bus is not just a vehicle, but an element in a larger system that encompasses also the charging infrastructure. For coupling and charging, several different topologies are possible, and careful consideration should be given to the planning and dimensioning of the complete system. Furthermore, a distributed opportunity charging system allows the reduction of battery for lower costs, but simultaneously raises the investments in infrastructure. Nevertheless, if the charging points can be utilised by a large number of busses, the net result should be positive. Therefore, the positioning of the charging points needs to be based on the lay-out of the lines and taking into account also the schedules of the busses. Furthermore, the roles of different stakeholders need also to be investigated.

In addition the experimental research at VTT is directly linked with modelling exercises, enabling adjusting the simulation algorithms with real-world data.

Keywords: Electric busses, demonstration, cold conditions, systemic approach, lab measurements.

1 Introduction

Mobility of people and goods are essential functions for today's society, but both are in the process of transformation. Key challenges for today's transport systems are reducing carbon emissions from the vehicles, cutting local emissions and noise, as well as alleviating congestion. However, advances in vehicle and engine technologies cannot any more solve the problems, but a wider array of options needs to be employed.

With the aid of ICT we can make vehicles more intelligent and connected, even fully automated, and build smart mobility services that link various systems and modes seamlessly to serve the needs of the urban "crawlers". In addition, consumers are increasingly favouring clean vehicles, and there are even indications that the attitudes are changing from a desire to own a car towards shared use and easiness of transport [1].

In urban environments public transport services need to form the backbone of the mobility, and busses have traditionally offered more flexibility than rail-based systems, but mainly due to the direct-electric drive rail has been considered more environmentally friendly. However, battery-electric busses are now capable of breaking this paradigm, and have the potential to dramatically reduce the carbon footprint, local emissions and noise of in-city bus transport.

Combined with smart ICT systems providing accurate timetables and multi-route combination service options for the consumers, fully electric city buses can offer an affordable and sustainable inner city mobility scheme. The technical maturity and feasibility of electric buses is being demonstrated in many places around European Union, whilst the Zero Emission Urban Bus System (ZeEUS) project coordinated by UITP and funded by the European Commission via FP7 acts as a spearhead, and has formed an observatory of the activities [2].

Furthermore, in quest of increasing the share of zero-emission drive in the Metropolitan Helsinki area public bus transport the local PTA, Helsinki Region Transport (HSL), responsible for organising public transport in the Helsinki Metropolitan area, 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 [3]. Similar actions are taken in various other major European cities, as well.

2 Electric bus trial environment in Espoo, Finland

2.1 On-going activity: "eBUS"

Since Finland has quite a challenging climate and the battery electric buses are still in a pre-commercial stage, the decisions to start the electrification of busses in the area were backed up with a launch of a comprehensive research and demonstration project called "eBus" [4].

It is a combination of field and laboratory testing of battery-electric buses, operated by Veolia Transport Finland Oy (a local subsidiary of Transdev SA), in real-world conditions and in real revenue service within an existing bus line (line 11) in the city of Espoo (adjacent to Helsinki). The line is simulating upcoming feeder traffic to the metro railway, which is scheduled to start service in this part of the Helsinki Metropolitan region in the fall of 2016. Figure 1 plots the line over a satellite photo of the area south and west to the local commercial centre Tapiola, and Figure 2 shows the speed vs. time profile of this line.

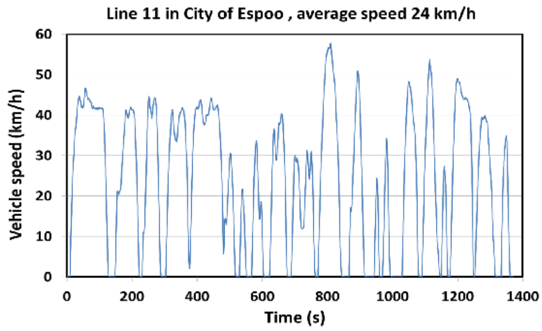

Figure 2: Speed vs. time profile of Line 11.

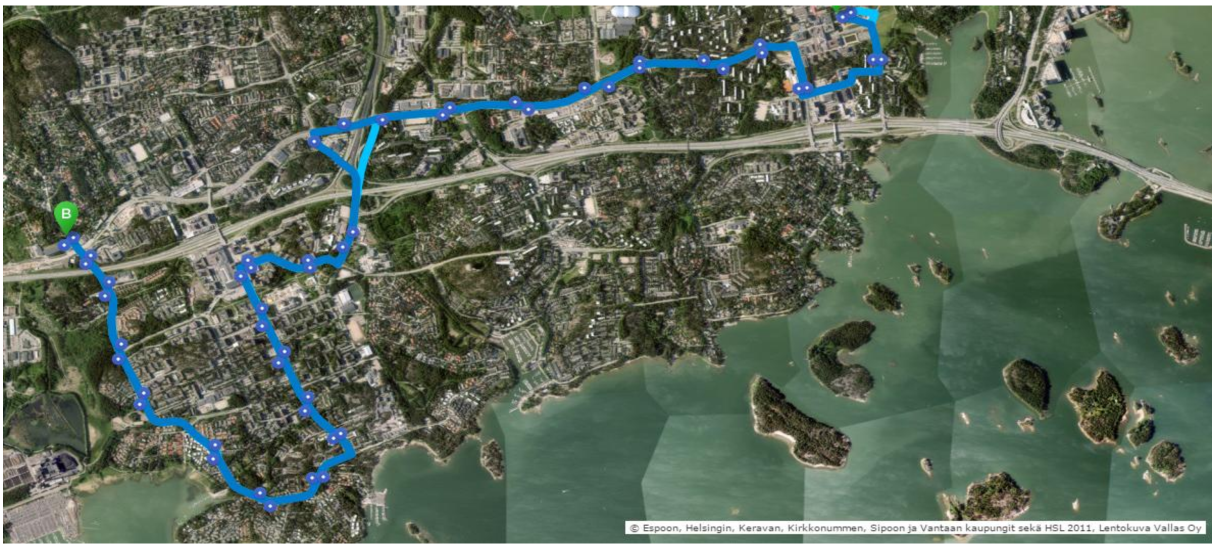

Figure 1: Map plot of Line 11.

Line 11 has 24 bus stops in 9.1 km or 26 bus stops in 10.1 km depending on the direction. The first bus starts at 5:42 and the last departure is at 23:47. Travel time one way is about 25 minutes, so the commercial speed is around 20-25 km/h depending on traffic.

Currently, four buses from different OEMs has been taken in service. Table 1 lists those four full-size 12 meter busses, and when they have taken their entry in service. Figures 3 to 6 shows the busses in their service livery.

Table 1. List of electric busses in eBus trial.

Make	Model	Entry in service
COBUS	EL2500	Oct 2012*
Ebusco	YTP-1	Dec 2013
VDL	Citea SLF-120 EL	Jul 2014
BYD	eBUS-12	Jul 2014

*Due to technical difficulties, the vehicle has withdrawn, and taken back to the manufacturer for update.

Figure 3: COBUS EL2500

Figure 4: Ebusco YTP-1

Figure 5: BYD eBUS-12

Figure 6: VDL Citea SLF-120 Electric.

2.2 Systemic approach - "eBusSystems"

Charging infrastructure in an essential part of an electric bus system, but – like busses – it is also still under intense technical development. In-depot charging is fairly straightforward, but going into a decentralised opportunity charging scheme brings more stakeholders into the scene, and mastering the arrangement becomes quite challenging. Therefore, "eBusSystems", an affiliate project to the "eBus", was initiated to consider these topics, and help local stakeholders – PTA, and PTOs and the municipalities - to find their way thru this complexity.

2.3 Consortium members, their roles and way to work together

Running a comprehensive systemic development platform requires good interplay of several parties. The "eBus" and "eBusSystems" projects are both parts of Electric Commercial Vehicle project entity (ECV), funded from the national electric vehicle programme EVE by Tekes, the Finnish Funding Agency for Technology and Innovation. ECV is set up to create a comprehensive and versatile research and test infrastructure for electric commercial vehicles [5].

Within the auspices of ECV, and to facilitate the commercial introduction of electric buses in Metropolitan Helsinki, VTT has orchestrated an ecosystem and a "living lab" environment for battery electric buses. Research activities encompass the entire chain of development necessary for the holistic approach: single components (such as battery) – electric powertrain – vehicle – charging infrastructure – energy supply – transport system analysis.

As the latest addition to the on-going activity, HSL is about to launch a new "eBusPilot" project for pre-commercial pilot with a small fleet of fully electric buses. With this exercise HSL aims to test a new innovative procurement for pre-commercial piloting. The idea of this demonstration experiment is that operators can test drive new technology buses without major financial risks before the final commercial procurement. This would be the last and final step before larger-scale commercial roll-out of electric busses to meet HSL's environmental and emission targets [6].

The stakeholders of this ecosystem include the PTA (Helsinki Region Transport), municipalities (Cities of Espoo and Helsinki), government institutions (Ministry of Transport and Communications, Transport Safety Agency), fleet operators (Veolia Transport Finland), vehicle suppliers (Ebusco, VDL, BYD), an utility (Fortum) and the supporting research community (VTT, Metropolia, Aalto University).

All the research partners will get and share the knowledge and experience gathered from running a set of battery-powered electric drive busses in real life operation in Finnish tough climate conditions, and to use it to optimize the design and use of EV busses and the supporting infrastructure.

2.4 Finnish climate is a challenge

Finland presents a particularly harsh environment to run public commercial bus service. Due to the local climate conditions, the ambient temperature can swing up to 60 °C between the high summer and mid-winter, even in these southern parts of Finland, where Metropolitan Helsinki area is situated. This certainly stresses the vehicles and their batteries to their limits at both ends of their operational range. Furthermore, maintaining comfortable riding conditions in these surroundings requires both sufficient heating and cooling of the passenger compartment. Therefore, an energy efficient HVAC system that does not jeopardize the total energy balance of the bus is needed.

3 System engineering – a prerequisite for a viable electric bus array

3.1 Available charging concepts and topologies

As for energy storage and charging the batteries there are several options under discussion: full-size batteries and overnight charging at the depot or smaller batteries combined with opportunity charging at end stations or along the route.

Also the interface between the grid supplying the power and the vehicle can be either conductive with a manual coupling, or with an automated overhead pantograph, as well as inductive and fully contactless.

All the topologies have their virtues, but unfortunately also vices. Therefore, there is no "fit for all" solution, and each case needs careful consideration. Proper systemic design is a crucial aspect to be taken into account when seeking successful city bus electrification. The optimal choices of battery dimensioning, vehicle design, operation concepts, as well as positioning and dimensioning of the charging infrastructure all depend on each other, and on the requirements of the transport system. The viability of every system must be assessed both in technical and economic terms.

3.2 Charging standards on their way

Because electric vehicles are still an emerging technology, neither the connectors between the charger and the vehicle, nor the protocols for the communication during the charging event are yet fully standardised.

Therefore, there are also uncertainties linked to charging infrastructure and related services, mostly due to the fact that the high-power fast charging technology is currently not standardised.

However, the availability of standardised high-power charging solutions would certainly streamline the work of infrastructure designer and builders, and help to procure systems where, for example, the interchangeability of fleet becomes possible. This will also help to secure the flexibility and long-term value of the infrastructure investments.

3.3 New business models and opportunities

Furthermore, new business models are also emerging: the energy utility can choose to invest in the batteries, and embed the cost in the price of the electricity supplied to the bus operator.

Also, balancing between the dimensioning the battery capacity and arranging charging opportunities can yield to a win-win situation regarding total costs and investments, when the battery capacity need not to suffice the whole day of driving or even over the whole stretch of the line, but only from one charging pole/point to another.

It is imperative, that the charging infrastructure has to be matched with the design and operation concepts of the vehicles. To reach an optimally performing and cost-effective system requires careful system engineering. This has to include proper analysis of the operation sequences and routes, and optimising the fleet for the duty.

3.4 Planning and positioning tool

To help all the parties involved, VTT is developing a GIS based planning tool for electric bus transport system. The tool utilises existing data from the environment, road network, public transport system and VTTs electric bus database. The tool forms an interface with relevant public transport planning tools. The objective is to be able to make sensitivity analysis on the planned working schedules for electric buses both in system and operational planning. Potential users of the tool are planners for the bus transport system, infrastructure, schedule and operation.

The tool can be used to make cost and functionality analysis for electrified bus lines. The economic viability of electric bus operations depends on the infrastructure, bus fleet and energy costs together with the amount of bus traffic. Infrastructure and bus fleet costs in turn depend on the characteristics of the charging system, the electric buses and the electrified bus lines.

Due to these factors there is a demand for GIS based planning tool, which facilitates the dimensioning of electric bus lines, as well as assessing the functionality and economic viability of the system. For example, the tool could help in choosing the right type of vehicle and charging station type and lay-out for different bus lines.

The GIS based planning tool can also be used to make reliability and sensitivity analysis. Reliability and sensitivity analysis are an important part of the tool, because the environment and public transport system contain large amounts of different variables. The tool helps the planners to prepare for different traffic and weather conditions. When starting to operate with new technology such as electric buses, the beginning always contains new variables and uncertainties. With the GIS based planning tool the planners can prepare themselves for changing situations caused by new technology like for example faults in the total cost of ownership calculus.

3.5 Total cost of ownership (TCO)

Analysis of the techno-economic performance of electric bus systems is crucial for the assessment of their viability for large-scale adoption in public transport. From the PTA perspective, some requirements are set for electrified bus systems. First, the size of the bus fleet must not be increased when replacing conventional buses with electric ones. Second, the operability of the electric buses must be at the same level as that of the conventional buses. Meeting these goals also implies that a bus operator (PTO) can rely on electric bus fleets to be a real reliable alternative for conventional buses when offering commercial traffic.

The total cost of ownership (TCO) is the equivalent annual cost incurring from owning and operating an asset, in this case a fleet of (electric) buses. The main costs related to operating a bus systems are labour costs of the drivers, as well as capital costs of the vehicle (including the traction battery), as well as costs of fuel and vehicle maintenance. An electric bus has a higher purchase price (capital cost) due to the battery system. On the other hand, vehicle efficiency is higher and the price of fuel (electricity) is lower compared to conventional diesel buses. An additional aspect with electric buses is that the supporting charging infrastructure has to be arranged.

VTT has developed a TCO calculation model, where electric buses with different design and operation concepts (depot charging vs. opportunity charging) can be analysed for TCO and compared with other technologies. The model addresses the most crucial parameters from vehicle, system and operation perspectives.

As a concrete case study, the first bus with commercial electric bus operation in the Helsinki region was analysed with the TCO tool by comparing three types of conventional diesel buses to the two basic conceptual designs for electric buses [7]. The study also comprised a sensitivity study on the most critical parameters affecting the TCO.

The results show that fully electric buses have the potential to become economically competitive in the best urban use cases (bus lines). However, reaching the value proposition of reduced TCO requires careful system engineering and technology with high usability and reliability. The electric buses, which are commercially available in the market today, cannot yet reach this level of operability and productivity. However, the technology is maturing at a good pace, and VTT foresees a major activation in commercially-driven electric bus systems deployment in a few years to come.

4 Scientific research and support services

4.1 In-laboratory testing facilities

To support the in-service demonstrations and trials of electric busses, VTT has built up comprehensive research facilities for research and development of electric commercial vehicles. The facilities comprise a heavy-duty chassis dynamometer, a power source/battery emulator, a battery lab and also equipment for on-route measurements. In addition, simulation tools for electric bus operation, charging and routing have been developed.

Figure 7 shows a picture of a full-size chassis dynamometer facility that allows simulation of any duty-cycle with good repeatability and reproducibility. Also different vehicle masses can easily be dialled in to reflect different levels of passenger load.

The basic chassis dynamometer test procedures used in EV measurements are directly adopted from VTT's normal test procedures for conventional vehicles [8]. Furthermore, VTT has developed electric energy consumption measurement methods for both passenger cars and busses.

As an example, in a passenger car study [9], the energy taken from grid was split and allocated for all consumers inside the vehicle. The principle remains the same for buses, although the scales may change, and the methodology was abridged to provide an overall value for energy consumption or efficiency for all subsystems in a bus. Apart from procedures, there is also hardware to support research on electric vehicles. Figure 8 shows a 320 kW battery emulator, installed adjacent to the dynamometer facility. It enables powering an electric vehicle directly from the grid, and emulating a traction battery with pre-programmed characteristics. With this kind of arrangement, the best-suited battery can be chosen to suit the particular features of the given service.

Figure 8: A 320 kW battery emulator enables powering an EV directly from the grid and simulating traction battery with programmed characteristics.

Figure 9 shows the overall lay-out of the test facility, and Figure 10 depicts some of the specialised devices and systems that enable high-speed performance measurements for electric drives.

Some measured data from the "eBUS" exercise has already been published in [10]. As an example of more recent results, Figure 11 depicts measured electric energy consumption of an electric bus over different duty cycles and passenger loads.

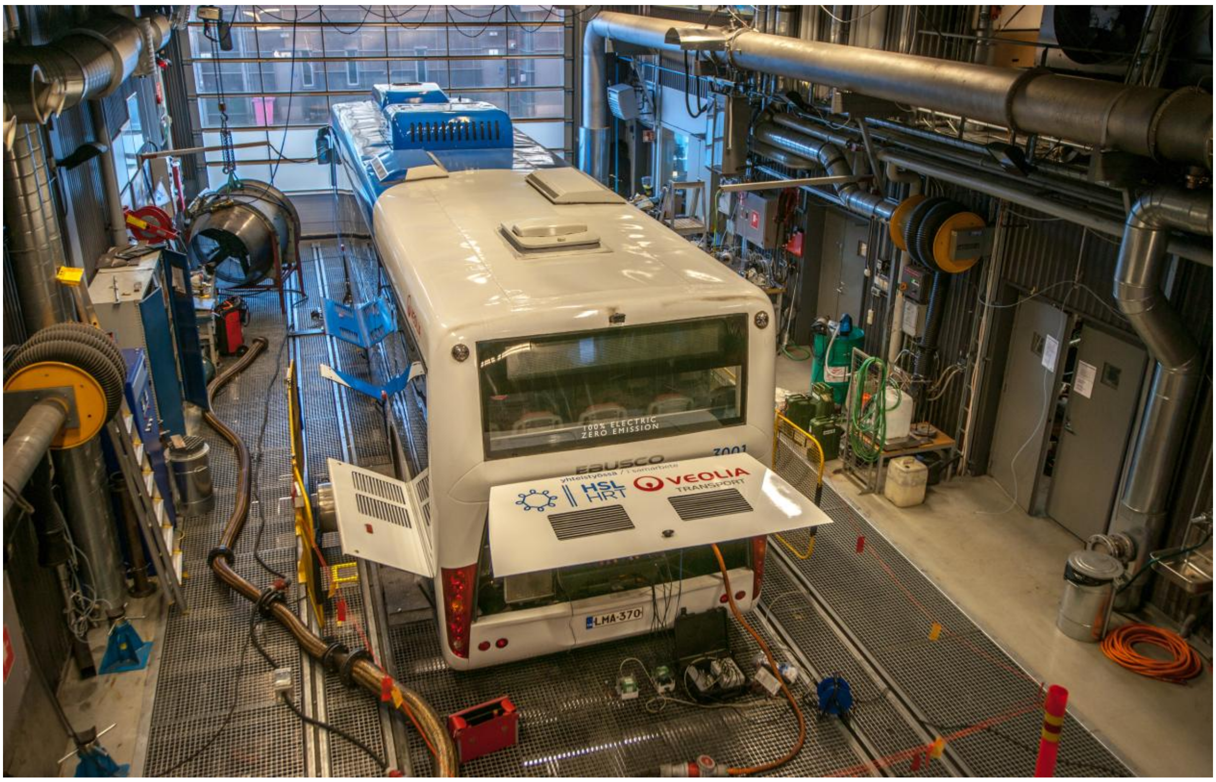

Figure 7: Heavy-duty vehicle test facility at VTT enables simulation of driving in controlled laboratory

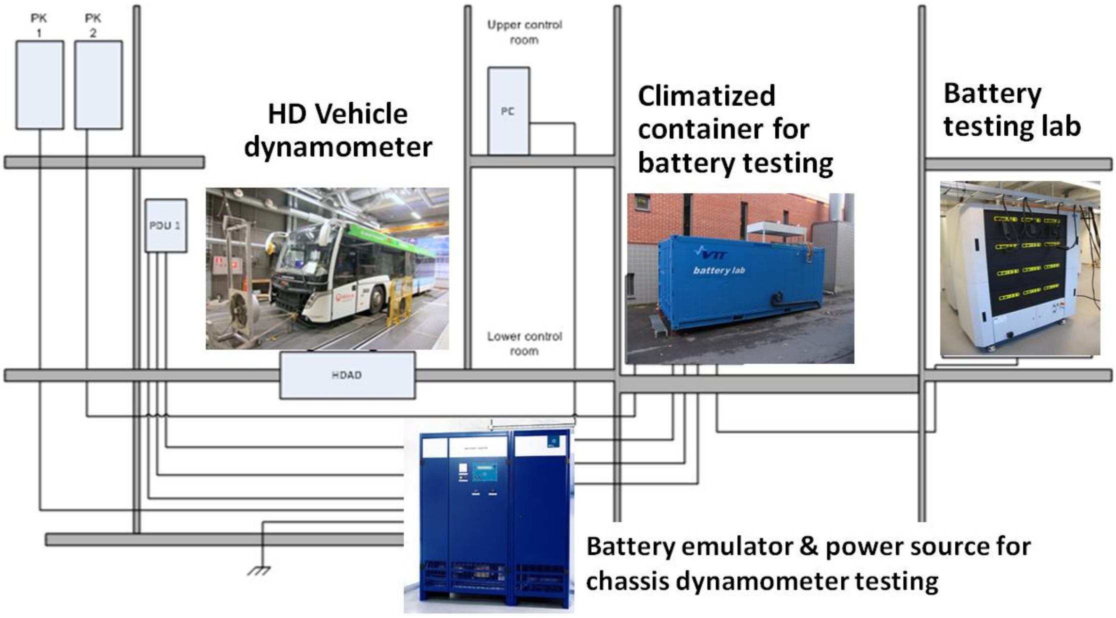

Figure 9: Overall lay-out and main component of the heavy-duty EV testing facility at VTT.

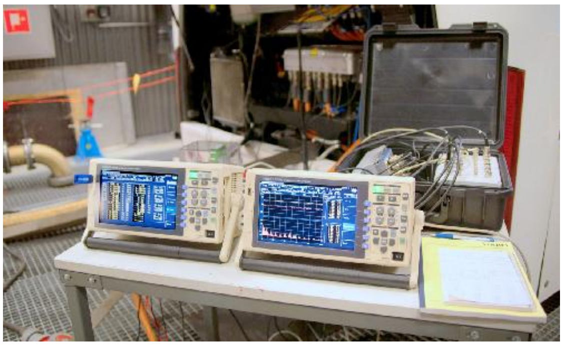

Figure 10: Specialised devices and systems enable high-speed performance measurements for electric drives.

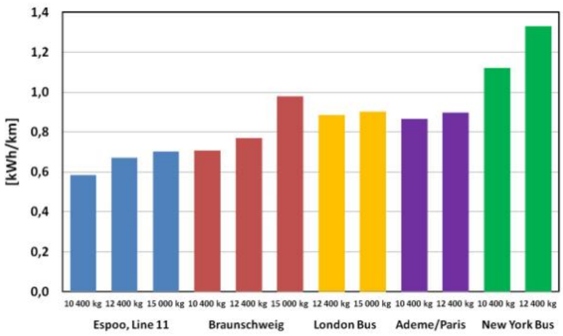

Figure 11: Electric energy consumption of an electric bus over different duty cycles and passenger loads and corresponding total vehicle weights.

If we consider the results depicted in Figure 11, we see how both the duty cycle and passenger load, reflected in different total vehicle running weights, clearly affects the energy consumption.

Particularly sensitive to the loading seems to be the New York Bus cycle, while London and Ademe/Paris seem to be less sensitive. Line 11 in Espoo appears to be quite "easy", as the energy use is only about half of that of the New York Bus cycle.

4.2 In-service data acquisition

In addition to the in-laboratory performance measurements, in-service and on-board data acquisition is also implemented in "eBUS". Test busses are equipped with data logging devices that read and record both slow and high-speed data during the daily service. As an example of such data Figure 12 shows energy use over eight different runs of the Line 11. Odd runs are from west (Friisilä) to east (Tapiola), and even runs are vice-versa.

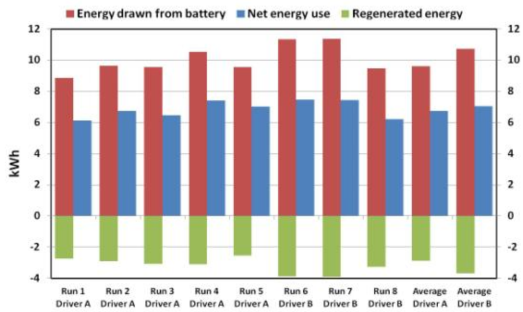

Figure 12: In-service electric energy consumption of a test bus running on Line 11, to and from Tapiola centre in city of Espoo.

As Figure 12 shows, energy consumption varies between individual runs of the line, and driver-specific averages are also different.

4.3 eMULE test platform

A full size light-weight electric prototype bus, the “eMULE” (Figures 13, 14), serving as a test bed for powertrain components and also as a gauge for the four (pre) commercial electric buses has also been built by VTT and its partners. The prototype bus enables the testing and development of the components of a complete electric powertrain within an independent research environment. Such a testing platform for heavy-duty vehicle components can also serve as a reference for component and subsystem manufacturers promoting their energy-efficient products.

Figure 13: Prototype bus “eMULE” being tested on VTT’s chassis dynamometer.

Figure 14: Despite its prototype status, “eMULE” is occasionally also carrying passengers in service over the Line 11.

The possible components to be tested and demonstrated in “eMULE” are not limited solely to electric powertrain components; in addition to electric motor, drive inverter and battery or super capacitor, many components affecting to energy efficiency that are common with diesel buses can be installed for testing. Some examples of these could be mechanical driveline, such as HVAC devices (including separate heating units and solutions), auxiliary devices and door systems. However, maximisation of overall energy efficiency entails the control of all energy flows, and it is with respect to this aspect that a key role with electric city buses may be played by the utilisation of waste heat energy and use of high-efficiency auxiliary equipment.

The idea was to keep the vehicle easily configurable enabling component interchangeability. To make this possible in practice, there is a “prototyping area” in the back of the bus (Figure 15). Even though being a tool for research, the bus was not limited to be used just for chassis dynamometer testing; instead it is fully fitted to be operable also in actual bus line service. It has been already used and the powerful but still energy efficient vehicle received positive feedback from the drivers.

Figure 15: Prototyping area of “eMULE”.

In addition to energy efficiency, an electric bus must be able to compete with diesel buses in terms of its reliability; this requires components that last several years in varying conditions. Experience has yet to be accrued on the durability of the components, and especially the impact of a cold climate in particular still needs to be assessed. Compared to commercial buses, the prototype bus could be equipped with more sensors and measuring instruments for collecting data on the status the environmental conditions and the components of the bus, when the vehicle is operated on a bus line. In the future, “eMULE” will be increasingly used to study the optimal control of energy flows, where heating and cooling of the passenger compartment plays an integral part. Maintaining the battery at an optimum temperature is also essential from the perspective of energy efficiency and battery life.

4.4 Modelling

With the laboratory tests, using a chassis dynamometer to simulate the driving cycle, detailed analyses have been made on how the consumed energy is distributed between the subsystems. Using computer simulation approach [11], enhancement suggestions for the identified highest consuming subsystems can be studied and overall energy saving scenarios defined. The increased efficiency can be calculated instantaneously while comparing different design alternatives for powertrain components. The simulation model has been already validated against the measurements on “eMULE”.

With the aid of simulations, different combinations of the powertrain components can be varied easily and their effect on the consumption in different driving cycles evaluated. The authors’ model consists of vehicle, driveline mechanics and electric component models (Figure 16).

Electrochemical energy from the battery is converted into mechanical energy and transferred on the wheels of the vehicle. The model takes a desired speed profile as an input which is delivered for the driver model that requests traction from the electric drive. The longitudinal vehicle dynamics model, including a tyre model, connects the torque acting on a wheel to movement of the vehicle. The required level of model complexity depends on the optimisation targets. For energy efficiency optimisation, the energy flow simulation from battery to different subsystems and components is essential.

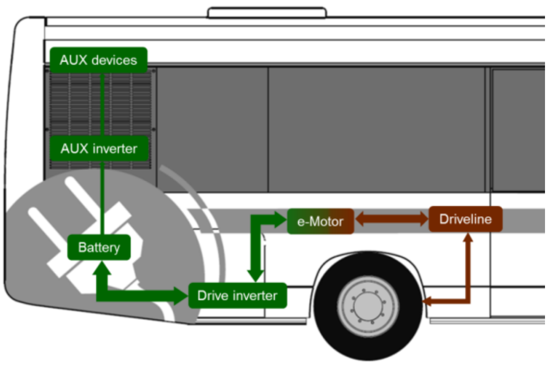

Figure 16: Main components of the bus model.

In addition to components that are mandatory for vehicle traction, also auxiliary devices should be included. From these, especially HVAC system plays an important role for the overall energy consumption in electric city buses, as cabin heating can consume more than a double of the energy used for traction. Hence, the conditions of the operation environment should be addressed. In Finland, the same bus will operate in the winter at -30 °C, and in the summer at +30 °C ambient.

For studying the optimal energy management strategies, which should be able to adapt into environment conditions, simulation of related control systems and thermal energy flows is also included. Therefore, the already verified powertrain model was complemented with a cooling circuit model of the powertrain components, from which waste heat energy recovery possibilities can be studied. The model was further augmented with a cabin model, where heat flows from the surrounding environment and HVAC devices can be evaluated. The system level model created in MATLAB Simulink has been connected with a Computational Fluid Dynamics model of the doorway losses calculating the heat flows during the bus stop events. Detailed analysis based on such simulations will soon be reported in a follow-up article.

The optimal energy management strategies found can be later integrated into drivers’ aid system incorporating a smart mission profile and location-based subsystem usage, in addition to guiding the driver towards more energy efficient driving style. For the purpose of TCO analysis, the vehicle-level work including measurements and modelling can be combined with the charging infrastructure and operation concept planning.

5 Conclusions and future outlook

VTT has built up comprehensive research facilities for research and development of electric commercial vehicles. The facilities comprise a heavy-duty chassis dynamometer, a power source/battery emulator, a battery lab and also equipment for on-route measurements. In addition, extensive analysis and simulation tools for electric bus operation, charging and routing as well as TCO assessment have been developed.

The current activities in the electric bus theme are soon to be augmented by a new and upscaled activity. This upcoming “eBusPilot” project will cover both Espoo and Helsinki. This time the buses will be procured by Helsinki Region Transport (HSL), and distributed to three or four operators. Thus, the technology risk and also the costs for the charging infrastructure will be borne by the PTA, and not the operators.

In Helsinki, the fast charging systems will be linked to the power supply of the tramway system. The “eBusPilot” project is expected to be the last learning phase, both for the PTA and the fleet operators, before entering normal tendering procedures for battery electric buses. The last step is needed to create confidence in the new technology by the operators, the passengers as well as by the PTA itself.

VTT and the PTA (Helsinki Region Transport) have been the key actors in orchestrating this setup.

Acknowledgments

The authors wish to thank Mr. Sami Ojamo and Mr. Lasse Tiikkaja of Veolia Transport Finland Oy for co-operation in the Finnish eBus projects.

The authors acknowledge also the financial support for the research work that was received from the Electric Vehicle Systems (EVE) programme funded by Tekes – the Finnish Funding Agency for Innovation.

References

[1] Hautala R., Karvonen V., Laitinen J., Laurikko J., Nylund N.-O., Pihlatie M., Rantasila K., Tuominen A.. Editors: Nylund N.-O. & Belloni K.. 2014. Smart Sustainable Mobility – A user-friendly transport system is a combination of intelligence, low carbon energy, and adaptable services. VTT Visions 5. 78 pp.

[2] ZeEUS, Zero Emission Urban Bus System, an FP7 Flagship project; http://zeeus.eu/, accessed 2015-01-28.

[3] HSL News bulletin, 05.06.2014. https://www.hsl.fi/uutiset/2014/hsl-mukana-maailman-ymparistopaivassa-joukkoliikenne-muuttuu-paastottomaksi-4934 (in Finnish)

[4] eBUS, http://www.ecv.fi/in-english/ebus/, accessed on 2015-01-28

[5] ECV, http://www.ecv.fi/in-english/, accessed on 2015-01-28.

[6] HSL News bulletin 21.01.2015, https://www.hsl.fi/en/news/2015/hsl-test-new-fleet-procurement-model-6013, accessed on 2015-01-30.

[7] M. Pihlatie, S. Kukkonen, T. Halmeaho, V. Karvonen, N.-O. Nylund, Fully Electric City Buses – The Viable Option, IEEE IEVC 2014, Florence, 17-19 December, 2014. (DOI not yet available.)

[8] N.-O. Nylund and K. Koponen, Fuel and technology options for buses. Overall energy efficiency and emission performance, VTT Technology 46, Espoo 2012. 294 p. + app. 94 p. http://www.vtt.fi/inf/pdf/technology/2012/T46.pdf

[9] J. Laurikko and K. Erkkilä, Assessment of the Energy Efficiency of the Propulsion System in an Electric Vehicle – Methodology and First Results, EVS25 Shenzhen, China, Nov. 5-9, 2010.

[10] Erkkilä K, Nylund NO, Pellikka AP, Kallio M, Kallonen S, Ojamo S., et al. eBUS – electric bus test platform in Finland. In: Proceedings of the 27th international electric vehicle symposium & exhibition (EVS27), Barcelona, Spain; November 17–20 2013.

[11] T. Halmeaho, P. Rahkola, J. Pippuri and K. Tammi, "Hybrid City Bus Design Evaluation Using System Level Simulations," In *Proc. ISIE 2014*, 2014.DOI: 10.1109/ISIE.2014.6864866

Authors

Juhani Laurikko works as Principal Scientist at VTT. He received a Doctor of Technology (D.Sc.Tech) degree in 1998 from the Helsinki University of Technology (now part of Aalto University). He joined VTT in 1985, and since that he has worked with environmental impacts of motor vehicles. Currently his principal areas of expertise are new propulsion technologies, alternative fuels and energy use in transport vehicles.

Mikko Pihlatie, holds a D.Sc (Tech) from Aalto University. He works as a Research Team Leader for the Vehicles and Electric Powertrains team at VTT. He is the coordinator of the national R&D network Electric Commercial Vehicles (ECV). His current research interests include battery systems, electric vehicles and systems, and TCO analysis.

Nils-Olof Nylund works at VTT as a Research Professor (Energy use in transport). He has a D.Sc (Tech) degree from Helsinki University of Technology. He has been working at VTT since 1979. He is the initiator of the HD energy efficiency work at VTT, and the person in charge for creating VTT's HD test facility.

Teemu Halmeaho received the M.Sc. (Tech) degree in mechanical engineering from Aalto University, Finland in 2012. In 2011 he joined the VTT Technical Research Centre of Finland and has studied electric machines and electric vehicles since then.

Samu Kukkonen works as a research scientist at VTT since 2010. He holds a Ms.Sc (tech) degree (2010) in power electronics from Tampere University of Technology. At VTT his expertise is in of high-power battery modules. He is also leading the standardization activities on electric city bus charging systems within ZeEUS.

Veikko Karvonen works as research scientist at VTT since 2010. He received a Ms.Sc (Tech) degree in transportation and highway engineering from Aalto University in 2012. Currently he is the lead researcher in the eBusSystems project.

Annakaisa Lehtinen works as a research trainee at VTT since 2014. She got a Ms.Sc (Tech) degree in transportation and logistics engineering from the Tampere University of Technology in 2014, and the theme of her master thesis was electric busses as part of the public transport system in city of Turku, Finland.

Reijo Mäkinen is the Director of Transport Services, Helsinki Region Transport (HSL). He holds a Ms.Sc. (Tech) degree from the Helsinki University of Technology, and has been working with the public offices for regional public transport services since 1995. He has been particularly active in developing the procurement system for public bus transport services at HSL to include environmental performance as one of the key elements.

Sinikka Ahtiainen works for the city of Espoo, in the management of traffic planning unit, as the development manager in charge of coordination of public transport services. She has a Ms.Sc. (Tech) degree from Helsinki University of Technology.