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SwissTrolley+

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New Vehicle Concept

State-of-the-art trolley buses need a diesel-powered auxiliary power unit (APU) to ensure maneuverability during a shortage of electricity. The engine, despite being rarely used, leads to increased vehicle weight and thus increases the energy consumption of the bus. When actually being used, the undersized APU runs mainly in cold-start mode, leading to extreme noise and pollutant emissions.

The goal of SwissTrolley+ is to avoid those drawbacks by replacing the APU with a high-performance traction battery. Additionally, the traction battery allows for regenerative braking, reducing the energy demand of the vehicle by about 15% compared to a state-of-the-art trolley. Furthermore, the battery enables up to 5 km of pure battery-electric driving outside the overhead wire network. This feature can be used to extend existing bus lines, or to remove parts of the overhead wire network, thus saving infrastructure maintenance cost. Finally, the battery capacity could also be used to stabilize the electricity grid by balancing the unsteady power demand, which is a major factor for energy pricing in a trolley network.

- Replace diesel-powered engine-generator set with battery.
- Reduce noise and pollutant emissions.
- Reduce energy consumption by regenerative braking.
- Save maintenance cost by removing parts of the overhead wire network.
- Save energy cost by applying peak-load shaving.

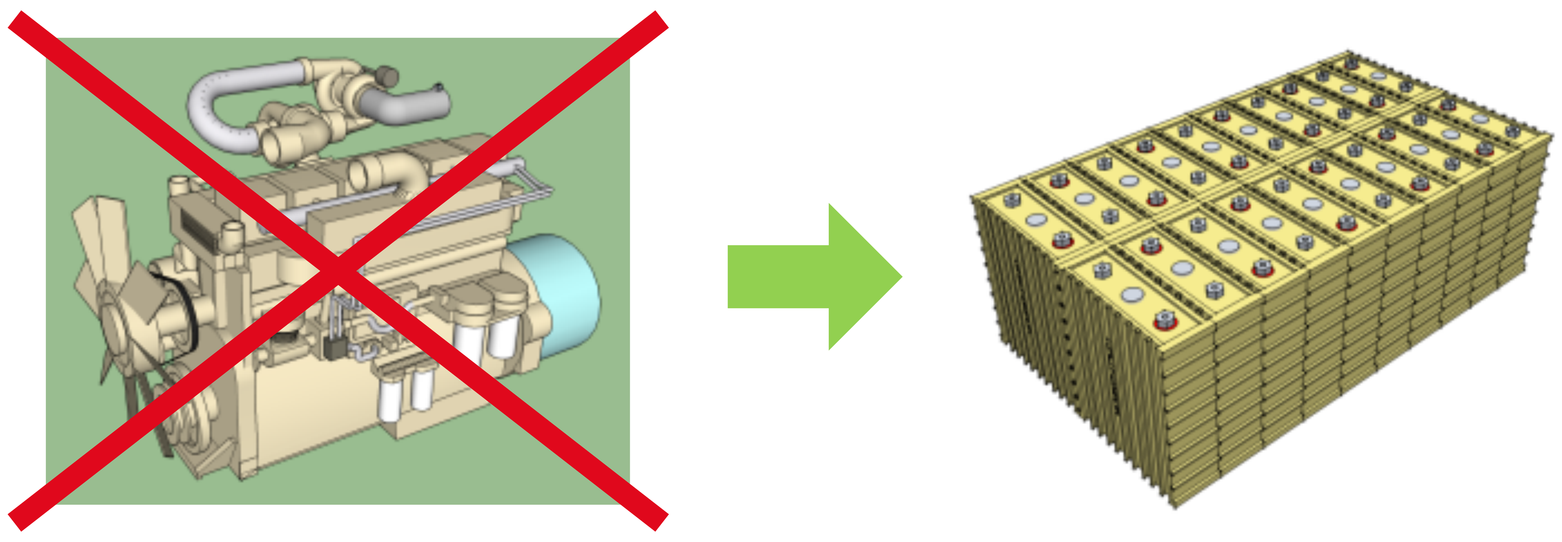

Figure 2: The diesel engine driven auxiliary power-unit (left) is being replaced by a high-performance traction battery (right).

Goals & Challenges

The SwissTrolley+ has two sources of power: the electricity grid, and the traction battery. During operation, the energy demand is mainly defined by the driver. The two power sources, however, provide a new degree of freedom: in each moment of time, the energy management system of the vehicle needs to decide whether to draw electric power from the grid, or from the battery. To solve the decision of how to "split" the power demand between power sources, expertise in control systems theory is necessary. Thus, the development of the energy management strategy is being conducted in close collaboration with the control systems experts of ETH Zürich. The following challenges have been identified:

- On-line energy management for maximal energy efficiency
- Optimal control theory for optimal performance

The energy management strategy should maximize energy efficiency of the vehicle, while ensuring that the driver's power request is met, and all operational constraints of all components are maintained. Such problem can be formulated as a dynamic optimal control problem, which only can be solved using dedicated tools from the theory of optimal control.

- Position-based charging strategy for wire-free zones
- Self-learning road map for minimal maintenance

When the bus is being operated on a bus line including sections that have been cleared from overhead wires, the energy management system needs to ensure that the battery contains enough energy to overcome the wire-free section in battery electric mode. Thus, during regular operation the battery needs to be constantly charged until the point of entry to a wire-free section. Such a position-dependent energy management strategy requires the integration of positioning data from a global satellite navigation system together with a suited road map. Ideally, this map is self-learning, such as to minimize maintenance effort.

- Battery-health conscious operating strategy for maximum battery lifetime

Battery lifetime is a crucial issue for operators of trolley buses. Usually, trolleys are designed for a lifetime of >20 years. With this project, the aim is to achieve a battery lifetime of >10 years, i.e., one battery replacement over the full lifetime of the bus. Battery health is influenced by many operational factors, such as min/max charging and discharging power, highest and lowest temperature, depth of discharge, etc. The energy management therefore needs to be carefully programmed such as to avoid damaging the battery.

- Peak-load shaving for cheaper electricity pricing

Caused by the tight timetable in public transportation, the bus drivers tend to maximize the acceleration and deceleration in the range of the passenger's comfort zone. Such driving behavior results in a strongly fluctuating power demand that is entirely unpredictable (see Fig. 4). The operator of the electricity grid needs to apply a large amount of expensive stabilization energy to balance the demand side. While the driver demands peak power (ca. 200 kW) only during the short acceleration phases, the average power demand is much lower (ca. 35 kW). With the traction battery, the peak power demand could be reduced and the grid load could be smoothened – eventually leading to a cheaper price of electricity.

- Reduction of the energy demand for HVAC

Generally, the energy demand of the systems for heating, ventilation and air-conditioning of a public transit bus makes up a substantial part of the total energy demand (ca. 30-40%). This project specifically investigates how the HVAC energy demand can be reduced, and how the HVAC systems can be operated more efficiently.

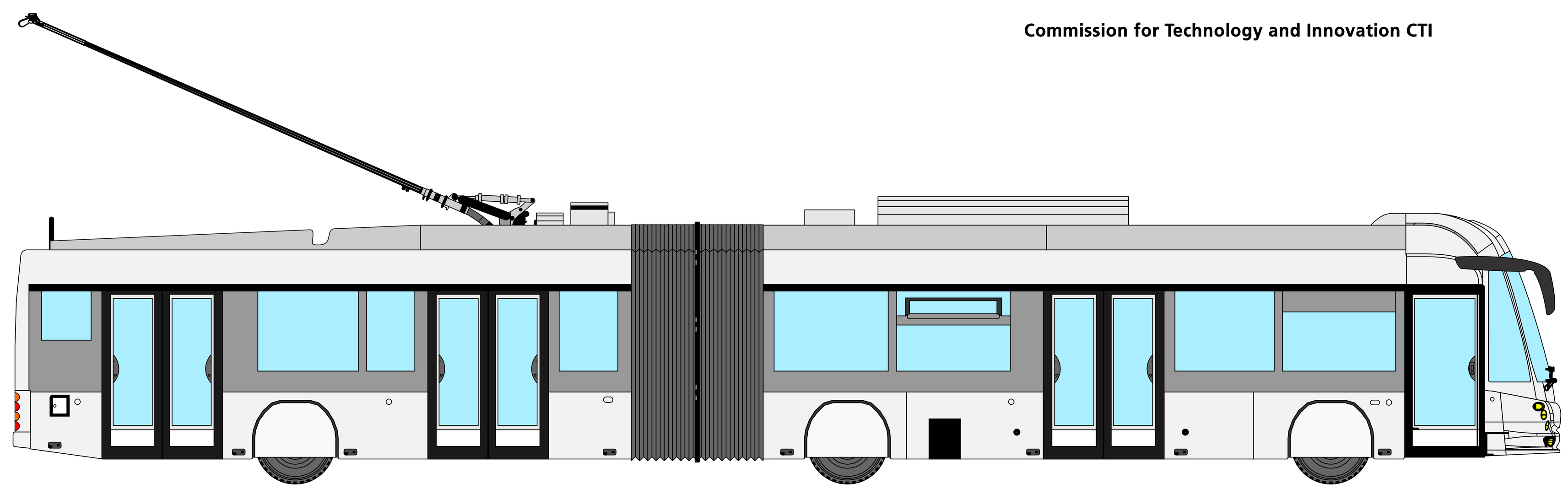

Figure 1: Technical Drawing of the new SwissTrolley+. The front of the bus as well as the hidden wheels create the impression of being more a streetcar than a regular trolley bus. This design attracts public attention and thus perfectly fits to the new types of buses.

Cooperation with BFH, HESS and VBZ

This project is a follow-on project of the very successful and and trusting cooperation between ETH and Carrosserie HESS AG during the AHEAD project. As a new partner, Verkehrsbetriebe Zürich (VBZ) provides the needed know-how and experience from the view of a public transportation operator in order to achieve the goals set. The Berner Fachhochschule (BFH) investigates the differences of currently available battery packs and tests their performance in various load scenarios. The process of battery aging is the other main research topic as accurate models are especially of interest for the exerted operation conditions and the financial aspect.

- Combine expertise of research and industry.
- Establish short development cycles.
- Ideally suited test environment on real bus lines.
- Benefit from specialization and collaboration of both universities.

Given the data of measured load profiles of conventional trolley buses, BFH will test and evaluate the effects of the power demands on different battery types. Their battery laboratory allows to simulate different climate conditions and thus make conclusions about the durability and the capacity decrease over time.

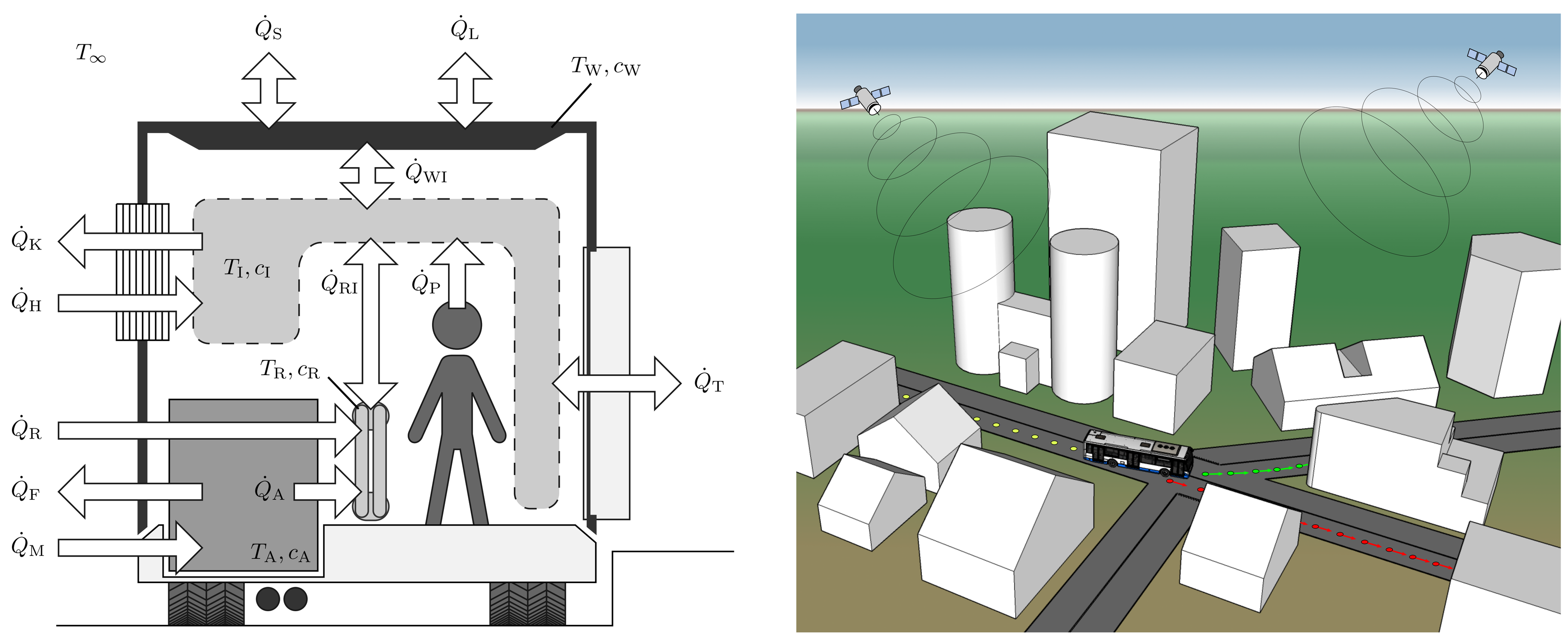

Figure 3: This project offers many research topics for student projects, internships and publications. On the left, a schematic illustration shows the heat flows of a thermodynamic study. On the right, the problems with GPS-based position estimation are depicted. Both fields offer amongst others the possibility to reduce the total energy consumption as well as improve the comfort for passengers, bus drivers, and common carrier.

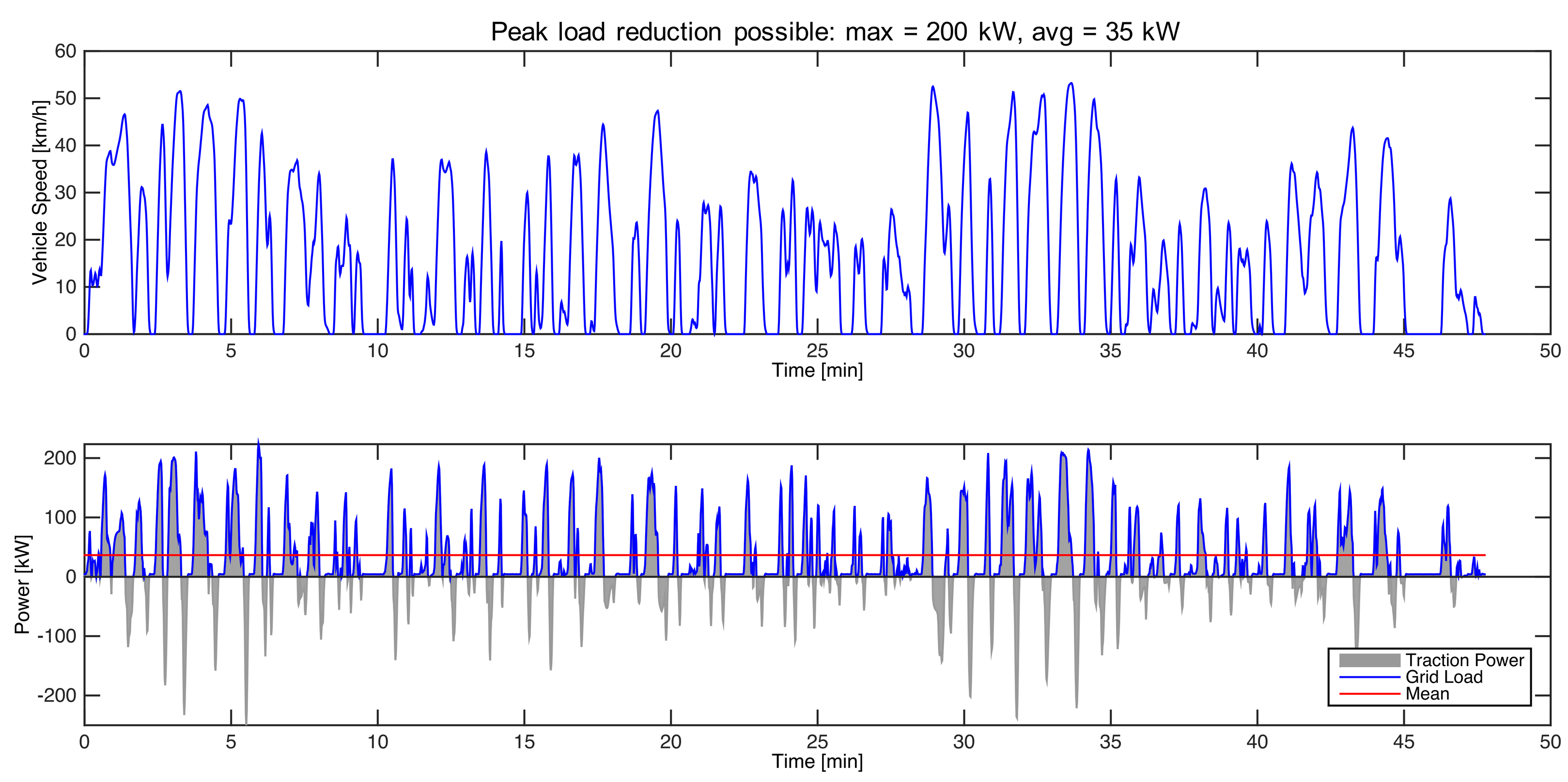

Figure 4: Measurement data of a standard trolley bus in operation show a quite aggressive velocity profile as depicted in the upper plot. Without a battery, the resulting power demand of a regular trolley bus includes peaks of up to 200 kW, whereas the average is only 35 kW. As a result, the grid operator must guarantee to provide the electricity to match these power peaks at all times, although the average load is only a fraction of it. Reducing the peak load will therefore not only relieve the power supply system but also allow to save money.

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