OPTIMIZING THE TECHNOLOGY SPLIT FOR AN ELECTRIC URBAN BUS NETWORK

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Introduction

This contribution is part of the move2zero project aiming at the development of a holistic concept for a fully decarbonized urban bus transport system in Graz. In response to the European Strategy for Low-Emission Mobility, including a timely adoption of zero-emission technologies for city buses [1], move2zero introduces zero-emission technologies for power generation and supply, as well as zero-emission technologies for the operation of vehicles and infrastructure. Furthermore, components with low emission factors and high reuse- and recyclability are strongly supported. Our contribution determines a combination of different technologies for electric buses such that the overall Life Cycle Cost over a 20-year horizon is minimized.

Technology Options

Based upon the current availability of technologies, the following electric technology concepts were considered as viable options for the project under study [2]:

Opportunity Charging (OPC)

The opportunity charging concept is based on the idea of frequently recharging buses during dwell times. Thus, a number of charging stations has to be located at suitable bus stops along the routes. By scheduling charging events of more than one bus line at charging stations at shared bus stops, synergies from joint usage of infrastructure can be gained and peaks in power demand can be reduced. In general, a distinction can be drawn between the type of energy storage system in use. Lithium-ion batteries and supercapacitors are both applicable under the OPC concept, but require different operational considerations with regard to energy supply.

Overnight Charging (ONC)

The overnight charging concept assumes that charging mainly takes place during night, when buses are not in operation. A major benefit of using these long available timeslots at the depot is the possibility to deploy low charging power levels. For large-scale transitions it has to be considered that simultaneous charging of the fleet poses high requirements on the electricity grid. If existing infrastructure cannot provide enough charging power, the necessary upgrade of the electrical infrastructure results in high investment cost. Moreover, range limitations of overnight charging buses make it usually impossible to directly replace one conventional powered bus by one electric bus.

Fuel Cells (FC)

Fuel Cell buses use electrical energy generated on board through an electrochemical reaction of hydrogen and air. As these propulsion systems offer high flexibility in terms of range, operational deployment similar to that of conventional buses is feasible. However, the daily consumption of energy requires a hydrogen filling station and regular supply of hydrogen. This can be realized through an off-site production plant and subsequent delivery or by an on-site hydrogen production plant, depending on the number of fuel cell buses deployed.

Each of these technology options has its distinct pros and cons with respect to driving ranges, filling and charging requirements and investment and running cost. The urban context and topology of a bus network adds an individual component to the optimal technology choice. In many cases, individual bus lines have characteristics making them most suitable for one technology, while other bus lines fit better

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for other concepts. Therefore, a technology mix, namely an individual technology decision for each bus line, can present the most cost-efficient solution.

Decision-Support System

In order to determine an optimal technology choice, a comprehensive evaluation of all available options, including cost assessments and operational planning, is needed. This complex task can be approached best by mathematical methods, in particular Integer Linear Programming (ILP). Thus, a mathematical model was developed to determine the optimal technology split for a given bus network by minimizing total cost of ownership. In conjunction with a comprehensive, but easy-to-handle data interface the model now serves as a decision support tool for the local bus operator in Graz.

The results of the studied optimization model depend on a number of different input assumptions. These input assumptions include technical parameters, such as charging power or range limitations; system parameters, such as routing information of bus lines or available charging spots; and cost parameters. The latter include discounted infrastructure and vehicle investments as well as energy prices over a time horizon from 2030 to 2050. The values of these parameters are, as in the nature of long-term planning problems of technologies under development, rather uncertain. Therefore, a wide set of factor combinations at different levels was studied in a scenario analysis.

Results

The results of our computations suggest that the deployment of a mixed fleet, even though not intuitive, can indeed lead to monetary advantages. Besides the optimal technology decision, vehicle as well as charging schedules and a detailed cost breakdown in individual system components are available for each scenario. Moreover, comparisons to a bus system operated by each individual technology alone are provided to the decision maker. In general, the cost of daily operation turned out to be the biggest cost driver. More than half of it originates from driver cost, which cannot be influenced significantly. The other part stems from energy cost of line operation. As energy cost can vary significantly for different technologies, they turned out to be one of the most critical factors. Infrastructure investments however, though they might be high in the first place, do not play a decisive role for the optimal technology decision.

Referenzen

[1] European Commission (2016), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A European Strategy for Low-Emission Mobility; https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52016DC0501 (Accessed: November 26, 2021)

[2] N. Fries and U. Pferschy, Decision-Support System for the Optimal Technology Split of a Decarbonized Bus Network, in *2021 IEEE 45th Annual Computers, Software, and Applications Conference (COMPSAC)*, Madrid, Spain, 2021 pp. 1279-1284. doi: 10.1109/COMPSAC51774.2021.00178