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The role of charging technologies in upscaling the use of electric buses in public transport: Experiences from demonstration projects

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ABSTRACT

Electrification of public bus transport services is currently being explored in various demonstration projects around the world. The objective of this paper is to (i) gather insights from electric bus demonstration projects with a focus on charging technologies (conductive, inductive) and strategies (slow, fast); and explore the role these factors may play as upscaling of electric bus deployment is considered. The focus is on the Nordic region. A survey with stakeholders involved with electric bus demonstration projects is performed for understanding the benefits and drawbacks of each solution, and identifying the main themes emerging from project implementation and upscaling. Advantages of the conductive charging include the maturity of the technology and its higher maximum charging power compared to currently available inductive alternatives. On the other hand, inductive technology entails other benefits, such as the lack of moving parts which could reduce the maintenance costs for infrastructure, as well as minimal visibility of the equipment. The main issues likely to impact the upscaling of electric bus use are related to the maturity, cost-effectiveness, compatibility, and charging efficiency of the available technologies.

1. Introduction

Public transport is crucial for the functionality of urban systems. Globally, much attention is presently given to reducing the environmental impacts of transport by shifting to clean fuels, while also improving service availability. In this context, electrification of bus transport is gaining popularity because of the high energy efficiency improvements that can be accrued, together with low emissions and noise reduction compared to conventional buses.

Although several studies focus on engine performance optimization and powertrain characteristics of electric buses for individual demonstration projects, only few studies analyze charging technologies in more detail (e.g. Millo et al. (2015), Kontou and Miles (2015), Bi et al. (2017), Bi et al. (2015)). Charging is one of the most important challenges to address when it comes to electric buses, not only from the purely technological perspective. Charging infrastructure requirements and implementation prospects are greatly affected by conditions in the specific location considered (Xylia et al., 2017b). The challenge is further exacerbated as cities plan for incorporation of electric bus technologies in everyday public transport services in order to lead a more widespread adoption of electric vehicles (IEA, 2017). A recent report published by the International Organization on Public Transport (UITP) lists more than 60 cases of electric bus demonstration projects around Europe (UITP, 2017).

The objective of this paper is to (i) gather insights from electric bus demonstration projects with a focus on charging technologies (conductive, inductive) and strategies (slow, fast); and explore the role these factors may play as upscaling of electric bus deployment

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is considered. The charging technologies studied are conductive and inductive charging. The charging strategies studied are slow (otherwise known as overnight) and fast charging. The expected results shall help understand the benefits and drawbacks of each solution, and map the charging-related challenges faced when upscaling the use of electric buses in public transport.

The main questions sought to be answered here are the following: *What are the characteristics of the various charging technologies and strategies at hand, and what are the main themes emerging when it comes to implementation? How can the various "lessons learnt" from demonstration projects facilitate planning for upscaling electrification of public bus fleets?* The first question addresses the first part of the aforementioned objective, while the second question addresses the latter part. The analysis draws from experiences around the world, reviewing existing literature and complementing it with expert knowledge from selected stakeholders. Particular attention is given to the Nordic region, where several initiatives are already in place.

Following the present introduction, Section 2 presents background on charging technologies while Section 3 presents the analytical approach, as well as the methods chosen for each part of the study. Section 4 presents the results of the literature review, where the available technologies and strategies for charging are discussed. Section 5 focuses on the experiences from demonstration projects for electric buses. The results from the aforementioned sections are discussed further in Section 6 where emerging themes are defined, followed by the conclusions of the study which are presented in Section 7.

2. Background

Electric powertrain types can be differentiated in battery electric and electric hybrid, see Fig. 2. Battery electric buses have only an electric motor, while electric hybrid buses have an additional internal combustion engine (ICE) which is usually deployed for supplying energy to auxiliaries. Electric hybrids are considered to be an intermediate solution between ICE and battery electric buses (Tzeng et al., 2005). The energy storage systems available include ultracapacitors, batteries and fuel cells. In the Nordic region, only battery and fuel cells are currently used as energy storage for buses, therefore ultracapacitors are excluded from the analysis. The main focus of the study is on batteries for energy storage, since it is the most common option provided by all major electric bus manufacturers.

The main technologies currently available for battery charging are depicted in Fig. 1, and can be aggregated in conductive (plug-in) and inductive (wireless). For conductive charging, direct contact is used between the connector and the charge inlet (Yilmaz and Krein, 2012). For inductive charging, the power is transferred through magnetic fields and no cables are needed (Yilmaz and Krein, 2012). The inductive system is built based on the bottom coil system topology, where a primary coil system is placed underground, and a secondary coil system is installed on board of the vehicle. This topology offers flexibility in the coil geometry design, but can be a source of inefficiencies due to the air gap between the primary and secondary coil (Lempidis et al., 2014).

Charging can take place either in stationary mode (when the vehicle is stopped) or dynamically (when the vehicle is moving). Conductive charging technologies can additionally be differentiated in overhead or ground/underground solutions. As mentioned earlier, inductive charging is an underground solution and can be either stationary or dynamic. In this paper, we are interested in the comparison between stationary conductive and inductive charging technologies. Dynamic inductive charging technologies are excluded from the analysis as the technology is yet at a very early stage of development, and is not yet being tested for buses in the Nordic region. Also trolleybuses are excluded. The latter is a dynamic conductive charging technology, but well-established technology since the 1970s, and thus considered to be mature. It is therefore not in the scope of the analysis, which is focused on emerging charging technologies.

The choice of charging strategy is linked to the powertrain technology, as well as the battery size and the available budget for infrastructure investments. The slow charging strategy is also known as overnight charging. With this technology, the charging happens in AC in the depot or parking space allocated for the vehicle over longer time periods. Fast charging, otherwise known as opportunity charging, requires the installation of a charging station that transforms AC to DC. Table 1 provides examples of fast-chargers for buses that are currently available in the European market.

The costs for charging systems can vary significantly. In fact, when comparing the costs of conductive vs. inductive fast charging systems for buses, we should assume that costs are affected by the conditions around each specific case, e.g. space availability and local electricity grid conditions.

Lindgren (2015) has collected information for a Swedish case study showing that conductive fast charging systems are cheaper than inductive (1.5 million SEK (150000 €[1]) and 2 million SEK (200000 €) respectively). In addition, the inductive charging system requires the installation of a pickup system that is estimated to cost 1 MSEK (100000 €) (Lindgren, 2015). This gives an indication of the cost difference between the two charging technologies.

Another study indicates a cost of 1 222 $/kW (ca. 9 750 SEK/kW or 975 €/kW)) for a stationary inductive fast charging system such as the Bombardier PRIMOVE, and 405 $/kW (ca. 3 250 SEK/kW or 325 €/kW) for a stationary conductive fast charging station, such as the Siemens and ABB models, including both the charger itself as well as the necessary grid connection costs (Bängtsson and Alaküla, 2015). Nevertheless, the costs of both charging systems are uncertain at this early stage of technology deployment, and are expected to decrease as higher commercialization rates for fast charging technologies are achieved.

Currently, there is lack of comparative studies for charging technologies and strategies to guide choices. A possible reason for this is that conductive overnight charging is currently the most established charging option. Reasons for this include the ease of installation, the maturity of the technology, and the lower overall cost of the infrastructure. For example, the costs for a simple

[1] *SEK is the Swedish currency (Swedish Krona). The average exchange rate for 2016 is 1SEK = 0.10€ (Oanda, 2016).*