Transportation Research Part B 000 (2017) 1–30

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Battery degradation and behaviour for electric vehicles: Review and numerical analyses of several models

Samuel Pelletier[a], Ola Jabali[a], Gilbert Laporte[a,*], Marco Veneroni[b]

[a] CIRRELT and HEC Montréal, 3000 chemin de la Côte-Sainte-Catherine, Montréal, H3C 3J7, Canada
[b] Dipartimento di Matematica "F. Casorati", Università degli Studi di Pavia, Via Ferrata 1, 27100 Pavia, Italy

ARTICLE INFO

Article history:
Received 16 June 2016
Revised 9 January 2017
Accepted 11 January 2017
Available online xxx

Keywords:
Electric vehicles
Bbattery degradation
Battery behaviour
Battery modeling
Green transportation

ABSTRACT

The use of electric vehicles for goods distribution opens up a wide range of research problems. Battery electric vehicles (BEVs) operate on batteries that have a limited life, as well as specific charging and discharging patterns which need to be considered in the context of their use for goods distribution. While many transportation problems associated with the integration of freight electric vehicles in distribution management problems have been investigated, there is room for further research on specifically how to model battery degradation and behaviour in such problems. The aim of this paper is to provide tractable models for transportation scientists that will allow predicting the lifetime degradation and instantaneous charging and discharging behaviour of BEV batteries.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

In recent years we have witnessed an increased interest in topics related to vehicle fleet composition, route planning and speed optimization in green logistics (see, e.g., Koç et al., 2014; 2016; Stasko and Gao, 2012; Kopfer and Kopfer, 2013; Kopfer et al., 2014; Goeke and Schneider, 2015; Sassi et al., 2015; Bektaş and Laporte, 2011; Demir et al., 2014; Gonzalez-Feliu et al., 2014; Psaraftis, 2015). The research carried out in these fields focuses on the design of distribution policies that will help decrease the environmental impact of goods distribution. An important research area lies in the development of models that can accurately predict exhaust emissions of conventional vehicles (e.g., Demir et al., 2011; Kirschstein and Meisel, 2015; Kamarianakis et al., 2011). In the same vein, increasing attention is being paid to the use of battery electric vehicles (BEVs) as a means of yielding green distribution practices (Pelletier et al., 2016; Schiffer and Walther, 2015; Montoya et al., 2015b; Bay and Limbourg, 2015).

Beyond the uncertainties surrounding the environmental impacts of freight electric vehicles, there exist performance and financial issues associated with their integration into distribution schemes. Although offering the advantage of much lower energy and maintenance costs, these vehicles typically have autonomy and payload limitations, and involve much larger initial investments than internal combustion engine vehicles. A common denominator to these financial and technical limitations is the vehicle's battery. The most common kind of batteries used in modern passenger and freight BEVs are lithium-ion batteries (den Boer et al., 2013), which in addition to being costly and restricting the payload and range of freight BEVs, have a limited lifespan and specific charging and discharging behaviours.

* Corresponding author.
E-mail addresses: Samuel.Pelletier@hec.ca (S. Pelletier), Ola.Jabali@hec.ca (O. Jabali), Gilbert.Laporte@hec.ca (G. Laporte), Marco.Veneroni@unipv.it (M. Veneroni).

http://dx.doi.org/10.1016/j.trb.2017.01.020
0191-2615/© 2017 Elsevier Ltd. All rights reserved.

1.1. Motivation for battery degradation modeling

When BEVs are used for goods distribution, they are usually charged at companies' facilities overnight and do not use public charging stations other than during drivers' breaks (Nesterova et al., 2013; Naberezhnykh et al., 2012; Taefi et al., 2016). This is because the long service time of most public charging stations create cargo security concerns as well as an inefficient use of the drivers' time (Naberezhnykh et al., 2012). Charging automotive lithium-ion batteries can take hours depending on the equipment used and on the capacity of the battery (U.S. Department of Energy, 2012), making fast charging infrastructures necessary for recharging during delivery routes; these, however, are scarce in most countries (International Energy Agency , IEA). En route recharging facilities are only useful in contexts where BEV routes are highly constrained by the battery capacity. Since one of the effects of lithium-ion battery degradation is a loss of battery capacity and hence a decrease in the vehicle's achievable range (Barré et al., 2013), and since such autonomy declines have been reported in actual freight BEV deployments (Taefi et al., 2016), long term operational flexibility can be preserved by taking steps to ensure that the battery is not excessively aged when this can be avoided.

Lithium-ion battery packs for BEVs are a major cost component of these vehicles (Electrification Coalition, 2013). The cost of BEV lithium-ion battery packs per kWh were up to $800 in 2012 (Cluzel and Douglas, 2012; Duleep et al., 2011) and should remain above $300/kWh in the next ten years (Gerssen-Gondelach and Faaij, 2012). However, it has recently been suggested that they have been decreasing faster than predicted and could already be about $400/kWh (Nykvist and Nilsson, 2015). Still, since lithium-ion battery packs in electric trucks can have approximate energy capacities of 100 kWh and more (e.g., Smith Electric Vehicles, 2015; Electric Vehicles International, 2015; Balqon Corporation, 2013), a significant portion of the vehicle's cost can still be attributed to the battery. Several factors regarding storage and operating conditions can influence the lifespan of these batteries (Barré et al., 2013). Having to replace the battery in electric delivery trucks over the course of their lifetime has been shown to significantly decrease their attractiveness (Davis and Figliozzi, 2013; Feng and Figliozzi, 2013; Lee et al., 2013). It therefore also seems logical from a cost perspective to try to incorporate certain battery health considerations into distribution schemes with BEVs.

1.2. Motivation for battery behaviour modeling

Several recent studies have successfully handled the routing issues associated with the integration of BEVs in distribution management problems, such as limited range and payload, and the possibility of recharging en route at stations or at the depot. Regarding battery modeling, most studies have treated the battery as having a fixed energy capacity. Such papers have modeled the charging process either as a fixed charging time penalty (Afroditi et al., 2014; Preis et al., 2014; Conrad and Figliozzi, 2011), as an energy recharging rate per unit of time (e.g., Lebeau et al., 2015; Hiermann et al., 2016; Goeke and Schneider, 2015; Schneider et al., 2014; Bruglieri et al., 2015; Felipe et al., 2014), or with piecewise linear approximations based on experimental data (Zündorf, 2014; Montoya et al., 2015a). During discharging, the energy capacity of the battery is either assumed to decline linearly according to the distance traveled (e.g., Hiermann et al., 2016; Schneider et al., 2014; Bruglieri et al., 2015; Felipe et al., 2014; Sassi et al., 2015), or by an amount determined according to an energy consumption model based on road forces acting on the vehicle (e.g., Lebeau et al., 2015; Goeke and Schneider, 2015; Preis et al., 2014; Bay and Limbourg, 2015).

It is clear that several routing problems associated with the use of freight BEVs have been solved, thus demonstrating that operations research can help to successfully integrate these vehicles into distribution operations by modeling and solving relevant problems (e.g., optimal paths, fleet size and mix, vehicle routing) which take into account the specific characteristics of these vehicles (Pelletier et al., 2016). Moreover, some of these problems have recently been tackled from a more strategic planning perspective through the development of models requiring simultaneous routing and charging infrastructure siting decisions (e.g., Schiffer and Walther, 2015; 2016; Yang and Sun, 2015). However, we believe that there is a need for further development regarding how to model the battery's discharging and recharging processes in a tractable way, which is still capable of taking certain fundamental battery behaviour characteristics into account.

For example, a battery's capacity should ideally be treated as a measure of electrical charge rather than energy (Sauer, 2009). The battery's state of charge (SOC) should therefore refer to the current proportion of electrical charge inside the battery with respect to the maximum possible charge it can hold (Bergveld, 2001), as opposed to the current amount of energy inside the battery with respect to a maximum energy capacity, as is typically the case in transportation planning problems. As a result, the instantaneous variation of the battery's SOC can be defined as the electrical current coming in or out of the battery divided by its maximum capacity (Moura et al., 2011), since current is a measure of electrical charge per unit of time. Furthermore, the power output of a battery corresponds to the product of its terminal voltage and current (Khajepour et al., 2014), both of which are subject to variations while discharging, according to the power profile associated with the driving cycle (Campbell, 2011). Even when assuming that a BEV travels at constant speed and hence requires a constant battery power output, the battery's terminal voltage (as it partly depends on the SOC) would decrease while discharging and its current would need to increase in order to maintain the required power output (Sauer, 2009). The battery's SOC variation with time therefore depends on the electrical current profile associated with the driving cycle.

Moreover, there exists a difference between available and maximum capacity. The latter varies with temperature and will fade over the battery's life, but the former also decreases when the battery is discharged with larger currents (Lam, 2011). This is because in order to avoid certain degradation mechanisms, the discharging process must be stopped if the

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات