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The viability of vehicle-to-grid operations from a battery technology and policy perspective

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ABSTRACT

The idea that electric vehicles can connect to the electric grid to provide ancillary services, such as frequency regulation, peak shaving and spinning reserves is compelling, especially in jurisdictions where traditional forms of storage, back-up or peak supply are unavailable or expensive. Since conception, the economic viability of vehicle-to-grid operations has been the subject of debate. A common shortcoming of most of the previous studies has been a proper accounting of Lithium-ion battery degradation in the development of business models. Very recently, papers on the viability of V2G were published for which the detailed account of battery degradation resulted in what appeared to be two ostensibly contradictory conclusions. In this paper, the authors of these two major studies jointly reconcile their previous conclusions by providing clarity on how methodologies to manage battery degradation can reliably extend battery life. The paper also reviews the associated technology and policy implications of better managing battery use in vehicle and electrical grid applications.

1. Introduction

Vehicle-to-grid (V2G) refers to the reciprocal flow of power between an electric vehicle (EV) and a recipient that could be, among other possibilities, the grid, a low voltage microgrid or a building. In addition to demand-shifting and the associated reduced electricity costs attained by avoiding peak tariffs at times of high demand, it also introduces the prospect of financial incentives for the consumer, through offering frequency regulation and energy storage facilities to the grid. Furthermore, V2G offers the possibility of increased use of localised renewables. Despite these incentives, a key concern has been the impact of V2G operations on the degradation of Lithium-ion batteries – which is central to both EV and V2G operations.

In the May 2017 issue of the *Journal of Power Sources*, Dubarry et al. (Dubarry et al., 2017c) presented the results of an experimental study on the impact of V2G operations on Lithium-ion battery degradation. Their results show that additional cycling to discharge EV batteries to the power grid, even at constant power, is detrimental to battery performance. In an apparent contradiction to this, in the June 2017 Issue of *Energy*, (Uddin et al., 2017b) presented a data and simulation study claiming that V2G can actually extend the life of Lithium-ion batteries in EVs. Given that both studies use very similar commercially available 18650-type cells with Graphite (GIC)/$LiNi_xCo_{1-x-y}Al_yO_2$ (NCA) negative/positive electrodes, the seemingly opposing conclusions is even more peculiar.

Following the publication of these papers, both studies have received considerable media attention – with most media outlets choosing to align themselves to one particular opinion over another. In this *short paper*, the authors reconcile their recent results – in summary, lithium ion battery degradation governs the economic viability of V2G. The subsequent policy, regulatory and economic implications for this is highlighted in this paper; chiefly, the requirement for new smart infrastructure and the need for business models which account for battery degradation are explored.

2. Lithium-ion battery degradation

It is well established in the scientific literature that Lithium-ion batteries age, i.e., they undergo degradation (Sarre et al., 2004; Vetter et al., 2005). The rate of degradation is often governed by how the battery is used, which is typically characterized by so-called *ageing stress factors* (Uddin et al., 2016a), including: capacity throughput (C_{TP}), temperature (T), State of Charge (SoC), swing in State of Charge (ΔSoC) and the magnitude of both charging and discharging current C_{rate} (Sarre et al., 2004; Uddin et al., 2017a; Vetter et al., 2005). In a causal framework, the *ageing stress factors* instigate or accelerate various physical degradation mechanisms that manifest in loss of lithium inventory, loss of active material and/or kinetics limitations (Dubarry et al., 2014,

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2012). The resulting physical degradation is typically quantified by energy storage systems engineers in two ways: *capacity fade* that affects the range of an EV and *power fade*, which is the increase in the internal resistance or impedance of the cell and limits the power capability of the system and decreases the efficiency of the vehicle.

Focusing only on capacity fade and power fade in this way is inherently limited, especially for prognosis. As was shown by Anseán et al. (Anseán et al., 2017), it is essential to also monitor physical degradation modes that do not necessarily induce a tangible capacity or power loss in the initial stage but that can become prominent towards end of life. These degradation modes are often associated with a phase of accelerated, nonlinear fading that seem unpredictable relying on capacity and power fade alone. Frisco *et al.* (Frisco et al., 2016) have shown that an accelerated second step of aging is possible for the GIC/NCA 18650-type cells tested in (Dubarry et al., 2017c) under certain conditions. It is therefore an essential parameter to consider for any prognosis study.

Such degradation modes can be quantified via the analysis of the changes in the voltage response of the cell and techniques such as incremental capacity and differential voltage (Bloom et al., 2005a, 2006, 2005b; Dubarry et al., 2006, 2012).

For GIC/NCA 18650-type cells tested in (Dubarry et al., 2017c) and (Uddin et al., 2017b) results for capacity fade and power fade after 550 days of storage at various temperatures and *SoC* s is presented in Fig. 1(a) and (b) (Uddin et al., 2017a). The analogous figures for degradation resulting from 3800 Ah of cycling (approximately 1200 equivalent charge/discharge cycles) are presented in Fig. 1(c) and (d) for various ΔSoC s and current. The results show that storing cells at progressively higher temperatures and *SoC* s cause higher capacity fade and power fade. On the other hand, the almost flat surfaces for capacity loss and resistance rise due to cycling suggest that, despite higher discharge rates and ΔSoC marginally exhibiting more degradation, capacity loss and resistance rise due to cycling is dominated by capacity throughput. The analogous analysis of physical degradation modes of (Dubarry et al., 2017c) is under review (Dubarry et al., 2017b) and it is showcasing differences in degradation mechanisms between the cycle and the calendar aging. It is also forecasting the apparition of the second stage of aging under all driving conditions. This second stage will appear faster if the cell experienced V2G.

3. A critical analysis of the Hawaii V2G study

The work of Dubarry et al. (Dubarry et al., 2017c) aimed at understanding the impact of bi-directional charging on commercial Lithium-ion cells in trying to maximize an EV owner's profit, i.e., by selling as much capacity as possible during one-hour periods where the grid needs it the most. Results showed that this additional usage of the batteries, even at constant power, is detrimental to cell performance and that it could shorten the lifetime of battery packs to less than five years. Another strategy that was investigated was the impact of delayed charging, aimed at reducing the load on the power grid at peak hours. The impact was found to be negligible at room temperature. However, it could be significant in warmer climates where the effect of high SoCs on battery degradation is more pronounced. By delaying charging, the batteries are stored at lower SOCs which is beneficial for most commercial Lithium-ion batteries.

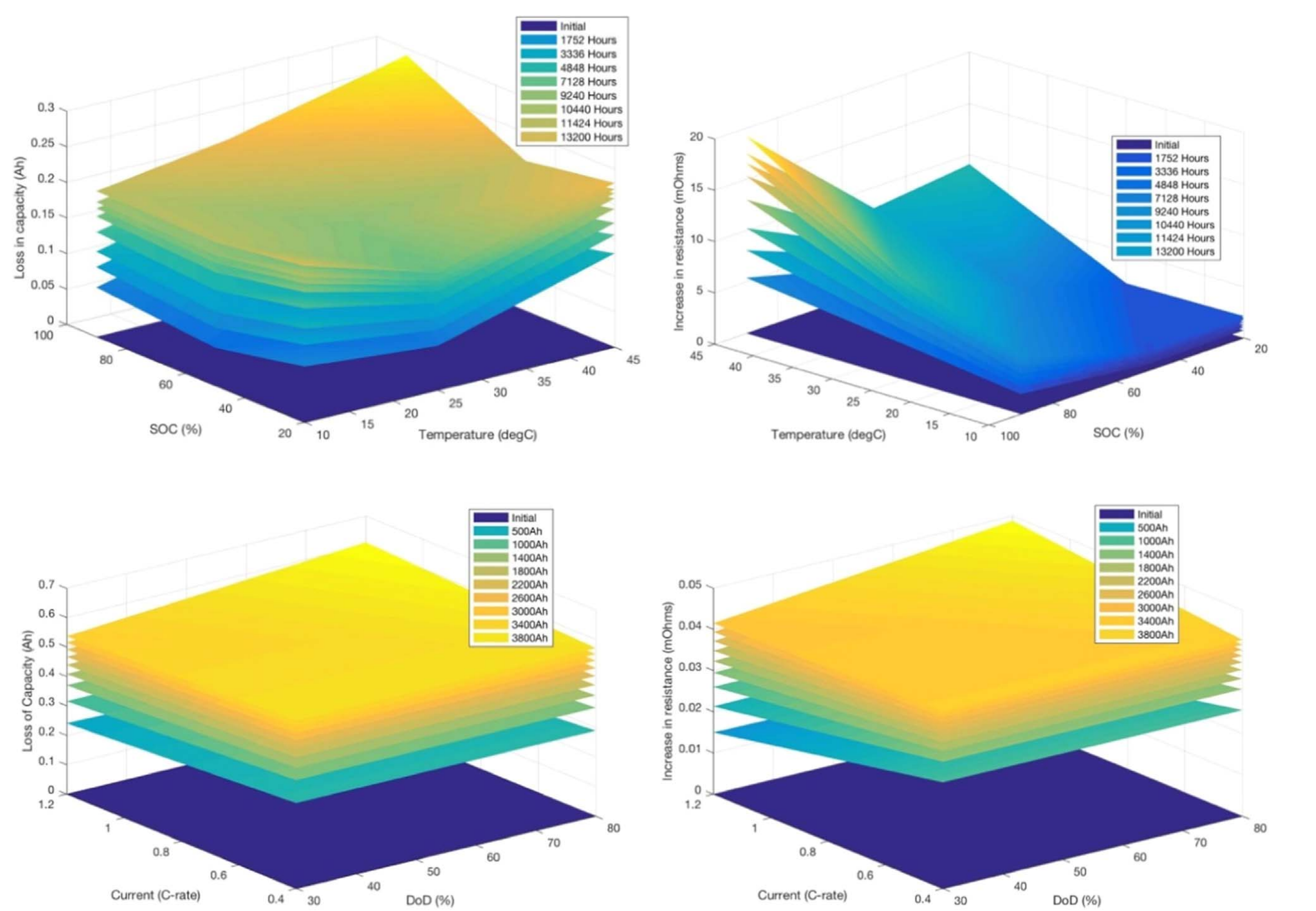

Fig. 1. Showing lithium battery degradation during storage (a) – (b) as a function of temperature and State of Charge; and battery degradation during cycling (c) – (d) as a function of swing in State of Charge and current (Uddin et al., 2017a).