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Economic analysis of second use electric vehicle batteries for residential energy storage and load-levelling

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HIGHLIGHTS

- EV Li-ion batteries can be reused in stationary energy storage systems (ESS).
- A single ESS can shift 2 to 3 h of electricity used in a house.
- While energy use increases, potential economic and environmental effectiveness improve.
- ESS supports smart grid objectives.
- Incentives like reduced fees are needed to encourage implementation of Li-ion battery ESS.

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ABSTRACT

The reuse of Li-ion EV batteries for energy storage systems (ESS) in stationary settings is a promising technology to support improved management of demand and supply of electricity. In this paper, MatLAB simulation of a residential energy profile and regulated cost structure is used to analyze the feasibility of and cost savings from repurposing an EV battery unit for peak-shifting. in situ residential energy storage can contribute to the implementation of a smart grid by supporting the reduction of demand during typical peak use periods. Use of an ESS increases household energy use but potentially improves economic effectiveness and reduces greenhouse gas emissions. The research supports the use of financial incentives for Li-ion battery reuse in ESS, including lower energy rates and reduced auxiliary fees.

1. Introduction

Reused batteries from electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) present an excellent, cost-effective option for energy storage applications that can help build 'smart grid' technologies, such as computer-based remote control, automation, and information management, to improve the reliability, efficiency and economics of electricity generation and distribution (U.S. Department of Energy, 2014). Such technologies can provide environmental and economic benefits to utilities, companies and homeowners through a complex system of systems (SoS) (DeLaurentis and Callaway, 2004) that responds to fluctuations in energy supply and demand by accessing decentralized, stored energy to distribute to energy consumers. Energy storage systems (ESS) are seen as critical to the development of the smart grid because they can provide load shifting and peak shaving from low electrical demand periods to peak electrical demand periods, thus helping to match supply and demand variability and potentially allowing for cost savings for energy providers and consumers (Ahmadi et al., 2014a, 2014b; Richardson, 2013; Williams et al., 2012). Energy storage applications located near the end user can provide much-needed relief to congested transmission and distribution systems (Del Rosso and Eckroad, 2013) and avoid the need for expansion of such systems simply to accommodate increases in peak demand. Onsite ESS can be used at homes, businesses and utilities, reducing energy losses and making it possible for homes and businesses to manage their own power consumption based on pricing and their own time-of-day energy needs.

Researchers have previously studied 'vehicle-to-grid' (V2G) technology that uses the EV battery to perform energy storage functions while it is in the vehicle (Yilmaz and Krein, 2013; Kempton and Tomic, 2005; Peterson et al., 2010). An EV battery in a V2G application feeds power back to the grid when the vehicle is plugged in for charging (Han and Han, 2013; Mullan et al., 2013; Peterson et al., 2013). There are numerous challenges to the

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viability of this technology. First, when in the vehicle, the EV battery is a valuable asset that is critically important to the range and performance of the vehicle. A V2G application would increase the number of charge–discharge cycles, significantly reduce the useful in-vehicle life of the battery, and ultimately increase the life cycle cost of the EV. Moreover, the type of cycling and depth of discharge experienced by the battery when it is connected to the grid would likely be significantly different than what it is designed for in the vehicle. Maintaining the control and stability of the power grid with many V2G applications would be difficult. More importantly, the use of the battery pack in a V2G application would not be permitted by the vehicle original equipment manufacturer (OEM) and would likely violate the vehicle warranty. Since many drivers would plug their EV in for charging during the night, a traditionally low-demand period of energy use, the complexity of managing demand with EV batteries is reduced if the demand is simply grid-to-vehicle in this period.

On the other hand, an EV battery that has been removed from service in the vehicle can provide round-the-clock energy storage while extending the usable life of the battery and increasing the overall work performed by the device for the initial investments of capital, energy and labour. The use of EV batteries for load-shifting, peak-shaving and energy backup has been studied in a number of demonstration projects (Daud et al., 2013; Gnanamuthu et al., 2013; Yoshimoto et al., 2009). The high cost of Li-ion batteries is the primary barrier to their adoption in energy storage applications. However, studies by Cready et al. (2003), Neubauer and Pesaran (2011) and Neubauer et al. (2012) have illustrated that second-use EV batteries could be provided at a sufficiently low cost.

Repurposing of EV batteries can be categorized into two business options. The first is to create arrays of packs for larger applications, such as energy leveling for renewable energy sources like solar or wind. The second option is to use repurposed batteries for peak-time energy shifting in smaller applications such as homes, office buildings and retail stores. Two key differences between these options are the potential market sizes and the number of the packs needed (Table 1). For example, in the Province of Ontario, which has a population of about 13 million people, there are over 3 million detached and semi-detached residential units, as well as hundreds of thousands of commercial settings in which repurposed EV batteries could be used to store energy bought off-peak. In contrast, there are at most 20 foreseeable large-scale applications for storing energy generated by renewable sources, and these applications would require immensely larger arrays of packs. For large applications related to the support of solar or wind power, the intermittent nature of renewable energy justifies the need for energy storage, such as what could be achieved through the use of thousands of repurposed EV batteries. Moreover, because the project is related to energy, the owners would have the expertise, location and personnel to support the technology safely and successfully. The presence of motivated early adopters would allow for greater market penetration of wind and solar energy.

However, there are financial drawbacks as well as safety and reliability risks associated with the creation of large EV battery storage units for power support. A large array of batteries would necessitate considerable technical sophistication related to controls, thermal management, and infrastructure required. The complexity of such systems rises considerably with size, raising risks of failure or malfunction, and likely deterring many businesses. Considering the current market penetration of EVs and PHEVs, the forecasted market penetration over the next two decades, and the expectation that the vehicles will likely remain in service at least 8 years on average, it is unlikely that enough vehicles will be coming out of service to supply and build large arrays of energy storage packs. Scaling the research performed by Richa et al. (2013) to the Canadian automotive market, the number of possibly available Li-ion EV and PHEV battery packs starts at about 400 in 2017 and increases to perhaps 45,000 in 2025. The limited availability of used EV batteries may also limit the pursuit of larger utilities projects that will require thousands of batteries. Another key issue when handling Li-ion batteries is the risk of fire and explosion (Fire Prevention Engineering, 2013; Mikolajczak et al., 2011). Thus, if risk is calculated as the product of probability and severity, large applications with many battery packs create a risk that is orders of magnitude greater than that of smaller installations (Department of Defense, 2000).

From a business standpoint, it is less risky to invest in a large number of small applications than a small number of large applications. Smaller applications can include numerous residential customers and a wide variety of commercial customers, including telecommunications companies (which may require 5 to 10 EV battery packs each), light commercial buildings (which may require 10 to 15 packs each) and food distribution centers (which may require 30 to 40 packs each). Telecommunications energy management is particularly promising due to the need for onsite energy storage and the large number of potential sites. The light commercial market could be highly profitable due to the greater potential cost savings to operators from access to unregulated electrical pricing. Additionally, commercial enterprises are likely to consider this technology as they will have the expertise, location and personnel to support the technology in its start-up and management. Office buildings could be prime locations for using repurposed EV batteries for energy storage due to the unregulated energy prices paid and the possibility of complementing the existing generator systems within buildings. However, using the batteries in this slightly larger application may require a significant amount of storage and safety girding, which may be difficult for urban locations or those with limited parking options. Further, urban locations may have greater risks due to the proximity of residences and community members. Still, the diversity of potential markets for energy storage provides increased financial security and risk aversion for potential investors.

Due to the limited availability of repurposed EV batteries and the previously discussed drawbacks associated with large energy storage applications, the current research focus is on the reuse of EV and PHEV batteries for residential energy storage and load-leveling. The next applications expected to be viable are fresh food distribution centers, which would demand large arrays. In Canada, there are 100–200 such facilities. These sites have large energy demands because they are essentially warehouse-sized refrigerators and freezers. This high energy demand and the highly controllable refrigeration equipment would work well with the repurposed battery technology. These sites have the capacity and personnel to support sophisticated technology, and have demonstrated interest and ability to adopt new technologies (e.g., fuel cell powered lift trucks). Moreover, these sites pay unregulated energy prices which can provide greater cost savings. Companies that run these refrigerated distribution centers, such as Walmart and Loblaw, are often early adopters of energy technology if a business case can be demonstrated. It is anticipated that residential and light commercial applications, among others, will be able to accept the generated capacity of used EV batteries for decades to come.

The second-use of an EV battery for energy storage and load-levelling would extend the use of the metal and other raw material resources manufactured into the battery cells, improve the life cycle material efficiency of the battery, and support the smart grid (Shokrzadeh and Bibeau, 2012; Walker et al., 2014). Li-ion batteries represent a significant financial and material investment, and their continued use can help reduce energy costs for residential and commercial consumers. An additional benefit to reusing EV batteries is the possibility of providing a more environmentally effective electrical grid. By using less energy during peak demand hours, electrical utilities can reduce their use of greenhouse gas-intensive energy sources such as natural gas and coal. There are