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Enabling fast charging – Vehicle considerations

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HIGHLIGHTS

- BEV refueling time requires 4–6 C-rate charging and large battery capacities.
- Peak charge rate less important than average rate for 150–200 mile range recharge.
- XFC significantly impacts BEV voltage design, which may impact other EVs.
- BEV-charging infrastructure coordination must provide consistent charge experience.

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ABSTRACT

To achieve a successful increase in the plug-in battery electric vehicle (BEV) market, it is anticipated that a significant improvement in battery performance is required to increase the range that BEVs can travel and the rate at which they can be recharged. While the range that BEVs can travel on a single recharge is improving, the recharge rate is still much slower than the refueling rate of conventional internal combustion engine vehicles. To achieve comparable recharge times, we explore the vehicle considerations of charge rates of at least 400 kW. Faster recharge is expected to significantly mitigate the perceived deficiencies for long-distance transportation, to provide alternative charging in densely populated areas where overnight charging at home may not be possible, and to reduce range anxiety for travel within a city when unplanned charging may be required. This substantial increase in charging rate is expected to create technical issues in the design of the battery system and the vehicle's electrical architecture that must be resolved. This work focuses on vehicle system design and total recharge time to meet the goals of implementing improved charge rates and the impacts of these expected increases on system voltage and vehicle components.

1. Introduction

Presently, plug-in battery electric vehicles (BEVs) are not capable of charging at rates that allow for a recharging time similar to refueling conventional internal combustion engine vehicles (ICEVs). Charging BEVs at a higher power should enable more travel and allow the driver to take advantage of lower electric fuel costs, thus improving the economics of BEV ownership. This work will explore the vehicle design considerations that require research, development, and deployment (RD&D) activities to meet the challenge of providing BEVs with similar performance to that of ICEVs. This work will include analysis of the drivetrain and auxiliary components of the vehicle with the exception of the battery cell- and pack-level considerations, though the battery system capacity and system thermal performance will be explored. In addition to this article, battery cell and pack design RD&D are described in the companion articles "Enabling Fast Charging – A Battery Technology

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Gap Assessment" and "Enabling Fast Charging – A Battery Thermal Management Gap Assessment." The economic and infrastructure challenges of charging stations to support these vehicles are discussed in "Enabling Fast Charging – Infrastructure and Economic Considerations."

In the current market, Tesla vehicles offer the fastest recharge rates with 120 kW from most of its Supercharger stations [1], though it is believed that some of these chargers can support up to 145-kW charging [2]. Porsche has demonstrated the Mission E concept vehicle, which can support up to 350 kW from a d.c. fast charger (DCFC) that operates at a d.c. voltage of 800 V. Porsche has plans to go into production with a vehicle based on this concept in 2020 [3]. Other BEVs in today's market, such as the Nissan Leaf and BMW i3 [4], have been designed around the prevailing 50-kW DCFC infrastructure [5]; however, the Chevrolet Bolt is reported to extend this power up to 55 kW [6] utilizing a DCFC with 150 A capability (or a 60-kW rating at 400 V). Meanwhile, BEVs are expected to continue supporting home and workplace charging with a.c. onboard chargers where DCFC infrastructure is expected to expand charging coverage and convenience for BEV drivers. It remains to be seen what impacts, in terms of cost to the vehicle and battery system, would be incurred to exclusively provide DCFC for refueling. However, to provide a refueling time comparable to that for an ICEV, it has been proposed that charging power will need to increase from the existing maximum of 120 kW to at least 400 kW, which we will refer to as extreme fast charging (XFC). This XFC will likely require an increased battery voltage rating from the existing 400-V consensus of passenger vehicles to reduce charging current and manage the cable size of the charger. A detailed discussion around this voltage change for the charging connector cable is included in the infrastructure and economics paper "Enabling Fast Charging – Infrastructure and Economic Considerations." In this paper, we will consider an 800- to 1000-V range as the design criterion for XFC. Table 1 defines future BEVs and compares differences between current or existing BEVs and future BEVs. The defined future BEV characteristics will be used for the analysis in this paper.

The objective of this work is to assess the impact to the vehicle due to the transitions of charging power, battery pack voltage, and battery pack capacity as proposed in Table 1. To assess this impact, the work will (1) evaluate the technical factors that limit XFC with respect to the BEV, (2) identify the factors that limit the operation of BEVs with respect to ICEVs, and (3) define key areas where the U.S. Department of Energy can play an active role in performing RD&D support for advancing the implementation of XFC capability in BEVs. In addition to surveying literature and the expertise at the Department of Energy's national laboratories, the team engaged industry to identify the key questions that need to be addressed to successfully implement XFC. These include understanding the XFC use cases and the effect on BEVs, how the BEV electrical architecture will be impacted by XFC, and finally understanding how XFC will impact the vehicle charging system design.

2. XFC use cases and effect on BEVs

Primarily, existing BEVs are charged with low power (1.4–7.2 kW) level 1 and level 2 electric vehicle service equipment (EVSE) at home and in the workplace. However, XFC can be a supplement for unplanned trips or for daily charging in regions without home or workplace access to level 2 EVSE, such as multiunit dwellings and dense urban environments [1]. Further, XFC can benefit other use cases such as long-distance travel or for taxis, commercial vehicles, and other shared fleets. We have identified the following design considerations that need to be addressed for XFC and will examine intercity travel impacts on battery capacity in the subsequent sections.

- How will these differing use cases (taxis, fleets, urban, rural, etc.) impact the frequency and duration of XFC events, and what effect will this have on vehicle design?
- How will the price of an XFC event affect whether drivers choose to charge at an XFC given no immediate travel need when level 2 EVSE is an alternative, and how does this impact vehicle design for battery life constraints and charging component design?
- Does XFC present an opportunity to allow a high level of electrification for autonomous vehicles and shared taxis?
- How can XFC handle regional differences such as electric vehicle (EV) credit, climate, and urban design in the Northeast, high commute miles in California, and rural applications?
- How does XFC affect the desired range and battery capacity of a BEV?

2.1. Intercity travel analysis for XFC

Intercity travel has been noted as the driving rational for XFC as a means to enable BEV travel that is comparable to ICEV travel. The analysis in this section will examine the travel time of existing BEVs as illustrated in the example shown in Fig. 1 for a trip from Salt Lake City, Utah, to Denver, Colorado. The methodology used for determining the charging time required for each BEV scenario in this analysis is detailed following the description of all travel scenarios, which are summarized in Table 2.

As a baseline, the trip is approximately 525 miles and takes about 8.4 h by an ICEV with one refueling stop that lasts 15 min. This stop is assumed to take about 10 min for setup, which includes activities such as taking a detour to a fueling station, waiting in a queue, setting up the dispenser, and paying, plus five minutes for fueling of the ICEV [9]. The travel times for the ICEV and all BEV scenarios in this analysis are calculated using an average travel speed of 65 mph. If the same route is driven with a 200-mile BEV, at least two charging stops would be needed to account for the shorter range of the BEV.

Starting with the 50-kW DCFC and 200-mile BEV scenario, it will take more than one hour to fully recharge a nearly empty battery. This is generally not acceptable to drivers on long trips where there

Table 1
Comparison between existing and future BEVs.

	Existing BEVs	Future BEVs
d.c. charging power	50–120 kW	>400 kW
Battery pack voltage	400 V for passenger vehicles [7] 800 V for some commercial vehicles [7,8]	800–1000 V
Battery pack capacity	20–90 kWh	>60 kWh
Vehicle range	80–300 miles	>200 miles
Charging connector	SAE J1772 CCS, CHAdeMO, Tesla	Revised CCS and CHAdeMO or a new XFC connector