

# Design of the Chevrolet Bolt EV Propulsion System

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## ABSTRACT

Building on the experience of the Chevrolet Spark EV battery electric vehicle, General Motors (GM) has developed a propulsion system with increased capability for its next generation Chevrolet Bolt EV. It propels a new larger electric vehicle with significantly greater electric driving range. Through extensive analysis the primary propulsion system components, which include the drive unit, traction electric motor, power electronics, energy storage, and on-board charging module, were optimized individually and as an integrated system to deliver improvements in propulsion system energy, power, torque and efficiency. The results deliver outstanding EV range and fun-to-drive acceleration performance.

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## INTRODUCTION

Battery electric vehicles (BEVs) have made sporadic inroads into the light-duty vehicle market since the start of the automotive industry over a century ago. Within the last five years, a new generation of BEVs has emerged, offering useful range for most commuters and a smooth and responsive driving character.

The Chevrolet Spark EV [1, 2], introduced in the US, Canada and Korea in 2014, is an excellent example of that generation. With an EPA label range of 82 miles, 0-60 mph acceleration under 7.5 seconds, and the ability to charge from a 50 kW DC station, the Spark EV is an affordable and fun-to-drive second car with exceptionally low operating cost and no tailpipe emissions.

To bring BEVs to a wider audience of mainstream customers, the Chevrolet Bolt EV must virtually eliminate "range anxiety" by greatly increasing driving range, while building on the strong performance of the previous generation. Key to achieving that goal is a propulsion system that can combine high levels of stored energy, efficiency, power and torque. This paper describes how the propulsion system for the Chevrolet Bolt EV was defined, starting from a challenging set of requirements that included enabling a 200 mile range, comparing design alternatives, and optimizing it through rigorous analysis.

## KEY REQUIREMENTS

The key requirements of the propulsion system for the Chevrolet Bolt EV were to significantly increase driving range and to maintain or exceed the excellent acceleration performance of the Chevrolet Spark

EV, when applied to a larger vehicle platform. Table 1 presents some of the main vehicle requirements of the Chevrolet Bolt EV at nominal conditions.

As seen in Table 1, the Chevrolet Bolt EV was targeted to be larger than the Chevrolet Spark EV, yet with improved performance, grade launch capability and, most importantly, driving range, exceeding a US Environmental Protection Agency (EPA) rating of 200 miles. The 200 mile target was developed based on the real customer driving data analysis of the Chevrolet Spark EV and the General Motors range-extended electric vehicle, Chevrolet Volt. That data suggested that a BEV with 200 miles of range could almost completely eliminate "range anxiety" for the vast majority of customers in daily driving situations.

Table 1. Vehicle Performance Requirements

|                  | Units | Chevrolet Spark EV | Chevrolet Bolt EV |
|------------------|-------|--------------------|-------------------|
| Vehicle Class    |       | A                  | B                 |
| Curb Mass        | Kg    | 1342               | 1625              |
| 0 – 60 mph       | Sec   | 7.5                | Under 7           |
| 0 – 30 mph       | Sec   | 3.1                | 2.9               |
| Max launch grade | %     | 28                 | 30                |
| EPA Label Range  | Miles | 82                 | 200+              |

The performance of the vehicle is also dependent on the ambient temperature and the battery energy level. Since the battery is optimized to support a large capacity, it is designed to use a large voltage range. As the remaining battery energy decreases, the battery

voltage decreases, which causes the power capabilities of both the battery and the motor to decrease. In addition to the nominal condition, performance requirements were defined to include this power diminishing effect and targeted to offer excellent driving experience for the customer even when the remaining battery energy was low. Figure 1 presents the acceleration requirement over the traveled distance.

To meet these key vehicle requirements the propulsion system had to be lightweight, compact, quiet, and robust to different driving conditions, including hill climbing, high-speed passing, extended freeway driving and operation in hot and cold temperature extremes.

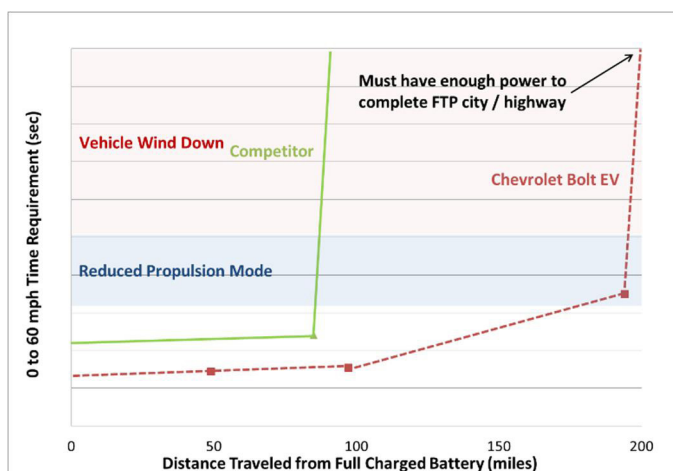


Figure 1. Vehicle Performance Requirement over Driving Range

## SYSTEM DESIGN

The first task in the system design was to convert vehicle requirements into propulsion system requirements. The greatly improved driving range depended on high overall system efficiency together with a large increase in battery energy capacity, but the increased battery capacity led to a larger and heavier battery pack. This and the larger targeted vehicle platform in turn led to an increase in total vehicle mass. To maintain or exceed acceleration performance therefore required a propulsion system with higher maximum torque and power capability than that of the Chevrolet Spark EV.

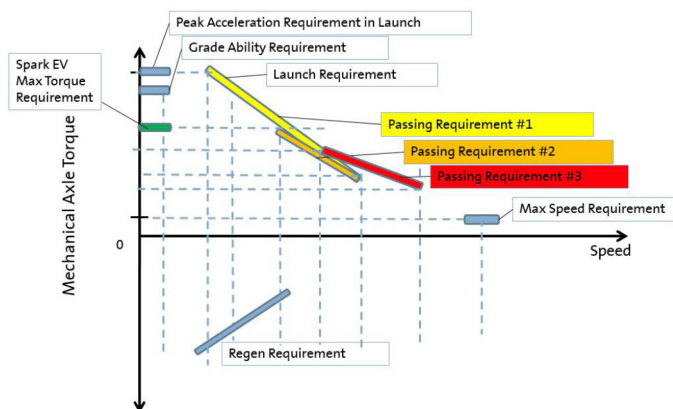


Figure 2. Drive Unit Axle Torque Requirements

Figure 2 shows the critical performance requirements and the corresponding torque/power required at the driven axle. Different performance targets (Vehicle launch, grade-ability, passing, regenerative braking, etc.) set torque requirements at different speeds. When combined, they became the torque envelop requirement. To achieve this level of axle torque and power, various combinations of inverter/motor pairs, associated drive unit designs, and gear ratios were considered.

Figure 2 also illustrates that the max torque requirement was greatly increased from that of the Chevrolet Spark EV. A higher motor to wheel ratio was necessary to deliver that higher peak torque. Since the Chevrolet Spark EV's planetary gear design was not able to achieve this high motor torque multiplication, alternative gear architectures were evaluated. In the end, an offset gear arrangement offered the best balance between performance and efficiency for the Chevrolet Bolt EV.

A Design for Six Sigma (DFSS) optimization process [3] was followed which considered several major design control factors as inputs. Key vehicle performance metrics, EV range, and grade launch capability were selected as responses to be measured. The battery temperature, energy variation effects and vehicle mass were considered as noise parameters in this design process (see Figure 3).

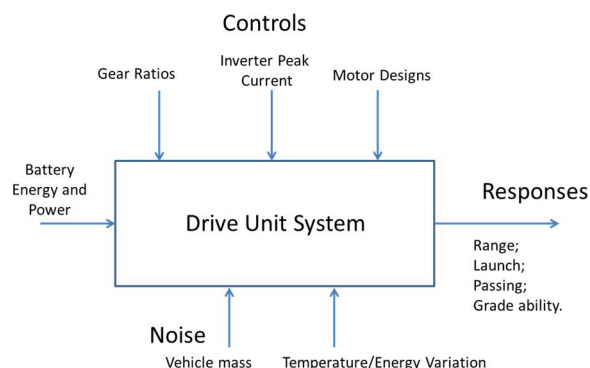


Figure 3. Design Optimization Setup

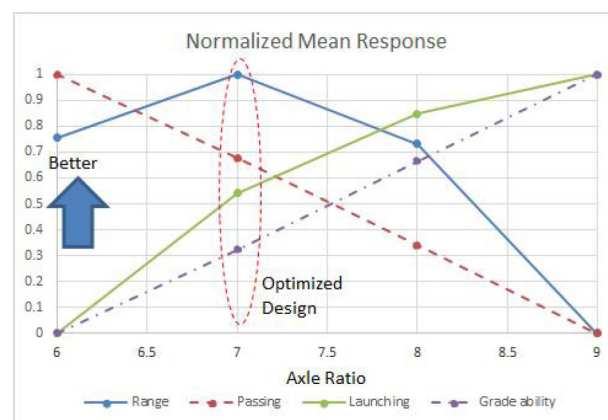


Figure 4. Axle Ratio Response Results in Design Optimization Process

The DFSS process was used to rigorously evaluate the design tradeoffs and achieve the optimal solution. For example, the analysis determined that, as gear ratio increased, launch acceleration and maximum grade capability improved (more torque) but high speed passing performance decreased. Ultimately, the gear ratio that offered the best balance between EV range (system efficiency) and overall vehicle performance was selected (see Figure 4). The selected design was determined to be the most robust for meeting all requirements over a wide temperature range and different vehicle masses. The DFSS process was used iteratively in combination with optimization for cost and packaging, performed in parallel. These factors often brought new constraints into the design process and a new tradeoff was required that resulted in further fine adjustments to the system design.

After all these factors were considered and thousands of simulation analyses were evaluated, the final architecture of the propulsion system was selected for the Chevrolet Bolt EV. As seen in Figure 5, the end result was that the propulsion system of the Chevrolet Bolt EV provides a much improved axle torque and power capability across the entire axle speed range compared to that of the Chevrolet Spark EV.

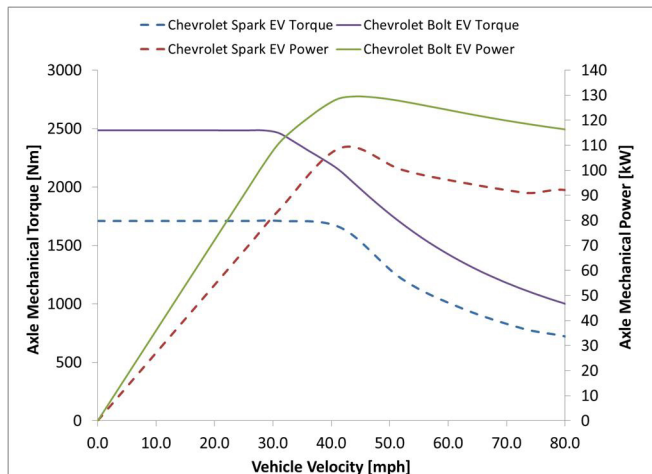


Figure 5. Axle Torque and Power Comparison between the Chevrolet Spark EV and the Chevrolet Bolt EV

The greatly increased EV range capability and performance improvement of the overall propulsion system rely not only on an optimized system design but also on improvements in each component of the propulsion system. In the following sections design improvements are explained for the battery, drive unit, electric motor, and power electronics.

## BATTERY

One of the key components for the Chevrolet Bolt EV propulsion system is the rechargeable energy storage system (RESS), commonly known as the battery pack. It provides a high voltage (HV) source of propulsion power and energy. The battery pack had to balance the need for high energy, power, and efficiency in a compact, lightweight package.

Table 2. Design Optimization Strategy and Enablers

|                                                                 |
|-----------------------------------------------------------------|
| Packaging/Space Utilization Optimization                        |
| Cell and Bi-cell Format Optimization                            |
| Power and Energy Ratio Optimization                             |
| Chemistry Selection                                             |
| Active Cooling and Heating Optimization                         |
| Safety and Crash Regulation Requirement with Optimized Topology |

To ensure a robust, well-balanced design capable of meeting these requirements, the process demanded an execution of design optimization strategies and enablers. (As shown in Table 2).

The optimization steps were:

1. **Packaging/Space Utilization Optimization:** The goal of the RESS internal design was to maximize usage of its internal space without compromising the integrity and robustness of the overall system. A distributed electrical system approach was used to balance the package space utilization between under body and under hood locations. Components (e.g., RESS heater, etc.) which are normally integrated into the battery pack were packaged to the under hood location to maximize the amount of space for battery cells.  
From the layout standpoint, the pack has five sections in total. A DC bus bar assembly is installed from each section to another and is looping through the entire pack to create HV circuit. A manual service disconnect (MSD) is placed to have RESS ability to disconnect from the propulsion system before the service. A battery disconnect unit (BDU) is used to control relays, fusing and current sensing function. It has the ability to activate the HV bus by bringing the HV Battery online in a safe, quite manner while providing isolation to chassis during all possible vehicle conditions. BDU also provides HV accessory load fusing and HV Battery Pack current sensing for state of charge and health monitoring.
2. **Cell and Bi-cell Format Optimization:** The cell and bi-cell design configuration was critical to the pack module's desired amount of power and energy. With a fixed amount of pack space available, it was essential to have the right number of modules/cells/bi-cells and to confirm that the required amount of power and energy could be achieve simultaneously. There are total 288 cells in the pack. The pack consist of 5 sections in total and each section has two modules. The amount of cells are evenly distributed within each of two modules. There are 96 cell groups in total and 3 cells per group.
3. **Chemistry Selection:** Selecting the right cell chemistry for EV batteries has a significant impact on both cost and performance. The amount of power and energy required for different vehicle applications is directly linked to the chemistry of the battery cell. These fundamentals characteristics were carefully examined from both material science and engineering design perspectives. The potential and limitations of various cell components (e.g. positive electrodes, negative electrodes,