

# Maximizing efficiency in EV charging with Eaton's battery configuration switch

## Abstract

An oft cited concern about the transition to electric vehicles (EVs) is the availability of high speed Direct Current Fast Charging (DCFC) infrastructure to enable convenient travel beyond the single charge range of today's vehicles. Many OEMs are considering a move to 800V architecture from the widely available 400V platforms of most mass market EVs. While this can have benefits to both vehicle efficiency and charging speed, it comes with a problem: much of the installed high power DCFC infrastructure in the U.S. and Europe is limited to 400 volts, necessitating additional, costly equipment for an 800V vehicle to properly interface. Eaton's Battery Configuration Switch (BCS) addresses this challenge with an innovative solution integrated into the EV battery pack. Designed for passenger and light-duty commercial vehicles, the BCS is a bi-stable device that efficiently transitions pack voltage between 400 and 800 volts to maximize charging speed on all publicly available infrastructure.

In its normal operating mode, the BCS connects two 400V sub-packs in series to achieve 800 volts. When reduced voltage is needed, it reconfigures the battery into two parallel 400V sub-packs, allowing the EV to charge efficiently on 400V DC fast chargers. This reconfiguration capability eliminates the need for multiple contactors, busbars, and harnesses, reducing cost and complexity while enhancing charging performance.

The BCS also enhances safety by using an internal rotary switch to prevent short circuits from collisions, software bugs, or contactor malfunctions. It maintains a stable position without low voltage hold current, improving vehicle efficiency and ensuring functionality even if low voltage power is lost.

Eaton's BCS represents a significant advancement in EV technology, offering a robust, efficient, and cost-effective solution for battery pack voltage reconfiguration, underscoring Eaton's commitment to innovation and excellence in power management.

## Introduction

The transition to electric vehicles (EVs) represents a pivotal shift towards a more sustainable and environmentally friendly future. However, despite the numerous benefits of EV adoption, several challenges remain, particularly in the realm of public charging infrastructure. The availability and accessibility of public charging stations are critical factors that influence consumer confidence and the widespread adoption of EVs.

To compound this concern, most early mass market EV platforms have used a nominal voltage under 400V DC, but many Original Equipment Manufacturers (OEMs) are looking to increase the voltage of their vehicle platforms. Increasing system voltage can be a virtuous circle for many key performance metrics of an electric vehicle. It can simultaneously increase performance and efficiency. But one major problem is that a significant amount of publicly available charging infrastructure is limited to 400V output since they were designed with those early vehicle platforms in mind.

This paper aims to explore these challenges of EV and EV charging incompatibility in detail, while also highlighting an innovative solution to maximize the performance of a higher voltage EV platform regardless of the EVSE's voltage. Improving charging performance and accessibility will ultimately foster a more robust and user-friendly EV ecosystem.

## What is DC fast charging

Most consumer EVs are charged on either Level 1 (110V AC) or Level 2 (220V AC) Electric Vehicle Supply Equipment (EVSE or chargers) that utilize an Onboard Charger (OBC) in the vehicle to convert Alternating Current (AC) power from the grid to Direct Current (DC) power that can be stored in the vehicle's high-voltage battery system. These charging methods limit power to less than 20kW because of the OBC within the vehicle and typical household AC circuits. **DC fast charging** on the other hand is a high-powered method of charging EVs that significantly reduces the time needed to recharge compared to standard Level 1 and Level 2 chargers by directly supplying the vehicle with the DC power it can store. Here's how it works and why it's important:

### How DC fast charging works

- **Direct Current (DC) delivery:** Unlike Level 1 and Level 2 chargers that supply Alternating Current (AC) power, which the EV must convert to DC for storage, DC fast chargers deliver DC power directly to the battery. This bypasses the vehicle's OBC, allowing for much faster charging.
- **High power output:** DC fast chargers can provide power levels ranging from 50 kW to 350 kW, enabling rapid recharging of EV batteries. For example, a typical DC fast charger can replenish an EV battery from 20% to 80% in 10-30 minutes.

### Importance of DC fast charging

1. **Speed and convenience:** The primary benefit is the significant reduction in charging time. This makes it feasible for EV owners to quickly recharge during long trips or busy schedules, minimizing downtime.
2. **Long-distance travel:** DC fast charging is crucial for enabling long-distance travel in EVs. It alleviates range anxiety by providing quick top-ups at strategically located charging stations.
3. **Increased EV adoption:** The availability of fast charging infrastructure is essential for the broader adoption of EVs. It makes EVs more practical for a wider range of users, including those who may not have access to home charging.
4. **Fleet efficiency:** For commercial fleets, DC fast charging allows for faster turnaround times, increasing operational efficiency and reducing vehicle downtime.

### Why 800V

Many consumer surveys cite charging speed and charger availability as primary concerns of EV adoption. Vehicle OEMs are constantly seeking to improve charging performance in order to help ease these concerns and improve the overall experience of owning an EV.

The voltage level of the EV has a tremendous effect on its performance, efficiency and charging speed. While most current generation EVs are 400V, some OEMs are exploring 800V architecture to tap into this virtuous cycle of improving performance and efficiency.

1. **Faster charging:** One of the primary advantages is the ability to support faster charging times. With 800V systems, EVs can charge more quickly when using compatible high-power chargers, reducing the time spent at charging stations. As shown in Figure 1, DC fast chargers are often limited by current (ex. 500A). An 800V EV can charge at twice the power for a given amperage.
2. **Improved efficiency:** Higher voltage systems can deliver the same power with lower current, which reduces energy losses due to heat. This increased efficiency can lead to better overall vehicle performance and longer battery life.

3. **Weight reduction:** By operating at a higher voltage, the electrical components, such as wiring and inverters, can be designed to be lighter. This reduction in weight can improve the vehicle's range and handling.
4. **Enhanced performance:** Higher voltage allows for greater power delivery to the electric drive motor, which can improve acceleration and regenerative braking capabilities. Figure 1 shows how a 400V EV requires twice the amperage as an 800V vehicle to achieve the same driving power and performance.

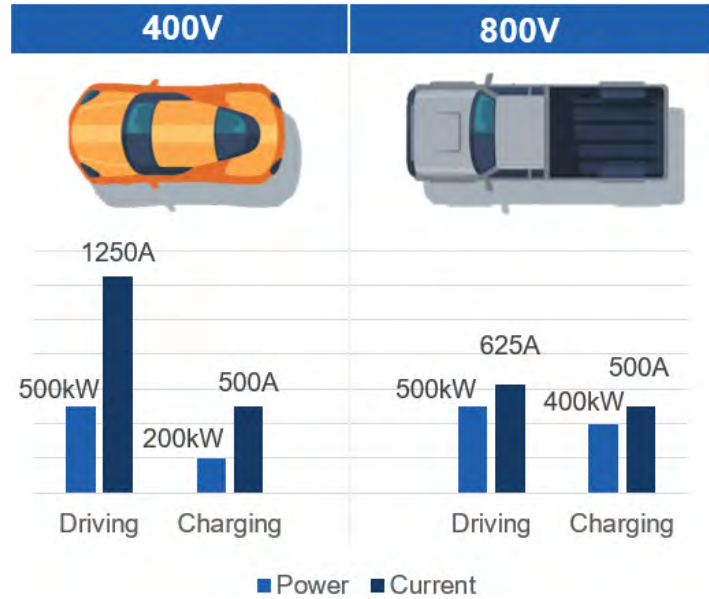


**Figure 1. Shifting to 800V can improve both driving and charging performance**

Overall, the shift to 800V architecture is seen as a key step in advancing EV technology, making electric vehicles more efficient, faster to charge, and potentially lighter and more powerful.

### State of DC fast charging infrastructure

Since DC fast charging is performed by the EVSE matching the vehicle voltage and dispensing DC power directly into the EV battery, an 800V vehicle is unable to charge at a 400V charger without some additional form of assistance (Figure 2).

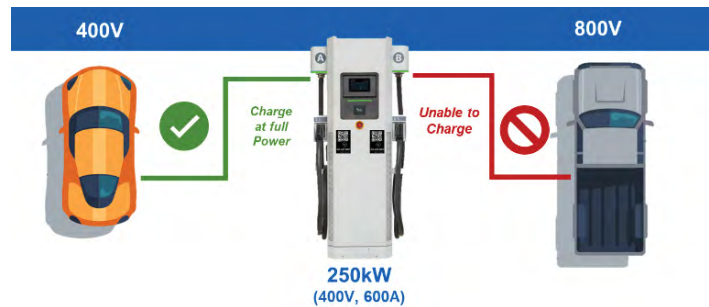


**Figure 2. An 800V EV cannot charge at a 400V EVSE without additional hardware**

The exact number of publicly available 800V DC fast charging stations is not readily available in the latest updates. However, the overall infrastructure for DC fast charging is expanding rapidly. As of Q3 2024, the US has nearly 192,000 public Level 2 and DC fast charging ports. This includes a growing number of high-power chargers that support 800V systems, especially as more EV manufacturers adopt this architecture.

One of the largest public charging networks in the United States and Europe is the Tesla Supercharging Network. Most Tesla superchargers (V2 and V3) are limited to 400V. As Tesla opens

its network to more OEMs, the public will have access to a large number of high-powered chargers that are limited in their ability to support 800V EVs. This means that an EV that does not have the ability to charge on a 400V DC fast charger would have a severely limited choice when it comes to public charging.

### Alternative ways to boost voltage

There are three strategies an EV can use to allow an 800V architecture to charge on a 400V EVSE. Each has limitations or compromises that must be considered, and implementation requires dedicated hardware on the vehicle.

#### Onboard DC/DC boost conversion

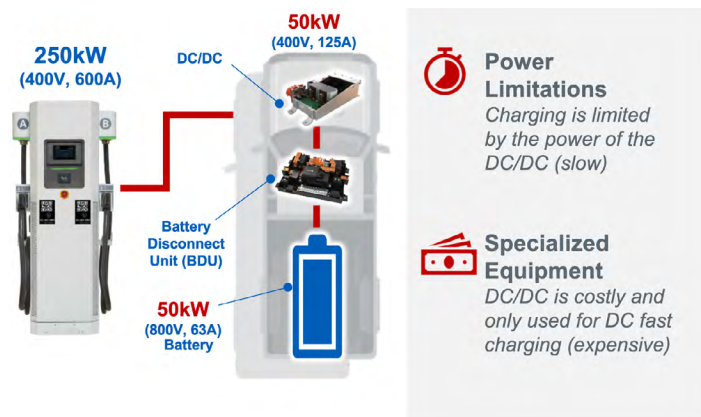


**Figure 3. Onboard boost conversion**

An EV can use a dedicated DC/DC converter to perform voltage boost conversion, stepping the charger voltage up to the required pack voltage. Figure 3 depicts the required DC/DC converter that must be included in the EV. This standalone hardware can be expensive, and the charging power will be limited by the power level of the converter used.

#### Onboard traction inverter as boost conversion

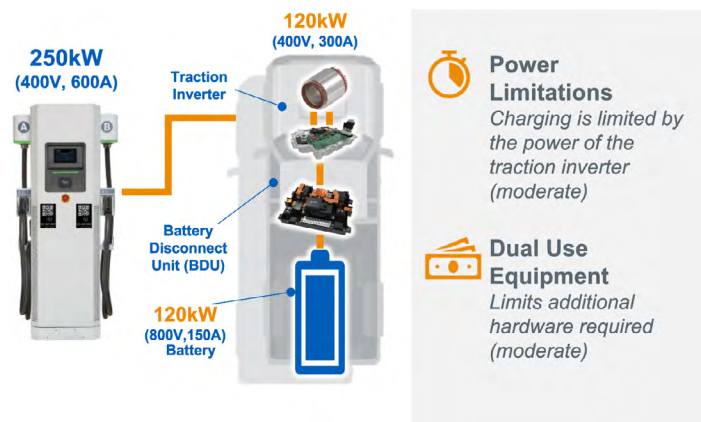


**Figure 4. Onboard traction inverter for boost conversion**

A potentially more economic means of boosting voltage can be to use the existing traction inverter module as the boost converter. Figure 4 shows this architecture layout which requires dedicated switching hardware to ensure the drive inverter and charging paths are isolated when not in use for boost conversion. The advantage is that most of the hardware is dual purpose, which reduces cost but it is still limited by the power level of the power electronics.

### Battery pack splitting and reconfiguration

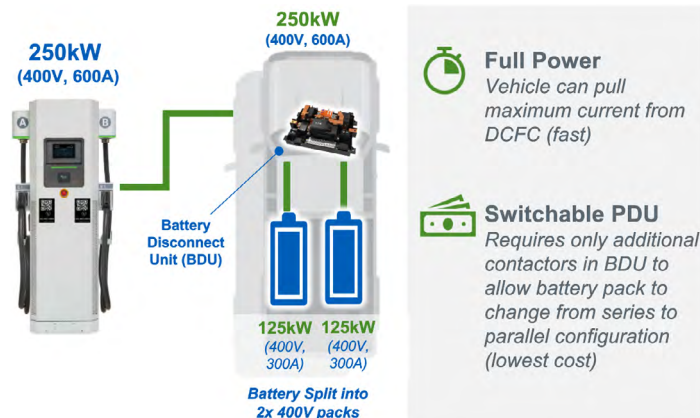


**Figure 5. Split pack voltage switching**

The final option is to use dedicated switching hardware within the battery pack to be able to change the series/parallel configuration of the EV's battery. Figure 5 shows this architecture using the EV's Battery Disconnect Unit (BDU) to divide the 800V battery into two virtual 400V batteries that can be charged directly by the EVSE. This method allows the battery to utilize the full amperage of the EVSE. Some considerations are that the virtual battery strings must stay in close voltage alignment and dedicated hardware is required in the BDU to safely perform this switching.

#### Eaton's battery configuration switch

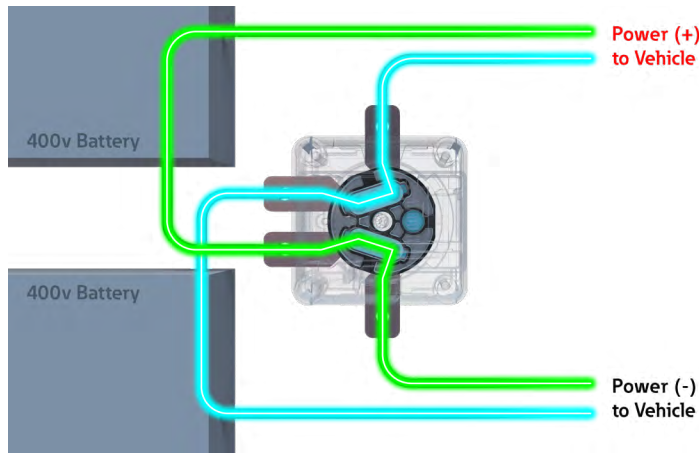
Eaton has introduced the Battery Configuration Switch (BCS), a dedicated single component that can be designed into an EV's BDU to safely transition battery pack voltage from 400V to 800V.



**Figure 6. Eaton's Battery Configuration Switch (BCS)**

The BCS consists of a rotary table with internal busbars that can configure the two halves of an 800V battery pack either in series (800V) or in parallel (400V) (Figure 6). The BCS can also be stopped mid transition to offer a 3rd state with total isolation. This can be used to replace traditional contactors in the EV architecture while maintaining isolation requirements.

#### 400V configuration (parallel)



#### 800V configuration (series)

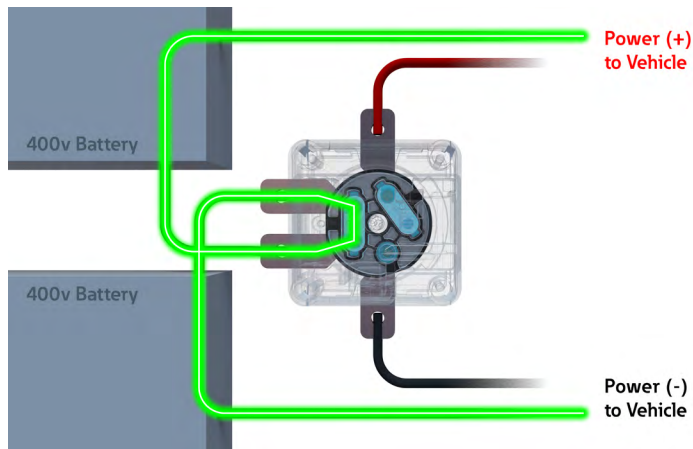


**Figure 7. BCS rotates to change from series to parallel configuration**

The conventional method of performing pack split voltage switching is to use three traditional contactors that must be selectively controlled to change from series to parallel (Figure 8). Replacing these three contactors with a single BCS (Figure 9) can simplify the BDU's mechanical design, eliminating multiple fasteners, busbars, and control harnesses. Additionally, the rotating nature of BCS also means that it is mechanically impossible to connect all sides of the device simultaneously, preventing the risk of a short current fault condition.

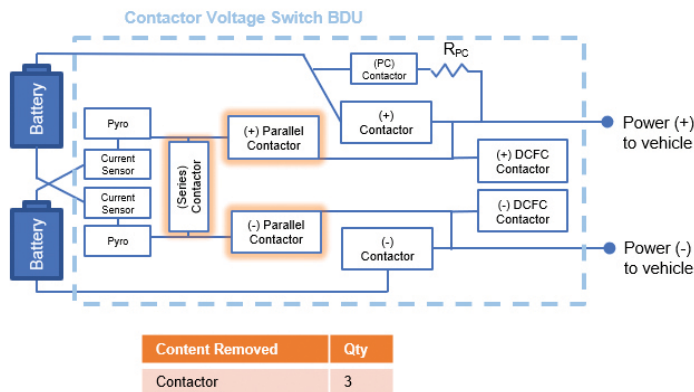


**Figure 8. Contactor based switchable BDU**

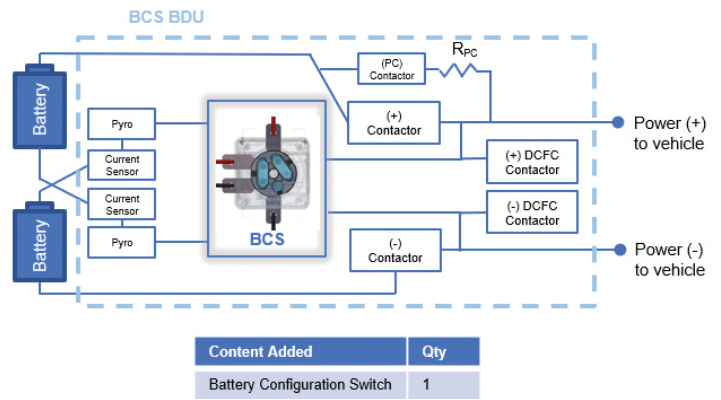


**Figure 9. BCS based switchable BDU**

BCS is a bi-stable device meaning that it does not require hold current to maintain configuration. This can improve efficiency and increases functional safety because the device will not change states in the event of a loss of 12V power. The device transitions through an off state each time it is commanded to move (Figure 10). This, combined with diagnostics, ensures that the device is never moved into a fault condition incidentally.

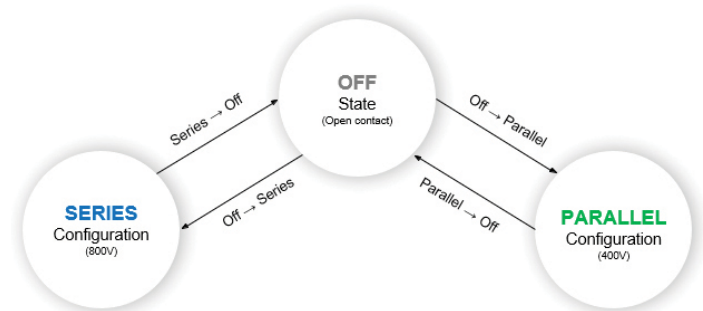


**Figure 10. BCS must pass through an off state when changing configuration**

#### Summary

Many EV manufacturers want to increase charging speed and performance while maintaining access to the broadest network of available charging stations. In order to accomplish this, they must design vehicles with the ability to charge on all DC fast chargers. Eaton's Battery Configuration Switch (BCS) allows 800V EVs to charge at maximum efficiency on any available EVSE with one innovative device that is added to the EV battery pack.

Underscoring Eaton's commitment to innovation and excellence in power management, the BCS represents a major step forward in electric vehicle technology.



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