35th International Electric Vehicle Symposium and Exhibition (EVS35)
Oslo, Norway, June 11-15, 2022

Requirements for the high voltage system disconnection procedure to improve serviceability of future EVs

Aljoscha Einspiegel[1], Norbert Schreier[1], Ludwig Seibt[1]
[1]*Esslingen University, Germany,*
Department of Mobility and Technology
(norbert.schreier@hs-esslingen.de)

Executive Summary

Disconnecting the high voltage systems is a basic task technical staff has to perform on electrified vehicles (EVs) for several maintenance and repair works on a very regular basis. Therefore, the procedure is crucial for serviceability as well as for cost-of-ownership of EVs. Although standardized in three steps, the procedure shows a wide range of application variants for different models. Our research addresses this issue by inspecting safety and legal requirements, analyzing recent studies and evaluating selected production cars. The goal is to identify requirements for an optimal solution of the high voltage (HV) disconnecting procedure.

Keywords: After Sales, EV, Case Study, Maintenance

1 Introduction

For many workshop tasks, it is required to deactivate the high voltage (HV) system due to reasons of occupational safety. The procedure usually takes place in an after sales service workshop. The form of the process is vital for the serviceability of EVs and critical for cost-of-ownership and customer satisfaction.

A survey of in-use EVs in 2017/2018 showed remarkable differences between several models and revealed immense potential for improvement [1]. Therefore, this study analyses the procedures for next generation EVs to identify vital requirements for an optimal solution.

2 Methodology

Figure 1 below illustrates the methodology of the research project. First step is a basic analysis of the relevant legal and occupational safety requirements. In a second step, we select a sample of current electric production cars. These will be inspected to find out which methods are primarily used for the high voltage system disconnection of the current EV generation. The second step is to briefly identify and review legal requirements and those for occupational safety. With this information on hand, we proceed to pinpoint typical maintenance and repair tasks and their requirements for the HV disconnection procedure.

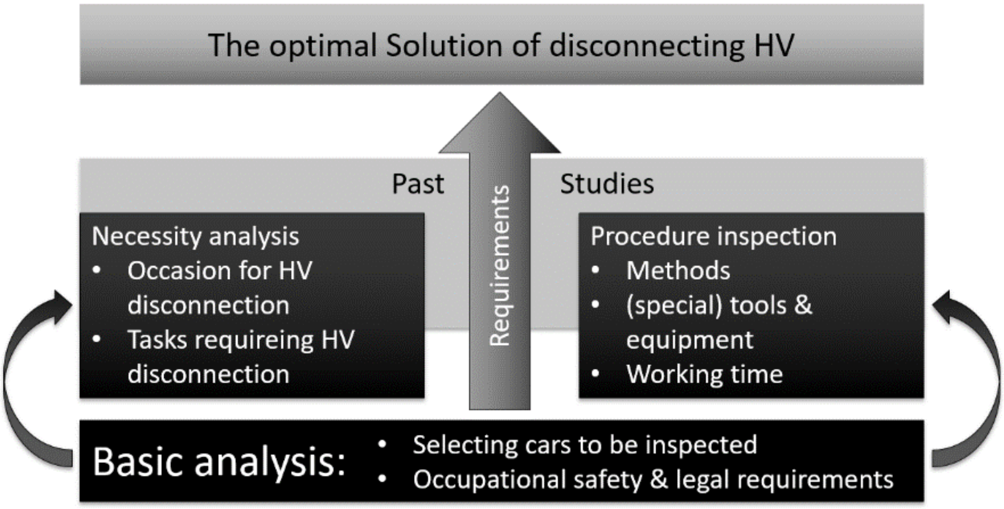

Figure 1: Study Layout

This considers typical after sales occasions and unexpected road site incidents as well. All those situations have particular requirements on the HV disconnection procedure. These are to be identified at this point and transformed into criteria for assessment. Next, the different procedures of the selected vehicles are assessed based on these relevant criteria. At this point, the information of past studies discussing slightly older EVs compliments the investigation. In the final step, we outline a proposal for an effective and efficient HV disconnecting procedure for future EV-generations.

3 Basic analysis

3.1 Occupational safety and legal requirements

Although the rules vary in different markets, many of them are based on international standards. Hence, we inspected the legal directives applied to Germany. The German standards DGUV-I 209-093 DGUV-V1 and DGUV-V3 build on DIN VDE 0105-100 which itself is based on the international EN 50110-1 and EN 50110-2. [2] Overall, the OEMs' implementation of specific occupational safety and legal requirements is very similar for a wide range of markets.

3.2 Selection of vehicles

As described, the study presented at the EVS 31 showed the HV disconnecting processes of various vehicle types from different manufacturers. In course of this, a number of differences were identified in the processes, e.g. the use of special tools and the process duration [1]. Now further recent production passenger cars that are as up-to-date as possible and available on the market are investigated. Vehicle 1 and 3 are fully electric Sport Utility Vehicles (SUV) from German manufacturers. Vehicle 2 is a fully electric vehicle from the sports car segment of a German manufacturer and vehicle 4 is a SUV from an American manufacturer. All cars have four-wheel drive.

4 Necessity analysis

4.1 Occasions and circumstances

Although standard procedures in the inspected documents expect the vehicle to be in a workshop, there exist other circumstances for HV disconnection. On the one hand we see emergency disconnection after a road accident to ensure a save evacuation of passengers. First responders perform those procedures following vehicle specific first responder guides. Since those procedures involve cutting and damaging wiring, they are not part of this study. On the other hand, roadside assistance personnel need to deactivate the HV system on a broken down vehicle enabling on site repairs without causing further damage. Hence, criteria as the need for a car lift or other special equipment and accessibility of the service plug are important.

4.2 Criteria for examination

Previous studies have shown that the main differences are in the use of special tools, workshop equipment, off board diagnostic systems, the process duration and the effort to execute the procedure [1], [3], [4], [5] & [6]. These differences lead to six criteria (shown in table 1) for the examination of the vehicles.

Table 1: Criteria for assessing the efficiency of high voltage system disconnecting procedures

Criteria	Best value	Worst value
Need for special tools	Standard tools only	Many model specific special tools needed
Accessibility of the service plug	Directly accessible in the car's interior	Plug is located behind lids and other components
Need for a car lift	Not necessary at all	Strictly required
Effort for process execution	Small number of work steps	Numerous mechanical and electrical work steps
Process duration	Several minutes	More than one hour
Need for off board car diagnostic system	Not necessary at all	Strictly required

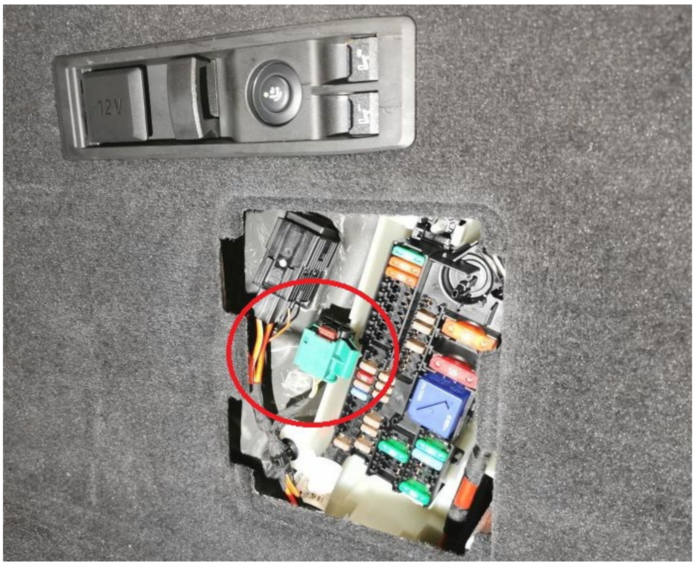

Figure 2: Easily accessible HV service plug in the trunk

5 Procedure Inspection

There are three basic steps to disconnect the high voltage system on electrified vehicles [2]:

1. Disconnecting the high voltage system
2. Securing against reactivating the high voltage system
3. Determining the voltage free status.

Applied to one individual EV model – see figure 3 as an example Mercedes-Benz EQC – , the procedure can be modelled in many different ways [3], [4].

Figure 3: Disconnecting HV System of a Mercedes EQC

5.1 Methods of disconnecting the HV systems

Each of the three steps mentioned above can be performed differently. From this point, emergency procedures for first responders will not be considered. The first step represents the actual deactivation of the HV system. One way is to open the pilot line by opening a small service disconnect plug. In consequence, the HV contactors (usually located within the battery system) will open resulting in voltage free status of the system. Another way to open the pilot line is to deactivate the low voltage system by disconnecting the negative terminal of the 12V battery. The result is virtually the same as if the service disconnect is unplugged. The third option is a bigger service disconnect plug that has several disengagement stages. The last stage here technically disconnects the two halves of the battery bisecting its voltage. One previous stage disconnects the pilot line as well. This leads to disengaging the main contactors preventing a possible electric switching arc. A final type of execution is to use an off board diagnostic system. After connecting the system to the vehicle the deactivation is triggered by the off board system only without even touching the vehicle.

The method of securing against reactivating the HV system depends on the disconnection method. Service plugs that are disengaged from the system after opening should be stored safely and an insolated dummy plug can cover the remaining open socket on the system. A padlock blocks service plugs that cannot be detached from the socket to make simple reconnecting impossible. Three ways to determine the voltage free status of the vehicle are possible. In the first solution, the vehicle itself shows the information with a message on the driver's display. Another option is to check the status with an off board diagnostic system. The third variant utilizes a manual measurement of voltage on HV fasteners or terminals requiring a high voltage capable measuring tool and personal protective equipment.

Multiple combinations of methods for the three step are possible and utilized by the OEMs. Further OEMs offer multiple methods for the steps for the same model. This enables the executing staff to react on the condition of the vehicle as well as the circumstances accompanying the occasion.

5.2 Comparison of HV deactivation procedures

As shown in Table 2, the analysis of the HV disconnecting processes of the selected vehicles is based on the criteria described in chapter 4.2. For vehicle 1, the process is carried out without the use of any special tools nor a diagnostic system. Only a padlock is needed to lock the service plug to secure the system against reactivating. This results in a low effort for the process execution because of the small number of work steps that have to be done, which is reflected in the low time requirement of 5 min for this particular process.

Special tools are also not required for vehicle 2. Furthermore, no padlock is needed, as the deactivation is completely automated via the off board diagnostic system and no service plug has to be disconnected for the standard HV deactivation procedure. However, the use of the diagnostic tester results in a higher time demand, which also applies to vehicle 3. On this vehicle, the deactivation process is similar to that on vehicle 2, but a service plug must be disconnected and secured with a padlock. For vehicle 4, only a manual deactivation without the use of a diagnostic system is provided. The associated work steps, such as the disassembly of HV housing covers, require the wearing of personal protective equipment (PPE). Furthermore, the determination of the voltage free status needs an insulation multimeter. The comparatively high number of works steps leads to a high effort for the process execution.

Overall, it can be seen that, compared with previous studies [1], none of the vehicles examined requires a car lift to carry out the deactivation process.

Table 2: Comparison of HV disconnecting procedures

High voltage system disconnection	Vehicle 1 (BEV) (2021)	Vehicle 2 (BEV) (2021)	Vehicle 3 (BEV) (2021)	Vehicle 4 (BEV) (2015)
Need for special tools	-	-	-	insulation multimeter, PPE
Accessibility of the service plug	easy access	no service plug*	easy access	easy access
Need for a car lift	-	-	-	-
Effort for process execution	low	medium	medium	high
Need for off board car diagnostic system	-	✓	✓	-
Process duration	5 min	38 min	30 min	N.N.
(✓) = required (-) = not required PPE = Personal Protective Equipment *for standard HV-disconnection process				

5.3 Tasks requiring deactivation of the HV systems

In order to obtain an overview of the activities for which a HV disconnection is needed, selected repair tasks were analyzed as shown in table 3. Based on the repair instructions of the vehicle manufacturers, it was inspected whether a HV disconnection is required or not. It has been shown that for mechanical work directly on HV components, e.g. refrigerant compressor, or in their immediate vicinity, a disconnection is always mandatory. In some cases, a disconnection is required for certain mechanical work tasks that are not directly related to the HV system, e.g. because a HV component has to be removed or a HV connection plug has to be disconnected during the associated preparatory work. An example for this is the replacement of the front axle shaft on vehicle 2 and 4.

Table 3: Selected work tasks

Replacement of selected parts/assemblies	Vehicle 1 (model year 2021)	Vehicle 2 (model year 2021)	Vehicle 3 (model year 2021)	Vehicle 4 (model year 2015)
HV charger	✓	✓	✓	✓
HV battery	✓	✓	✓	✓
refrigerant compressor	✓	✓	✓	✓
axle shaft (front)	–	✓	–	✓
axle shaft (rear)	–	–	–	–
brake pads and discs	–	–	–	–
driver airbag	✓	–	–	–
front door	–	–	–	–
front bumper	–	–	–	–
(✓) = HV system disconnection required (–) = HV system disconnection not required				

6 Conclusion

In practice, the variety of high voltage system disconnection procedures is decreasing. Simultaneously the complexity of the process itself decreased and none of the investigated vehicles requires a car lift for the procedure. This can be deemed as result of the shift from conversion to purpose design of EVs in the last years.

In this study, several requirements were identified to improve the serviceability of EVs. Since an optimal solution has to be safe, easy and quick to perform, the most crucial requirements are the effort for the process execution that is a result of the complexity of the process, and the process duration. In addition, the process is easier if it does not involve the use of external diagnostic systems, special tools or a car lift.

This investigation showed that vehicle 1 offers the best high voltage system disconnection process compared to the other vehicles. This procedure could be the target model for future EVs. Moreover, in terms of occupational safety it is desirable that this particular procedure will become a template for an industry standard for deactivating the high voltage system on all future EVs.

References

[1] N. Schreier et al, *Maintenance and Repair Impacts on Electric Vehicles,* presentation at Electric Vehicle Symposium - EVS 31, Kobe, Japan, 2018. Conference.

[2] Deutsche Gesetzliche Unfallversicherung e.V. (DGUV): *DGUV Information 209-093: Qualifizierung für Arbeiten an Fahrzeugen mit Hochvoltsystemen*, https://publikationen.dguv.de/widgets/pdf/download/article/3982, accessed on 2021-12-13.

[3] BMW AIR: *De-energise the high-voltage system*, repair instruction no. REP-REP-RAI0161-6125900 - V.6., accessed on 2021-11-23.

[4] Mercedes-Benz WIS: *Deenergize high-voltage on-board electrical system/put high-voltage on-board electrical system into operation*, repair instruction no. AR47.70-P-1000EQ, accessed on 2021-11-23.

[5] BMW AIR: Flat Rate Units: *Disconnecting high-voltage system*, workshop flat rate unit no. 61 25 900, accessed on 2021-12-16.

[6] Mercedes-Benz ASRA: *Carry out power disconnect on high-voltage on-board electrical system (After quick test)*, workshop flat rate unit no. 47-9300-01, accessed on 2021-12-16.

[7] Mercedes-Benz WIS: *Manually deenergize high-voltage on-board electrical system*, repair instruction no. AR47.70-P-1010EQ, accessed on 2021-11-23.

Authors

Norbert Schreier is Vice Dean and Academic Director of the faculty Mobility and Technology at Esslingen University of Applied Sciences, Germany. On behalf of BMBF/DAAD he coordinates the Sino-German double-degree study program Automotive Technology at the CDHAW at Tongji University, Shanghai.

Aljoscha Einspiegel, Research Assistant at the Center for Automated Driving and Service Technology (CAST), Esslingen University of Applied Sciences, Germany

Ludwig Seibt, Research Assistant at the Center for Automated Driving and Service Technology (CAST) and Laboratory for Vehicle Electronics and Control Systems, Esslingen University of Applied Sciences, Germany