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After Sales Service Strategies for HV Battery Diagnosis and Repair

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Executive Summary

While the diagnostic and repair capability of HV batteries is an important factor for future E-mobility, significantly different concepts can be found at actual electric vehicles (EVs) in use. This study gives an overview of the state-of-the-art concepts. The research results provide important findings to improve design and quality of future EVs and to develop customer oriented as well as efficient after sales service strategies.

HV battery diagnosis in after sales service uses defined measured values like static voltage, current and temperature from inside the battery system and combines them with derived values, the characteristic maps from development and testing and onboard fault detection. The process to determine and display the actual SOH value in EVs on market differ considerably. Ranging from the purpose as a driver information in the car with relatively low requirements on accuracy to a decision factor in repairing or changing the HV battery for the service expert in the workshop. It can be stated, that the method design follows the shown purposes. As the SoH value is an important factor for specifying the residual value of an used EV, it will gain weight in the future as the numbers of EVs in the market grow. To get an reliable and accurate SoH value, a defined testing procedure has to be implemented, wether in use or in the workshop.

Evaluating the repair systems for in-use HV batteries different levels of repair can be found in the market from whole HV battery exchange to complex repair processes by replacing cell modules or other faulty parts of the battery system. In addition, there is a range of service strategies when it comes to the repair location of the vehicle and of the battery. When EV population approaches mass market, repairing EVs and their batteries in any OES and selected IAS workshop appears to be the only sustainable solution due to superior customer experience as well as to the ecological, economical and social factors.

1 Introduction

Despite further expected cost reduction [1], the HV battery with a value added share of up to 50 percent is seen as the main core of an Electric Vehicle (EV) [2]. This high proportion of costs illustrates the relevance of a diagnosis and repair concept for HV batteries for customer satisfaction and cost-of-ownership during the whole lifetime of an EV [3]. For these reasons customer oriented and efficient After Sales Service strategies for HV battery diagnosis and repair are becoming an important factor for future E-mobility. At the moment, vehicle manufacturers are pursuing various strategies, which are presented in the course of this study. The development of suitable strategies represent a major challenge for the various After Sales Service areas.

The area of After Sales Service can be divided into the subareas of customer service, spare parts supply and accessories business. The customer service is mainly concerned with vehicle maintenance, warranty processing and provides individual service offers to the customer. The spare parts supply consists of the areas disposition, procurement, production, storage and distribution and ensures the supply of spare parts [4]. In analyzing diagnosis and repair for HV batteries this study focuses in the fields of vehicle maintenance and spare parts.

2 Methodology

To provide important insights for academic research and to improve design and quality of future EVs this study focuses on the following research questions:

1. How can the current State of Health (SoH) of the HV battery be diagnosed in the service workshop? Which parameters and tools can be used for diagnosis?
2. Which level of repair is used for the repair concept?
3. Which locations should repair HV batteries?

This study is part of the research program "E-Mobility Service" evaluating implications of the after sales service on the outlook of electric mobility (see figure 1). The research program is supported by e-mobil BW GmbH - funded by the state of Baden-Württemberg - and is conducted in the Center of Automotive Service Technology (CAST), Automotive Engineering Faculty of Esslingen University. Starting with the study "Electromobility – Implications for After Sales" [4] and [5] the topic "Maintenance and Repair Impacts on Electric Vehicles" has been presented at the EVS 31 [6].

In this part of the research program, the diagnostic and repair strategies of the HV batteries of current EVs, which are available on the German market, are analyzed. In addition, important work tasks of diagnosis and repair of HV batteries are evaluated in practice on selected electric vehicles.

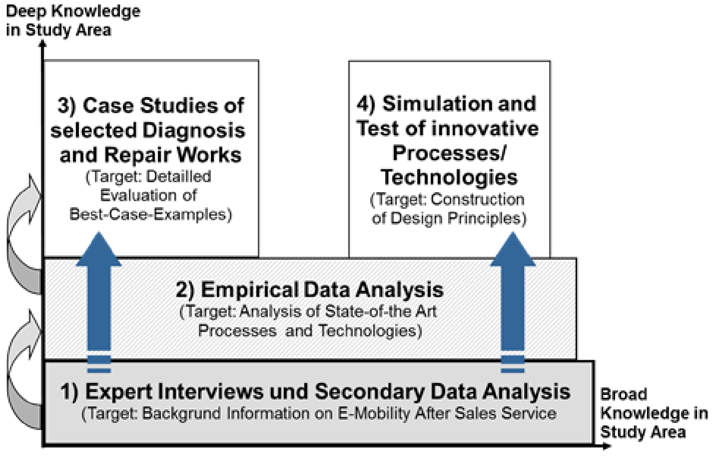


Figure 1: Study Design E-Mobility Service

In addition to a literature search, a qualitative survey is conducted in the form of personal expert interviews. This should provide background information about current problems and solutions of the respective actors. The interviews are conducted using interview guides, which are provided in advance to respondents. In the course of the interviews, five experts from various car manufacturers and suppliers have been interviewed, all have extensive experience of more than five years in that field.

A next step is the analysis of the strategies and processes of the respective manufacturers. For this purpose, eight vehicle manufacturers were examined within the framework of two student project works. Here, workshop information systems of the respective vehicle manufacturers were analyzed. The detailed assessment of the HV diagnosis and repair strategy is based on defined criteria as showed in figure 2 and consists of customer convenience/repair time, expected quality and cost-of-ownership.

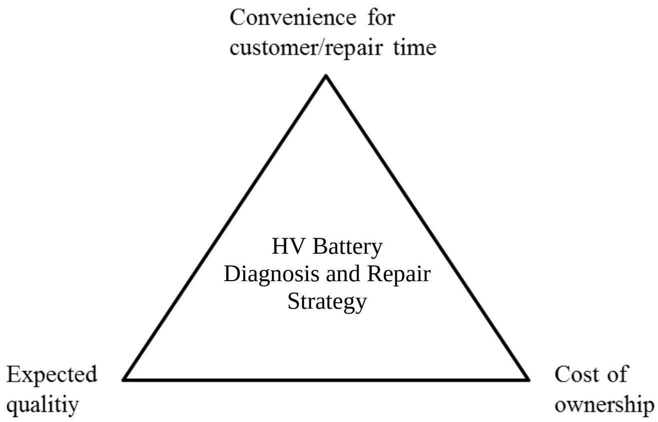
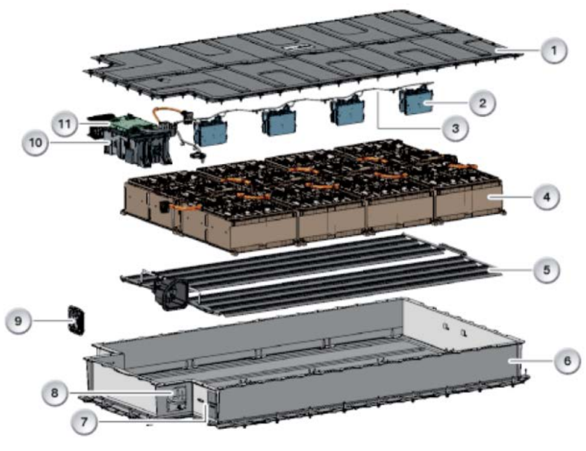


Figure 2: Criteria for customer oriented diagnosis and repair strategy for HV battery

The customer experience takes into account the geographical network of service locations and an estimation about the duration of the diagnosis and repair process. The criterion of expected quality assesses the depth and accuracy of diagnosis or the repair quality. For the cost of ownership the costs due to the repair time and the necessary spare parts are estimated and rated.

3 Diagnosis and Repair Strategies for HV Batteries in Use

While a large part of the current hybrid vehicle car park have a nickel metal hydride (NiMH) battery, it is expected that the NiMH battery will disappear from the vehicle sector in the next years [8]. Because of this, the focus in this study is on the lithium-ion battery technology. This technology forms the basis for most modern concepts regarding the electrification of powertrains of all types of vehicles [9], as shown in figure 3.



Parts Description:
1 Case Covers
2 Cell supervision circuit
3 Wiring harness for cell supervision circuit
4 Cell module
5 Coolant duct with coolant duct and heating
6 Housing
7 Electronic connector
8 Connection of refrigerant line
9 Vent hole
10 Safety box
11 Battery management electronics (SME)

Figure 3: HV battery system of BMW i3 and parts description [10]

3.1 Diagnosis

The several expert interviews with OEM and OES in addition to secondary data analysis indicate typical reasons for the diagnosis of HV batteries in use. On one hand diagnosis of the traction battery is indicated when the charging process is slowing down extensively or the capacity is decreased substantially. Those effects occur after a considerable lifetime and are part of the normal battery aging process. Further indications for a battery diagnosis are check ups ahead vehicle sales or after a crash of the vehicle. The latter case is a common precaution when the housing, the cover or the wiring harness is damaged.

All vehicles inspected use onboard equipment to determine the condition of the traction battery. Moreover, none of the consulted OEM experts named any other physical quantity than static current, voltage, time, temperature or derived quantities as electrical power, capacity or resistance being measured for diagnostic purpose in the field. Major faults are expected to be detectable using these mentioned measured values. This corresponds to Rezvanizaniani et al. [11] who identified the

- Environment temperature
- Discharging current rate
- Charging rate (fast charging)
- Depth of Discharge (DoD)
- Time intervals between full charge cycles

as the most fundamental reasons for the traction battery’s aging and degradation [11].

When determining the SoH most manufacturers use the EV’s onboard diagnostics monitoring voltage, current, temperature and derived variables at several positions within the battery system. The actual readout of the SoH variable through an ordinary vehicle diagnosis device is the current state of technology. Consequently, the fault diagnosis of electrified powertrains appears to be quiet similar to diagnosing conventional automotive systems [12]. However, the processes used to determine and display an actual value for the SoH of the battery differ considerably in many cases. The range of methods is best described by three examples.

The first exemplary car shows a SoH bar chart on the very right of the instrument cluster next to the broader state of charge (SoC) bar chart (figure 4) at any time. So the onboard diagnostics is monitoring measured values and derived variables and calculates a value for the SoH.

Figure 4: Instrument cluster Nissan Leaf, model year 2011 [13]

The second exemplary method uses a measurement routine with specific environmental parameters. The onboard diagnostics computes the SoH without a request when the environmental parameters are within the defined limits. The EV battery has to be discharged beneath 40 % SoC, leaved untouched (without driving or charging) for at least two hours and then charged to 100 % SoC. The SoH value determined in this way can be read out through the ordinary diagnosis device (figure 5) within three weeks [14].

Figure 5: Diagnostics software XENTRY

The third example is an extensive workshop diagnostic process (figure 6). The OES diagnosis device and an AC charging wire have to be connected to the car. Now the SoH diagnosis process discharges the traction battery using power consumers like AC, heating, fans, window defroster and headlights. Afterwards the battery is charged to 100 % SoC using the onboard charger (AC). The SoH is determined through the charged energy and displayed on the diagnosis device [15].

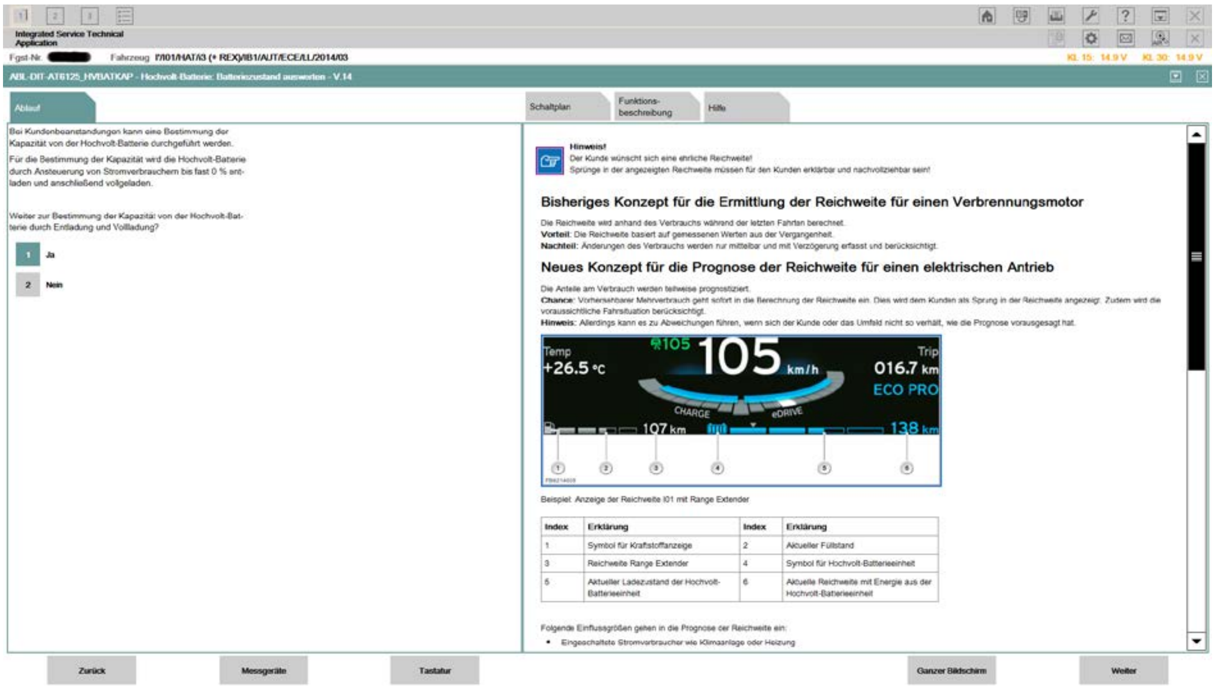


Figure 6: Diagnostics software ISTA [16]

The three examples are now evaluated in terms of the selected criteria as shown in the following table.

Table 1: Evaluation of SoH determination

	Case 1	Case 2	Case 3
	Vehicle 8	Vehicle 4	Vehicle 1/2
Convenience for customer/repair time	+	0	−
Cost of ownership	+	+	−
Expected quality	−	0	+

The first example is very convenient for the customer because the SoH of the battery is shown constantly and easily understandable. However, this method is expected to be imprecise since the remaining battery capacity is not measured directly but calculated on basis of derived values. In the second case the SoH value will be more accurate because the capacity is partly measured and extrapolated. The SoH can only be read by a diagnostic device. That requires a workshop visit and makes it less convenient for the customer. The third case delivers the best accuracy since one entire charging cycle is measured under specified environmental conditions. However it lacks in customer convenience and produces high costs due to the extensive workshop diagnostic process.

3.2 Repair Strategies

If the diagnosis reveals one or more faults in the battery system, it becomes necessary to repair or replace the battery. At this point, the question arises as to which parts of a HV battery can typically be defective. According to the experts interviews and Gollob, defects are to be expected on the following parts [17]:

- Cells or Cell Modules
- Cooling system
- Isolation
- Cables
- Connectors
- Electronics
- Sensors
- Contactors
- Fuse
- Housing
- Sealing
- Membranes

Especially for environmental and economical reasons, the repair should be considered very advantageous in comparison to the replacement of the entire battery. For this purpose, nine electric vehicles from eight different manufacturers were examined. As shown in Table 2, five battery electric vehicles (BEV), one range extended battery electric vehicle (REEV) and three plug-in hybrid electric vehicles (PHEV) of various model years were selected.

Table 2: Repair Strategies for HV Batteries

	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5	Vehicle 6	Vehicle 7	Vehicle 8	Vehicle 9
model year	2016	2018	2018	2018	2017	2018	2018	2018	2017
type	[PHEV]	[REEV]	[PHEV]	[BEV]	[PHEV]	[BEV]	[BEV]	[BEV]	[BEV]
repair strategy	decentralized	decentralized	centralized	centralized	decentralized	centralized	centralized	centralized	decentralized
repair location vehicle	all OES workshops	all OES workshops	all OES workshops	all OES workshops	specialized workshop	specialized workshop	all OES workshops	all OES workshops	specialized workshop
repair location battery	all OES workshops	all OES workshops	repair factory	repair factory	specialized workshop	repair factory	repair factory	repair factory	specialized workshop
possibility to replace cell modules at the workshop	✓	✓	-	-	✓	-	-	-	✓

Regarding the HV battery repair strategy, OEMs are pursuing different approaches. Basically, a distinction can be made between a centralized and a decentralized approach. The central approach is to send the whole battery pack to a centralized repair factory of the manufacturer for the repair. With the decentralized approach it is intended to repair the battery directly in the workshop. This requires a repair concept to open the battery and replace the affected cell modules and maybe other defective parts. The high voltage battery has to be removed from the vehicle regardless whether it can be repaired in the workshop or exclusively in the repair factory.

As shown in figure 7, strategic differences exist in the repair location of the battery as well as in the definition of the workshops to which the customers can turn to with an EV (repair location of the vehicle). When looking at the decentralized approach in more detail, it can be seen that, depending on the configuration of the OEM's service network, either all Original Equipment Service workshops (OES) or only a part of specialized OES workshops can carry out the battery repair. Even with the central approach, differences can be observed at this point. As already described, here the removal and installation of the battery is done by the workshops and the repair is done by the manufacturer. For most of the manufacturers examined, the removal and installation is possible at all OES workshops. Only one manufacturer has intended this work exclusively for specialized workshops.

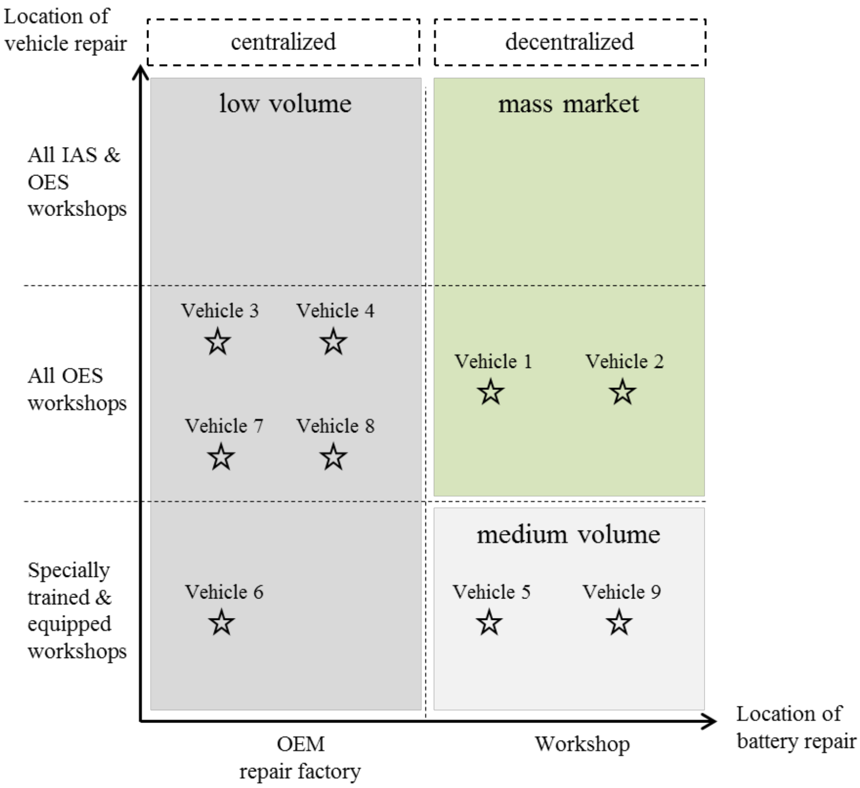


Figure 7: Overview of the repair strategies

Apart from the OES workshops many independent aftersales service workshops (IAS) operate in the markets. As the expert interviews proved, the Block Exemption Regulation of the European Commission gives the independent workshops the opportunity to purchase the documentation, the tools, the diagnostic equipment and the training necessary to repair all vehicles. This includes those with electrified powertrain. However, due to the small number of older vehicles with a lithium based traction battery at the time being, independent workshops still avoid the investment to prepare for repairing EV batteries at the time being.

The evaluation of the different repair strategies brings the following results. For better clarity vehicles with similar repair strategies are bundled to cases for further analysis. This leads to four main cases that are assessed in table 3.

Table 3: Evaluation of the repair strategies

	Case 1	Case 2	Case 3	Case 4
	Vehicle 1/2	Vehicle 3/4/7/8	Vehicle 5/9	Vehicle 6
Convenience for customer/repair time	+	0	–	–
Cost of ownership	+	–	+	–
Expected quality	–	+	0	+

A solution where customer can turn to any OES workshop is always best for the customer convenience (see case 1). The expected quality of the repair process is optimal for the cases 2 and 4 since an OEM repair factory exclusively takes care of the batteries. These facilities have highly qualified experts as well as the best equipment and processes for these activities. However, the upkeep of repair factories and hazardous materials transportation consumes time and money. The wider the group of people working on the batteries, the more difficult quality assurance becomes. This affects the quality evaluation of cases 1 and 3.

Finally, it appears reasonable for low volumes, not to enable all workshops for removal and installation of the battery system. In addition, it can be efficient in those cases to repair the traction battery not in the workshops but in regional repair factories. With growing volumes batteries should not be shipped to a repair factory because of the higher costs and longer repair time. In approach to mass market in terms of customer experience the strategy should be transferred to repair the vehicles and their batteries in each OES repair shop. At this point with many EVs and an aging EV fleet in the market, it is likely that IAS organizations will make use of the Block Exemption Regulation to enter the EV after sales market.

4 Conclusion

This study gives an overview of the state-of-the-art diagnosis and repair concepts for HV batteries.

The diagnosis of the HV battery uses the stated measured values from inside the battery system and combines them with the characteristic maps from development and testing and onboard fault detection.

The process to determine and display the actual SOH value in actual EVs differ considerably. Ranging from the purpose as a driver information in the car with relatively low requirements on accuracy to a decision factor in repairing or changing the HV battery for the service expert in the workshop with high requirement on accuracy. It can be stated, that the decision on the methods follows the shown purposes. As the SoH value is an important factor for specifying the residual value of an used EV, it will gain weight in the future as the numbers of EVs in the market grow. To get an reliable and accurate SoH value, a defined testing procedure has to be implemented, wether in use or in the workshop.

Evaluating the repair systems for in-use HV batteries different levels of repair can be found in the market from whole HV battery exchange to complex repair processes by replacing cell modules or other faulty parts of the battery system. In addition, there is a range of service strategies when it comes to the repair location of the vehicle and of the battery. When EV population approaches mass market, repairing EVs and their batteries in any OES and selected IAS workshop appears to be the only sustainable solution due to superior customer experience as well as to the ecological, economical and social factors.

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