www.dergipark.gov.tr
ISSN:2148-3736

El-Cezerî Journal of Science and Engineering
Vol: 10, No: 1, 2023 (66-80)
DOI :10.31202/ecjse.1161081

ECJSE

Review Paper

Periodic Maintenance & Repair Approaches for Electric Vehicles

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Received: 12.08.2022 **Accepted:** 11.01.2023

Abstract: Global electric vehicle sales reached a record level in 2021 despite pandemic conditions and difficulties in the supply chain. Total electric car use has exceeded 16.5 Million. Approximately 70% of this increase consists of battery-powered electric vehicles. Statements regarding the restriction/prohibition of internal combustion engine vehicles for the near future are announced by many countries; Incentives provided in this context increase the orientation towards the electric vehicle market. In Turkey, electric car sales correspond to 5.03% of total sales, according to 2021 data. The increasing use of electric cars is expected to bring about changes in maintenance & repair processes in the after-sales service line, which is one of the basic requirements for the automotive industry and has significant commercial potential. In many studies, it is stated that the maintenance & repair costs of electric cars suitable for urban use are 20-35% more economical than cars with internal combustion engines. This advantage becomes even more evident, especially for fleets. It is stated that these costs for fleets correspond to 7-12% of the total cost of ownership on a vehicle basis, depending on the vehicle type and purpose of use. In this study, periodic maintenance & repair approaches specific to electric cars will be included. It is aimed to develop a perspective on this subject, which is very new in Turkey. It is addressed to individual / corporate (public) users for maintenance & repair activities specific to electric vehicles, which are considered to be far from standards and have many uncertainties in the current situation. By mentioning the basic maintenance & repair processes and procedures based on the power system components of the vehicles, different from the internal combustion engine vehicles; It is aimed to raise awareness on the subject.

Keywords: Maintenance & repair approaches for battery electric vehicles, after-sales service line for electric vehicles, periodic maintenance.

1. Introduction

It is reported that electric car sales in Europe correspond to 17% of total car sales in 2021 and approximately 5.5 million electric cars are used in total. Looking at the market shares of new electric car sales in Europe for 2021, Norway (86%) ranks first. This is followed by Iceland (72%), Sweden (43%), Netherlands (30%), France (19%), Italy (9%), and Spain (8%). In this context, it is stated that the main factors that increase the sales of electric vehicles in Europe are the standards regarding CO_2 emissions, the purchase subsidies and tax advantages [1]. In Turkey, the sales of conventional internal combustion engine vehicles increased by 105.1% in 2021 compared to 2020 and electric vehicle sales increased by 237.2% [2].

In the automotive sector, periodic (daily, weekly, monthly and yearly), preventive (before failure), and corrective (after failure) maintenance & repair processes are widely operated for the after-sales facilities based on traditional vehicle concepts [3]. It is considered that these approaches in electric vehicle concepts should be carried out with 4 main processes [4].

Considering the standard conditions, the annual maintenance & repair period is 10,000 km for gasoline engine vehicles and 15,000 km for diesel engine vehicles as a reference. This value goes up to the 30,000 km band for electric vehicles. In this context, service intervals are specified as

How to cite this article
Topal, O., "*Periodic Maintenance & Repair Approaches for Electric Vehicles*" El-Cezerî Journal of Science and Engineering, 2023, 10(1); 66-80.
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30,000 km for Renault Zoe 2, 1 year or 18,000 km for Volkswagen ID.3 and ID.4, 1 year or 15,000 km for Hyundai Kona Electric, and 2 years or 28,000 km for BMW i3. However, Tesla's approach draws attention here. There is an approach to taking it to the service when needed in the usage document. In addition, electric and hybrid vehicles throughout the European Union, are subject to a compulsory vehicle inspection once every 2 years after completing their 4th year [5][6].

Unlike traditional internal combustion engine vehicles, technical personnel involved in maintenance & repair activities, as well as in R&D, design, and production processes specific to electric vehicles, must have professional specified training and customized equipment. In this direction, standards based on professional competence specific to technical personnel who will intervene in electric vehicles have been put forward by the Motor Industry Institute in England. Global activities are carried out to ensure that the requirements for maintenance & repair work for electric and hybrid vehicles are met and to define special training and certification processes, especially for technical personnel who will work in this field. In this context, it is stated that different levels of training approaches are offered for competency-based standards [7]. Training activities cover standards on electric vehicles. Carrying out the safe maintenance & repair of vehicles and, if necessary, repair processes are included. In addition, it is aimed to carry out activities under with the procedures determined by electric vehicle manufacturers. The scope of the studies carried out to train qualified personnel for the electric vehicle sector in Hungary, Slovakia, and the Czech Republic. A project has been put forward on the European axis called Green Wheels, which aims to standardize the workforce skills globally. On the other hand, in Germany, some regulations set prerequisites for minimum health and safety requirements for employees who are working in the electric vehicle sector [8]. In Canada, all technical personnel working in after-sales services in the automotive industry, including personnel -who will work with electric and hybrid vehicles with high voltage system- have to obtain a license. It is stated that the relevant employees should have approved competency pieses of training and relevant certificates following with the determined local standard [9].

In Turkey, the National Occupational Standard, which was created by the Vocational Qualifications Authority (MYK) No. 5544 under the name Battery Electric Vehicle Maintenance and Repairer, was published in the Official Newspaper of the Republic of Turkiye dated 19/10/2015 and numbered 29507 [10]. In this direction, the definition of the profession, which is expressed as Battery Electric Vehicle Maintenance and Repairer, was officially put forward for the first time in Turkey.

According to the occupational health and safety, environmental protection, quality, and other relevant job instructions, battery electric vehicles; that cover the detection of simple or complex, routine or non-routine faults, the sound/vibration interpretation, the decision to secure the vehicle electrically and to remove the security, replacement of parts within the intervention limits, structural adjustments related to working performances, periodic, preventive and reparative maintenance. In addition, the installation or inspection of accessories and additional equipment suitable for the vehicles; also covers the completion of maintenance and repair processes and ensuring the proper operation of electric vehicles. Performing necessary desktop and road tests along with fault detection hardware and software; also includes using, updating, and making the necessary measurements and tests on the vehicle and its components based on the reference values given by the vehicle manufacturer [11]. With the maintenance & repair operations carried out in the final sense, electric vehicles; It is based on operating for the longest time, with the highest performance, in a way that ensures the safety of the driver, passenger, and cargo. The directive makes it responsible for the accuracy and quality of the maintenance & repair operations carried out or supervised under its supervision, making the vehicle safe, carrying out following the manufacturer's instructions, and ensuring the safety of other people working with it [11]. The aforementioned standard, which also determines the competencies of technical personnel at different levels who can intervene in electric vehicles, has not yet been put into effect, although it was published in the Official Newspaper of the Republic of Turkiye. In coordination with its counterparts in the international area, the standard is primarily based on making the working environment and conditions safe for the maintenance & repair operations of the electric vehicles. The requests that necessary measures be taken against the risks of gas leakage, burning, explosion and electric shock that may occur during the said maintenance & repair activities carried out in closed and/or open areas. It also specifically states the necessity of using personal protective equipment for risk situations that may occur. In this respect, it is also stated in the standard that all maintenance & repair activities to be carried out for electric vehicles must comply with the current Effective Occupational Health and Safety (OHS) requirements, especially environmental legislation.

Maintenance & repair processes, which have significant commercial potential in the aftermarket for the automotive industry. With the increasing use of electric vehicles, this sector will inevitably change. Conventional internal combustion engines consist of a large number of moving parts; especially in power drive systems, potentially requiring significant labor and consumables. Thanks to the structures that do not require intensive maintenance, especially the electric motors and propulsion batteries used in the powertrain systems, significant advantages are provided in the maintenance & repair processes and requirements specific to the new generation electric vehicles.

In addition, as in internal combustion engine vehicles, in electric vehicles, the systems level is commonly used as brakes, tires, wipers, air conditioning system, etc. Periodic maintenance & repair processes currently carried out for components/structures should continue to operate. In the case of electric vehicles, there is no common brand-independent approach for the final maintenance & repair procedures for the propulsion battery, drive motor, power converters, and control components.

It is reported by Delphi Technologies that maintenance & repair requirements are increasing for hybrid and electric vehicles that have an average lifespan of 20 years. In this context, the high voltage battery is considered the most critical component to be considered within the scope of maintenance & repair of electric vehicles [12].

For the automotive industry, especially for individual uses, the costs incurred for maintenance & repair processes can be overlooked. There are various studies on this subject which have an important place in life-cycle cost analysis and should be carried out periodically. On the other hand, it has been determined that battery electric vehicle of the same quality and used in similar conditions generally require less maintenance than internal combustion engine vehicles. It has been revealed that the number of materials and labor used, and therefore, provides a gain in maintenance costs. So much so that the maintenance & repair cost for internal combustion engine (gasoline) vehicles in the United States is about $1,200/year, while electric vehicles are $900/year [13]. Similarly, on electric vehicles, conducted by Cap HPI in 2018; In a study based on data for 3 years/100,000 km, it was revealed that electric cars cost an average of 23% less than gasoline cars [14]. In Turkey, according to the current data for 2022, the maintenance & repair cost for internal combustion engine (gasoline) vehicles is approximately 74 € per year [1], while this value is 117 € per year [2] for electric vehicles.

The negative perspective experienced due to the high initial purchase costs of electric vehicles complicates the transition from traditional internal combustion engine vehicles to electric vehicles. In this context, when the total cost of ownership is taken as a basis, gains extending to years, especially from the continuous expenses within the scope of maintenance & repair, appear as an important alternative to electric vehicles. In the medium/long term, low energy (fuel) costs, incentives for reduced (or zero) emissions and renewable energy-supported charging station installation, as well as a reduction in maintenance & repair costs, and high initial purchase costs for electric vehicle concepts, are considered as a balancing factor. [15-18].

2. The Main Maintenance & Repair Approaches for Electric Vehicles

Details of the recommended service processes for electric vehicles are determined by the relevant vehicle manufacturers like other automotive industries. In general, construction of the drive motor for electric vehicles (in the case of using central structure); it is ensured that the mechanical parts up to the wheel such as the gearbox, shaft, axle, and differential are maintained with traditional methods, as in standard internal combustion engine vehicles for the driveline. On the other hand, electric vehicles have regenerative braking systems, unlike traditional braking systems. When these structures are used effectively, especially brake pads/discs, hydraulic, etc. in brake systems. by providing less wear/use of components/consumables; provides longer periods of use. In addition, regenerative brake structures have more complex structures and control algorithms than normal brake systems. Due to the battery capacities of electric vehicles, the total loaded weight increases compared to internal combustion engine vehicles of the same quality. Due to the nature of the drive motors in electric vehicles, they provide high torque. Especially with electric vehicles that offer advantages in accelerations to 0-100 km/h, this advantageous situation causes rapid wear for the tires with the increase in vehicle weight. It is considered that it would be appropriate to check the wear level of electric vehicle tires at more frequent intervals or to use special tires for electric vehicles, especially in vehicle usage modes that offer high torque.

It is recommended that electric vehicles be stored in closed garages as much as possible. Especially when the weather conditions outside are very hot or very cold. In the first operating phase, the operating performance of the high-voltage drive batteries is adversely affected. This may lead to a reduction in the life factor of high voltage drive batteries. For example, the propulsion batteries in electric buses are usually placed on the roof of the vehicle. In cold climate conditions, buses that parked on a open area for all night instead of closed areas. Condensation situations that may occur on the surfaces where the battery cells come into contact with the heat increase during the first operation and short-circuit situations that may occur due to this should be taken into consideration.

In this paper, 4 basic level approaches are presented for maintenance & repair procedures for electric vehicles. In this context, the maintenance carried out for the simple faults that occur first can be evaluated. It usually consists of a procedure based on low-cost, easy-to-replace parts, components, or interventions after a breakdown/failure for components.

The second approach is preventive maintenance. The component or processes are based on their functional failure within the expected life cycle of components and are based on intervention according to predefined procedures, usually without replacing the relevant component.

Within the scope of predictive maintenance processes, which are specific to electric vehicles and differ from traditional automotive maintenance approaches, an approach is presented by testing the presence of malfunctions and/or the functionality of the systems. According to the results obtained, it is considered to require maintenance, based on the condition of the relevant component or component. In this direction, a revision program is provided.

Finally, it is foreseen to carry out proactive maintenance activities. An approach to predetermined system-level work cycles in electric vehicles, allowing the programming of repairs that may be required. Together with an accompanying warning mechanism, they are approaches that aim to minimize the discontinuities that may occur in possible failures [19]. Figure 1 summarizes these basic approaches.

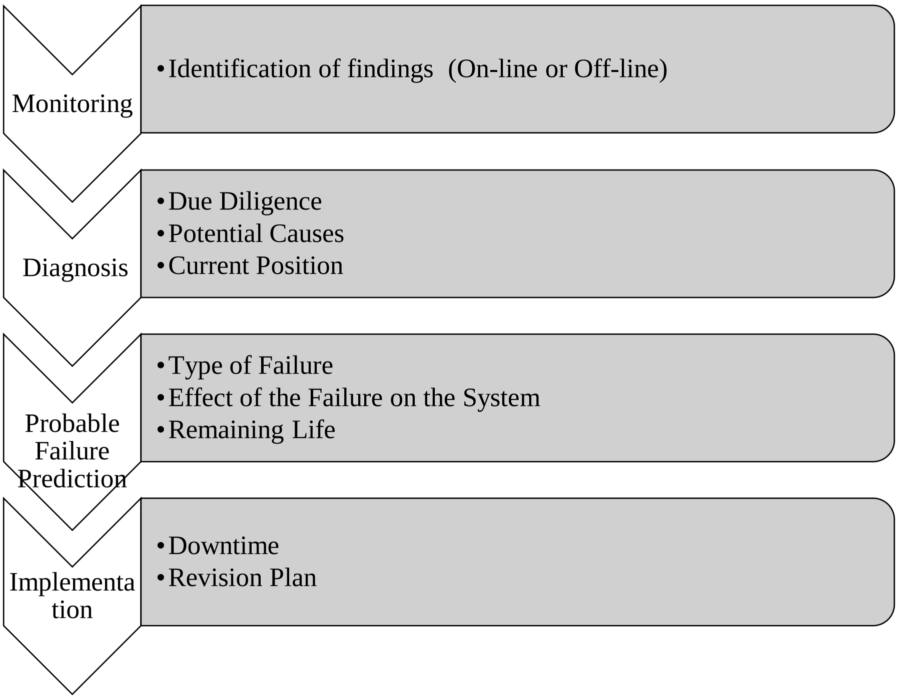

Figure 1. The basic levels of maintenance & repair approaches in electric vehicles

Based on the maintenance & repair processes specified; powertrain system components (propulsion batteries, drive motors and gearbox), charging systems (external and/or in-vehicle), cooling units of power system components, regenerative braking systems and accompanying periodic checks of hardware/software that carry out vehicle command and control functions are required. Within the scope of maintenance & repairs of electric vehicles, it should be considered that especially the propulsion system components have high voltage. The certificates required by the technical personnel who will be involved in maintenance & repair and breakdown interventions for conventional motor vehicles are not valid for electric vehicles. In electric vehicles, the system level nominal voltage value varies between 350 -800 V DC (depending on the brand/model). In addition, it is necessary to have special equipment for maintenance & repair and adequate knowledge and equipment on intervention methods for parts, equipment and components that are not encountered in traditional automotive concepts in electric vehicles.

In addition to the competencies required of the technical employees for the maintenance and repair of electric vehicles, the area in workshops where the maintenance is carried out and the equipment to be used must also be made suitable and safe. Even when electric vehicles are not working, sometimes potentially dangerous situations should be considered. It is possible to encounter undesirable results with possible physical contact with some equipment in the electric vehicle, which can store static electricity.

Energy is transmitted to all high-voltage power system components (from the propulsion battery to the drive motor) by the high-voltage cables in electric vehicles. Contact should not be made with these orange-colored cables or any of the related equipment without taking the necessary precautions. It is possible that the protective measures are not provided and/or activated by the vehicle manufacturer, etc. causes can have fatal consequences.

In addition, during maintenance & repair operations for electric vehicles, exposure to electric current or unexpected/experienced (due to accident, etc.) battery deformations; fire, harmful chemical leakage, etc. situations are among the potential risks. Due to the electromagnetic interference that occurs during the operation of the vehicle, especially the hybrid and electric vehicles, the propulsion engine, the suitability of the technical personnel to work in terms of health should be considered.

Along with that pacemakers, implants, epilepsy, etc. are not appropriate for the technical service activities for staff who are carriers / with health problems.

2.1 Before Periodic Maintenance & Repair Activities

First of all, necessary safety precautions against high voltage must be taken in maintenance & repair activities for electric vehicles. It is considered that some of the procedures to be followed will reduce the possible risks. Primarily, insulated gloves, shoes, etc. against the risk of high voltage. It is recommended to use insulated mats in working areas with the right personal protective equipment.

Maintenance & repair operations for electric vehicles must be carried out in a specially reserved area. In this respect, it is necessary to pay attention to this issue in workshops that offer mixed services (both electric and conventional motor vehicles). Possible incorrect activation/activation of smart switches and/or buttons of electric vehicles, etc. It is recommended to start related studies by using special locking mechanisms that prevent such situations. In this way, unintentional activation of the high voltage source and/or user systems of the vehicle will be prevented and possible vehicle movement will be prevented [20].

The technical personnel who will take part in the work must have sufficient training and equipment. Within the scope of maintenance & repair work to be carried out specifically for electric vehicles, there are basic safety procedures that must be followed first [21][22]. These issues, which are vital for safe operation, provide a general approach, providing the basis for all power systems used in electric and/or hybrid vehicles, regardless of voltage level.

The primary issue in maintenance & repair works to be carried out for electric vehicles is to ensure/check whether electrical isolation is provided in the vehicle. For this, after turning off the ignition/start button of the electric vehicle (putting it in off mode), the charging cable (if plugged in) must be disconnected, and then the MSD (manual service disconnect)- if used- must be opened (physically removed). Thus, the electrical connection of the high voltage drive battery with other systems is terminated. In this sense, it is necessary to open the MSD, which is deployed separately according to the system architecture of the battery pack/s. Afterward, the vehicle must be externally grounded, and an electrical connection (bonding) of all exposed conductors must be ensured to prevent the formation of different voltage potentials. In order not to be exposed to possible voltage discharges in the system, it would be appropriate to wait for at least 10 minutes after these preparations are made without any intervention.

High voltage cables indicating in orange-colored in electric and hybrid vehicles, if necessary, taking into account the instructions of the vehicle manufacturer; It would be appropriate to clean it before maintenance. However, it should also be taken into account that these high voltage cables carry the risk of arcing or electric shock caused by short circuits that may occur due to the insulation or outer shell or being damaged/destroyed, being in contact with energized components.

Electrical insulation measurement in the electric vehicle should be made to confirm that it is at the value determined following with the relevant ISO 6469 standard, unless otherwise specified by the manufacturer. Before the intervention/operation is made afterward, absolutely necessary to check whether the high voltage cables and related components are energized. If possible, pilot/monitoring, etc. at the system level via the vehicle control computer. It is necessary to start the relevant intervention processes by switching to the mode/position. In this context, the MSD should be locked against the risk of involuntary (unannounced) re-commissioning to prevent unwanted incorrect interventions. In Figure 2, MSD and emergency stop buttons can be seen on different brands of electric vehicles are shown.

Figure 2. MSD (manuel service disconnect) and emergency stop switches in electric vehicles

Test and measurement equipment and other accompanying peripheral components to be used during the works must be compatible with the voltage level of the vehicle.

3. Component Based Periodic Maintenance & Repair Processes for Electric Vehicles

In this paper, an approach is presented based on the training given to work in electric vehicles with high voltage systems prepared by the Battery Electric Vehicle Maintenance and Repairer, National Occupational Standard prepared by the Turkish Vocational Qualifications Authority and Deutsche Gesetzliche Unfallversicherung (DGUV). In this direction, periodic maintenance & repair processes for electric vehicles, specific to power drive system components and applications that are deemed appropriate to be presented are included.

Before starting the maintenance & repair operations to be carried out with electric vehicles, the current versions of the diagnostic/service software prepared by the vehicle manufacturers and/or service providers must be used. Also, the preliminary preparation processes in the previous section should be carried out. The vehicle must be electrically secured and the necessary physical and technical safety checks must be made. Related tests and measurements are to be carried out. Afterward should be implemented procedures following with the vehicle mileage, service life, seasonal conditions and the basic procedures determined by the vehicle manufacturers. It is considered to be the most basic approach to ensure the smooth operation of electric vehicles.

3.1 Periodic Maintenance of Auxiliary Battery: It is critical that the 12 V / 24 V auxiliary battery (battery) used in electric and hybrid vehicles provides wake-up (initial energizing function) for all other systems. First of all, should be check the physical condition of the auxiliary battery's ports and the battery box for cracks, cracks, etc. Physical damage conditions are visually inspected. In addition, in the case of electrical connections (connectors), possible discoloration, contamination, abrasion, etc. conditions are controlled. In particular, possible color changes should be observed in the cables and connection points/connectors. In such a situation, it is possible to be exposed to the risk of high currents. For this case, it is recommended to measure in this way.

It is also possible to control the electrolyte level and terminals of the auxiliary battery. In case of possible oxidation, it is necessary to clean the terminals and/or change the relevant cables. If a damaged battery is detected, the battery must be replaced completely. The capacity test should be applied to the auxiliary battery (battery) after the procedures. The auxiliary battery that has been removed from the vehicle for any reason during the work/operations must be charged before it is reassembled on the vehicle.

3.2 Periodic Maintenance of High Voltage Propulsion Battery: There are 2 basic levels of maintenance/use approaches for main drive batteries in electric vehicles. The first is charge level control, which is ongoing maintenance carried out by the end user. They are considered basic maintenance/use approaches that can be applied on an individual basis. The charge/discharge cycle that the propulsion battery will be exposed to due to the use of electric vehicles directly affects the service life of the propulsion battery. In this regard, unlike conventional lead-acid batteries, 100% charging and 0% discharge should be avoided as much as possible. Ideally, it is recommended to keep the charge level of the propulsion battery between 20% and 80%. Both overcharging and deep discharges reduce the usable battery capacity over time; causing serious reductions in battery life.

In addition, extremely hot/cold environmental conditions have a negative effect on the performance of electric vehicle propulsion batteries. For this reason, indoor parking should be provided if possible, especially when not in use (in which case the battery cooling/heating unit is also disabled because the system is turned off). In addition, it would be appropriate to avoid direct sunlight exposure, especially in cases where it is necessary to park in outdoor areas.

Most of the failures in the electric vehicle industry are caused by propulsion batteries. Especially the increasing use of vehicles and the inability to carry out effective maintenance & repair processes for propulsion batteries are seen as the main reason. In the current situation, high voltage propulsion batteries are one of the leading failures encountered for electric buses in public transportation systems, which is the most common electric vehicle usage area in Turkey [23].

System designs are made by the manufacturers based on providing long-term service under normal conditions for the propulsion batteries, where the maintenance & repair processes that can be done by the end-user are quite limited. In this context, solutions with 8 years or 150,000 km warranty for high voltage drive batteries are offered by various OEMs under market conditions.

Secondary-level maintenance & repair approaches for high voltage drive batteries should be carried out by authorized technical personnel. Firstly, physical control of the connection points of the high voltage drive battery and the battery surface is provided. In the scope of physical control, possible swelling, corrosion, leakage and/or cracks, etc. situations are observed. In addition, control and cleaning procedures should be carried out against contamination, humidity and/or oxidation against electrical leakages that may be caused by self-discharge of the battery or possible contact with the chassis.

Afterward, the high voltage drive battery and the BMS system are checked as a whole utilizing the diagnostic system. If diagnos any historical fault records, must be examined. Before the first physical intervention is made, an electrical insulation test measurement must be carried out based on the system and it should be determined whether or not there is any insulation problem. After the energy inputs and outputs of the drive battery are disconnected from the system, the isolation measurement is repeated and control is also provided based on the vehicle platform. Apart from many high-voltage propulsion batteries developed for electric vehicles, the insulation measurement is carried out via battery power distribution units, and battery-specific control is provided. In addition, the energy, data, and cooling (if any) input/output connections of the drive battery should be checked for appropriateness and tightness (cooling system). Functional performance tests should be performed by making measurements for energy, data, and flow (liquid or air in cooling systems).

The suitability of the measured values should be checked based on the reference values offered by the manufacturer.

According to the examinations and the results of the measurements, battery deformations that occur by an accident in such cases must be taken into consideration. Opening the propulsion battery packs in suitable conditions; cell/module-based examinations are required. In particular, the opening of the battery pack must be provided in the necessary/sufficient environmental conditions. The operations within the process must be carried out by technical personnel who have received special training and whose competence level is appropriate. In this context, a different education level is defined in the Battery Electric Vehicle Maintenance and Repairer National Occupational Standard for such heavy maintenance & repair operations that must be done primarily by the high voltage drive battery supplier/manufacturer. Similarly, the electrical safety of the vehicle must be ensured for the said propulsion batteries which are disassembled from the vehicle and subjected to heavy maintenance & repair processes. For the intervention to be made, the MSD (if used) included in each battery pack (in some electric vehicle designs, there may be structures consisting of more than one battery pack) is opened and after removing the security lock is provided. After a sufficient wait (at least 10 minutes for possible discharge situations), the energy input/output connection connectors of the battery are disconnected. The high-voltage drive battery is also attached to the appropriate positions determined by the manufacturer, allowing it to be separated from the vehicle and transported. If deemed necessary according to the measurements and the data obtained from the diagnostic device, the battery pack may be opened, subject to the procedures of the vehicle manufacturer (battery supplier) and under special safety conditions. At the module and cell level, examinations/measurements are carried out under laboratory conditions and the detections made with the diagnostic device are controlled.

In this context, one of the most critical mistakes made in market conditions for high voltage drive batteries is wrong approaches to increase the battery life or to eliminate the fault through changes made in the field at the module or cell level. This method, which can lead to extremely dangerous results, may cause complete deformation of the battery pack under possible extreme operating conditions, by paving the way for serious imbalances that may occur between the newly added battery modules and/or cells in the existing situation. It should be evaluated that this situation may cause dangerous results up to fires caused by high voltage propulsion batteries in electric vehicles [24][25].

For the reasons stated above, changes to be made in batteries, especially at the cell level, should be carried out in appropriate laboratory conditions, following with standards. The processes should be operated meticulously and the measurements and evaluations for the battery pack should be checked under load. After the changes are made by considering the determined conditions, electrical and physical controls should be provided. The battery pack can then be turned off. After the controls are carried out by making measurements at the battery pack level, appropriate insulation materials should be used for the package sealing. In this respect, it is critical that the mandatory checks are carried out, since the high voltage propulsion batteries, which are subjected to standard ECE R100 tests under normal conditions, will not be subjected to this test again after the heavy maintenance & repair processes to be carried out from the possible module cell level . It is especially evaluated and recommended that it is appropriate to receive support from an accredited institution. In Figure 3 can be seen the precautions provided for the intervention for the high voltage drive battery.

Figure 3. The intervention of high voltage propulsion battery pack used in electric vehicles

It would be appropriate to inspect the area where the high voltage propulsion battery pack, which was removed from the electric vehicle, is deployed in the vehicle, and to clean it if necessary. It is reassembled to the vehicle using the methods specified with an approach similar to the disassembly of the propulsion battery. All electrical and mechanical connections are made. The electrical isolation measurement is repeated and after a negative situation is not observed, the MSD is activated and the system is energized. In this context, the controls to be performed with the diagnostic device are also important. Detection of the charge level of the propulsion battery, and control of the charging status according to the vehicle configuration (fast/slow charge), depending on the need. In this way, the control of the charging process is also carried out (control of the state of charge of the battery and charge - fast/slow - levels are provided).

3.3 Periodic Maintenance of Drive Motor and Motor Control Unit: In the new generation electric vehicles, the structures in which the propulsion motors are located appear in different configurations. In this context, the most common EDU (electric drive unit); are compact systems in which the drive motor, motor driver, and gearbox are together. In addition, axle-integrated engines, which are described as portal axle structures, and central engine structures, as in traditional vehicle system architectures, are among the basic configurations currently used. Finally, hub motor (in-wheel) structures, which are expected to become widespread in the next generation of electric vehicles, are also evaluated in this context.

In the maintenance & repair approaches specific to the drive motors in electric vehicles, firstly the working acoustics of the drive motor is checked when the vehicle is idle and while driving. Similar to the drive battery, energy, data, and cooling (mostly liquid-cooled structures are used) connections/sealings and mounting parts (brackets) should be controlled. Checks of engine bearings, gearbox, and connection adapters to the driveline are carried out. If necessary, cleaning, oil levels of gears, and physical controls are provided. With the help of the diagnostic device, historical records are also taken and further investigations are carried out.

Electrical and mechanical output values (current, voltage, torque, revolution) of the drive motor are measured. The measurement results are checked for compliance with the reference values given by the manufacturer. The mechanical power output of the drive motor and speed/torque controls are provided. If deemed necessary, similar cleaning and lubrication processes are carried out inside the bearings. By displacing the energy input/output cables, external electrical isolation control of the motor is provided.

Depending on the physical condition of the peripheral components (energy, cooling inputs/outputs, sensor, and data units) of the drive motor, color changes that may occur especially in cables/connectors are taken into consideration. Changing of cables and connectors is carried out for the evaluation and necessity of high current exposure situations. Another point to be considered is that in case of possible high current exposure (protection will be provided over the motor driver under normal conditions), the motor windings are also subject to deformation. In this context, it would be appropriate to make (electrical) measurements on the motor windings. Finally, the sealing and liquid flow rate test at the inlets and outlets of the cooling system is also examined to see if there is any corrosion effect, and if necessary, cleaning is carried out.

In addition, the operating condition of the drive motor in generator mode should be checked for regenerative energy recovery. That is specific to electric vehicles. In this sense, necessary functional tests and measurement of regenerative energy gain values are carried out within the scope of maintenance & repair works to be carried out.

Apart from the routine controls, the data obtained for different situations detected by the diagnostic device; may also be necessary to repair the drive motor by removing it from the vehicle. Against such situations, it is ensured that the drive motor is displaced from the vehicle by first disassembling all connection points and moving it from suitable locations determined by the manufacturer. Studies are to be carried out at this stage and possible revisions should be carried out in the presence of the drive motor manufacturer and the appropriate laboratory environment. Possible problems that may be encountered are the deformation of the windings, the disintegration of the bearing, and the jamming of the rotor and etc.

3.4 Periodic Maintenance of Cooling Units of Power System Components: The main components of electric vehicles, which are the drive battery and the drive motor group (inverter, on-board charger, DC/DC converter), need to be cooling/heating. These systems also should be maintained and repaired. These types of equipment are important for the efficient performance of these propulsion systems. Based on the system architectures used in electric vehicles, it is seen that in some solutions, air-cooled structures for propulsion motors and/or batteries are preferred. The performance of the cooling system should be checked first in the maintenance & repair works to be carried out for the liquid-cooled structures, which are mainly preferred for the system architectures and components used. Flow, amount (level), and concentration measurements of the coolant should be performed. The tightness, insulation, and corrosion of the pipes where the cooling liquid is carried must be checked. Finally, the functional tests of the fans and pumps included in the content of the systems in question, and the cleaning of the filters (if necessary, replacement) should be performed.

Also, another thermal management function for high voltage drive batteries is the heating function. To ensure 25-30 °C nominal operating conditions, thermal management of the bars should be made based on the external environment and operating conditions. It is an important issue to provide the effective performance conditions expected from the batteries.

The thermal management of the batteries is provided by air, water, and hybrid methods. Battery thermal management systems with air can be considered in two groups natural and forced convection systems. In these systems, the air to be used to heat/cool the battery is taken directly from the atmosphere. The advantage of using air as a fluid in battery thermal management systems is low cost, easy maintenance, low weight, simple design, and no leakage problem. On the other hand, the disadvantages can be expressed as the low thermal performance of the air, high-temperature difference between the batteries, high fan power, and noise used in the system.

Liquid-cooled/heated battery thermal management systems, on the other hand, have the batteries in direct contact with the liquid. These systems are used to prevent overheating, especially in battery packs with high charge/discharge capacity. The fluid used in these systems should have a dielectric structure with low viscosity, high thermal conductivity, and thermal capacity.

In addition, after the use of electric vehicles for a long time (more than 4/5 years or 100,000 km), the cooling requirements will be needed increase due to the expected increase in the internal resistance of the cells, especially in the propulsion batteries. In this sense, this should be taken into account, especially in the cooling capacities and thermal calculations to be determined.

3.5 Periodic Maintenance of Charging System: Electric vehicles perform the charging function via AC and DC charging systems. The system solution includes a plug, pantograph, and wireless charging systems. The equipment that should be included in the vehicle system architecture, which is suitable for the AC charging infrastructure, which is the basis of the plug charging concepts, which is especially common in the automobile class, is the onboard charger. Vehicle charge control units are used for DC charging systems. Similarly, all energy and communication connections of the mentioned equipment are physically checked (color change, contamination, abrasion, rupture, etc.) and maintenance & repair processes are started. As with other power system components, a measurement is provided for possible exposure to high currents by taking into account the color changes that occur in the electrical connections. In addition, the most important issue is the control and physical cleaning of the charging connector and plug structures. Based on the charging concept of the electric vehicle, the charging process is performed and the charging performance is evaluated. One of the most basic problems encountered is the heating due to long charging times and the deformations that occur due to the charging plug-inlets on AC charging systems. Finally, similar periodic maintenance approaches on maintenance & repair should be observed on the charging station side as well as on the vehicle side according to following with specifications declared by the manufacturer.

4. Performing Vehicle Range Tests

After the maintenance & repair works based on the power system components specific to electric vehicles, road performance (range) tests should be carried out based on the range values given by the vehicle manufacturers, taking into account the relevant standard conditions and the usage status extending to years. It is recommended to analyze the energy consumption according to the range value obtained based on of the sources (main drive system and auxiliary systems) that cause power consumption. In this context, performance measurements, including regenerative energy gain values, are evaluated by taking into account the records taken from the vehicle as well.

It is appropriate to consider the vehicle dynamics (tire pressure/diameter, etc.) that will directly affect the vehicle's energy consumption, and additional consumptions from auxiliary systems (heating/cooling, interior/exterior lighting systems).

Road performance (range) tests for control purposes; allows the evaluation of the effectiveness of the maintenance & repair operations carried out. Utilizing specially determined test conditions, the efficiency of all connections and systems on the vehicle is reviewed at the specified engine speed ranges, within the prescribed speed limit and time on appropriate tracks. During the tests, all electrical and mechanical parts of the vehicle, sound, and vibrations coming from the drive motor are evaluated.

Finally, the braking performance of the electric vehicle at the appropriate distance at certain speeds (for the regenerative braking function, unlike the mechanical maintenance & repair process of the brake system) is also checked. The suitability of the obtained measurement and observation results is evaluated based on the reference values offered by the manufacturer.

5. Evaluation and Conclusion

Today, the intense competition environment, including the automotive industry, carries the maintenance & repair activities carried out within the scope of after-sales services among the important parameters that affect consumer preferences. In addition, the competition in question reduces profitability in vehicle sales; which causes the after-sales service sector to be evaluated as an important commercial gain factor, beyond being a support mechanism.

It is stated that the profit from the after-sales services of the enterprises operating in the automotive industry is higher than the profit from vehicle sales. According to the results of the research conducted for one of a brand operates in Turkey, reported that 54% of automotive dealer turnover incomes from vehicle sales, 24% from after-sales services, and 22% from other activities. Accordingly, it has been concluded that only 12% of the total profitability is obtained from vehicle sales, 34% is obtained from other activities and 54% is obtained from after-sales services [27].

It is considered that the automotive industry is considered the locomotive sector of the Turkey economy. Possible changes to be experienced with the development of the electric vehicle sector are important. With the increasing use of electric vehicles, it is expected that the possible axis shifts to be experienced in the automotive industry and subsequently the effect of electric vehicles on the after-sales service lane. In the current situation, it is considered that maintenance & repair processes are based on time intervals determined according to traditional methods for the automotive sector; a clear time or km interval based on power system components. For electric vehicles that perspective should not be presented. Despite the ongoing/will continue standard maintenance & repair approaches for traditional automotive systems/components (tyres, wipers, brakes, air conditioners, filters); periodic maintenance & repair operations are likely to be carried out on the basic components of electric vehicles such as the drive motor, motor control unit and battery. Generally, that will not go beyond version updates is envisaged in the software on systems. In addition, these applications need to be carried out by the end user through remote access, with an infrastructure to be provided, without the need for electric vehicles to come to the services.

However, the after-sales maintenance & repair concepts specific to new-generation electric vehicles will be introduced with the application of on-site repair approaches without waiting in case of malfunctions or similar malfunctions regarding the aforementioned power system components. Based on the expectation of large-scale business volume/lane change to be experienced in this area, it is evaluated that with the spread of electric vehicles, operators should direct their activities by taking into account the new processes in their fields of activity.

Author's Contributions

All research and writing processes belong to the author.

Conflict of Interest

I declare that there is no conflict of interest in this study.

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