INNOVATIVE APPROACH TO ELECTRIC VEHICLE DIAGNOSTICS

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Abstract

Electromobility is associated with the ever faster development and introduction of new electric vehicles to the market. They use an electric motor to drive the wheels of the vehicle and the necessary electricity is stored in traction batteries. Electric vehicles have a different construction than traditional vehicles i.e. those powered by internal combustion engines. For this reason, the manner of use, maintenance and service are different. Familiarization with selected operational issues of electric vehicles positively affects the reliability of their use as well as safety and comfort of driving. An important component of electric vehicles is the traction battery. Its proper operation influences the long-term preservation of the initial energy capacity and, thus, the range of the vehicle. The article presents tests of the state of traction batteries of a small electrically powered city vehicle. The vehicle, the batteries and the diagnostic devices used to assess the condition of the battery are described in detail. Based on the literature analysis and the observation of market trends, a fast and effective method of assessment of the technical condition of batteries in electric vehicles is proposed. The method has been tested on the selected vehicle. The technical condition of the battery in the vehicle was assessed after 4.5 years of operation and 30,000 km mileage.

Keywords: ecological transport; electric vehicle; diagnostics; battery charging

1. Introduction

Currently, two global trends may be observed and they are also becoming increasingly visible in Poland. The first of these is the production of energy from renewable energy sources, especially photovoltaic cells. The second trend is electromobility, which is the tendency to drive different types of vehicles with electric motors for the transport of people and goods [45]. There are many technical and organizational challenges related to electromobility [41]. Vehicles in the 21st century can run on more environmentally friendly fuels which include biofuels [22], natural gas [48] and hydrogen [14], rather than petrol or diesel. However, electromobility and photovoltaics are the two main areas of activity that contribute to meeting the low carbon scenario [3].

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Electric means of transport began to appear on the streets at the beginning of the second decade of the 21st century. They have many advantages over their predecessors powered by internal combustion engines. For instance, they are quiet because they do not have a noisy internal combustion engine [23]. They are also characterized by a very good driving performance in the form of rapid acceleration which is a result of the torque characteristics of electric motors [17]. Moreover, driving electric vehicles is very straightforward because it does not require the use of a gearbox. In addition, electric vehicles are ecological as they do not emit exhaust gases or other substances into the atmosphere [43]. In the first few years of their presence on the market, electric vehicles were only dedicated to urban driving due to their short range on one battery charge [29]. However, after several years of the development of traction battery systems, they are now able to accumulate enough energy to travel 400 km or more on a single charge. This means that electric vehicles can be used not only for urban driving over short distances, but also for traveling between cities and even for longer international journeys [32].

In order to achieve the free movement of an electric vehicle on short and long routes, in addition to capacious traction batteries, sufficient infrastructure to charge them is required [49]. The most common solution for charging vehicle traction batteries is the use of a low-power on-board single-phase AC charger with a rms phase voltage of 230 V. Such chargers have a power of 2 kW to 7 kW and they most often use Schuko electrical plugs, which are the most common standard in Europe and in many countries across the globe. This is the slowest way to charge a vehicle's battery, but it is the most accessible method for the home, garage or garden of the user. This method is usually used to slowly charge the battery at home during the night or at work during the day. Charging posts with a power output of up to 22 kW are usually used to charge vehicle traction batteries in public areas, they provide a three-phase alternating current to the on-board chargers fitted in the vehicle [15]. These points of access to the power grid usually use Type 2 charging terminals that are equipped with charging posts for the vehicles [6]. Fast DC chargers are used for the rapid charging of electric vehicle batteries [7]. This term refers to the large stationary chargers, which are the converters of alternating current from the power grid into the direct current (AC/DC converters) required to charge the vehicle's traction batteries. With such a solution, the vehicle does not need to be equipped with an on-board charger as fast DC chargers usually have capacities ranging from 40 kW to as high as 150 kW [16]. Fast chargers usually use two charging standards, CCS and Chademo which correspond to plugs which have a specific shape and specific current parameters.

Once the appropriate vehicle has been selected, along with the corresponding charging method, the user only needs to provide the electricity required to charge the vehicle. This aspect of vehicle use provides the most evidence of how ecological electric vehicles really are. Electric vehicles are not fully ecological if the electric current required to charge them comes from fossil sources such as coal or natural gas [28]. In this case, the greenhouse gas emissions produced in the process of providing electricity for the electric vehicle will effectively be shifted from its place of use to the place of electricity production, i.e. the power plant [4] [13]. This has one obvious advantage in that the electric vehicle does not emit any harmful substances in the centres of crowded cities

[35]. However, for an electric vehicle to be considered fully ecological, the electric current required to charge it should come from RES (renewable energy sources) [38]. In recent times, solar power and wind energy have become the most popular RES in the world [10]. In order to generate electricity from the wind, expensive and large-scale infrastructure in the form of windmills is required. Photovoltaic panels are used to produce energy from the sun, as they can be mounted on the roofs of buildings, on the ground and even on the roofs of vehicles. Of course, the amount of energy produced will depend on the number of photovoltaic panels installed [27]. Photovoltaic systems are the basis for distributed electricity generation in many European and other countries worldwide. The photovoltaic system is designed to meet the needs of individual farms, buildings or companies. The size of the photovoltaic system depends on the number of electricity consumers at a given location, their peak power requirements and the overall energy demand. An electric vehicle can then be regarded as an electricity consumer and a storage location of such an energy generating system.

At present, most photovoltaic systems are built and connected to the existing power grid (on-grid connection). This means that the excess electricity produced by the photovoltaic system can be fed into the power grid. A building powered by such a system also has the ability to draw electricity from the power grid when the photovoltaic system is unable to provide adequate power or when it is not operating, for example, at night. The more expensive solution is an off-grid connection. It does not require the presence of a power grid at all, but it needs expensive stationary batteries capable of accumulating large amounts of electricity. Currently, the batteries used for mobile and stationary applications are very expensive [9]. For example, their cost is about half the cost of the electric vehicle that they power. That is why most photovoltaic systems are currently operating in the on-grid mode. The creation and application of effective diagnostic algorithms for monitoring inefficiencies in the operation of the system [8], [12] is a big challenge for scientists and engineers involved in the development of photovoltaic systems. Lithium-ion batteries from vehicles can also be used in stationary energy storage [36]. Due to this, it is possible to build off-grid stations for charging electric and hydrogen vehicles [30].

After several years of using photovoltaic systems, the costs incurred are reimbursed. Then, the owner practically does not pay for electricity. Thus, it can almost completely reduce the cost of charging an electric vehicle. The amount of energy needed to charge electric vehicles is quite large and should be optimized and managed [40]. For this purpose, mathematical modelling is very often used to predict the energy produced by the photovoltaic system and to predict the energy consumed by the vehicle during battery charging [34].

The use of an electric vehicle is significantly more environmentally friendly than the use of a vehicle with an internal combustion engine [31]. Scientists in Slovenia have calculated that there is a significant difference in the carbon footprint of both propulsion sources [33]. This should stimulate the further development and marketing of electric vehicles. Both the traction electric motors and the remaining components of the electric vehicle powertrain are optimized for maximum efficiency [47] [18].

In the second and third decades of the 21st century, both electric vehicles, chargers and photovoltaic systems have become devices in the Internet of Things and Industry 4.0 [11]. They are able to acquire measurement data and use them for performance monitoring and self-diagnosis [21]. They are also able to transfer measurement data to a data cloud for displaying reports and for more advanced on-line and off-line diagnostics. On-line diagnostics are possible because the data can be read in real time. Off-line analysis is also possible due to the collection of large volumes of data in the cloud. Both on-line and off-line data analysis use advanced algorithms to detect anomalies and optimize the operation of the entire system. An example would be the measurement of the data from photovoltaic systems.In such systems, the energy consumers and the chargers must communicate with each other and notify the user of certain decisions. For instance, in the area of charging vehicles from renewable energy sources, the user can easily obtain a lot of data that may be used in an advanced way to enhance the operation of the system, e.g. data concerning the state of the electric batteries may be used to predict the range of the electric vehicle before it requires subsequent charging [1]. Semi-autonomous or fully autonomous electric vehicles are appearing on the roads more and more often [44].

As mentioned before, electric vehicles may be considered fully ecological when the electricity required to charge them originates from renewable energy sources. If a photovoltaic system exists in the on-grid mode, the multiplicity of its functions must take into account the power consumption necessary to charge the electric vehicle. We must also be aware of the fact that the performance of the photovoltaic system depends on the season of the year and the intensity of sunlight, which in turn depends on the geographical conditions and current weather. This means that even a large photovoltaic system is not always able to generate adequate power and the amount of energy required to charge an electric vehicle [46].

Due to a number of advantages, electric drive systems are more and more often used to drive individual and collective means of transport [2]. These vehicles are becoming cheaper and have an increased range on a single battery charge. As a result of mass production, electric vehicles are being offered at even lower prices. They are purchased not only by individual owners, but also as a fleet of company vehicles [5] [39]. They are very often the core of companies offering car sharing services [19]. Electric vehicles are also increasingly used by courier companies [42].

Another important market aspect, apart from the production and sale of electric vehicles, is their diagnostics and repairs [25]. Some electric vehicles are diagnosed and repaired in a similar way to their combustion engine predecessors. This happens when the manufacturer of such a vehicle model used the platform of an internal combustion vehicle to convert it into an electric drive. However, most automotive concerns decided to build electric cars from scratch using all the advantages of an electric drive. Authorized and unauthorized repair shops must learn a new approach to servicing electric vehicles as those possess different structure, different scope of individual warranty and post-warranty inspections, and in addition, a completely different approach to handling high-voltage components (up to 500 V). This requires completely different knowledge, competences and other skills from the staff.

Now is the time to quickly enter the market for a wide range of services for electric vehicles. Pioneers will have to blaze the trail, but in times of market boom, they will be ready to deliver the highest level of service at competitive prices.

2. Challenges in the field of electric vehicle diagnostics

The diagnostics and servicing of electric vehicles results from the market needs. Electric cars requiring diagnosis of a fault, which is accompanied by the illumination of a control lamp on the instrument panel, are appearing more and more often in car repair shops. Customers also ask by phone whether a particular workshop will take up such an order. Many owners of unauthorized car workshops are open to new technologies and undertake such orders with curiosity [24]. More often than not, however, the diagnostics of modern electric and hybrid vehicles is beyond their capabilities. Employees do not have the appropriate knowledge and tools (workshop or computer) to perform the service and must send the customer back. There are also questions about regular servicing and repair of the above-mentioned vehicles. It appears that customers are looking for a cheaper alternative to post-warranty service of their electric vehicles. They claim that lower electricity costs compared to gasoline or diesel fuel save money [37], however, a very expensive service at an authorized service provider (ASP) eliminates all savings. It becomes apparent that many authorized and unauthorized car repair shops are currently unable to provide this type of service, apart from minor work involving the replacement of tyres, light bulbs or brake pads. Thinking about the future in the Lublin region and throughout the country, many companies have decided to invest in innovations that will enable the provision of services for electric cars.

According to the authors, an innovative vehicle diagnosis and servicing service should include:

- innovative approach and implementation of the process of diagnostics and servicing of electric vehicles - constituting a process innovation;
- an innovative approach and implementation of the organization of workshop infrastructure, equipment and employee training – constituting a non-technological (organizational) innovation.

In order to obtain the necessary and up-to-date knowledge about the diagnostics and servicing of electric cars, one of the Lublin companies approached the authors who deal with this field. The main premise for selecting specific people is the fact that one of the authors has had an electric car for several years and is the author of many peer-reviewed scientific articles on this subject. There was an agreement between the partiesfor the conduct of scientific research and market analysis. The research was completed with a report which results in specific recommendations ready for implementation in the ordering company. These recommendations have been divided into several subject areas. One of these is the implementation of an innovative approach to the diagnostics and servicing of electric vehicles. But apparently, there are no clear guidelines on the part of producers or legislative bodies of the European Union on how to do it. The scientist proposed the development and introduction of internal standards and procedures in this area in the company. He also proposed to use of specific diagnostic tools to effectively test vehicles to detect and repair a damaged component. The scientist proposes the methods in the workshop that have so far been used only in the best research laboratories. Training employees in the basics of the operation of modern electric vehicle components will help identify potential damage locations. The use of research methods and tools and the collection of knowledge from the orders performed will allow for quick and efficient diagnostics. The author recommends road or dyno driving with saving selected diagnostic signals to a file, which can be analysed on-line and off-line.

The company interested in the implementation of that method realized the risks posed by servicing electric cars. It was understood that adequate workshop infrastructure was needed to carry out a professional service and repair process. This fact results in the company's willingness to build a completely new workshop, which would be prepared to provide innovative services. The company intends to introduce a new approach to the provision of services, taking into account the permanent presence of contact with a scientific unit and/or an individual scientist in order to consult difficult cases. It turns out that Lublin scientists are very open to this type of cooperation. Additionally, technical universities can provide qualified engineering staff for authorized and unauthorized workshops. After the infrastructure has been built, the workshop intends to provide innovative services.

3. The state of science in the field of electric vehicle diagnostics

The process of performing diagnostics on electric vehicles is subject to intensive development at an international level by scientists, automotive companies with their own authorized service providers and independent workshops dealing with the diagnosis of vehicles of various brands [10]. Each of these groups has an interest in the development and commercialization of innovations in this area.

3.1. Scientific research conducted at universities and research institutes

The research group at the University of Economics and Innovation in Lublin conducts scientific research in the field of innovative approaches to the diagnostics of more and more advanced devices, such as passenger cars and utility cars with electric drive. Due to such tests, diagnostic methods are developed which allow, for example, the continuous monitoring of selected measurement signals and their use to assess the correctness of operation or the prediction of damage. On the basis of such research, for example, advanced algorithms used by on-board diagnostics are created. The results of such research, conducted on a global level, often constitute the basis for the introduction of new directives, regulations, norms and standards introduced at the level of the European Union or individual countries. They are primarily aimed at the safe use of electric vehicles, environmental protection and assistance in mobility management [20], especially in the centres of large cities [26].

3.2. Research conducted by automotive concerns

Automotive concerns producing and selling electric vehicles are obliged to diagnose and service them during the warranty and post-warranty period. First, they have to produce vehicles with certain self-diagnosic characteristics resulting from the directives and regulations set out above. Without their possession and efficient operation, it is not possible to obtain partial approval, and thus whole vehicle type approval and the sale of vehicles in selected markets. An example is the known system of the OBD (on-board diagnostics) diagnostic connector. Automotive concerns have authorized service providers that provide services only for the vehicles of a given concern or for a merger. Their task is to ensure the highest standards of diagnostics and vehicle servicing. It is no secret that companies' income from this type of activity is often higher than from vehicle production. Diagnostics and service at ASP is obligatory for newly purchased vehicles in order to maintain the manufacturer's warranty. The high prices of the services provided encourage owners of electric cars to look for alternative places for diagnostics and servicing their vehicles.

3.3. Actions by independent car repair shops

In Poland, a group of independent car repair shops of various brands is fighting for the right to diagnose and service electric vehicles. It is also supposed to be the highest level of services provided; however, with the use of universal diagnostic testers (for various brands) and spare parts from the OEM (original equipment manufacturer) or cheaper alternatives, but of the appropriate quality.

4. An innovative approach to servicing and repairing electric vehicles

An innovative approach to servicing and repairing electric vehicles is to break all habits related to servicing and repairing vehicles with an internal combustion engine. It is in vain to seek general guidelines in this regard. These rules are rudimentary and relate to selected aspects of service or repair. However, a person dealing with them at the level of each important component (such as an electric motor or traction batteries) can make a number of recommendations that may be invaluable when working with an electric vehicle.

4.1. Adequate workshop infrastructure

The adequate workshop infrastructure includes both the workshop building itself and the necessary equipment and other elements. Of course, the building is the most important element of infrastructure. Here, a two-fold approach can be taken, similar to the production of electric vehicles as well. You can convert, adapt the existing workshop infrastructure or plan a modern workshop for diagnostics, servicing and repairing electric cars from start to finish. The author recommends using the second approach.

The construction of a dedicated workshop increases the safety, efficiency and effectiveness of works carried out in this area. The security requirements are not self-evident and are not collected in a single document. By researching the market and the requirements of individual suppliers of components (especially traction batteries), it is possible to collect such data and create guidelines for employees. The most important recommendations include the existence of separate diagnostic and workshop stands for each vehicle. This allows control of the flow of unauthorized people in the vicinity of serviced vehicles. The author's experience shows that the use of indirect measures, such as separating special zones from the general space, does not work. Of course, each room must be equipped with fire-fighting and anti-shock equipment.

4.2. Workshop equipment

Another important element of the equipment of such a workshop are meters, tools and other small items of equipment. All the necessary items can be found in a special package, shown in Figures 1 and 2. The workshop should also be equipped with fire protection equipment as shown in Figure 3.

Fig. 1. An example of a set of equipment for a workshop servicing electric vehicles [50]

Fig. 2. An example of a set of equipment for a workshop servicing electric vehicles [50]

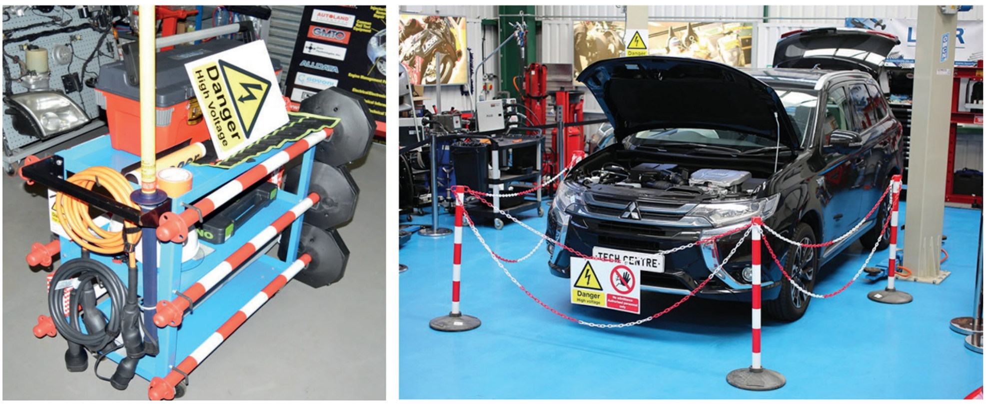

Fig. 3. Electric shock protection measures in the workshop [51]

4.3. Staff training

Appropriate education and the training of workshop staff has to meet the national requirements. The authors mean getting a major in automotive electrical engineering. Every action of working with electricity, even the simplest, requires appropriate qualifications and knowledge. Unfortunately, even the most extensive knowledge of electricity and many years of experience does not keep us safe. Accidents "at work" happen to even very experienced electricians. Of course, the knowledge gained over the years allows us to avoid obvious threats. Nevertheless, even the most trivial work related to electrical installations up to 1kV must be performed with the power supply switched off. This is necessary even when it comes to very simple activities such as changing light bulbs, sockets or laying power cables. If, however, it is necessary to perform work "under voltage", then security is necessary. In the event of an electric shock, the belayer person is able to cut off the power supply as well as to provide first aid. However, such works are of a quite special type, are rarely performed, and usually of a control and measurement nature.

The type and degree of completed education does not matter. It may be a basic vocational school, a technical school, first or second degree study or maybe postgraduate studies. It is about acquiring basic information, knowledge and qualifications in the field of automotive electrical engineering. Such grounds are necessary to apply for a SEP (Association of Polish Electrical Engineers) certificate up to 1 kV. This is the recommended route. Currently in Poland, students of electrical faculties of the first degree pass SEP exam in the scope of exploitation of particular groups of electrical devices up to 1 kV. It is also possible to obtain a SEP certificate for non-electricians. Then, the state examination before the commission is preceded by longer training covering the issues presented in Table 1.

Table 1. The subject and scope of the training [52]

No	Hours	Subject
1	1	Organizational classes
1	2	Fundamentals of electrical engineering
3	2	Basics of professional drawing and work documentation
4	4	Electrical materials science
5	5	Protection against electric shocks. PN-HD 60 364 standard
6	5	Protection against electric shocks (rules for the construction of electrical devices)
7	8	Practical exercises in assembling the installation and troubleshooting
8	4	Protection against electric shock in electrical installations (installations in special versions)
9	4	Occupational Health and Safety with devices, installations and power networks, fire protection
10	4	Ordinance of the Ministry of Economy of 23.04. 2013, item 492
11	1	Internal and qualifying examination

After passing the exam before the commission, the employee receives the rights and qualification certificate for a period of five years, as shown in Figure 4.

Fig. 4. Example of the qualification certificate of the Association of Polish Electrical Engineers

According to the authors, for the diagnosis of innovative electric and hybrid vehicles, specialized diagnostic devices are needed in the form of:
- laboratory multimeter,
- clamp multimeter for measuring current,
- wattmeter with energy calculator,
- oscilloscope, 2 analogue channels,
- CAN adapter,
- diagnostic device.

4.4. Further recommendations

Servicing electric vehicles can be exemplified by electric vehicle traction batteries. A large European producer of battery packs for passenger cars, vans and buses is the German company BMZ, which also has its own large production plant in Poland. BMZ provides each of its customers with instructions for servicing and repairing manufactured batteries [54]. Nobody knows it better than the producer.

The fact that the manual is not written in Polish by Poles, but in English, proves that the Polish market is still not very significant for the large global producers of traction batteries. It is an indirect confirmation of innovation and the duration of the existence of innovations on the Polish market. In the introduction, the manufacturer refers to the importance of all recommendations for the safety of employees as well as for the time of correct operation of the battery pack. The owner of the workshop, or the manager acting on his behalf, should ensure that several of these instructions are professionally translated into the polish language and presented to the workshop staff for review. It is also possible to organize bespoke training by experienced BMZ employees.

5. Diagnostics of traction batteries in an electric vehicle

5.1. Research object – Renault Twizy

The diagnostic process in an electric vehicle is carried out on the example of assessing the condition of batteries in an electric vehicle after several years of use. Customers often ask for this type of service when purchasing a used electric vehicle. Traction batteries are one of the main and also most expensive components in an electric vehicle.

The tested vehicle was a Renault Twizy, which over 4.5 years of use, had covered approximately 30,000 km in urban driving conditions. The research consisted of finding a diagnostic device capable of communicating with the vehicle's electronic control unit via the OBD (on-board diagnostics) socket. The author visited one of Lublin's independent car repair shops providing diagnostics services for all brands of vehicles. The tested vehicle in the workshop is shown in Figure 5.

Fig. 5. Electric vehicle Renault Twizy at Bosch Service [53]

5.2. Diagnostic device

A suitable diagnostic device is the Bosch KTS, the connection of which to the vehicle's OBD socket is shown in Figure 6. Figure 7 shows a desktop computer with software installed that allows data to be displayed on the monitor screen for viewing and printing.

Fig 6. Bosch KTS connected to the vehicle

Fig. 7. Bosch KTS diagnostic device

5.3. The process of diagnostics of lithium-ion batteries

The aim of the research was to diagnose the condition of traction batteries. For this purpose, the actual values in the tab: Battery management system-> WN 4.0 battery are displayed. As shown in Figure 8, it allows tracking of values such as:

- Battery charge status (SoC, State of Charge)
- Battery voltage High Voltage (HV)
- Total energy balance
- Vehicle mileage
- Power supply to the driver
- HV battery, max. Cell voltage
- HV battery, max. Cell voltage

Going deeper in the menu, you can read the actual values of the voltages of individual battery modules, as shown in Figure 9.

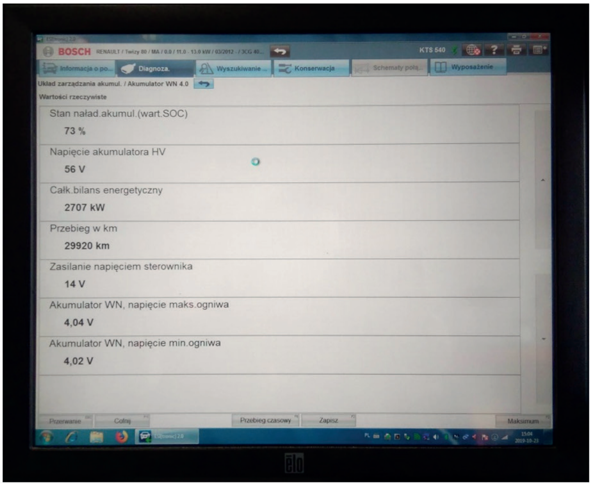

Fig. 8. Bosch KTS software screen

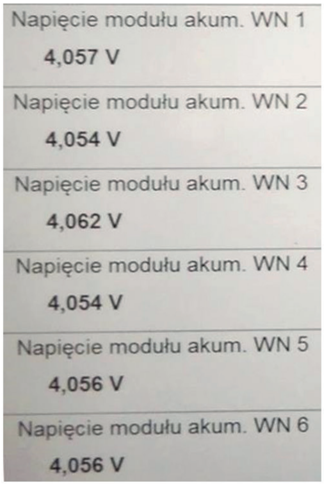

Fig. 9. Measurement of module voltage in Bosch KTS

The algorithm for the diagnosis and assessment of the technical condition of an electric vehicle traction battery developed by the authors should include:

- Total discharge of the traction battery in order to measure the voltages of individual battery modules and performing statistical calculations in order to find the target with the greatest voltage deviation compared to the mean value.
- Conducting a slow charging process along with measuring the amount of electricity consumed, then comparing the value measured with the watt-meter with the energy calculator with the increment resulting from the total energy balance. These values should be related to the nominal value of the energy capacity of the battery. If the measured values are much lower than the nominal value, it can be concluded that the energy storage has lost its capacity.
- Measure the instantaneous power and consumed energy at intervals of 15 minutes. The battery must be fully charged until the charging process is completed automatically. From the measurements, graphs of the power course and the energy consumed over time should be made.
- To fully charge the traction battery, measure the voltages of individual battery modules. Performing statistical calculations in order to find the target with the greatest voltage deviation compared to the mean value. Such a comparison is needed to assess the degree of voltage balance of individual battery modules.
- If the vehicle can be quickly charged with a DC charger, repeat the measurement in this case.

The research shows that after 4.5 years of using the vehicle, during which it has covered about 30,000 km in urban driving conditions, the condition of its traction batteries is very good. The differences in the voltage values of the individual modules are very small. The decrease in the capacity of the actual battery pack compared to the nominal capacity was measured and amounted to 8.721%. According to the manufacturer's warranty, there is an obligation to replace the battery pack when its capacity drops by 20%. These conditions relate to the long-term lease of batteries.

6. Conclusions

The ever increasing number of electric vehicles requires more and more charging stations. All media reports and statistical analysis show that the vehicle charging infrastructure should be developed first, which will encourage users to buy electric vehicles. Electric vehicles are inherently green as they do not emit any harmful substances to the environment. This is a significant argument for their use in the centres of large cities, where pollution by exhaust gases is very high due to the huge number of vehicles and numerous problems with the ventilation of selected metropolises, which cause the formation of smog. Electric vehicles seem to be the only effective solution to fight smog.

Due to the short time of market implementation of electric vehicles, their diagnostics, servicing and repair are not yet sufficiently developed. It is necessary to conduct research and develop works in this area in order to create effective diagnostic procedures. There are also legislative gaps in this area at the level of many European countries (not to mention less developed ones). There is still a lot to do in terms of the provision of infrastructure for charging electric vehicles (parking spaces, free and fast charging points) [16].

Such deficiencies mean an obvious market niche that will have to be eliminated in the coming years. Opening a business covering the diagnostics, service and repair of electric vehicles is a highly promising investment. This results from the global trend called electromobility, which has been developing rapidly in the world for several years, and has recently also appeared in our country.

The conducted analysis and tests show the following general conclusions in the field of electric vehicles:

1. Almost all car companies have electric drive models introduced to the market.

2. Electromobility is a global megatrend that is also slowly entering Poland.

3. There are different standards for charging electric vehicles; type 2 plugs are standard in Europe and DC charging with 50 kW chargers.

4. There is a wide range of electric vehicle chargers that vary in power and price.

5. As a result of using one's own vehicle (author's Renault Twizy) and testing various vehicles on the market (Nissan Leaf), you can gain experience related to the operation, servicing and repair of electric vehicles.

The conducted analysis and tests reveal the following conclusions in the field of electric vehicle diagnostics:

1. Lack of an internal combustion engine does not eliminate the need to service the vehicle's on-board systems. The EOBD socket still exists in electric vehicles and is the way to communicate with the vehicle and diagnose electrical components.

2. By applying an innovative approach to electric vehicle diagnostics, high efficiency in vehicle diagnostics can be achieved. The use of a scientific approach, including road driving with saving selected diagnostic signals to a file, is a much more effective method of diagnosis than carrying out tests while stationary.

3. Diagnostics of electric vehicles requires diagnostic equipment to communicate with selected makes of vehicles. The report suggests how to use cheap and universal equipment for professional diagnostics.

4. Diagnostics of electric vehicles requires knowledge of the structure and communication of the CAN bus. Training employees in this area will allow them to gain an advantage over the competition. It will allow faster and more precise identification of incorrectly working components.

5. Modern software for visualization and saving signals from an electric vehicle to a file is necessary for quick vehicle diagnostics.

6. A company operating in the field of electric vehicle diagnostics should permanently cooperate with an individual scientist or research institute carrying out research in this field.

7. A company undertaking the servicing and repair of electric vehicles should:
- have an appropriate workshop infrastructure;
- have procedures in place for dealing with selected hazardous situations as internal standards;
- have employees that are properly educated and trained to meet national requirements.

8. A company operating in the field of servicing and repairing electric vehicles should permanently cooperate with suppliers of OEM components and spare parts for EVs. It should also benefit from the training they offer.

7. Nomenclature

OBD on-board diagnostics
RES renewable energy sources
OEM original equipment manufacturer
ASP authorized service provider

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