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ELECTRIC VEHICLE BATTERIES AND CHARGING INFRASTRUCTURE: CHALLENGES AND OPPORTUNITIES

In today's world, as we move towards more sustainable and environmentally friendly transportation, electric vehicles are becoming a centerpiece. The article "Electric Vehicle Batteries and Charging Infrastructure: Challenges and Opportunities" analyzes the current state and prospects for the development of electric vehicle batteries and charging infrastructure.

The purpose of the article is to highlight the problems associated with charging infrastructure, the use of different types of batteries for the development of the electric vehicle sector and ways to solve them. The article explores the current battery technologies used in electric vehicles, in particular lithium-ion batteries, and points out the advantages and disadvantages of each type. By comparing energy density, charging speed, and service life, the article helps to understand which batteries may have advantages in the electric vehicle market in the future. The main motivations for the transition to electric vehicles are to reduce emissions of harmful gases, attract renewable energy sources and reduce dependence on oil resources. The research is based on key aspects of the introduction of electric vehicles: improvements in battery technology to ensure greater efficiency and durability; the need to develop an efficient and affordable charging infrastructure for electric vehicles; the importance of fast charging for convenience and efficiency, and to reduce charging waiting times, making electric vehicles more attractive to users; and the development of battery recycling and reuse systems.

The article examines the challenges associated with the development of charging infrastructure. It analyzes issues such as the limited availability of charging stations, different charging standards, and the efficiency of existing networks. In addition, the article highlights strategies that can be used to overcome these challenges, such as incentivizing infrastructure development and standardizing charging connectors. The economic and environmental benefits of the transition to electric transport and the need for joint efforts by governments, manufacturers, and infrastructure companies to overcome the challenges and ensure the sustainable development of this industry are discussed. Overall, the article provides an in-depth overview of the current state and prospects for the development of key components of electric vehicle infrastructure, contributing to the understanding and resolution of the challenges associated with the transition to more sustainable and environmentally friendly transportation.

As a result of further research, a conceptual approach to innovation and investment in the development of batteries for electric vehicles and charging infrastructure is proposed to overcome current challenges. The practical implications of the research findings for the transport industry are in the recommendations provided to facilitate cooperation between all stakeholders and are essential to achieving success.

Keywords: electric vehicle, charging infrastructure, electric vehicle battery, charging stations, electric energy.

INTRODUCTION

Electric vehicles have been the main trend in the growth of such vehicles in recent years. Most European countries have set the goal of switching to electric or hybrid vehicles and abandoning internal combustion engines. At the moment, the electric vehicle market is at the stage of active development. The number of electric vehicles on the road is growing, which indicates an increasing interest in this technology. The European Parliament voted in favour of a complete ban on new cars with internal combustion engines by 2035. The next step is approval from the EU Council [1].

The main advantage of electric vehicles is their environmental friendliness, as they do not emit harmful substances into the air and are therefore suitable for use in urban environments. They are also quieter, have a smoother ride and lower maintenance costs. However, at present, the high price and insufficient charging infrastructure are the main obstacles to the mass adoption of electric vehicles. The introduction of electric vehicles as an environmentally friendly alternative has significant potential to address environmental, energy and transport issues. However, the effective introduction of these vehicles requires government support, the development of charging infrastructure and further research into battery technology. The key aspects that explain their importance are: driving range and battery capacity, development of efficient and affordable charging infrastructure, charging speed, battery fire safety, and diversification of the energy mix.

The world is gradually moving towards the electric vehicle era, and battery production is becoming a priority for many countries [2]. Continuous improvements in battery technology are helping to increase battery capacity and improve driving range. The widespread distribution of charging stations in cities, car parks, public places and motorways is an attractive proposition for potential buyers. The availability of a sufficient number of charging stations provides convenience and reliability for EV owners, as they can charge their cars at a time and place that is convenient for them. The development of fast charging, which allows electric vehicle batteries to be charged in a short time, helps to reduce waiting times and makes electric vehicles more attractive to a wider audience.

Electric vehicle batteries can be used as a means of storing electricity and help to even out the load on the grid. Charged electric vehicles can serve as reservoirs of stored electricity that can be used during peak periods or during power outages. This contributes to the stability of the grid and the expansion of renewable energy sources.

The aim of the study is to investigate and describe the problems of charging station infrastructure and batteries for electric vehicles and consider ways to solve them. In this regard, it is necessary to analyse the results of testing and testing the fire resistance of the electric vehicle battery system and the safety of charging stations.

ANALYSIS OF LITERATURE DATA AND FORMULATION OF THE PROBLEM

Batteries are a key component of electric vehicle technology that provides electrical energy storage for propulsion. The main type of batteries used in electric vehicles is lithium-ion batteries. The choice of a specific battery type for an electric vehicle depends on various factors, such as driving range, charging time, cost and availability. Lithium-ion batteries are widely used due to their advantages in terms of energy density and weight, but other battery types also have their own unique advantages that may be considered in certain cases.

An important player in the battery technology market is A123 Systems, a company founded in 2001 that specializes in the development and production of batteries for electric vehicles, power sources, tools and other devices. One of A123 Systems' main products is lithium-ion batteries, in particular nano phosphate lithium iron phosphate ($LiFePO4$) batteries. These batteries are known for their high resistance to overheating, long service life and relatively safe operation compared to other types of lithium-ion batteries. A123 Systems manufactures batteries of various sizes and capacities that can be used in small electronic devices and large power systems. The company actively researches and develops new technologies to improve the performance, safety and durability of its batteries.

Based on the Bloomberg NEF lithium-ion battery supply chain ranking, Visual Capitalist has shown battery production capacity by country from 2022 and projected to 2027, highlighting China's dominance. Most of the parts and metals that make up a battery, such as lithium, electrolytes, separators, cathodes and anodes, are predominantly made in China. [2]. New battery materials and designs are being developed to increase energy density, extend driving range, reduce charging time, and improve overall life expectancy.

Other types of batteries are also used in electric vehicles, such as lithium-polymer batteries (Li-Po): These batteries have similar characteristics to lithium-ion batteries, but they are more flexible and can be made in different sizes and configurations. This allows them to be used in a wider variety of electric vehicle designs. The original type of batteries, called "lithium-polymer", were technologically a further development of conventional lithium-ion batteries and lithium batteries. The main difference was the use of a dense polymer electrolyte [3] .

Supercapacitors are another type of battery. Supercapacitors, also known as electric motors, have a high energy density and are capable of delivering a large energy flow. They are often used as additional energy sources to improve performance and to store energy during braking. Supercapacitors are electrochemical capacitors that differ significantly from conventional capacitors in their virtually unlimited durability, lower current losses and higher power density. At the same time, they are much smaller in size. In other words, this is a new generation battery that can open up numerous prospects in the energy sector and in electric vehicles [4]. The research and development of new battery materials, such as lithium-sulfur and lithium-metal batteries, opens up opportunities to increase energy density and improve capacity. These results bring Ukrainian technology much closer to being used in modern life. Globally, this development is unprecedented and exists only at the theoretical level, and the creation of a laboratory prototype is a significant breakthrough in the field of battery manufacturing [5]. The main advantages of lithium-sulfur (Li-S) batteries are their high energy density and potentially low cost. In addition, raw materials for lithium-sulfur batteries are cheaper and more readily available than those used in lithium-ion batteries. However, lithium-sulfur batteries have limited cyclic stability, which means that their efficiency decreases over time.

The use of new technologies such as nanomaterials and nanostructures can help improve the charge rate and battery life. "New bulk materials, film and powder technologies have made it possible to create rechargeable batteries and supercapacitors with high specific capacity, as well as high-quality permanent magnets. As a result, new efficient components have emerged: embedded electronic systems, sensors and mechanical drives (stepper, collector and brushless motors), galvanic cells and rechargeable batteries, etc. These components have become the basis for creating 3D printers, small aircraft (drones, etc.), electric vehicles, etc." [6].

However, there are several challenges to the widespread adoption of electric vehicles related to battery technology. Some of them include:

1. Cost: Batteries are expensive components of electric vehicles and represent a significant proportion of the total cost of the vehicle. Reducing the cost of batteries is considered an important step to increase the affordability of EVs for the general consumer.

2. Life cycle and disposal: Batteries have a limited life cycle, after which they lose their original energy density. Efficient disposal of used batteries is an important task to reduce the environmental impact and efficient use of renewable resources. The development of battery reuse programmers, as well as recycling and disposal technologies, are important steps in creating a sustainable and environmentally responsible infrastructure for battery systems.

3 Fire safety: Fire safety is an important aspect of electric vehicles because they use lithium-ion batteries, which can be potentially dangerous if misused or damaged. Batteries must be designed and manufactured to meet fire safety standards. The United Nations Economic Commission for Europe (UNECE) Resolution No. 100 "Specific requirements for the approval of vehicles with regard to specific requirements for electric drivetrains" (abbreviated as R100) has been significantly amended. New test requirements have been introduced in the approval process for motor vehicles and battery energy storage systems (REESS) to ensure safe operation of batteries and a higher level of safety for vehicle occupants. These new test requirements were adopted in July 2016 [7].

The deployment of an efficient charging infrastructure is a key element in the success of the electric vehicle industry. A convenient, accessible, and reliable network of charging stations is needed to increase the popularity of electric vehicles. Large cities, motorways and public places such as shopping centres and car parks should be equipped with charging stations [8]. Developing fast charging standards and standardising different types of charging connectors are also important aspects. Despite significant progress in the development of fast charging stations, the charging time for electric vehicles remains long compared to refueling a traditional car. The development of fast-charging technologies and the growth of the charging station network is an important aspect to ensure the convenient use of electric vehicles.

PURPOSE AND OBJECTIVES OF THE STUDY

At a time when the electric vehicle market is setting records, there is still no clarity on the standardisation of charging ports. How many and what types of chargers are needed now, in which regions do their customers live, where are there shortages, and where will this go in the future?

First, let's look at the types of charging stations for electric vehicles available in the world:

Level 1 is the lowest charging level and lowest connection security. . It usually takes about 12 hours to restore the vehicle's charge using this method. This process takes place without any special equipment, using a standard wall socket and a special AC adapter.

Level 2 is a standard AC charging station that can be installed at home or used at petrol stations. It is used for charging all types of electric vehicles with standard connection sockets and built-in protection. The charging time is approximately 6-8 hours for batteries with a capacity of 20-24 kWh.

Level 3 is the most powerful level, which uses AC stations. It is suitable for both single-phase and three-phase networks.

Level 4 - This type of charging station uses direct current. The power of these stations may be too high for some electric vehicles. However, cars that support this standard can charge their batteries up to 80% in 30 minutes. Such stations can be found in city car parks and highways, although they are quite rare in Ukraine, as they require a separate powerful power supply line. In addition, the cost of such charging stations is quite high.

Since the characteristics of levels 1-4 are constantly being amended, a classification of charging stations by charging power can be used: [9]

1. For household 230 V AC power supplies up to 16 A (3.7 kW), often referred to as cable power supplies.

2. For accelerated charging from 230 V/400 V AC power supplies from 16 A to 40 A (3.7 kW to 30

kW).

3. Fast charger or "Supercharger" - fast charging with direct current supplies power to the battery bypassing the inverter. This is a large stationary equipment with a capacity of 10 kW to 400 kW.

It is worth noting a separate type of Tesla Supercharger charging stations, which differ from the standards discussed above in their specificity of use. In practice, these are not even just charging stations, but energy pumps that can charge a car's batteries up to 50% in 20 minutes, up to 80% in 40 minutes and up to 100% in 75 minutes. Tesla Superchargers have an impressive charging capacity of 135 kW DC. The connectors of these stations vary depending on the region of use: in the US, they use three types of connectors, in Europe - five. This variety of connectors makes it much more difficult to operate Tesla vehicles that have been imported from the US to European countries.

Charging stations can also be classified according to the principle of use: - stations intended for stationary installation; - stations for portable use in one or more locations; - stations for portable and stationary use. [9]. The international standard IEC 62196-2 defines the types of electrical connectors and charging modes for electric vehicles. In May 2012, the eight largest European and American manufacturers (Audi, BMW, Chrysler, Daimler, Ford, General Motors, Porsche, Volkswagen) announced that a single Combined Charging System standard would be used for all their electric vehicles.

Rapid developments in high-power charging station technology, such as High-Power Charging (HPC), can significantly reduce charging times for electric vehicles. This includes the use of higher charging capacities, higher voltages and improved cooling systems, which allow batteries to be charged efficiently in a short time. Wireless charging technology, known as inductive charging, allows electric vehicle batteries to be charged without the need for wires. This can be a convenient and innovative solution that allows you to charge your car while it is parked at specially equipped sites or even while you are driving.

RESEARCH RESULT

Many countries in the European Union have set ambitious targets to reduce carbon emissions and promote a shift to non-conventional road transport systems. This includes banning the sale of new petrol and diesel cars in the future, as well as providing financial incentives for the purchase of electric vehicles, reducing taxes on them and providing charging infrastructure. The EU plans to set zero emissions for new cars from 2035. The US is committed to achieving a target of 50% of total electric vehicle sales by 2030. Of course, to achieve such goals, infrastructure needs to be developed in parallel.

In June 2023, more than 1.2 million new electric vehicles were registered worldwide, and one in five of them was electric. In total, electric vehicles, together with hybrid cars, account for a third of the global car market. In Ukraine, as of June 2023, according to the Institute of Research, 61,019 electric vehicles were registered, including 59,009 cars, 2,005 trucks and 5 buses.

However, there are still challenges related to battery technology for the large-scale deployment of electric vehicles. Today, there are several types of batteries that are considered promising for electric vehicles: lithium-ion, lithium-sulfur, lithium-polymer, solid-state, graphene, air-lithium and other batteries. Engineers developing batteries for electric vehicles continue to improve power systems to increase their energy capacity and, consequently, the range of electric vehicles. They strive to achieve performance that is on par with that of traditional cars.

The most common type of battery used in most modern electric vehicles is lithium-ion. They have a high energy capacity, long service life and a wide temperature range. Developers are trying to improve their efficiency and reduce their cost. It is important to note that at the current stage of industrial production, the use of electric vehicles in urban areas is becoming even more relevant due to the introduction of lithium-ion batteries to the market in recent years. These batteries can reduce the full charging time to 10-20 minutes due to their higher charging current and voltage.

When choosing a promising type of battery for an electric vehicle, manufacturers pay attention to factors such as energy efficiency, cost, environmental friendliness and the ability to integrate into the automotive infrastructure. Reducing the cost of an electric vehicle battery is a key factor in the growing popularity of electric vehicles. Optimising production processes and using more efficient technologies can significantly reduce the cost of battery production. The use of more economical and affordable materials, new assembly or wrapping methods can reduce the cost of a battery without sacrificing performance. Developing a second life for batteries: The use of used batteries from electric vehicles in renewable energy or other applications can extend their life cycle and reduce costs throughout the chain. Overall, reducing the cost of an electric vehicle battery requires a comprehensive approach, including technical innovation, manufacturing improvements, and collaboration across sectors.

To date, there are no unified approaches to determining the optimal operating modes of renewable energy sources depending on the capacity of electric vehicle batteries and charging methods, given the unpredictable nature of such electricity production. This, in turn, requires research into the operating modes of charging stations based on two or more renewable energy sources. One of the key tasks is to determine the capacity of the photovoltaic battery and wind turbine, as well as the storage devices, depending on the energy capacity of the electric vehicle battery and the duration of the required charge [11,12].

Forecasting the production of renewable energy, such as solar and wind, is an important aspect for the efficient management of charging stations that consume this energy. Various methods and approaches are used for this purpose. One of the main ways is to use meteorological data such as wind speed, solar radiation intensity, temperature, etc. This data can be used to calculate the expected production capacity from wind and solar installations. The use of statistical methods, such as regression analysis, allows for the development of forecasting models based on historical energy production data. Such models can take into account seasonal changes, daily fluctuations and other factors. For solar energy, cloud image analysis using satellite data can be used to determine cloud cover and predict solar radiation. Ensemble methods are a combination of several forecasting methods to obtain more accurate results. For example, both statistical methods and machine learning can be used. In addition to forecasting, adaptive control methods are used to adjust charging station operating modes in real time to the current energy production situation.

The most promising method of using renewable energy is artificial neural networks, which can be used to create complex forecasting models. They can take into account the multifactorial relationships between meteorological parameters and energy production. All of these methods are used to develop renewable energy production forecasting models that help to adapt charging station operating modes in a timely manner and optimise the use of available energy.

During the time a battery is used in a vehicle, it is charged and discharged. When batteries lose some of their capacity after prolonged use in electric vehicles, they can be used in a second life, for example as energy storage systems or backup power sources. Once batteries have lost their useful capacity, they must be disposed of properly. Recycling requires special attention to environmental aspects, as many of the materials used in batteries can be harmful to the environment. The development and improvement of recycling technologies is an important task to ensure sustainability and minimise the negative impact of batteries on the environment.

The use of mathematical models to predict the outcome of EV battery recycling can be an important tool for assessing the efficiency, cost-effectiveness and environmental impact of different recycling methods. Mathematical models can describe the kinetics of chemical and physical processes that occur during battery recycling. For example, the decomposition of materials at elevated temperatures or the dissolution of certain substances in liquid media. Mathematical models can include heat and mass balances to account for the heat energy released or absorbed during the recycling processes, as well as the transport of substances in the system. The models can describe the chemical reactions between different battery materials and the environment during the recycling process. This can help predict the products of the reactions and their environmental impact.

Mathematical models can estimate the cost of different disposal methods, including energy, equipment, materials and labour costs, as well as assess the efficiency of the process in terms of yields of useful products and waste, and can include an assessment of the environmental impact of different disposal methods, including emissions, water and air. Various numerical methods can be used to develop such mathematical models, as well as experimental data to validate and calibrate the models. As the recycling process can be quite complex and dependent on many factors, the development of accurate and reliable mathematical models is an important task to ensure the efficiency and sustainability of EV battery recycling [13].

Fire safety is indeed one of the most important aspects of electric vehicles. Due to their design, battery and electrical systems, it is important to take measures to prevent and control fires. The batteries in electric vehicles are highly energy intensive, so it is important to ensure that they are working and charging properly to avoid overheating. A fire can be caused by incorrect charging equipment connection, damage or poor quality components. Collision fire safety, where batteries or electrical systems can be damaged during accidents, which can lead to a fire. It is important to design the vehicle in a way that reduces the risk of fire after a collision.

Electric vehicles have control systems that monitor the condition of the batteries and electrical systems. These systems can detect elevated temperatures or other anomalies that may indicate a possible fire hazard. It is important to ensure that battery compartments are provided with adequate ventilation and cooling systems, which can prevent battery overheating and fire. Electric vehicles can be equipped with special extinguishing systems that are automatically activated in the event of a fire. In addition, fire extinguishers can be installed in electric vehicles to ensure a quick response to a fire.

There are safety standards that define the design requirements for electric vehicles and their components, including batteries, in order to prevent fires and minimise risk. Thus, the automotive industry is currently undergoing key changes, and these changes require the need to revise the relevant technical regulations. For example, changes to the United Nations Economic Commission for Europe (UNECE) Regulation No. 100 "Specific provisions relating to the approval of vehicles with regard to specific requirements for electric drivetrains" (abbreviated as R100). Significant changes have been made to the approval process for motor vehicles and battery energy storage systems (abbreviated as REESS). The test procedures, their list and a brief description are given in Table 1.

Table 1 - Stages of testing battery energy storage systems (REESS)

Appendix No.	Name of the test	Brief description
8A	Vibration testing	The objective is to test the safety of the EHS in a vibration environment to which the EHS may be exposed during normal vehicle operation. The equipment is subjected to a sinusoidal vibration with logarithmic transients for 15 minutes in the frequency range of 7 Hz to 50 Hz. This cycle is repeated 12 times within 3 hours.
8B	Thermal shock and cycling tests	The resistance to sudden changes in temperature must be assessed. The REESS is exposed to a temperature of 60 °C for at least 6 hours, followed by a temperature of 40 °C for a further 6 hours. The cycle is repeated 5 times.
8C	Mechanical impact	The safety under inertial loading, which can occur, for example, in the event of a road traffic accident, is tested. The REESS is accelerated or decelerated to the values given in R100.
8D	Mechanical integrity	Safety is tested under contact loads that may occur in the event of a road traffic accident. The REPS must be crushed between the pad and the impact plate at a specified force for a specified time.
8E	Fire resistance	The purpose is to test the resistance of the CEPBE to fire from outside the vehicle. The driver and passengers must have sufficient time to leave the vehicle in the event of a fire.
8F	External short-circuit protection	The operation of the short-circuit protection must be checked. This function must interrupt or limit the short-circuit current during use to protect the REESS from further accidents caused by short-circuit current.
8G	Overvoltage protection	Evaluation of the effectiveness of overcharge protection. The REESS should be charged until the charger stops charging, or limits the charging process, or the REESS charge reaches 2 times the battery capacity.
8H	Over-discharge protection	The performance parameters of the over-discharge protection must be checked. The REESS must be discharged until the device discharges itself or limits the discharge, or until it discharges to 25% of the rated voltage.
8I	Protection against overheating	Test the efficiency of the device against internal overheating during operation when the cooling system fails. During the test, the REESS is continuously charged and discharged with a constant current to raise the cell temperature. The REESS is then placed in an oven where the temperature is increased to the specified.

Fire resistance test - Annex 8E. The purpose of this test is to check the resistance of the REESS to fire originating outside the vehicle, for example due to a fuel leak (from the vehicle itself or another vehicle in the vicinity). The test is required for REESS containing a flammable electrolyte. It is not required if the lower surface of its casing is more than 1.5 m above the road. The test is performed either with the complete REESS system or with the associated subsystem, including the cells and their electrical connections. One sample is tested. At the manufacturer's discretion, the test is carried out on the vehicle or its structural parts. The device under test shall be placed on the structure. The device shall be driven by the flame of the fuel placed in the pan under the device.

Test conditions: ambient temperature min. 0°C, charge state at the upper 50 per cent of the normal operating charge state, at the beginning of the test all protective devices that affect the function of the test device and are relevant to the test result must be functional. The temperature behaviour of lithium-ion batteries is shown in Table 2.

Table 2 - Temperature behaviour of batteries

Temperature.	Behaviour of lithium-ion batteries
Up to 60°C	Normal operating and storage temperature (up to 85°C for some models)
70 - 90 °C	The graphite anode and electrolyte are self-heated. Self-ignition approx. 80 °C at 100% charge; 130 °C when discharged - Evaporation of electrolyte components => pressure increase => cell rupture
130-150 °C	Folding PE, PP or PE/PP separator closes the pores (shut-off)
>150 °C	The separator melts due to an internal short circuit => further heating => thermal discharge occurs in minutes
130-250 °C	The cathode material reacts exothermically with the electrolyte => small amount of oxygen is released => flammable gases escape at a pressure of approx. 13.8 bar (opening of the cell ventilation cover)
>660°C	Thermal discharge - Some cathode materials decompose and change their crystal structure => small amounts of oxygen are released - Heat leakage is a self-sustaining, continuous exothermic chemical reaction that is triggered by malfunctions or damage to the lithium-ion battery and leads to overheating => cannot be interrupted from the outside => results in a fire - Melting of an aluminium current conductor (cathode) - The release of graphite dust with a possible risk of fire, especially with large batteries in rooms, and damage to equipment due to short circuits.

Description of a real-life test of electric vehicle batteries [15]. The battery system (REESS) with the appropriate test fixtures was placed in the test shaft. Thermocouples were placed on the test equipment to provide an overview of the temperatures at different points during the test. In addition to temperature, the battery voltage was measured. The fuel used was petrol, which was ignited remotely by an electric igniter. The temperature of the petrol was higher than 20°C, so no preheating was performed. Direct exposure to the flame took place for a set period of 70 seconds. Then, for 60 seconds, the indirect flame with a screen was applied. After removing the flame tray, time was allowed for the battery temperature to drop to ambient temperature. During the test, no signs of explosion were recorded in any of the batteries. After the flame was removed, no spontaneous combustion was observed, and no significant voltage drop was recorded, meaning that the batteries were operable during and after the test.

The graphs (Figures 1, 2) showing the temperature and voltage curves during the traction battery test show that starting from the 25th second, the voltage measurement failed. The voltage of the traction battery was measured after the test and it was recorded that there was no voltage drop, the battery was operational (Fig. 3). The entire test process was recorded by a video camera.

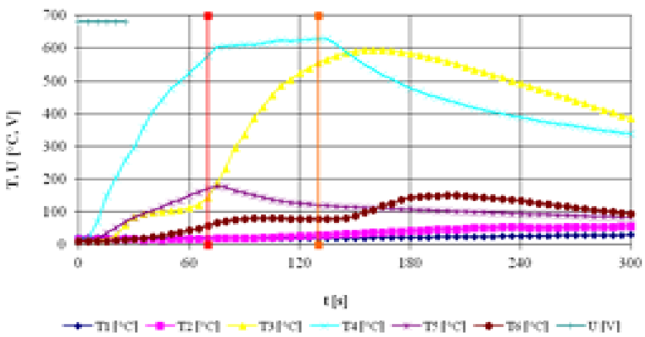

Figure 1 - Graph of the temperature measured during the fire resistance test of the battery system

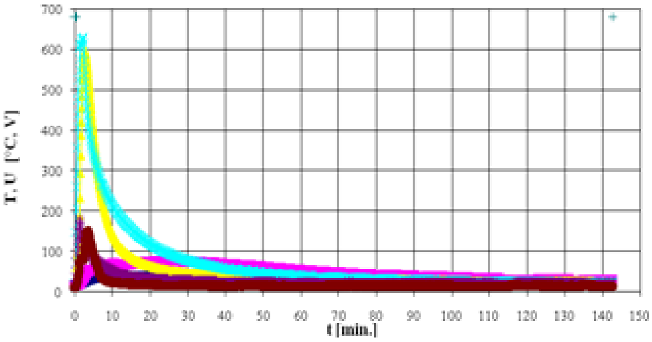

Figure 2 - Voltage plot measured during the battery system fire test (REESS)

Placement of thermal elements: T1 is the top of the battery from the inside; T2 - the side of the battery from the inside; T3 - the side of the shield - from the inside; T4 - casing temperature - bottom; T5 - temperature of the casing - top (lid); T6 - Temperature at the entrance to the test shaft at a height of 1.5 m from the floor;U - at the 25th second of the test, the insulation of the measuring wires burned out, followed by a short circuit of the bare wires.

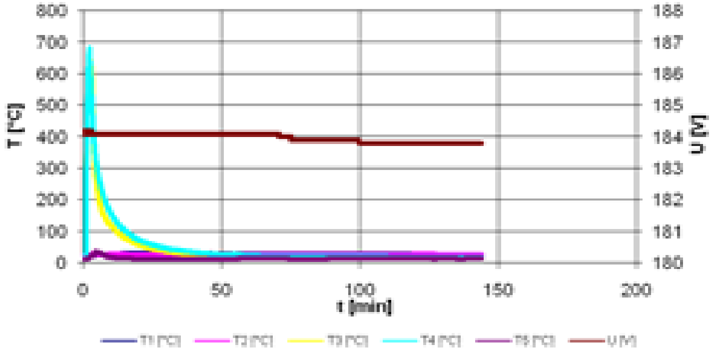

Figure 3 - Temperature and voltage graphs measured during the battery system fire test (REESS)

Placement of thermal elements: T1 - temperature inside the battery on the left side; T2 - temperature inside the battery on the right side; T3 - Surface temperature of the bottom of the battery on the left side; T4 - surface temperature of the bottom of the battery on the right side; T5 - Ambient temperature at the entrance to the test shaft; U is the voltage at the battery terminals.

Electric vehicles are environmentally friendly and do not emit CO2, SO2, NOx, which cause greenhouse effects and other health problems They operate using electrical energy, which can be generated from renewable energy sources such as solar and wind energy [14].

From the discussions on the impact of batteries on vehicle fire emissions, especially hydrogen fluoride (HF) and organic solvents (electrolytes), it was clear that despite many tests carried out, there is still disagreement among experts on measurement methods and effects. to be assessed. In particular, answers are awaited on the use of necessary protective equipment for rescuers.

Overall, fire safety is an integral part of the development and operation of electric vehicles. Engineers and researchers continue to improve technologies and standards to ensure that EVs are reliable and safe in relation to fire.

At a time when the electric vehicle market is reaching record levels, the issue of standardisation of charging stations and charging ports remains unresolved. Questions arise about the number and types of chargers needed at the moment, as well as the distribution of customers in different regions and the existing shortages. All of these aspects and their future solutions are being discussed with electromobility experts and representatives of authorised dealers.

Large investments may be required to build and deploy charging infrastructure. This may include government subsidies, partnerships with energy companies, or co-financing with third parties. Business models may include charging based on time, power or volume of electricity consumption. Within the European Union, projects are being developed to create international infrastructure networks of charging stations. This makes it easier for electric vehicles to travel across borders and ensures seamless charging.

The complexity of building and deploying charging infrastructure depends on various factors, such as project scale, grid availability, permitting procedures and financing. The location of charging stations should be strategically distributed, taking into account the needs of users and the possibility of increasing the number of stations in the future. One of the main challenges for the charging infrastructure is the insufficient number of stations compared to the growing number of electric vehicles. This can lead to queuing, a lack of accessible stations and reduced convenience for EV owners.

Different models of electric vehicles may use different charging standards, such as CHAdeMO, CCS, Tesla Supercharger, etc. This can pose challenges for EV owners who may be dependent on a particular standard. However, most new charging stations offer multifunctional connectors or adapters for compatible charging of different models.

Connecting charging stations to the electricity grid requires an adequate electrical connection and capacity. This may require upgrading the electrical infrastructure or installing additional equipment to provide the required capacity

Managing a network of charging stations. With a large-scale charging infrastructure, there may be a need to remotely monitor and manage charging stations. This may include a system for managing and monitoring stations, charging flows and charging factors.

DISCUSSION OF THE RESULTS OF THE STUDY

According to the ČSN EN 50604-1 Regulation for the Transport and Use of Lithium Batteries for Electric Vehicles and ISO 6469-1:2019 - Electric Road Vehicles, both tested batteries withstood the effects of fire during the test and there were no signs of explosion. The traction batteries have successfully passed the certification process due to the positive result of the fire test. The battery system (REESS) for trolleybuses is currently nearing the end of the approval process.

The results of previously published studies on this topic should be summarised and compared with the results of vehicle fires of conventional engines. Measurement methods and results of existing internationally available radio frequency and flue gas emission measurements on cell and electric vehicles. Reproducible, realistic measurement methods and, if necessary, recommendations for firefighters should be developed for fire emissions from electric vehicles and compared with conventionally powered vehicles.

In addition, it is necessary to determine the structure of the charging network, namely the types of charging stations and the required number of charging stations. Given the absence of standards for the required number of charging stations and charging network design rules established by the state, it was decided to adapt the standards for the number of petrol stations and use them for the infrastructure for charging batteries for electric vehicles, which faces several challenges that affect its development and efficiency.

The uneven distribution of charging stations across different regions and the lack of charging stations in some locations can create problems for EV owners and limit the use of EVs. Building and maintaining charging infrastructure requires investment. Securing funding can be a challenge, especially in regions with limited resources. Locating charging stations in urban areas where space is a limited resource can be challenging. The desire to use renewable energy for charging can be challenged by limited resources and fluctuations in renewable energy production.

SUMMARY

Electric vehicles (EVs) are environmentally friendly and do not emit CO2, SO2, NOx, which cause greenhouse effects and other health problems. They operate using electrical energy, which can be generated from renewable energy sources such as solar and wind power.

As electric vehicle batteries contain a significant amount of energy, following certain measures and protocols for fire safety is critical. Electric vehicle batteries are designed to withstand high temperatures and fire. They usually have built-in cooling and ventilation systems that control the temperature during charging and use. In addition, batteries are made of materials that have a high level of fire resistance and minimise the risk of fire.

Many electric vehicles are equipped with battery management systems that automatically monitor the temperature and charge of the battery. If anomalies or high temperatures are detected, the systems can take action to reduce the risk of fire by providing insulation and short-circuit protection. In the event of a battery fire, it is important to provide ventilation to help remove toxic gases and smoke. Additionally, drainage systems can be installed to ensure that water and other substances are removed in the event of a fire.

Modern charging infrastructure is constantly evolving and adapting to the growing demand for electric vehicles. Technological developments are aimed at improving the speed and availability of charging, making the use of electric vehicles more convenient and suitable for mass use. The proper design of charging infrastructure requires a comprehensive approach to determining the parameters of the charging station network. It is necessary to forecast the change in the electric vehicle fleet in the region under study. In the absence of long-term statistical data, it is proposed to use a sociological survey with the subsequent drawing up of a consumer portrait.

The absence of a single standard for charging ports across different electric vehicle models can lead to a complicated charging process, especially in public places. Advances in technology are increasing the capacity of charging stations. However, there is a challenge in providing enough power to quickly charge a large number of cars at the same time to avoid overloading the power grid.

Infrastructure development needs to be able to meet the growing demand for charging stations depending on the number of EVs on the road. Addressing these challenges requires cooperation between EV manufacturers, energy companies, government agencies and other stakeholders to ensure an efficient, reliable and convenient charging infrastructure. Many companies operate extensive networks of charging stations covering different regions. These networks can provide access to stations through mobile apps and charging cards.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request.

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