The American Journal of Engineering and Technology
ISSN 2689-0984 | Open Access

TYPE Original Research
PAGE NO. 74-81
DOI 10.37547/tajet/Volume07Issue02-10

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Technological barriers and strategies for overcoming them in the development of a charging station network

OPEN ACCESS

SUBMITED 24 December 2024
ACCEPTED 26 January 2025
PUBLISHED 28 February 2025
VOLUME Vol.07 Issue02 2025

CITATION

Anton Nedelko. (2025). Technological barriers and strategies for overcoming them in the development of a charging station network. The American Journal of Engineering and Technology, 7(02), 74–81. https://doi.org/10.37547/tajet/Volume07Issue02-10

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Abstract: The article examines challenges encountered in the process of establishing charging station networks for electric vehicles, proposes solutions to address them, and focuses on identifying barriers such as standard incompatibility, difficulties in implementing and using different types of devices, and power limitations.

The methodological approach is based on the analysis and comparison of charging infrastructure models implemented in various countries, addressing current issues and development prospects. Based on the identified barriers, proposed solutions include equipment standardization, the creation of intelligent station management systems, and the modernization of power grids to meet growing demands.

The findings indicate that the development of a charging station network requires consideration of multiple factors: technical standards, economic feasibility, and environmental safety requirements. The conclusions drawn will be useful for infrastructure developers, researchers in the field of sustainable transportation, and government entities involved in environmental and transportation policy.

The conclusion emphasizes that overcoming technological barriers in creating an accessible and efficient charging station network is essential for the widespread adoption of electric vehicles, which will contribute to the development of a sustainable and environmentally friendly transportation system.

Keywords: Charging stations, electric vehicles, infrastructure, standardization, power grid,

technological barriers, innovation, ecology.

Introduction: The development of charging station infrastructure for electric vehicles is a crucial task in the transition to sustainable transportation systems. This is driven by the growing interest in electric vehicles in recent years, due to their environmental benefits, economic advantages, and the reduction of dependency on fossil fuels. For instance, in Kazakhstan, the number of registered electric vehicles is projected to exceed 40,000 by 2035. Notably, this forecast was made at the end of 2022, predicting only 1.1 thousand electric vehicles in 2023. However, this figure was six times lower than the actual number recorded by early 2024 [9].

Issues such as incompatibility of charging devices, overloading of power grids, and discrepancies in charging standards are slowing the development of necessary infrastructure. At the same time, the growing number of electric vehicles requires the modernization of existing networks and the implementation of new technologies to improve their efficiency. The relevance of this issue lies in the need to find solutions to overcome these obstacles, ensuring the widespread adoption of electric transportation.

Unlike existing studies, this work focuses on a comparative analysis of global practices while proposing specific measures to overcome barriers in the context of Russia, the Republic of Kazakhstan and the Republic of Uzbekistan.

The purpose of this study is to identify technological obstacles in the creation of charging station networks for electric vehicles and propose solutions for their resolution. To achieve this goal, the following objectives are set: to identify technological issues, propose methods for their elimination, and assess their practical feasibility considering the characteristics of the existing energy and transportation infrastructure.

The practical significance of this study lies in the development of recommendations aimed at improving the performance of existing charging stations and facilitating the implementation of new technologies.

METHODS

The development of infrastructure for electric vehicles and overcoming technological barriers in establishing charging station networks is increasingly relevant given the growing interest in electric mobility. Scientific studies on this topic address various aspects, as described below.

Technological challenges of electric mobility are discussed in several articles [1, 2, 4]. In the work of Goncharov V. and Yankevich N. [2], existing issues in charging infrastructure for electric vehicles, such as the incompatibility of different types of charging stations and vehicles, are analyzed. The authors emphasize the need for standardization of charging processes and the integration of charging stations into existing power grids as a critical step for the effective deployment of infrastructure.

In the studies by Andreev A. A. and Amangaliev E. Z. et al. [1, 4], the authors examine the schemes and equipment used in electric and hybrid vehicles, as well as the prospects for the development of charging stations. Particular attention is given to the requirements for these stations, including the power of charging devices, compatibility with various vehicle models, and the necessity of managing energy flows within the grid.

The legal aspects of electric mobility are also a significant focus, as highlighted in articles [3, 5, 6]. Sarsembaev M. A. addresses the issues of legal regulation in the field of electric mobility and the digitalization of transport engineering. The importance of implementing modern technologies, such as smart charging stations, within existing legal frameworks is underscored. Additionally, the regulation of electric vehicles and charging stations under the legislation of Kazakhstan and Russia is discussed.

Economic challenges related to the affordability of electric vehicles are explored in the article by Aslanov R. and Muradilov S. [7], which analyzes economic barriers such as the high cost of electric vehicles and the limited number of charging stations in Kazakhstan. The article also highlights the necessity of government incentives, including tax benefits and infrastructure subsidies, to reduce barriers for consumers and accelerate the transition to electric vehicles.

In the work of Moshkov V. B. et al. [8], trends and challenges in the adoption of electric vehicles, as well as issues related to infrastructure development, are considered. The authors stress the need for a comprehensive approach that includes not only infrastructure development but also educational programs and raising awareness of the benefits of electric mobility.

For statistical data analysis, sources [9-11] were utilized, with information drawn from websites such as zakon.kz, ida.kz, and qazaqgreen.com. Sources [12-14] were also used to demonstrate large companies involved in the installation of fast charging stations in the Republic of Kazakhstan, information about whose activities is posted on the official websites of the organizations.

Thus, studies dedicated to the development of infrastructure for electric vehicles cover a wide range of

topics, including technological, legal, and economic aspects. However, it should be noted that existing research provides insufficient attention to the integration of charging stations into urban transport systems and the effective management of energy flows in light of the increasing number of electric vehicles.

The methodological approach of this study is based on the analysis and comparison of charging infrastructure models implemented in various countries, with a focus on current challenges and development prospects.

RESULTS

The establishment of infrastructure for charging stations serving electric vehicles is a complex and multifaceted process encompassing design, installation, operation, and maintenance. Each of these stages involves addressing specific technical challenges related to power supply, safety, automation, and integration with urban and industrial infrastructure.

The integration of charging stations into urban transport systems is a crucial step toward creating an environmentally friendly and energy-efficient environment. This involves installing stations for use by buses, trolleybuses, taxis, and other forms of public transport. Such integration minimizes vehicle downtime by ensuring their readiness for operation throughout the day. Intelligent charging systems equipped with fast-charging capabilities and energy distribution functions based on grid load reduce peak loads on the city's power system and optimize resource utilization. Additionally, this integration lays the foundation for efficient traffic flow management and improved urban mobility. In the long term, the integration of stations will contribute to reducing carbon dioxide emissions, thereby improving the environmental situation in major cities.

Currently, the highest concentration of public charging stations is observed in Almaty and Astana, with over 100 stations in each city. These stations are primarily located in parking areas of large shopping centers, business centers, and along major roads. For example, in Almaty, charging stations can be found in the Mega shopping mall, while in Astana, they are situated in business districts.

Outside of Almaty and Astana, the fast charging station infrastructure is less developed. In certain regions, such as Pavlodar and Aktau, only one station is available, creating challenges for electric vehicle drivers, particularly during long-distance travel across the country [10]. The leading companies representing access to the use of fast charging stations for motorists on the territory of the Republic of Kazakhstan are: Arlian Energy, the authorized capital of the company reached 630 million tenge. Since the middle of 2023, the company has taken active steps towards the development of charging infrastructure in the city of Almaty. DC charging stations with a capacity of 120 kW are being installed [12]. The next company is eDrive.kz, a system integrator in the field of charging infrastructure for electric vehicles. The company supplies charging stations of various capacities from 3 kW to 180 kW AC and DC [13]. Also worth mentioning is the EVS organization, which provides a full range of services for electric vehicles: networked electric vehicle charging measurements, an application for convenient monitoring, and other related services. The firm's goal is to make the electric vehicle experience comfortable and efficient. Currently, there are more than 40 charging stations in the network [14]. The geography of charging station locations in Kazakhstan for 2024 is illustrated in Figure 1.

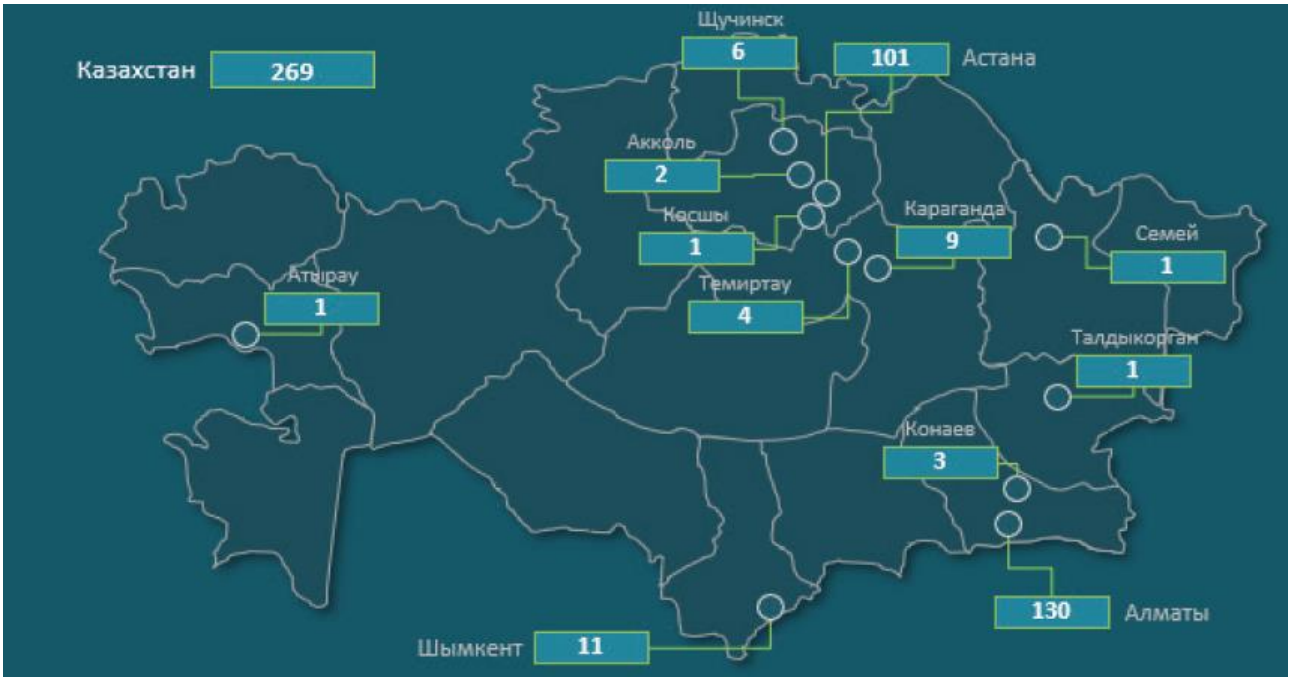

Fig. 1. Geography of the location of charging stations in Kazakhstan for 2024 [11]

The first step in developing a network of charging stations is designing the entire infrastructure, which includes selecting installation locations and determining the power and type of charging devices. Each device has specific operational features, which are illustrated in Figure 2.

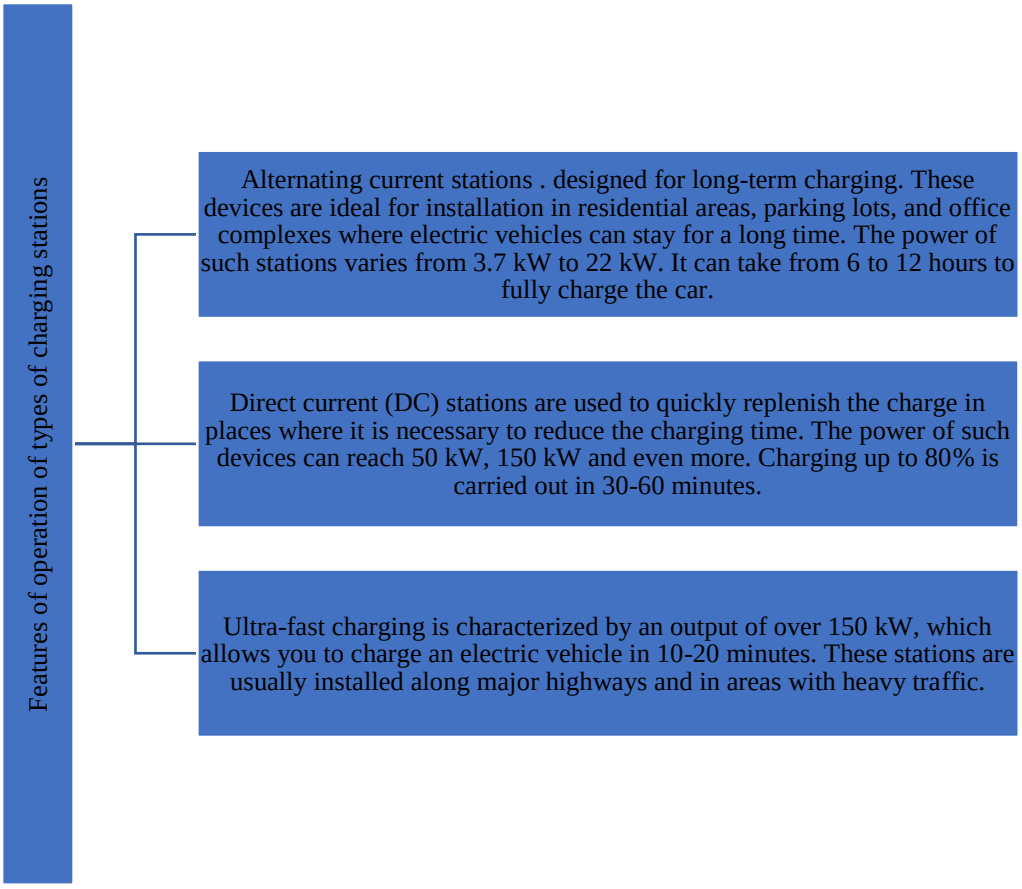

Fig. 2. Features of operation of types of charging stations [2, 4, 5]

When designing the network, it is essential to consider population density, traffic flows, and the accessibility of facilities for connection to power grids. The use of geographic information systems and algorithms helps predict locations where demand will be high. The process of connecting charging stations to the existing power grid requires careful development of technical solutions, with key aspects including energy load calculations, infrastructure adjustments, and the implementation of intelligent management systems.

Charging stations, particularly those supporting fast charging, require connection to high-capacity power grids. For instance, a 50 kW station requires a 400 V network with three-phase power capability [2, 4, 5].

The selection of equipment for charging stations demands attention to multiple factors, such as power capacity, safety, compatibility with communication protocols, and management systems. Proper selection of connectors and communication protocols between the charging station and the vehicle is crucial. The most common connectors include Type 1 and Type 2 for alternating current, used in Europe; CHAdeMO and

CCS for direct current, popular in Japan and Europe;

and Tesla Supercharger, a standard for Tesla vehicles [2, 4, 5].

To prevent breakdowns and ensure timely repairs, remote monitoring systems are developed, allowing real-time tracking of station operations. To enhance user convenience, integrating the charging station network with payment platforms and informational services is essential.

Users should be able to pay for charging via mobile applications, bank cards, or contactless methods. Payment platforms must integrate with both local and international systems.

To optimize network operation, a centralized platform is required for monitoring the condition of charging stations, updating software, and analyzing statistics. Mobile applications for users enable locating nearby charging stations, checking their availability, and processing payments.

After installing charging stations, it is vital to establish a system of regular maintenance, including technical inspections, replacement of worn components, and software updates. Real-time monitoring systems help promptly identify malfunctions, preventing prolonged downtimes [1, 6, 7].

Thus, developing a network of charging stations for electric vehicles requires addressing numerous factors, including infrastructure design, equipment selection, grid connection, and safety assurance.

DISCUSSION

The main technological barriers to the development of charging stations for electric vehicles are illustrated in Figure 3.

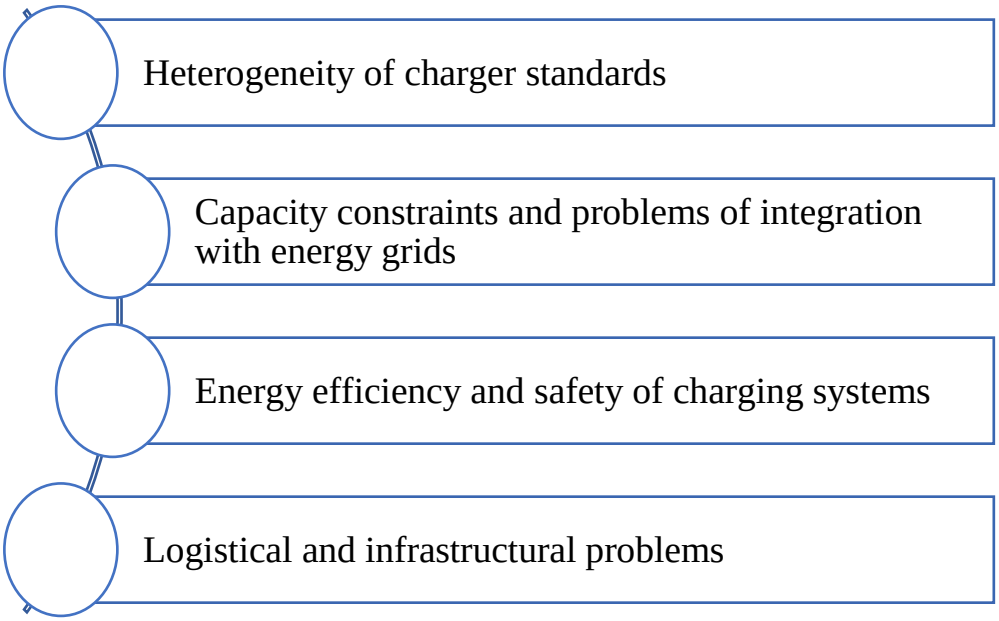

Fig. 3. The main technological barriers in the development of charging stations for electric vehicles

One of the obstacles to establishing an effective infrastructure for electric vehicles is the incompatibility of connectors and communication protocols between vehicles and charging stations. Furthermore, the various protocols for transmitting information about battery status, charge management, and integration with payment systems complicate the integration process. The diversity of these protocols, depending on manufacturers and regions, necessitates the development of adapters, converters, and specific software, which increases both capital and operational costs.

Additionally, as the number of electric vehicles increases, so does the demand for higher-capacity charging stations. Alternating current (AC) devices used for standard charging require less power compared to direct current (DC) devices designed for fast charging. In large cities, despite a developed infrastructure, there are often power limitations that restrict the connection of new stations.

The challenge is further complicated by the need to

synchronize charging processes with the current state of the grid. Modern methods of managing charging stations using algorithms to optimize load help mitigate the risks of overloading, but challenges related to integration with distributed energy systems remain unresolved [3, 5, 8].

Another issue for charging stations concerns energy efficiency and safety. Fast-charging devices often face overheating, which necessitates the use of advanced thermal management and temperature control systems. High thermal losses reduce overall charging efficiency and shorten equipment lifespan.

Charging devices must provide protection against short circuits, overloads, voltage fluctuations, and other network instabilities. Monitoring and diagnostic systems, which allow for the timely detection of malfunctions and risk minimization, remain essential elements in the development of new models.

As the number of electric vehicles grows, the need for an extensive network of charging stations that maximizes accessibility while minimizing costs becomes evident. The placement of charging devices must consider various factors, such as traffic density, energy availability, and territorial characteristics. Furthermore, with the increasing number of charging stations, the demand for technical maintenance, calibration, and software updates also rises.

Strategies for overcoming these barriers in the development of charging station networks are detailed in Table 1 [1, 6, 7].

Table 1. Strategies for overcoming barriers in the development of charging station networks *(compiled by the author)*

Criterion Name	Description	Implementation Challenges	Effectiveness
Scalable Infrastructure	Development of modular charging stations that scale as demand increases.	Requires additional initial investment and potential adjustments for future equipment adaptation.	Allows for an increase in the number of stations based on demand.
Interoperability	Ensuring compatibility between different types of electric vehicles and charging stations from various manufacturers.	Challenges in unifying charging connectors, standards, and protocols; require coordination with manufacturers.	Reduces technical issues but requires time for standardization.
Energy Consumption Optimization	Use of smart charging stations with power regulation and integration with intelligent grids.	Technical difficulties in integrating with existing power grids and management systems.	Improves grid resilience, reduces overload risks, and lowers electricity costs.

Charging Systems with Renewable Energy Sources	Integration of solar panels or wind turbines into charging stations to reduce grid load.	High installation costs, dependency on weather conditions, and challenges with energy storage.	Effectively reduces reliance on traditional energy sources but may require additional expenditures.
Automated Charge Management	Implementation of management systems that distribute load among charging stations and manage charging times based on demand.	Requires technical infrastructure and software for energy flow analysis and management.	Reduces strain on power grids and increases station efficiency.

Thus, the development of charging infrastructure for electric vehicles is associated with several challenges, including standard incompatibility, difficulties in integrating with power grids, and safety concerns. However, considering advancements in technology, these barriers can be overcome. Standardization, the

implementation of smart grids, the optimization of station placement, and the integration of renewable energy sources are crucial steps toward creating an efficient charging infrastructure.

CONCLUSION

The study identified technical issues hindering the creation of an efficient, scalable infrastructure for charging stations serving electric vehicles. Several approaches were proposed to address these challenges: the standardization of equipment to resolve compatibility issues with charging devices; the modernization of power grids to provide the necessary capacity for an increasing number of stations; and the implementation of intelligent charging station management systems to optimize energy distribution and enhance infrastructure efficiency.

Adopting these measures will enable the development of electric vehicle infrastructure, ensuring its stable operation under growing demand. The proposed solutions can serve as a foundation for improving existing stations and for establishing new standards in the field of electric mobility.

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