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SIMULATION MODEL OF A FINITE MULTI-SERVER QUEUEING SYSTEM FOR EVALUATING FAST CHARGING OF ELECTRIC VEHICLES ALONG MOTORWAYS

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Анотація

Перехід до електромобілів вимагає розвитку ефективної інфраструктури швидкої зарядки вздовж автомагістралей. Це дослідження представляє нову імітаційну модель для оцінки місць швидкої зарядки, обладнаних кількома зарядними пунктами з метою прогнозування сукупного попиту на електроенергію та продуктивність зарядки в умовах майбутнього руху електромобілів. Використовуючи моделі черг і моделювання на основі подій, ця робота надає важливу інформацію про очікуваний час очікування і вимоги до потужності, що слугує цінним вкладом для моделювання трафіку та інструментів оптимізації розподілу електромобілів.

Ключові слова: швидка зарядка, підзарядка вздовж автомагістралей, розумна зарядка, моделі черг, моделювання на основі подій, статистична оцінка.

Abstract

The shift towards electric vehicles (EVs) necessitates the development of efficient fast-charging infrastructure along motorways. This study introduces a novel simulation model for evaluating fast charging sites equipped with multiple charging points, aiming to predict the aggregated power demand and charging performance under future EV traffic conditions. Utilizing queueing models and event-based simulation, this work provides critical insights into the expected waiting times and power requirements, serving as valuable input for traffic simulation and EV assignment optimization tools

Keywords: fast charging, recharging along motorways, smart charging, queueing models, event-based simulation, statistical evaluation.

Introduction

The transition to electric vehicles (EVs) represents a pivotal strategy in the global effort to mitigate climate change by significantly reducing greenhouse gas emissions [1]. As the adoption of EVs accelerates, the focus intensifies on overcoming the inherent limitations of current EV technology, particularly the limited range of these vehicles compared to their petrol-fueled counterparts. This limitation underscores the critical need for a robust, accessible charging infrastructure, especially along motorways, to ensure that travel remains convenient and time-efficient, thereby alleviating range anxiety among EV users.

While existing literature extensively covers the deployment of distributed AC charging infrastructure at residential locations [2, 3], there remains a conspicuous scarcity of research on the development and integration of fast charging for long-distance travel along motorways where these are most needed. This gap is particularly acute in the context of understanding the dynamics of EV charging demand and the performance of fast charging [4]. The challenges are multifaceted, encompassing not only the technical and economic aspects of installing and maintaining such infrastructure but also the consequential impact on the electric grid [5].

In light of these considerations, this study is attempts to fill the existing research gap by developing a comprehensive simulation model designed to predict the demand for, and performance of, fast charging along motorways. This model aims is to provide critical input data for the traffic simulation software SUMO [6], focusing on key parameters such as the aggregated power demand and expected charging performance. The simulation tool also calculates expectable waiting times, contributing valuable insights for the multi-objective EV assignment optimizer developed as part of the R&D project eAlloc [7]. By addressing these aspects, the study not only seeks to enhance the current understanding of fast EV charging infrastructure requirements but also to facilitate the development of more efficient and user-friendly charging solutions that can support the widespread adoption of EVs.

The primary research objectives are to simulate charging sites with a variable number of charging points, to consider the dynamic power demand of fast charging, and to visualize the statistical results. The simulation aims to predict the demand for charging points at charging sites along motorways and to assess the expected charging performance for future EV traffic loads. The practical value of this research lies in its contribution to strategic planning for electric vehicle infrastructure development. By forecasting the demand for fast charging points and evaluating the performance of charging sites, stakeholders can make informed decisions regarding the allocation of resources and the deployment of charging infrastructure extensions to meet future needs.

Research results

The developed simulation tool models a charging site as a finite multi-server queueing system [8, 9] with a specified number of charging points and limited waiting space, as depicted in Figure 1 with for example three charging points and a parking area that can host maximally four EVs.

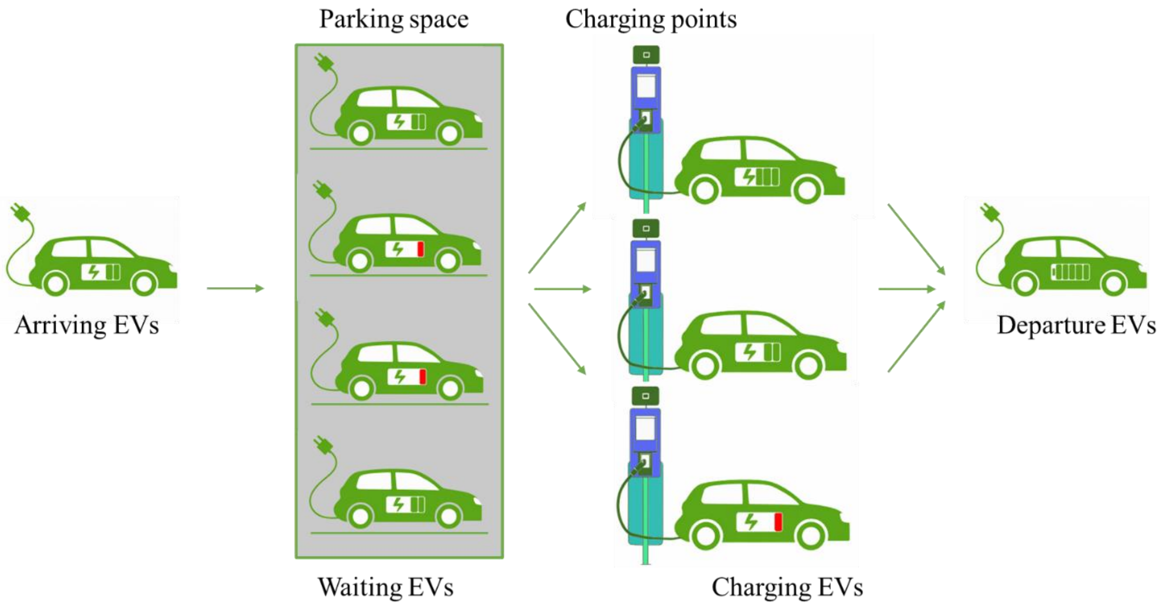

Figure 1. Charging Site as a finite multi-server queueing system

The arrival of electric vehicles (EVs) is assumed to follow a negative-exponential inter-arrival time distribution, reflecting the independence of random vehicle arrivals. The charging process is modelled with an Erlang-2 distribution, to consider a common mean service time and the typical similarity of charging times. Furthermore, the state of charge (SoC) of the EV battery upon arrival is assumed to be Beta distributed around 20%, indicating that vehicles arrive with a mean charging demand of 80% of the battery capacity. The according distribution functions are shown in Figure 2.

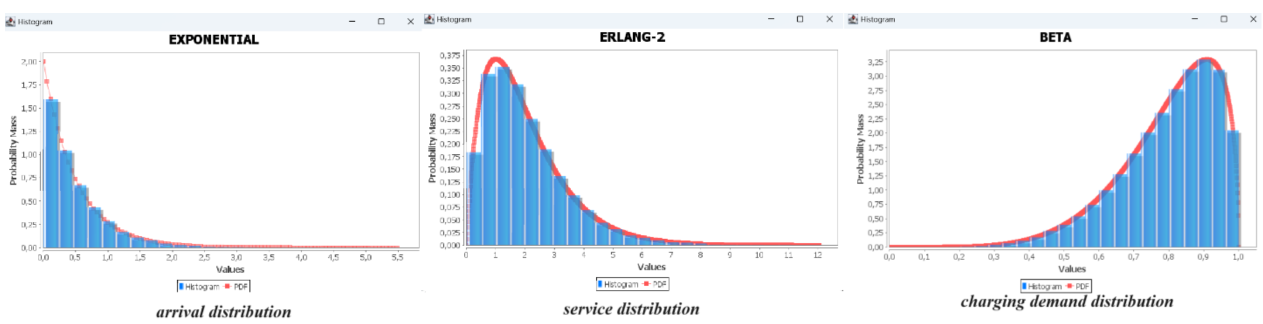

Figure 2. Random distributions foreseen to model EV arrivals, charging times and demands

The study employs an event-based simulation approach, implemented in Java, to simulate the dynamic interactions at the charging site. This involves generating arrival events based on the specified distribution function, managing the queue of waiting vehicles, and simulating the charging process at available charging points. The simulation tracks key metrics such as waiting times and power demands to analyze and visualize the system's performance.

The simulation's output undergoes statistical analysis to evaluate the efficiency and effectiveness of charging site configurations. This includes examining the waiting times for EVs to access charging points and the overall power demands placed on the charging site. By analyzing these metrics, the study aims to identify potential bottlenecks and areas for improvement in the EV charging infrastructure. Visualization of key statistical measures such as mean, standard deviation, and percentile distributions are utilized to provide a comprehensive overview of the system's performance under various scenarios.

Conclusion

This study presents a comprehensive approach to understanding the future demands and performance of fast-charging sites along motorways. Through the use of finite multi-server queueing system simulations, implemented via event-based simulation in Java, and thorough statistical analysis and high-quality visualization of the statistical results, the developed tool and the thereby enabled research provide valuable insights into the dynamics of fast charging for electric vehicles. The findings highlight the importance of adequate planning and investment in charging infrastructure to accommodate the anticipated shift towards electric mobility.

REFERENCES

1.Tang C., Tukker A., Sprecher B., Mogollón J.M., Assessing the European Electric-Mobility Transition: Emissions from Electric Vehicle Manufacturing and Use in Relation to the EU Greenhouse Gas Emission Targets, Environmental Science & Technology, vol. 57, no. 1, pp 44-52, 2023, DOI: 10.1021/acs.est.2c06304.

2.Huang Q., Yang L., Hou C., Zeng Z., Qi Y., "Event-Based EV Charging Scheduling in a Microgrid of Buildings," in IEEE Transactions on Transportation Electrification, vol. 9, no. 1, pp. 1784-1796, 2023, DOI: 10.1109/TTE.2022.3201084.

3.Jansson D., Niklasson N., Dimensioning of Charging Infrastructure Using Model-Based Systems Engineering, Dissertation, KTH, Stockholm, Sweden, 2022, retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-325912.

4.Witt A., Determination of the Number of Required Charging Stations on a German Motorway Based on Real Traffic Data and Discrete Event-Based Simulation, LOGI – Scientific Journal on Transport and Logistics, vol. 14, no. 1, 2023, DOI: 10.2478/logi-2023-0001.

5.Lee Z.J., Sharma S., Johansson D., Low S.H., ACN-Sim: An Open-Source Simulator for Data-Driven Electric Vehicle Charging Research, 2019 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm), Beijing, China, 2019, pp. 1-6, DOI: 10.1109/SmartGridComm.2019.8909765.

6.Lopez P.A., Behrisch M., Bieker-Walz L., Erdmann J., Flötteröd YP., Hilbrich R., Lücken L., Rummel J., Wagner P., and Wießner E., Microscopic Traffic Simulation using SUMO. In: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 2575-2582, 21st IEEE International Conference on Intelligent Transportation Systems, IEEE, 4.-7. Nov. 2018, Maui, USA, (2018), DOI: 10.1109/ITSC.2018.8569938.

7.eAlloc, “Dynamically Optimizing the Allocation of e-cars to Charging Sites”, Austrian Climate and Energy Fund (KLIEN), 3rd call Zero Emission Mobility, https://projekte.ffg.at/projekt/4031006, accessed: 2023-03-14.

8.Kleinrock L., “Queuing Systems, Volume I: Theory”, John Wiley, 1975.

9.Kleinrock L., Gail R., “Queueing systems: problems and solutions", John Wiley, 1996.

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