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SIMULATION AND OPTIMIZATION OF ELECTRIC VEHICLE CHARGING IN LOW-VOLTAGE DISTRIBUTION NETWORKS USING PYTHON

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Abstract
The article presents a simulation model of an LV power distribution network with integrated charging stations for electric vehicles, implemented in the Python programming environment using the pandapower library. The model combines static loads (households and public consumers) and dynamic loads based on real hourly profiles of charging stations from public points in Hamburg, Germany. Through a 24-hour simulation, the change in the voltage profile, active power losses, and the total load of the network under different charging modes are analyzed. The results show that the simultaneous charging of several electric vehicles leads to a decrease in the voltage at the end nodes to 0.90 p.u. and an increase in active losses by over 20% compared to the minimum values. The proposed model provides a reliable basis for studying the impact of electric vehicles on the LV power distribution network and for developing strategies for optimal and intelligent charging management (smart charging).
Keywords: charging station, energy flows, smart charging, efficiency.

INTRODUCTION

Over the past decade, electric vehicles (EVs) have become one of the main elements of the transition to a sustainable energy system. Their mass penetration leads to an increasing load on low-voltage electricity distribution networks, which were not originally designed to accommodate dynamic and concentrated charging modes[1].

According to forecasts by the European Commission and the International Energy Agency, the share of electric vehicles in the total vehicle fleet will exceed 30% by 2030, which will lead to serious challenges for electricity distribution system operators [2,3].

The main problems associated with the integration of charging infrastructure include voltage reduction in the terminal sections of low-voltage networks, increased active and reactive losses, possible overloading of transformers and cable lines, as well as the occurrence of imbalances between phases during single-phase charging.

At the same time, charging stations can also be considered as potential active elements of "smart grids", capable of interacting with the grid through power management, charging time and even two-way Vehicle-to-Grid (V2G) energy exchange [4,5].

In this regard, it is necessary to develop realistic simulation models that allow for a quantitative assessment of the impact of electric vehicle charging on the operation of low-voltage grids [6,7].

The Python programming environment, in combination with the pandapower library, offers a powerful and open toolkit for modeling, analysis, and optimization of

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power systems.

This work aims to develop and analyze a simulation model of a low-voltage grid with integrated electric vehicle charging stations, which takes into account both static and dynamic system loads.

Through 24-hour simulations, voltage profiles, active losses, and the impact of simultaneous charging on grid stability are evaluated. The results obtained can serve as a basis for developing strategies for smart charging management and for integrating renewable sources into low-voltage distribution systems.

SIMULATION MODEL

The simulation model was developed in Python 3.10 using the pandapower library for building and analyzing power networks. The model describes a 0.4 kV distribution network presented in Figure 1, which includes four consumer nodes and three electric vehicle (EV) charging stations.

The purpose of the simulation is to evaluate the impact of different charging modes on the voltage profile and power losses in the network, in the presence of both dynamic (EV) and static (baseline) loads.

The model contains five buses: Bus 0 (Slack Bus), the connection point to the main network, with a nominal voltage of 0.4 kV. Buses 1–4 are consumer nodes connected in series by four lines with different lengths and parameters presented in Table 1, corresponding to a typical LV cable network.

The line parameters are chosen to ensure a realistic voltage drop at high load.

Permanent loads are defined in the nodes, which represent the main electricity consumption (domestic and public needs), and are presented in Table 2.

Table 1 - Parameters of LV cable lines

№	R, Ω/km	X, Ω/km	Ir, A	L, km	Type
W1	0.253	0.066	245	0.07	NAYY-120
W2	0.443	0.069	179	0.1	NAYY-70
W3	0.641	0.069	144	0.16	NAYY-50
W4	0.868	0.075	0.123	0.168	NAYY-35

Table 2 - Values of permanent loads

Bus	P (kW)	Q (kvar)
Bus 1	250	135
Bus 2	16,9	5
Bus 3	49,7	4
Bus 4	13,34	2

The simulation model includes three charging stations for electric vehicles, connected to nodes Bus2, Bus3 and Bus4, respectively. The charging stations are modeled as active loads, whose load varies over time depending on real hourly profiles reflecting the behavior of users in an urban environment. Each profile is represented by a set of 24 active power values in kW, saved in an external CSV file (ev_profile_hamburg.csv).

To achieve a more realistic model, scaling factors have been applied that reflect the different power and charging station types. Charger 1 is modeled as a fast charging station. Charger 2 (Bus3) is a standard AC station (type 2). Charger 3 (Bus4) is a slow charging station for overnight charging. Their maximum powers are presented in Table 3.

Table 3 Charging station powers

№	Pmax, kW
Charging station 1	200
Charging station 2	100
Charging station 3	20

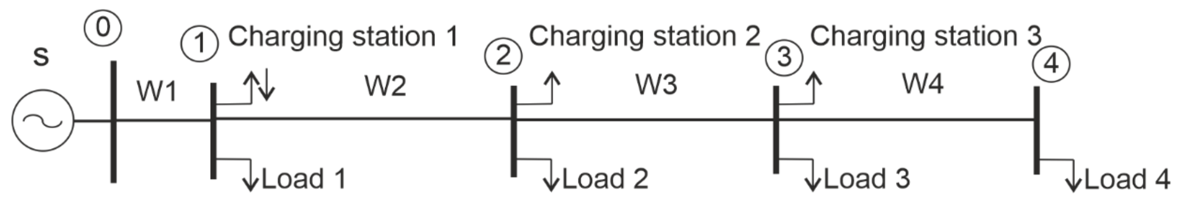

Fig. 1. *Scheme of the studied network*

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This distribution provides a representative spectrum of real-world chargers, from home to public fast-charging stations. In the model, they are treated as dynamic loads that are updated for each simulation hour, unlike static baseload consumers.

In this way, the model reflects the typical daily two-peak load observed in real-world networks with electric vehicle infrastructure, with a morning peak from 07:00 to 10:00 h and an evening peak from 17:00 to 21:00 h.

RESULTS

This section presents the results of simulations conducted on the developed model of a low-voltage (0.4 kV) distribution network with integrated charging stations for electric vehicles.

The aim is to study the influence of hourly electric vehicle load on the voltage profile and active power losses in the presence of static and dynamic loads.

The simulation covers 24 hours with hourly resolution, with the load being minimal in the early hours and increasing significantly in the evening due to the simultaneous switching on of charging stations and household consumers.

The results are presented graphically, illustrating the key network parameters, such as voltage at nodes, power losses, and total load.

Figure 2 shows the change in voltage over time for all nodes of the network during the 24 hours.

A clear trend of voltage reduction is observed during hours of increased load, especially between 18:00 and 21:00, when charging stations operate at maximum power. Bus1 maintains its voltage around 1.03 p.u., reflecting the stable power supply of the network. Bus2 and Bus3 show a drop to approximately 0.98–0.96 p.u., following the increase in the load on the network. Bus 4 has the most significant drop, its voltage reaching around 0.90 p.u. at peak load, which is close to the minimum permissible limit according to standard requirements.

After 22:00, as the load decreases, the voltage gradually recovers to nominal values. This result confirms the expectations that the connection of electric vehicle charging stations in the final sections of the low-voltage network can cause significant voltage deviations and require optimization of the power supply scheme or the implementation of intelligent charging management algorithms (smart charging).

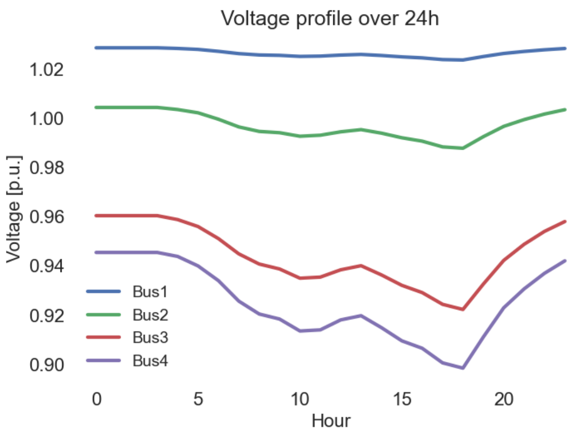

Fig. 2. *Voltage profile over 24h*

Figure 3 presents the change in active power losses in the low-voltage network within the 24-hour simulation period. The losses are calculated based on the results of each power flow analysis and reflect the impact of the load on the overall efficiency of the system.

In the early hours of the day (0:00–5:00 h), the network operates at low load, dominated by static loads. During this period, active losses are minimal at around 50 kW, which corresponds to a normal mode at low load and stable voltage.

With the increase in dynamic loads (charging of electric vehicles) after 6:00 h, a gradual increase in losses is observed, reaching values of over 58 kW around noon.

The most significant increase in losses is registered in the evening hours between 18:00 and 21:00 h, when all charging stations are simultaneously active. During this interval, active losses reach a maximum value of around 63 kW, which is an increase

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of approximately 25% compared to the minimum values during the night. After 22:00 h, losses decrease back to around 51 kW, in parallel with the decrease in load.

This relationship confirms that the load from electric vehicles has a direct and significant impact on energy losses in the low-voltage network. At higher values of the load in the final sections of the network, losses increase. This emphasizes the need for optimal distribution of charging and the possible implementation of smart load management algorithms that minimize energy losses during peak periods.

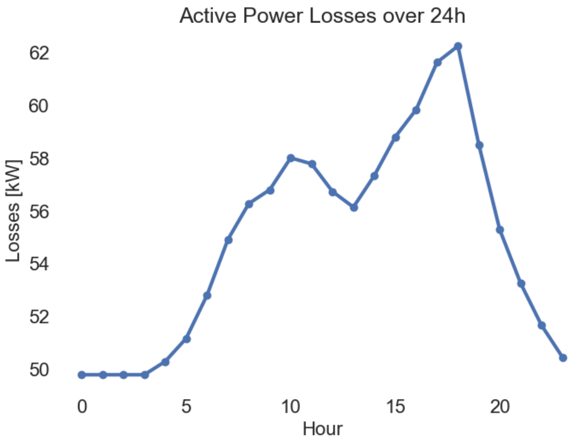

Fig. 3. *Active Power Losses over 24h*

Figure 4 presents the hourly variation of the active power of the three EV charging stations connected to nodes Bus2, Bus3, and Bus4, respectively. The profiles are based on real measurements from public charging points in Hamburg (Germany), scaled by factors reflecting the different installed power of each station.

A characteristic feature of all profiles is the pronounced two-peak load, which is typical for urban environments with a high concentration of EV users. This two-peak behavior creates a challenge for maintaining a stable voltage in the low-voltage network and leads to increased currents and, accordingly, to higher active losses, as seen in Figure 3.

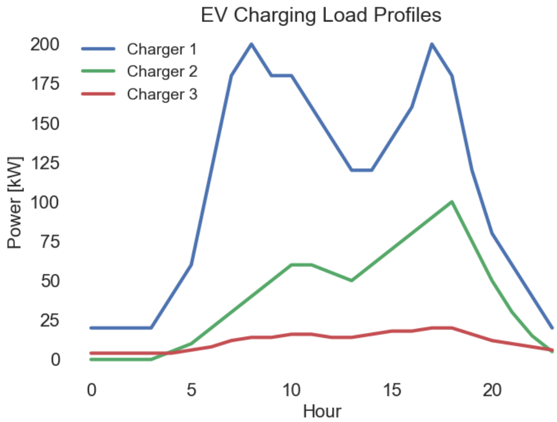

Fig. 4. *EV Charging Load Profiles*

Figure 5 presents the average voltage values for all nodes of the low-voltage network, calculated over the 24-hour simulation period. Figure 5 clearly shows the gradual voltage decrease along the power line, from the supply node (Slack bus) to the end nodes (Bus4).

The average voltage at the Slack bus remains stable and close to the nominal value of 1.0 p.u., since this is the node directly connected to the external network and sets the reference level for the entire system.

At Bus1 and Bus2, a minimal drop (about 1–2%) is observed, while at the end nodes, Bus3 and Bus4, the voltage decreases to approximately 0.97 p.u. and 0.95 p.u., respectively.

This trend is fully expected and confirms the results of the dynamic voltage profile observed in Figure 2. It reflects the cumulative effect of loads and line length, leading to larger active and reactive voltage drops at the network end points.

However, the observed decrease at Bus4 suggests that with more frequent charging of electric vehicles or with simultaneous charging of several stations, local voltage compensation may be required, for example, through regulators or distributed reactive power sources.

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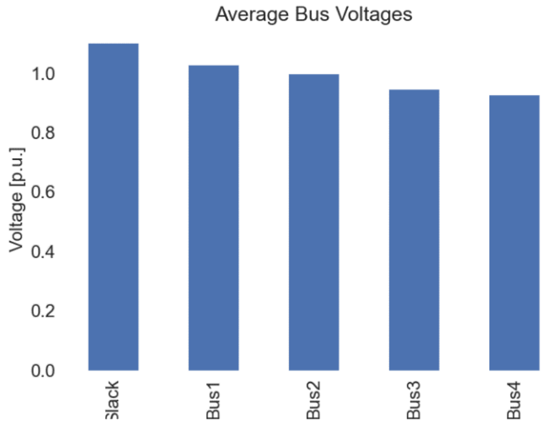

Fig. 5. Average Bus Voltages

Figure 6 presents the relationship between the hourly load of the three charging stations and the total load of the network.

The nature of the graph clearly demonstrates the cumulative effect of the simultaneous inclusion of the charging stations on the total load of the network.

CONCLUSION

In this study, a simulation model of a low-voltage distribution network with integrated charging stations for electric vehicles was developed and analyzed, implemented in the Python programming environment using the pandapower library. The model includes both static loads and dynamic loads based on real hourly profiles of charging stations, which allows for a reliable representation of the network behavior under different operating modes.

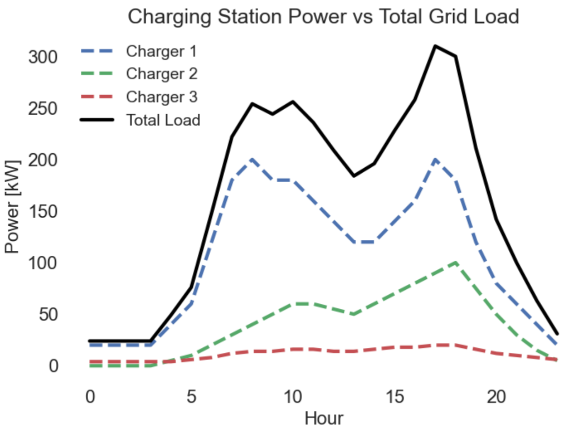

Fig. 6. Charging Station Power vs Total Grid Load

The results show that the inclusion of electric vehicle stations has a noticeable impact on the voltage profile and energy losses in the low-voltage network. During peak charging modes (evening hours between 18:00 and 21:00 h), a decrease in the voltage at the end nodes to about 0.90 p.u. is observed, as well as an increase in active losses by over 20% compared to the minimum night values.

These effects confirm the need for adaptive charging management and consideration of local network constraints when planning charging infrastructure.

The simulation model demonstrates flexibility and expandability, for example, by adding renewable energy sources (photovoltaic systems), battery buffers, or optimization algorithms for smart charging. This makes it a valuable tool for exploring future scenarios of electric vehicle penetration and for evaluating measures to increase the energy efficiency and reliability of low-voltage power distribution systems.

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REFERENCE

[1] T. Unterluggauer, F. Hipolito, J. Rich, M. Marinelli, and P. B. Andersen, "Impact of cost-based smart electric vehicle charging on urban low voltage power distribution networks," Sustainable Energy Grids and Networks, vol. 35, p. 101085, Jun. 2023, doi: 10.1016/j.segan.2023.101085.

[2] B. Azzopardi and Y. Gabdullin, "Impacts of electric vehicles charging in Low-Voltage distribution networks: a case study in Malta," *Energies*, vol. 17, no. 2, p. 289, Jan. 2024, doi: 10.3390/en17020289.

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doi: www.doi.org/10.70456/.........................

[2] I. Nutkani, H. Toole, N. Fernando, and L. P. C. Andrew, "Impact of EV charging on electrical distribution network and mitigating solutions – A review," IET Smart Grid, vol. 7, no. 5, pp. 485–502, Feb. 2024, doi: 10.1049/stg2.12156.

[3] M. Hungbo, M. Gu, L. Meegahapola, T. Littler, and S. Bu, "Impact of electric vehicles on low-voltage residential distribution networks: A probabilistic analysis," IET Smart Grid, vol. 6, no. 5, pp. 536–548, Aug. 2023, doi: 10.1049/stg2.12123.

[4] A. Tayri and X. Ma, "Grid Impacts of Electric Vehicle Charging: A Review of Challenges and Mitigation Strategies," *Energies*, vol. 18, no. 14, p. 3807, Jul. 2025, doi: 10.3390/en18143807.

[5] R. Reibsch, J. Gemassmer, and T. Katerbau, "Low voltage grid resilience: Evaluating electric vehicle charging strategies in the context of the grid development plan Germany," *eTransportation*, vol. 20, p. 100323, Feb. 2024, doi: 10.1016/j.etran.2024.100323.

[6] E. Widl and A. Walle, "Electric vehicle charging energy management for voltage control in low-voltage distribution networks," *IET Conference Proceedings.*, vol. 2024, no. 5, pp. 325–328, Jan. 2025, doi: 10.1049/icp.2024.2047.

[7] R. A. Ibrahim, I. M. Gaber, and N. E. Zakzouk, "Analysis of multidimensional impacts of electric vehicles penetration in distribution networks," *Scientific Reports*, vol. 14, no. 1, Nov. 2024, doi: 10.1038/s41598-024-77662-6.

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