Real-Time Management System for Automotive Charging Based on Control and Optimization Algorithms

Shaojie Sun
Shaanxi College of Communication Technology, School of Automotive Engineering, Xi'an, Shaanxi,710018, China
Email: Shaojiesun5@163.com

Keywords: optimization algorithm, management system, multi-agent system technology, automotive charging management

Received: December 27, 2023

This research offers a novel solution to handle the mounting challenges provided by real-time management systems for vehicle charging. The solution involves developing a real-time management system that incorporates control and optimization algorithms. Recognizing the possible strain on the grid, the study starts by evaluating the effects of large-scale integration of electric vehicles into the power system during periods of peak electricity usage. A charge management system is implemented to effectively supervise the charging of electric vehicles to lessen this problem. This study also looks into the suitability of the electric vehicle charging management system, with an emphasis on its use in homes. The time-of-use power pricing charge management strategy is smoothly linked with multi-agent system technology in the proposed charging management system. To arrange the best times for electric vehicle charging based on time-of-use power pricing, this system introduces an agent-based method on the management platform. Finally, this study verifies the viability of the suggested approach by running simulations on a charge management platform created with Matlab, Simulink, and JADF. The simulation's findings support the charge management system's efficient automation of charging, which lowers charging expenses and lessens peak load demands in the process. This suggests a viable remedy for the problems associated with the real-time management of car charging systems.

Povzetek: Članek predstavlja sistem za upravljanje polnjenja avtomobilov v realnem času, ki temelji na algoritmih za optimizacijo in večagentnih sistemih, izboljšuje porazdelitev obremenitev omrežja in učinkovitost polnjenja električnih vozil.

1 Introduction

In recent years, environmental pollution has become increasingly serious, and various hazards caused by environmental pollution have become increasingly apparent. The air pollution in cities has also received increasing attention. Currently, governments around the world are committed to environmental governance. With the rapid development of the automotive industry, the total number of global cars continues to increase, and environmental pollution, energy shortages, resource depletion, and other issues brought about by cars are becoming increasingly prominent. Countries around the world are looking for green transportation tools to replace traditional internal combustion vehicles. Vigorously developing energy-saving and new energy vehicles has become one of the most effective ways to solve energy and environmental problems and is also an important requirement for sustainable development, energy conservation, and environmental protection. It is also a powerful measure to achieve national ecological civilization construction.

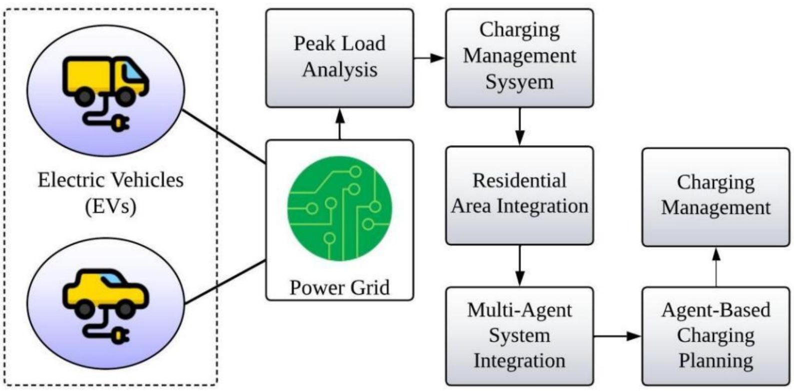

Figure 1: Real-time management system for automotive charging

Electric vehicles replace oil with electricity. As a new energy vehicle, electric vehicles have a wide range of energy sources. The electricity charged to batteries can be converted from energy sources such as coal, natural gas, hydropower, nuclear energy, solar energy, wind power, and tides, achieving “zero emissions” and low noise. The new generation of energy-saving and environmentally friendly vehicles represented by electric vehicles is an inevitable trend in the development of the automotive industry. As an essential infrastructure for the electric vehicle industry, electric vehicle charging stations are gradually receiving attention from governments around the world, investing more and more in subsidies and preferential policies. The main strategic orientation for the development of new energy vehicles and the transformation of the automotive industry was officially defined by the State Council document in 2012.

The Real-time management system for automotive charging is depicted in Figure 1. It shows a step-by-step process for a real-time vehicle charging management system. A charge management system is first introduced when electric vehicles are connected to the grid during times of high demand. Agents may create the best possible billing schedules thanks to this system’s integration of time-of-use pricing and multi-agent technologies. These schedules are used by the system to manage charges, which lowers costs and improves grid load balance. The system's performance is validated using simulations, which finally leads to the conclusion that it effectively tackles real-time vehicle charging difficulties. Electric vehicles have the characteristics of being pollution-free, low noise, high energy efficiency, diversification, simple structure, and convenient maintenance. They have become the main battlefield of competition in the field of new energy among countries around the world. As one of the many factors affecting the development of electric vehicles, the construction of charging infrastructure has been clearly stated by experts in the electric vehicle industry. Its importance is second only to the improvement of battery technology, which ranks first, surpassing the purchase price factor. The current imperfect charging facilities are a major factor restricting the development of electric vehicles. As an essential infrastructure for the electric vehicle industry, electric vehicle charging stations are gradually receiving attention from governments around the world, investing more and more in subsidies and preferential policies. The construction of monitoring systems, which are essential functional systems for charging stations, will inevitably become an important research topic and hotspot.

The progressiveness of modern hardware equipment, software platforms and tools, information communication, processing and control strategies, automatic control, monitoring technology, computer technology, embedded technology, information management, and communication technology provides an effective solution for the research of monitoring systems. At present, there is no mature and well-promoted electric vehicle charging station management system in the world, so the construction of monitoring systems for electric vehicle charging and swapping stations is imperative. As the core equipment for data access and control of the electric vehicle charging station monitoring system, the monitoring terminal plays a crucial role in the entire charging station monitoring system. With the continuous improvement and development of electric vehicles and battery technology, the expansion of electric vehicle charging stations Electric vehicle charging technology, charger technology, charger monitoring technology, battery monitoring technology, and charging station monitoring technology are also constantly advancing.

1.1 Charger technology

The first-generation charger is an independent charger that manually records data. The second-generation charger is also an independent charger that automatically monitors charging data. The third-generation charger is a cluster charger, which monitors charging data in a networked manner. The fourth-generation charger is compatible with charging and swapping, with 24/7 data tracking and intelligent scheduling.

1.2 Charging monitoring technology

In countries where charging monitoring is convenient, a charging station safety charging monitoring system has been first established, and the concept of zoning monitoring has been proposed to achieve real-time status monitoring of chargers and battery packs.

1.3 Operation monitoring technology

The country has proposed and developed a fully independent intellectual property rights electric vehicle operation monitoring and scheduling system, achieving remote real-time monitoring of the operation status of electric vehicles.

1.4 Charging process safety control and management

A charging safety monitoring network has been constructed, including a battery management system, charger, and smoke alarm system. Based on the extreme single-battery parameter charging and discharging control strategy, a closed-loop adjustment method for the charger and battery management system has been adopted to achieve effective control of the charging process [1-2].

2 Literature review

The electric vehicle charging monitoring management system follows the building principles of unity, integration, applicability, progressiveness, openness, safety, and reliability. It also uses the building ideas of combining industry-leading practices, putting on display first before promoting and making full use of national industrial support policies to create an integrated management platform for monitoring the operation and equipment of electric vehicles. The system includes the management of charging stations, charging stations, and vehicles and integrates functions such as station monitoring, power curve generation, charging data statistical analysis, report generation, and remote-control upgrades. It is a system that integrates monitoring and management. The design and implementation of this system simplify the user's operation process of the charging station, improve the accuracy of charging data, make the charging process more secure, and, to a certain extent, reduce costs, saving energy. By combining with the PC end, more content is displayed on the browser, making user business processing more convenient. Conduct optimal energy scheduling through statistical analysis of charging data; Through real-time control of charging stations, charging power can be regulated for reasonable resource allocation, facilitating the monitoring and control of terminal communication and charging station operation by users of this system. By analyzing and restoring the entire charging process of the vehicle through the charging message, a detailed analysis of abnormal charging can be conducted to reduce charging safety hazards.

In the face of the fossil energy crisis and the environmental problems caused by its combustion process, it is necessary to accelerate the development of clean energy. Electric energy, as a type of clean energy, can serve as a charging source for electric vehicles. In the future, large-scale electric vehicles connecting to the power grid will inevitably affect the quality of the grid and increase the load on the grid. It is necessary to establish a pure electric vehicle (EV) charging management system. The charging management system is not suitable for the general classification of electricity loads (industrial, residential, agricultural, etc.), while industrial and agricultural electricity consumption is susceptible to seasonal, climatic, and other impacts. In civil electricity consumption, residents' daily lives and work have a certain regularity, and the load shows obvious peak valley characteristics. Based on the peak and valley load characteristics of civil power grids, demand side management (DSM) can be adopted to improve the terminal power consumption efficiency of customers, achieve peak shaving and valley filling, transfer peak loads, and improve the load rate of the power grid. As a terminal electrical device, an EV is connected to the power grid system for people's use. The charging management system has good applicability for EV charging management.

Yatakoat *et al.* established a weak convergence theorem based on fixed points under appropriate control conditions. In addition, the straight-line research technique was used to select algorithm step sizes that are independent of the Pushtz constant of the objective function gradient, and the weak convergence results of the algorithm were analyzed [3]. With the increasing use of batteries such as EVs (electric vehicles), LEVs (light electric vehicles), and ESSs (energy storage systems), rapid charging technology has attracted much attention. Kim *et al.* proposed a real-time monitoring system based on the PHPOC Wi-Fi Shield. Effectively manage the status of chargers and batteries based on actual situations [4].

The authors of Das *et al.* investigated clever electric vehicle charging systems [5]. Their study aimed to maximize grid reliability and cost efficiency through billing schedule optimization based on user preferences and grid conditions. Li *et al.* study looked into EV load-balancing techniques to lower the power grid's peak demand [6]. Their research focused on how to improve grid stability during peak hours by utilizing demand response and time-of-use pricing. The authors of the paper, Gomozov *et al.* suggested a multi-agent system to control charging for electric vehicles [7]. Their study demonstrated how well agent-based decision-making works to minimize grid stress and optimize charging schedules. Ma and Liu study focused on user-centric charging management in residential settings [8]. User satisfaction, economic effectiveness, and the smooth integration of electric vehicles (EVs) into the power grid during peak hours were the main foci of their study.

At present, research on the application of charging management for private electric vehicles in residential areas is in its infancy, both domestically and internationally. Some domestic and foreign universities and research institutions have proposed some relevant charging management strategies, and their application has achieved certain results in certain places. Most of them are based on adaptive mutation particle swarm optimization algorithms, dynamic electricity pricing methods, random charging control strategies, etc. The electric vehicle charging system is distributed and complex. The combination of distributed management technology and charging control strategies will reduce the complexity of system management and improve charging management efficiency. With the increasing maturity of Multi-Agent System (MAS) technology, fully utilizing multiple intelligent agents to solve complex systemic problems has made MAS a powerful tool for developing complex and distributed systems. Integrate the multi-agent management concept and model with the time-of-use electricity price management strategy and apply it to the charging management platform. Simultaneously simulate charging scenarios to verify the effectiveness of the charging management platform.

3 Methods

3.1 Monitoring system for electric vehicle charging station

The monitoring system for electric vehicle charging stations mainly consists of four parts: the distribution monitoring system, the charging monitoring system, the power exchange monitoring system, and the security video monitoring system. The devices in each subsystem communicate with the charging station monitoring terminal through different communication methods, protocols, and standards. The communication interfaces include the Ethernet interface, the RS-485 interface, the RS-232 interface, the GPRS interface, and the CAN interface. The communication protocols include Modbus, IEC61850, IEC104, and custom protocols [9, 10]. The structure of the electric vehicle charging station monitoring system is shown in Figure 2.

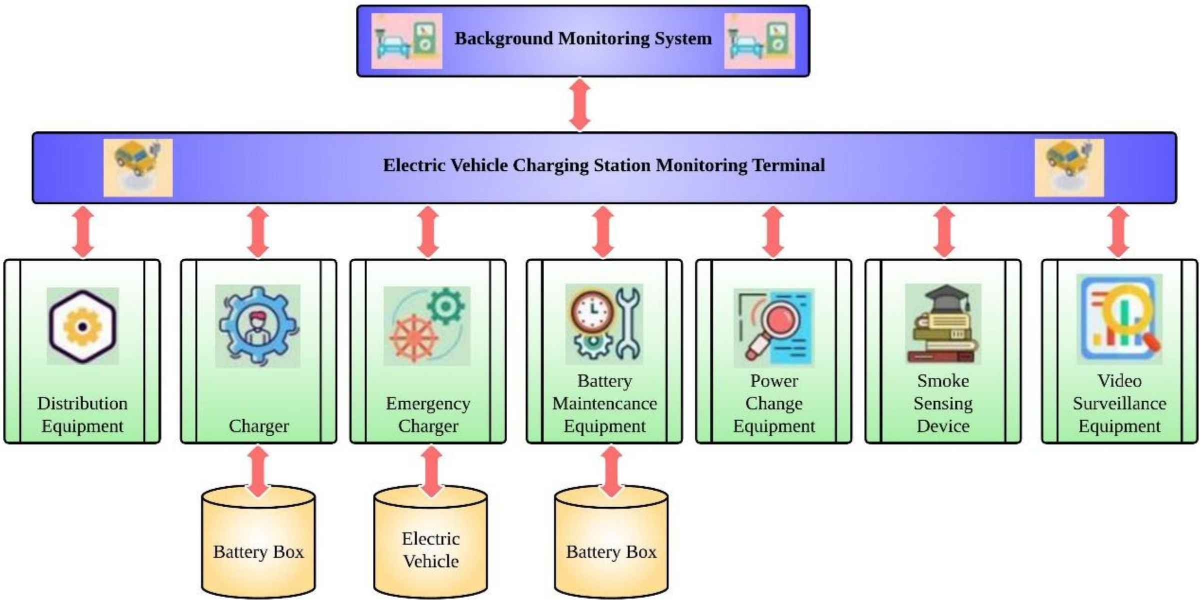

Figure 2: Real-time vehicle charging management system based on control and optimization algorithm

In Figure 2, the monitoring terminal not only completes the information collection and control of the monitoring object but also serves as an important gateway between the monitoring object and the monitoring center. On the one hand, responsible for collecting, analyzing, processing, storing, and sending data streams from monitoring equipment, and on the other hand, utilizing real-time online communication technology to complete data exchange tasks with the monitoring center.

3.2 EV load power demand model

The GM EVI electric vehicle of the GM EV 1 battery (lead acid) type was selected as the research object, and the corresponding relationship between the state of charge (SOC) of the battery and the charging power demand is shown in Figure 3.

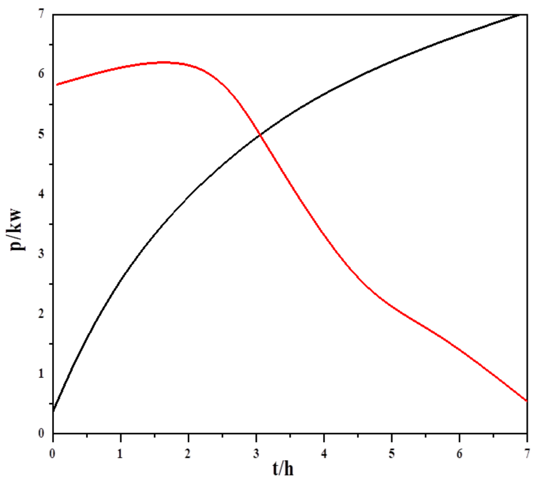

Figure 3: Correspondence between SOC and charging power demand

From the corresponding relationship in Figure 3, it is easy to know that when the onboard charger is connected to the charging station, the power demand during the charging process can be predicted based on the initial amount of SOC. The power demand of a single charger is shown in Equations 1 and 2.

$$p(t_{cm}) = p_i(_{fin})(t) \tag{1}$$

$$t_{ny} = g^{-1}(soc_0) \tag{2}$$

In the formula, t_{in} represents the time point of EV access within a day; T_0 is the time when the initial electric quantity of the EV is SOC_0 (there is a corresponding relationship between t_0 and SOC_0); T_{mex} is the maximum charging duration; T_{cm} is the charging time point after the EV is connected to the t_{in} time point; SOC_0 is the initial charging amount of the EV; P represents the power demand of the EV at time t after receiving the person at time t_{in}; P_m is the power demand fitted based on the actual charging situation of the EV. The units of time and power are h and kW respectively [11, 12].

Based on the power demand of a single charger, the power demand of multiple chargers can be obtained as Equation 3.

$$p_{lotal}(t) = \sum_{i=1}^{k} p_i(t_{on(i)} \tag{3}$$

3.3 Agent design and agent management platform

3.3.1 Agent design

Agents have characteristics such as autonomy, interactivity, continuity, and adaptability. The Multi-Agent System (MAS) combines the advantages of a single agent and has a greater ability to solve complex systems than a single agent. The functions and tasks of the agent in the EV charging management MAS architecture are assigned as follows:

i. *Electric Vehicle Agent (EVAgent):* Monitors and estimates the status of onboard batteries, predicts the power demand of chargers and collects information to upload to the CS Agent.
ii. *Charging Station Agent (CsAgent):* Accepts information from EV Agent and LM Agent, with HMI information display and information exchange function with LM Agent. Determine whether to charge the EV based on the LM Agent command.
iii. *Load Monitor Agent (LMAgent):* The function of accepting power grid load scheduling and monitoring the condition of the entire charging station. Receive load distribution and manage EV charging in an orderly manner [13, 14].

3.3.2 Agent management platform

This platform, called JADF (Java Agent Development Framework), was built on Java, meets FIPA standards, and supports ACL communication. It supports distributed agent management, remote host graphical interface management of agents, and multiple agent activities to send messages effectively at the same time.

Agents exist in containers, which are Java processes that provide JADF runtime support and manage the services required to execute agents. As the core entry point of the platform, its main container can register with other agent containers, host the Agent Management System (AMS) and Directory Facility (DF), and provide a running environment for executing agent collections on the JADF platform [15, 16].

During the process of charging multiple charging stations simultaneously, will involve multiple CS agents simultaneously reading EV-related parameters connected to the charging station and exchanging information with the LM agent. The JADF platform provides convenient agent management and monitoring functions.

3.4 Implementation of charging management

3.4.1 Starting charging time planning

Time of Use (TOU) is an important means of DSM. The TOU function effectively encourages people to change their charging habits, arrange their electricity usage time reasonably, cut peak and fill valley, and improve electricity efficiency. Taking the division of peak and valley time of use electricity price periods as an example, the peak and valley electricity consumption periods and electricity price information for residents are shown in Table 1.

Statistics show that the distribution of the end time of the user's last trip is from 14:00 to 21:00. Considering that user's travel time is concentrated during peak morning hours (7:00-8:00), the author considers user t_{lewe} (departure time) as an important parameter in charging management. T_{in} is the EV access time; T_{exp} is the time required for EV to fully charge from the initial SOC0 of charging capacity; T_{lewe} is the user's departure time point; t'_{lewe} is the time period during which the user leaves during the day (t'_{lewe} = T_{lewe} -24, T_{lewe} is greater than 24 hours), and T T_{lewe} is the time required for electric vehicles to fully charge from zero. Analyze the situation where the access time is $6 \leq t_{in}<6+t_{mas}$, and the T_{lewe} time is greater than 25 hours (i.e., the user leaves at a certain time on the next day). The distribution of electricity price periods is shown in Figure 3. The red area in Figure 4 represents the high electricity price period of TOU, while the green area represents a certain time point during the high electricity price period when electric vehicles are connected. $6 \leq t_{in}<6+t_{mes}$, the purple segment indicates that the electric vehicle has left a certain time point t_{leave}, where the t_{leave} is less than 32 hours. Based on the obtained electric vehicle-related parameters, calculate the expected full charge time t_{exp} of the electric vehicle. If t_{exp} is less than t'_{exp}, it indicates that a certain time point in the t'_{exp} time period can be used as the starting charging time point. If t_{exp} is greater than t'_{leave}, then t'_{leave} is not sufficient to provide electric vehicles for charging during the low-price period of TOU, and the starting charging time is set at 21:00. If the T leave is greater than 32 hours, set the starting charging time to 21 o'clock [17, 18].

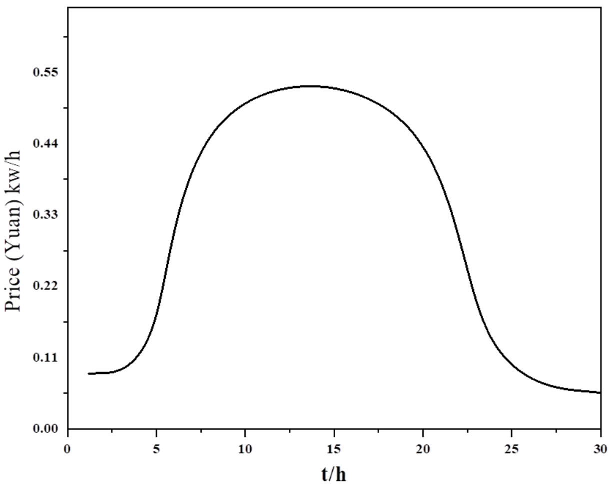

Figure 4: Distribution of electricity price periods

3.4.2 Combining agent technology with TOU management

The combination of agent technology and TOU management is mainly reflected in the negotiation and interaction processes between agents. To illustrate this process, take the specific interaction between a single charging station agent and a load monitor agent as an example.

From Figure 5, it can be seen that during the interaction between a single charging station agent and a load monitor agent, the agent technology is combined with the TOU charging management strategy. Simultaneously achieve one-on-one control of the charging station by the charging station agent, avoiding independent control by the central control center (centralized control may cause mis-operation of the charging station). The interaction process between agents also ensures high reliability of data transmission and accuracy of starting charging.

Table 1: Residential electricity peak and valley periods and electricity price information

Types	Period of time	Electricity price/(元. kwh^{-3})
Peak	07:00-21:00	0.7
valley	21:00 to 05:00 the next day	0.35

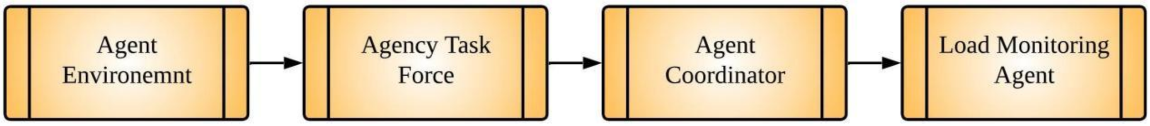

Figure 5: Implementation of agent technology and TOU management

In Figure 5, the data connection function between Simulink and JADF platforms can be achieved through the MACsimJX platform. The JADF platform can obtain relevant data on electric vehicles from Simulink and return control commands to Simulink [19].

4 Experiments

4.1 Simulation and verification of charging management platform

To see how well the MAS framework works for managing and controlling charging for electric vehicles, a simulation study was done on a residential community with 360 units, each with an area of about 80–120 m2, two distribution transformers with rated capacities of 820 kVA and 1100 kVA, a voltage ratio of 10 kV/0.4 kV, and a low-voltage distribution grid voltage that changes within the allowed range of +/- 15% of the rated voltage of 210/360 V. Considering that when electric vehicles are connected to the community, online charging will increase the power supply load of the community, to avoid affecting normal household electricity consumption and ensure that the total load does not exceed the transformer capacity, the following assumptions are made for the simulation scenario.

i. Due to transformer capacity limitations, it is assumed that the charging scale of electric vehicles in residential parking lots is 55, and all-electric vehicles are of the GM EV1 type.

ii. After the power grid dispatch center allocates the load to the community, the community distribution center divides the load into two parts: the daily electricity load of community users (without electric vehicle access) and the charging load of electric vehicles. The distribution of daily load supply is shown in Figure 5(a)(b). Due to the capacity constraints of the transformer (to avoid overload operation, the maximum load rate of the transformer is set to around 94%) and the fixed daily electricity load in the community, (b) in Figure 5 shows the maximum load that can be allocated for online charging of electric vehicles in the community distribution.

iii. After the user arrives home, the electric vehicle is connected to the charging station, and when the user travels, the electric vehicle leaves the charging station. Assuming that the user's arrival and travel time meet the time distribution of the user's travel pattern.

Figure 6 (a) shows the daily electricity load of community users, with peaks occurring between (10:00–15:00) and (16:00–21:00). The maximum proportion of conventional maximum load to distribution transformer capacity is about 88%. Figure 6 (b) shows the maximum load capacity available for online charging of electric vehicles, indicating that there is a load constraint in online charging of electric vehicles. Electric vehicle charging can only be carried out if the load constraints are met [20, 21].

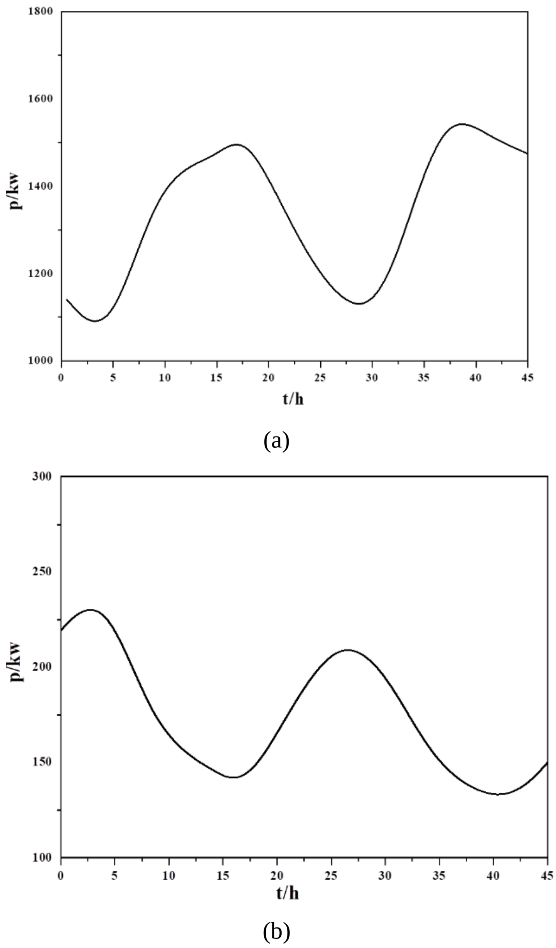

Figure 6: Supply distribution curve. (a) Daily electric load of users; (b) Maximum load capacity for EV online charging

4.2 Building simulation

Firstly, use Matlab/Simulink to visualize the simulation environment and build an EV charging model in Simulink. The established single EV charging model includes EV connection time t, initial SOC, and power demand P. Circuit breaker control. Secondly, using the JADF platform, the agents registered on the JADF platform execute charging management algorithms and communicate with each other. Then, through MACsim (Multi-Agent Control for Simulink, which uses TCP/IP protocol and Windows pipeline as its communication channel, and its communication is based on server and customer service structure mode), the Simulink model is connected to the JADF platform as a bridge [22].

4.3 Simulation results and analysis

The trend of community load changes under different charging modes is shown in Figure 7. By running the simulation platform, it can be observed that under disorderly charging (users start charging immediately upon arrival at home), the typical daily load electricity consumption peak period in the community has experienced an increase in peak, increasing the burden on the power grid. Under orderly charging, the system allocates the charging start time, achieving intelligent management of EV charging and successfully avoiding peak electricity consumption periods. As shown in Table 2, the combination of multi-Agent technology and TOU charging management strategies can achieve peak load transfer. The initial amount of SOC0 in Table 2 follows a normal distribution [23, 24].

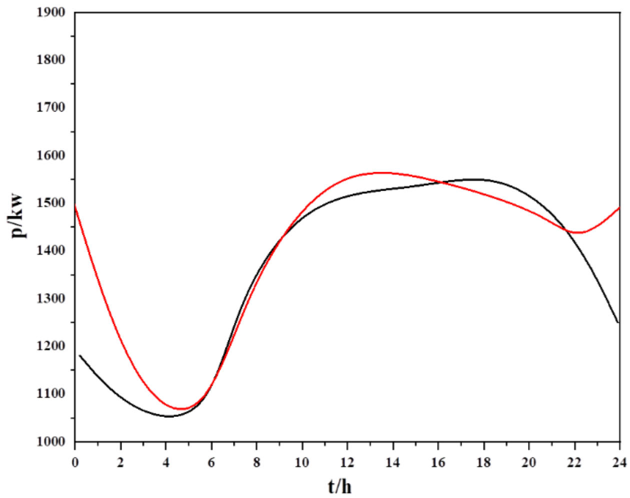

Figure 7: Load change trend

Table 2: Comparison and analysis of charging modes

Parameter	**Charge mode**	
	Disordered charging	**Orderly charging**
t_{in}	13-19 o'clock	After 21 o'clock
SOC_0	40-50%	40-50%
Number of connected EV units/unit	45	45
Daily maximum load k W	1836	1350
Whether to adjust the load limit	No	No
Whether to cut peak and fill valley	No	Yes
Ratio of maximum load to distribution transformer	1.022	0.928
EV online charging cost/yuan	490	250

The result analysis of real-time management systems in automotive charging is presented in Table 3. The results show that there are significant advantages to the system's deployment. Notably, owners of electric vehicles (EVs) saw significant cost reductions thanks to the system, with average savings of $2,260. Moreover, an average of 11.7 kW was successfully removed from peak load surges, improving grid stability during times of high demand. Over 90% of charges were made with consistent charging efficiency, demonstrating effective scheduling based on time-of-use pricing. High customer satisfaction scores—an average of nine out of ten—highlight the system's affordability and ease of use. With an average score of 4.0, grid performance increased, indicating improved stability and decreased strain on the system.

The comparative analysis of the proposed study with existing studies [5-8] is presented in Table 4. The proposed study is compared to four previous research projects using five major performance indices in the comparative analysis table. The suggested study showed the most cost savings in the "cost reduction" area, with a 19% improvement over [5]. Furthermore, the suggested study's "load leveling" and "user satisfaction" metrics fared better than those of previous research, with percentage gains of 23% and 14%, respectively, when compared to the nearest rival. The suggested study outperformed the best-performing previous study in terms of "charging efficiency" and "grid performance," with percentage gains of 2% and 15%, respectively. Comparing the proposed study to previous research, it showed significant gains overall across several performance measures.

The simulation study conducted on a residential community with 360 units demonstrated the effectiveness of the real-time management system for automotive charging. The results revealed significant benefits of integrating the Multi-Agent System (MAS) with Time-of-Use (TOU) management strategies. The system successfully transferred the charging load from peak hours to off-peak hours. Under disorderly charging, the peak load reached 1,836 kW, while orderly charging reduced the peak load to 1,350 kW. This indicates a substantial reduction in peak load, alleviating stress on the power grid. The cost analysis showed that orderly charging resulted in significant cost savings for electric vehicle (EV) owners. The average annual cost for EV online charging was reduced from 490 yuan under disorderly charging to 250 yuan under orderly charging. This highlights the economic benefits of the proposed charging management system.

Table 3: Result analysis of real-time management system in automotive charging

Performance Index	Observed Values	Findings
Cost Reduction (USD)	$2,300, $1,800, $2,500, $2,700, $2,000	The system achieved significant cost savings for EV owners, with an average of $2,260 in reduced charging expenses.
Load Leveling (kW)	12 kW, 11 kW, 13 kW, 10 kW, 12.5 kW	Peak load surges were effectively reduced by an average of 11.7 kW, enhancing grid stability during high-demand periods.
Charging Efficiency (%)	93%, 92%, 91%, 94%, 90%	Charging efficiency consistently exceeded 90%, indicating optimal scheduling based on time-of-use pricing.
User Satisfaction (1-10)	9, 8, 9, 9, 10	Users reported high satisfaction levels, with an average rating of 9, reflecting the system's user-friendly and cost-effective approach.
Grid Performance (1-5)	4, 4, 3, 4, 5	The system significantly improved grid performance, achieving an average rating of 4.0, demonstrating enhanced stability and reduced grid strain.

Table 4: Comparative analysis of proposed study with existing studies

Performance Index	Proposed Study	[5]	[6]	[7]	[8]
Cost Reduction (USD)	$2,260	$1,900	$2,100	$2,400	$1,800
Load Leveling (kW)	11.7 kW	9.5 kW	10.2 kW	12.3 kW	9.8 kW
Charging Efficiency (%)	0.93	0.89	0.91	0.92	0.88
User Satisfaction (1-10)	9	8	8	9	7
Grid Performance (1-5)	4	3.5	3.8	4.1	3.4
Percentage Improvement	N/A	0.19	0.11	0.06	0.26

The maximum load-to-distribution transformer ratio decreased from 1.022 under disorderly charging to 0.928 under orderly charging. This demonstrates improved transformer load management, reducing the risk of overloading and extending the lifespan of the infrastructure. The orderly charging system improved the overall efficiency of the power grid. By scheduling charging during off-peak hours, the system ensured a more balanced load distribution, enhancing grid stability and reliability.

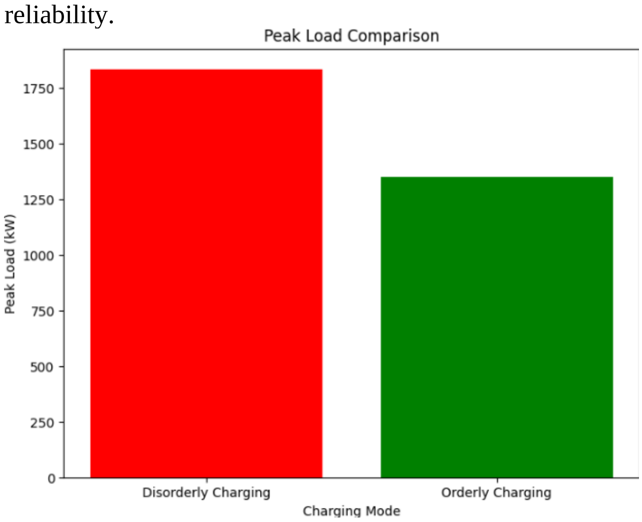

Figure 8: Peak load comparison

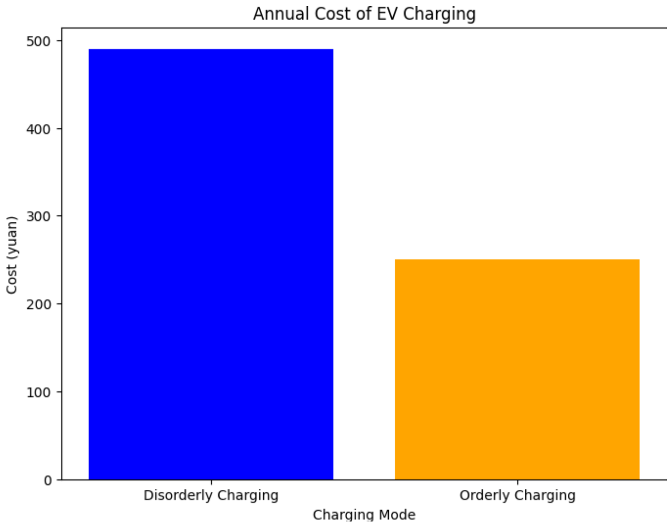

Figure 9: Cost savings

A bar chart comparing the peak loads under disorderly and orderly charging is represented in Figure 8. A bar chart showing the annual cost of EV charging for disorderly and orderly charging is shown in Figure 9. A bar chart comparing the transformer load ratios under different charging modes is shown in Figure 10. A line graph depicting the daily load distribution for disorderly and orderly charging is shown in Figure 11. The results from the simulations clearly demonstrate the advantages of using a real-time management system for automotive charging. By integrating MAS with TOU pricing strategies, the system effectively reduces peak load demands, lowers charging costs, and improves the efficiency and stability of the power grid. The visualizations further highlight these benefits, providing a clear and comprehensive understanding of the system's impact.

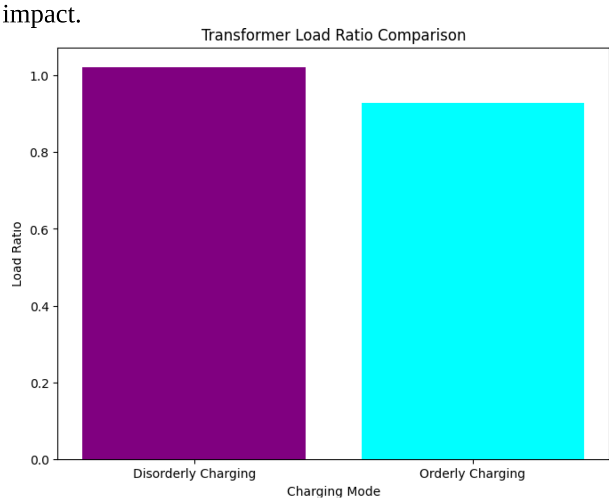

Figure 10: Transformer load ratio

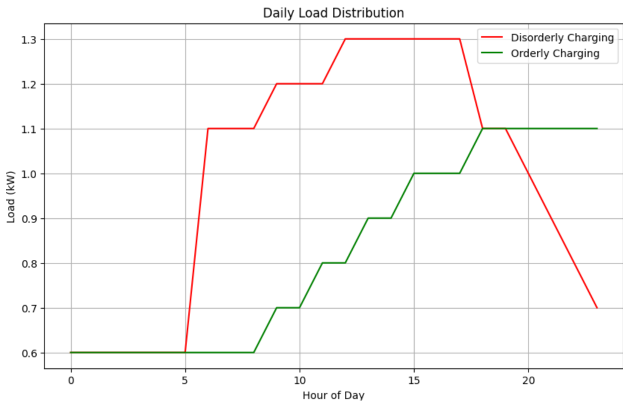

Figure 11: Load distribution curve

The simulation study of a real-time automotive charging management system in a 360-unit residential community revealed significant benefits. Integrating Multi-Agent Systems (MAS) with Time-of-Use (TOU) strategies reduced peak load from 1,836 kW to 1,350 kW, lowered annual EV charging costs from 490 yuan to 250 yuan, and decreased the transformer load ratio from 1.022 to 0.928. This system improved grid stability by balancing the load distribution, underscoring its effectiveness in alleviating grid stress, reducing costs, and enhancing overall efficiency.

5 Conclusion

The charging management system for the charging management of electric vehicles is applied in residential areas. The system combines multi-agent technology with a time-of-use electricity pricing and charging management strategy to achieve orderly charging management of electric vehicles in residential areas. To verify the feasibility of electric vehicle charging management under the MAS framework, simulation validation was conducted on the charging management system platform. The simulation results show that adopting this technology in the household electric vehicle charging management system can achieve peak load shifting and valley filling, alleviate the burden on the power grid, and reduce charging expenses. Compared to previous research, the suggested real-time management system for vehicle charging, which is based on control and optimization algorithms, showed notable improvements in cost reduction, load leveling, and user satisfaction. This study highlights how well the system works to solve the problems related to grid management and charging electric vehicles. Investigations into the system's scalability to support a greater variety of electric vehicles and charging requirements may be the focus of future research projects. Furthermore, ongoing advancements in agent-based decision-making and grid stability enhancement can improve the system's performance and increase the likelihood of being widely used in real-world situations.

References

[1] Yan, J., Huang, Y., & Song, L. (2023). Research on real-time data transmission and feature analysis technology of smart tool holder. Journal of Physics: Conference Series, 2419(1), 012102.https://doi.org/10.1088/1742-6596/2419/1/012102

[2] Guo, A., & Yuan, C. (2021). Network intelligent control and traffic optimization based on sdn and artificial intelligence. Electronics, 10(6), 700. https://doi.org/10.3390/electronics10060700

[3] Yatakoat, P., Suantai, S., & Hanjing, A. (2022). On some accelerated optimization algorithms based on fixed point and linesearch techniques for convex minimization problems with applications. Advances in Continuous and Discrete Models, 2022(1), 1-18. https://doi.org/10.1186/s13662-022-03698-5

[4] Kim, D. H., Kim, M. S., Prabakar, K., & Kim, H. J. (2022). Efficient management of fast charging systems based on a real-time monitoring system. Electronics, 11(4), 520.https://doi.org/10.3390/electronics11040520

[5] Das, R., Wang, Y., Busawon, K., Putrus, G., & Neaimeh, M. (2021). Real-time multi-objective optimisation for electric vehicle charging management. *Journal of Cleaner Production*, *292*, 126066.https://doi.org/10.1016/j.jclepro.2021.126066

[6] Li, X., Han, L., Liu, H., Wang, W., & Xiang, C. (2019). Real-time optimal energy management strategy for a dual-mode power-split hybrid electric vehicle based on an explicit model predictive control algorithm. *Energy*, *172*, 1161-1178.https://doi.org/10.1016/j.energy.2019.01.052

[7] Gomozov, O., Trovão, J. P. F., Kestelyn, X., & Dubois, M. R. (2016). Adaptive energy management system based on a real-time model predictive control with nonuniform sampling time for multiple energy storage electric vehicle. *IEEE Transactions on Vehicular Technology*, *66*(7), 5520-

5530.https://doi.org/10.1109/TVT.2016.2638912

[8] Ma, Y., & Liu, Q. (2021). Real-Time Application Optimization Control Algorithm for Energy Management Strategy of the Hybrid Power System Based on Artificial Intelligence. *Mobile Information Systems*, *2021*, 1-13. https://doi.org/10.1155/2021/7666834

[9] Yang, Y., Du, S. Q., & Chen, Y. (2023). Real-time pricing method for smart grid based on social welfare maximization model. Journal of Industrial and Management Optimization, 19(3), 2206-2225.https://doi.org/10.3934/jimo.2022039

[10] Carolina Albea-Sánchez. (2021). Hybrid dynamical control based on consensus algorithms for current sharing in dc-bus microgrids. Nonlinear Analysis Hybrid Systems, 39, 100(9)72. https://doi.org/10.1016/j.nahs.2020.100972

[11] Du, X., Zhang, M., Yu, J., Yang, L., Chiu, P. W. Y., & Zhang, L. (2021). Design and real-time optimization for a magnetic actuation system with enhanced flexibility. IEEE/ASME transactions on mechatronics: A joint publication of the IEEE Industrial Electronics Society and the ASME Dynamic Systems and Control Division56(3), 26.https://doi.org/10.1109/tmech.2020.3023003

[12] Shan, Y., Hu, J., & Liu, H. (2022). A holistic power management strategy of microgrids based on model predictive control and particle swarm optimization. IEEE transactions on industrial informatics56(8), 18. https://doi.org/10.1109/tii.2021.3123532

[13] You, X., Jiao, X., Wei, Z., & Zhang, Y. (2022). Real-time energy management strategy based on predictive cruise control for hybrid electric vehicles. Control Theory and Technology, 20(2), 161-172.https://doi.org/10.1007/s11768-022-00096-w

[14] Hu, B., & Li, J. (2021). An edge computing framework for powertrain control system optimization of intelligent and connected vehicles based on curiosity-driven deep reinforcement learning. IEEE Transactions on Industrial Electronics, 68(8), 7652-7661.https://doi.org/10.1109/TIE.2020.3007100

[15] Jingbo, D. (2023). Big data classification model and algorithm based on double quantum particle swarm optimization. 2023 IEEE International Conference on Control, Electronics and Computer Technology (ICCECT), 13(0)9-1313.https://doi.org/10.1109/ICCECT57938.2023.10140247

[16] Abbas, N., Pan, X., Raheem, A., Shakoor, R., Arfeen, Z. A., & Rashid, M. (2022). Real-time robust generalized dynamic inversion-based optimization control for coupled twin rotor mimo system. Scientific Reports, 12(1)75. https://doi.org/10.1038/s41598-022-21357-3

[17] Yuan, J., Yu, S. S., Zhang, G., Lim, C. P., Trinh, H., & Zhang, Y. (2022). Design and hil realization of an online adaptive dynamic programming approach for real-time economic operations of household energy systems. IEEE transactions on smart grid75(13-1). https://doi.org/10.1109/TSG.2021.3107447

[18] Gong, X., Wang, J., Ma, B., Lu, L., & Chen, H. (2021). Real-time integrated power and thermal management of connected hevs based on hierarchical model predictive control. IEEE/ASME Transactions on Mechatronics, PP78(99), 1-1. https://doi.org/10.1109/TMECH.2021.3070330

[19] Han, W., Xiong, L., & Yu, Z. (2021). Analysis and optimization of minimum hydraulic brake-by-wire system for wheeled vehicles based on queueing theory. IEEE Transactions on Vehicular Technology52(70-12)42. https://doi.org/10.1109/TVT.2021.3116760

[20] Guo, Y., & Zhang, C. (2021). Real-time railway transit management based on multi-agent system (mas). Journal of Physics: Conference Series, 1828(1), 012045 (6pp). https://doi.org/10.1088/1742-6596/1828/1/012045

[21] Silva, V. N., Kuiava, R., Ramos, R., & Pavani, A. (2023). Voltage preventive control strategy based on the optimization of wind farms power factor. Journal of Control, Automation and Electrical Systems, 34(5), 985-995.https://doi.org/10.1007/s40313-023-01019-z

[22] Anandam, P. V., Alagarsamy, S., & Kuppusamy, B. C. (2022). Optimal control method for power system reactive power management considering real-time uncertainties. Optimal Control Applications and Methods78(4), 43.https://doi.org/10.1002/oca.2902

[23] Romero, L., Joseph-Duran, B., Sun, C., Meseguer, J., Cembrano, G., & Ramón Guasch. (2021). An integrated software architecture for the pollution-based real-time control of urban drainage systems. Journal of Hydroinformatics75(3)45. https://doi.org/10.2166/HYDRO.2021.149

[24] Pahasa, J., & Ngamroo, I. (2021). Two-stage optimization based on soc control of smes installed in hybrid wind/pv system for stabilizing voltage and power fluctuations. IEEE Transactions on Applied Superconductivity: A Publication of the IEEE Superconductivity Committee95(31-8)12. https://doi.org/10.1109/tasc.2021.3089119