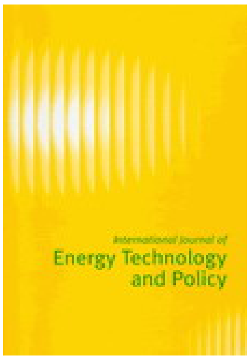


International Journal of Energy Technology and Policy

ISSN online: 1741-508X - ISSN print: 1472-8923
https://www.inderscience.com/ijetp

Load coordination control method of new energy vehicle charging pile based on Markov chain

Shun Liu, Yajuan Zhou, Yue Lu, Yang Liu, Qingtao Li

DOI: 10.1504/IJETP.2024.10061519

Article History:

Received:	07 July 2023
Last revised:	08 September 2023
Accepted:	24 October 2023
Published online:	10 May 2024

Copyright © 2024 Inderscience Enterprises Ltd.

Load coordination control method of new energy vehicle charging pile based on Markov chain

Shun Liu

State Grid Beijing Haidian Electric Power Supply Company,
Beijing, 100031, China
Email: liushun91321@163.com

Yajuan Zhou*

Energy Internet Research Institute,
Tsinghua University,
Beijing, 100084, China
Email: zhouyajuan127@163.com
*Corresponding author

Yue Lu, Yang Liu and Qingtao Li

State Grid Beijing Haidian Electric Power Supply Company,
Beijing, 100031, China
Email: 339545765@qq.com
Email: 19612213@qq.com
Email: liqingtao@bj.sgcc.com.cn

Abstract: In order to reduce the load peak valley difference of a charging station and improve the stability of load operation, a load coordination control method of new energy vehicle charging station based on Markov chain was proposed. The Markov chain theory is applied to determine the state transition form of the new energy vehicle charging load, and the required charging time is calculated. The least square method and inverse linear regression equation are used to predict the output load of new energy vehicle charging station. The load objective function and constraint conditions of the charging station are constructed, and the load coordination control objective is determined to achieve accurate control of the charging load. The experimental results show that after using this method, while meeting the charging demand, the peak to valley load difference can only reach 1.70 kW. This shows that the method can ensure the operation stability of a charging station.

Keywords: Markov chain; new energy vehicles; energy crisis; load control; power grid operation; least square method.

Reference to this paper should be made as follows: Liu, S., Zhou, Y., Lu, Y., Liu, Y. and Li, Q. (2024) 'Load coordination control method of new energy vehicle charging pile based on Markov chain', *Int. J. Energy Technology and Policy*, Vol. 19, Nos. 1/2, pp.105–119.

Copyright © 2024 Inderscience Enterprises Ltd.

Biographical notes: Shun Liu received his Master's degree in Electrical Engineering from North China Electric Power University. He is currently an Engineer in the State Grid Beijing Haidian Electric Power Supply Company. His research fields include line loss management, and integral energy market extension.

Yajuan Zhou received her Master's degree in Mechanical and Electronic Engineering from the Mechanical Department of North China Electric Power University. She is currently a Researcher in the Energy Internet Research Institute. Her research interests include digital transformation of energy, new power system, and energy internet technology.

Yue Lu received his Master's degree in Software Engineering from Northwestern Polytechnical University. He is currently an engineer in the State Grid Beijing Haidian Electric Power Supply Company. His research fields include line loss management, and integral energy market extension.

Yang Liu received her Master's degree in Control Theory and Control Engineering from North China Electric Power University. She is currently a Senior Engineer in the State Grid Beijing Haidian Electric Power Supply Company. Her research fields include power marketing service management, and electricity market extension.

Qingtao Li received his Master's degree in Power System and Automation from Sichuan University. He is currently a Senior Engineer in the State Grid Beijing Haidian Electric Power Supply Company. His research fields include power marketing service management, and electricity market extension.

1 Introduction

With the increasingly serious energy crisis and ecosystem problems, new energy vehicles have gradually become the main trend of energy structure optimisation and vehicle development in the future. New energy vehicles are the main development direction of the current and future automotive industry. The research and development of new energy vehicles have a significant impact on ensuring China's energy security and sustainable development of the ecosystem. When a large number of new energy vehicles are charged at the same time, it may affect the stability of the local power grid operation, increase the load capacity of the original power system, generate load peaks, and bring new challenges to the local power grid load carrying capacity. At the same time, it is also necessary to consider the optimisation and improvement of the current power grid (Yu et al., 2022; Suvvala and Kumar, 2023; Rubino et al., 2023). A large number of literature research results show that the increasing number of new energy vehicles leads to serious load superposition problems in the charging pile, which threatens the energy supply quality of the local power grid. Therefore, it is urgent for the development of new energy vehicles to reduce the adverse impact of charging pile load on the local power grid to the greatest extent and improve the charging efficiency of charging devices under the existing power grid structure.

In previous studies, some experts and scholars proposed a series of load coordination control methods for new energy vehicle charging pile, and there are corresponding problems in the application of these methods. For example, Wu et al. (2022) proposed a hybrid network electric vehicle charging pile operation state prediction method based on convolutional neural network and long short-term memory network. This method can achieve coordinated load control of charging pile to a certain extent, but the control effect is different from the expected effect. Liang et al. (2022) proposed an optimisation method for the charging scheme of electric vehicles in residential areas with balanced load time distribution under the shared charging pile. This method can realise the load within the specified time, but it cannot be applied all day. Mi et al. (2021) proposed a frequency coordinated control method for new energy power systems based on model-free algorithms and electric vehicle assisted regulation, which can be applied in environments with fewer vehicles. However, after applying the above method, it was found that the number of new energy vehicles increased exponentially.

The performance of traditional methods in reducing the load peak valley difference of charging pile and improving the stability of load operation is cross. This research takes this opportunity to propose a more advanced load coordination control method for new energy vehicle charging pile based on the current grid structure and Markov chain. The innovative technical route of this method is as follows:

1. Determine the state transition form of new energy vehicle charging load: firstly, use Markov chain theory to analyse the state transition law of new energy vehicle charging load. Determine the transition probability between different charging states through statistical analysis of historical data, and establish relevant state transition models.
2. Predicting the output load of charging piles: based on the historical load data of charging piles, the least squares method and linear regression inverse equation method are applied to predict and estimate the future load demand of new energy vehicle charging piles. Accurately predict the load curve of the charging station by establishing a prediction model that is suitable for the actual situation.
3. Construct load coordination control objectives and constraints: based on predicted results and actual demand, construct a new energy vehicle charging pile load objective function and constraints. Considering factors such as the available capacity and power supply capacity of the charging station, determine the goal of load coordination control to achieve precise control of the charging load.
4. Implement load coordination control: based on the load control objectives and constraints, take corresponding scheduling measures, such as flexibly adjusting the power supply capacity of the charging station, optimising the charging duration, etc., to achieve load coordination control. By real-time monitoring and feedback control, the load of the charging station is accurately controlled, enabling it to maintain stable load operation while fully meeting the charging needs of new energy vehicles.

This method combines Markov chain theory, predictive models, and load control methods to achieve precise control of the load of new energy vehicle charging stations, effectively reducing the peak valley difference of load, and improving the smoothness of load operation. The experimental results show that this method has excellent load control ability, can maintain the stability of the charging pile load, and meet the charging needs of new energy vehicles to the greatest extent.

2 Determine the conversion form of charging load state for new energy vehicles

The idea of load prediction for new energy vehicle charging stations is to establish appropriate prediction models, combine historical data and various influencing factors, and accurately predict future load demand. Its expected goals include high prediction accuracy, short-term and long-term prediction ability, comprehensive consideration of multiple factors, and real-time requirements. This can improve the efficiency of charging facilities, optimise resource allocation, enhance user experience, and enhance the stability of the power system. In order to propose a more reasonable and advanced load coordination control method for new energy vehicles charging pile, it is necessary to first analyse the current state of new energy vehicle charging load. When charging new energy vehicles, they generally go through four stages: trickle, constant current, constant voltage, and float charging (Mi et al., 2021; Ding et al., 2023). The first two stages take relatively short time and the overall voltage change is not significant, which can be considered as a constant power charging stage. In this study, the charging characteristics of new energy vehicles are determined according to the state of charge (*soc*), as follows:

$$soc = \frac{A_C}{A} \times 100\% \tag{1}$$

where A_C represents the remaining power of the battery of new energy vehicles; A refers to the rated power of new energy vehicles. Integrate this charging feature with Markov chain to analyse the SOC state transition of new energy vehicle charging.

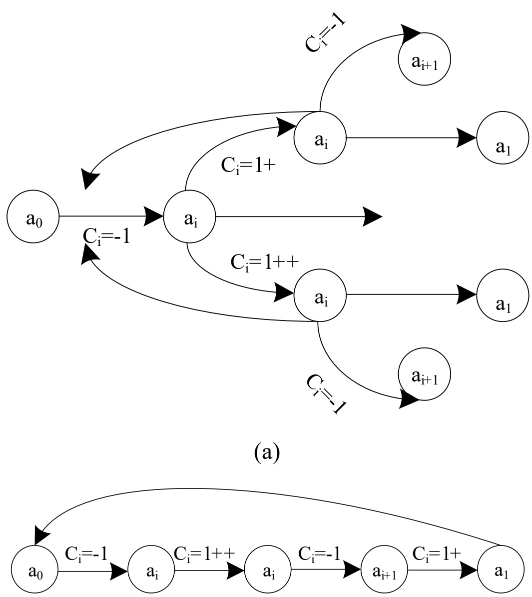
According to previous literature research results, Markov chains are a model that describes stochastic dynamic systems and can be applied to determine the state transition of new energy vehicles in subsequent time periods. Set the current charging state of the new energy vehicle to b_1 and the next charging state to b_2. At this time, the charging state of the new energy vehicle can be represented by a Markov chain as:

$$P(b_1 \to b_2) = P(b_1 | b_2) = P_{12} \tag{2}$$

According to Markov theory (Dong et al., 2022; He et al., 2021), the content in formula (2) is displayed using Markov chain images. To better draw this image, new energy vehicles are divided into two types: private cars and public cars. The specific changes in charging state can be represented in the form of Figure 1.

In Figure 1, $c_i = -1$ indicates that the new energy vehicle is in a driving state, $c_i = 1+$ indicates that the new energy vehicle is in a slow charging state, $c_i = 1++$ indicates that the new energy vehicle is in a fast charging state, and $c_i = 0$ indicates that the vehicle is stationary, neither charging nor driving. In order to meet the use needs of different new energy vehicle users, the charging pile needs to judge the user's charging needs according to the Markov state transition analysis results.

Figure 1 Schematic diagram of Markov transformation of charging load state for new energy vehicles, (a) private car (b) bus



(a)

(b)

At the same time, this study will also use user driving habits as one of the reference conditions. According to the fitting results of users' vehicle habits, the remaining electricity of new energy vehicles is predicted. The remaining power of the vehicle is closely related to the travel kilometres of the user on that day, and also determines the charging time of new energy vehicles (Usatenko et al., 2022; Liu et al., 2021b). Through analysis, it can be found that the fitting result of daily mileage data of new energy vehicles conforms to the law of Normal distribution, so its probability density formula can be written as follows:

$$f_l(L) = \frac{1}{\sqrt[x]{2\pi\mu_L^2}} U^{\left[\frac{(\ln x - \tau_i)^2}{2\mu\tau_i}\right]} \tag{3}$$

According to this formula, the initial battery charge of new energy vehicles is calculated as follows:

$$soc_{i,j} = \left(soc_{i,u} - \frac{L_i}{L_m} \right) \times 100\% \tag{4}$$

Among them, $soc_{i,u}$ represents the charging capacity of the new energy vehicle after charging is completed; L_i represents the daily kilometres travelled by the user; L_m represents the mileage that can be driven when the battery is fully charged. According to this formula, the charging duration of new energy vehicles can be preliminarily determined:

$$T_i = \frac{\left(soc_{i,u} - soc_{i,k}\right) \times D_i}{p_i \times \sigma} \tag{5}$$

Among them, D_i represents the battery capacity of new energy vehicles; p_i represents the charging power of new energy vehicles; σ represents to the charging efficiency of new energy vehicles.

Through the above calculation, the charging habits of new energy vehicle users and the required charging time for new energy vehicles can be determined. By integrating and analysing the content obtained from formula (2), a complete process of charging load state transition for new energy vehicles can be obtained.

3 Load prediction of new energy vehicle charging pile

The main advantages of load forecasting for the new energy vehicle charging station model include improving the utilisation efficiency of charging facilities, ensuring the stability of the power system, alleviating charging pressure, and promoting the development of new energy vehicles. Among them, the initial contribution was the development of prediction algorithms based on Markov chains. Markov chain utilises historical data to establish accurate state transition models, helping to predict the transition patterns of charging pile loads and providing reliable theoretical basis for charging management. Through this method, new energy vehicle charging stations can more effectively allocate and dispatch resources, improve the utilisation rate of power supply capacity, ensure the stability of the power system, alleviate charging pressure, improve user experience, and promote the development and popularisation of new energy vehicles. The above analysis of the charging habits of users of new energy vehicles, based on some requirements in this study, makes assumptions about the charging and discharging process of new energy vehicles:

a the user’s charging goal is until the battery is fully charged

b the new energy vehicle adopts the conventional charging mode, and the charging efficiency is set to 0.9

c new energy vehicles are charged and discharged once a day, and can be charged in various areas.

With the increasing number of new energy vehicle charging pile, the energy load of each substation gradually increases. Under the premise of the existing power supply capacity, the charging of new energy vehicles has seriously affected the safe operation of the power grid (Su et al., 2021; Liu et al., 2021a; Li et al., 2021). Therefore, it is necessary to propose a more reasonable load coordination control method for charging pile of new energy vehicles.

In this study, Markov chain is used to analyse the charging state and charging conversion process of vehicles in detail, and to predict the current load status of charging pile of new energy vehicles based on it. Use the obtained historical load data of charging pile, apply the least square method to carry out linear regression, and then predict the load of new energy vehicle charging pile according to the derivative result of the regression equation.

The load problem of charging pile is regarded as a linear regression problem, which can be expressed as:

$$E = \min \sum_{i=1}^{n} \left(y_i - y_{ie} \right)^2 \tag{6}$$

Among them, y_i represents the obtained historical data; y_{ie} represents the estimated value obtained after applying the least squares method. The specific estimation process is set as follows:

$$y = \sigma_0 + \sigma_1 x \tag{7}$$

Among them, σ_1 represents the regression variable in the regression equation; σ_0 represents the constant term in the regression equation. Substituting formula (7) into formula (6) yields:

$$E = \min \sum_{i=1}^{n} \left(y_i + \sigma_0 - \sigma_1 x \right)^2 \tag{8}$$

To take the derivative of this formula, if the extreme point of this function is set to the point where the partial function is equal to 0, then:

$$\begin{cases} \dfrac{\varepsilon E}{\varepsilon \sigma_0} = 2 \sum_{i=1}^{n} \left(y_i + \sigma_0 - \sigma_1 x_i \right)(-1) = 0 \\ \dfrac{\varepsilon E}{\varepsilon \sigma_1} = 2 \sum_{i=1}^{n} \left(y_i + \sigma_0 - \sigma_1 x_i \right)(-x_i) = 0 \end{cases} \tag{9}$$

Integrating the above formulas and using Cramer's rule, the process is as follows:

$$\begin{cases} \sigma_0 = \dfrac{\sum x_i^2 \sum y_i - \sum x_i \sum y_i x_i}{n \sum x_i^2 - \left(\sum x_i \right)^2} \\ \sigma_1 = \dfrac{n \sum x_i^2 \sum y_i - \sum x_i \sum y_i}{n \sum x_i^2 - \left(\sum x_i \right)^2} \end{cases} \tag{10}$$

Among them, σ_0 and σ_1 are the calculation coefficients of the regression equation, respectively (Kim et al., 2022).

Use the above process to make real-time predictions for power generation and consumption units as well as load consumption units. On the basis of the above prediction results, adjust the charging time and charging load of new energy vehicles, and integrate them with the calculation value of formula (15) to obtain the predicted load that may be required to be output by the charging pile.

4 Load coordination control of new energy vehicle charging pile

4.1 Construction of load objective function of new energy vehicle charging pile

According to the above research results, the load of the new energy vehicle charging pile is coordinated and controlled. In the process of load coordination control, it is not only necessary to meet the charging demand of new energy vehicles, but also to ensure the economy of the charging pile and the bearing capacity of the regional power grid. Therefore, the objective function of total load operation cost of charging pile in the study area is set as follows:

$$\min S = W_{\gamma}'^{m} \times \left(\left(m_{1,k} w + m_{2,k} r + g_k \right) \times \left(\frac{h_0 \left(1 + h_0\right)^n}{\left(1 + h_0\right)^n - 1} + \alpha \right) \right) \tag{11}$$

where $m_{1,k}$ represents the number of existing fast charging pile in the study area; w represents the operating load of the fast charging pile; $m_{2,k}$ represents the number of existing slow charging piles in the study area; r represents the operating load of slow charging pile; g_k is the operating load of the charging pile foundation in the study area; h_0 is the bank rate; α represents the operating load fluctuation value of charging pile; $W_{\gamma}'^{m}$ is the charging probability of the charging pile. To ensure that the calculation results of this objective function meet the current requirements, the charging power constraint function is set as follows:

$$\begin{cases} Z_{ij} = M_i \sum M_j \left(Q_{ij} \cos \mu_{ij} + V_{ij} sIN \mu_{ij} \right) \\ O_{ij} = M_i \sum M_j \left(Q_{ij} \cos \mu_{ij} - V_{ij} sIN \mu_{ij} \right) \end{cases} \tag{12}$$

where Z_{ij} represents the active power injection of the charging pile, and is the difference between the input power of the charging pile generator and the load; O_{ij} represents reactive power injection of charging pile; M_i is the voltage amplitude of charging pile; Q_{ij} is the real part of the admittance matrix (Mi et al., 2021; Oladigbolu et al., 2022) of the charging pile; V_{ij} represents the imaginary part of the admittance matrix of the charging pile; μ_{ij} represents the phase angle difference between different nodes. On the basis of this constraint, the constraint conditions of voltage amplitude of charging pile are proposed as follows:

$$M_i^{\min} \le M_i \le M_i^{\max} \tag{13}$$

Among them, M_i represents the rated voltage amplitude of the power grid in this region; $M_i^{\min}$ represents the lowest voltage amplitude value of the charging pile in this area; $M_i^{\max}$ represents the highest rated voltage amplitude of the power grid in this region. After sorting out the above contents, the capacity constraints of the charging pile access point are obtained. The specific calculation process is set as follows:

$$E_{C,jk} \le E_{j,\max} \tag{14}$$

where $E_{C,jk}$ represents the charging power of the charging pile connected to the grid node; $E_{j,\max}$ represents the maximum injection power that the power grid nodes in the study area can undertake.

Using the above constraints, complete the overall operation process of the objective function and use it as the basis for load coordination control.

4.2 Load coordination control of new energy vehicle charging pile

Using the objective function preset in the above process, the load coordination control process of the charging pile is planned on the premise that the charging pile has the ability of automatic decision-making.

Suppose that when the charging pile is charging the new energy vehicle, the current state of charge of the charging pile is $F_{de,i}$, and the departure time is $t_{dep,i}$. The initial state of charge and battery capacity can be obtained from the charging pile management system, and the single charging cycle of the charging pile can be obtained under normal conditions:

$$T_\gamma = \frac{\left(F_{de,i} - F_{ini,i}\right) t_{dep,i}}{Z'_\gamma \omega_i} \tag{15}$$

where ω_i represents the charging efficiency of charging pile; Z'_γ represents the power of charging pile to charge new energy vehicles.

If the new energy vehicle needs a large amount of electricity, the Charge cycle can be appropriately increased to achieve the vehicle charging goal. In order to achieve the goal of balancing the load of charging pile in the study area, according to the preset decision-making parameter table of charging pile, the grid load capacity in each period is divided into the charging probability distribution of charging pile, and according to this distribution and the calculation result of formula (15), the total load margin $U'_{set,m}$ of charging pile in this area is determined:

$$U'_{set,m} = \sum\nolimits_{j \in \theta_m} U'_{sup,j} \tag{16}$$

Among them, θ_m represents the markers for each time period. On this basis, calculate the working probability of different charging pile in the specified time period:

$$W'^{m}_{\gamma} = \frac{T_\gamma}{\sum\nolimits_{j \in \theta_m} U'_{sup,j}} \tag{17}$$

where W'^{m}_{γ} represents the charging probability of the charging pile (Yang and Li, 2022; Li et al., 2022).

Use this formula to determine the daily operation state of the charging pile, and bring the calculation result of this formula into the load objective function of the new energy vehicle charging pile. If the calculation result meets the constraint conditions of the objective function, use this calculation result to control the operation state of the charging pile. If the calculation results cannot adapt to the constraint conditions of the objective function, the second calculation shall be carried out, and other charging pile shall be selected to complete the charging process to avoid the problem of overload.

The design content in this paper is introduced into the local controller of the charging pile system, and the control method is realised through voltage regulation and current regulation. After sorting out the above contents, the design of load coordination control method for new energy vehicle charging pile based on Markov chain has been completed. The innovative points of the load coordination control method for new energy vehicle charging stations based on Markov chain are concentrated in the following aspects. Firstly, using Markov chain theory to determine the state transition form of charging loads helps to accurately grasp the transition probability between charging states and establish a state transition model for charging loads. Secondly, by calculating and predicting the charging duration of new energy vehicles, it can better meet the charging needs of vehicles and provide reliable power supply. Thirdly, use the least squares method and linear regression inverse equation to predict the required output load of the charging station, establish a prediction model suitable for practical situations, and provide accurate reference basis for load coordination control. Finally, by constructing a load objective function and constraint conditions, the goal of load coordination control is determined, and precise control of charging load is achieved to improve grid stability and charging facility utilisation efficiency.

5 Experimental analysis

5.1 Experimental preparation

The experiment was completed in the form of example test, taking a residential area in the city as the research object. This residential area has an independent three-phase power grid, the grid bus is the balance node of the overall power grid, and the voltage is set at 1.50 p.u. Fifty public new energy vehicle charging pile are set in the residential area, and the power of each phase of each charging pile is the same.

During the experiment, it is assumed that the owners of new energy vehicles are willing to participate in charging activities, and the charging time is from 7:00 a.m. on the same day to 7:00 a.m. on the next day, and they are all in constant power charging mode. To reduce the impact of the experiment, the above data is imported into the simulation calculation software, and the relevant functions in MATLAB software are used to construct the experimental environment with the experimental data. At the same time, the Monte Carlo method is used to randomly generate the access input of electric vehicles. This part of data includes the initial power, charging time and final power. To ensure that this experimental environment has high computing power, the running time of the calculation section is set to 1.821 seconds, and the data processing time is set to 2.215 seconds. Integrate the above content and complete the experimental preparation phase.

5.2 Experimental indicator setting

The index is set as two parts in the experiment, which are the fluctuation of load curve after the application of different control methods and the load peak valley difference of charging pile. Among them:

1 The load curve fluctuation can preliminarily analyse the load balance control effect of different control methods, and determine the load change of each charging pile in the experimental area during the experimental cycle.

2 The load peak valley difference can be used to calculate the specific load of the charging pile after the application of different control methods, and obtain more accurate experimental results. The calculation formula for this experimental indicator can be expressed as:

$$\tau = \varepsilon_{\max} - \varepsilon_{\min} \tag{18}$$

where $\varepsilon_{\max}$ represents the maximum load of the charging pile; $\varepsilon_{\min}$ represents the minimum load of the charging pile.

Organise the above indicators and analyse the control performance of this method and the other two methods.

5.3 Experimental plan design

According to the preset experimental plan and comparison indicators, it is assumed that 50, 100, and 300 vehicles will participate in the experiment. The load variance of different numbers of new energy vehicles in this experimental area is obtained through numerical simulation. The specific data is shown in Table 1.

Table 1 Variance of new energy vehicle load with different quantities in the experimental area

No.	*Number of new energy vehicles*	*Load variance (kW^2)*
Zx-01	50	0.85×10^5
Zx-02	100	8.74×10^5
Zx-03	300	6.10×10^5

Analysing the data in Table 1, it can be found that when a large number of new energy vehicles are charged, the load connected to the experimental area will increase and then decrease, which has a negative impact on the stability of the power grid operation in the experimental area. Therefore, it is necessary to control the load of 50 charging pile in this area. In order to determine the corresponding application value of method of this paper, method of Wu et al. (2022) and method of Liang et al. (2022) are selected for comparative analysis, and the load conditions of each charging pile under different vehicle conditions after the application of the three methods are analysed.

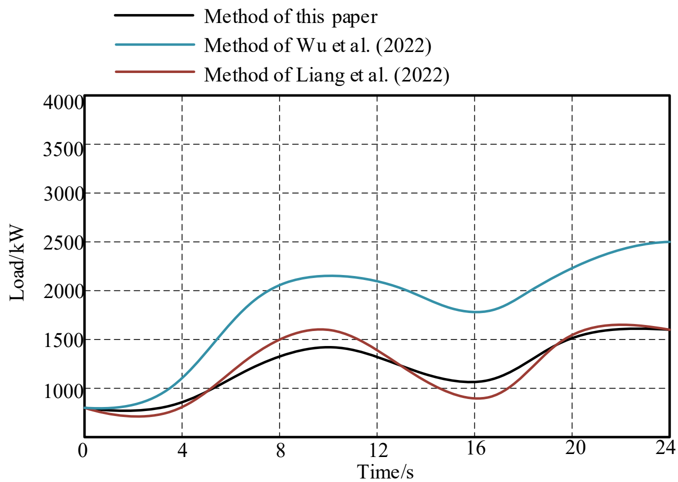
5.4 Analysis of experimental results

5.4.1 Analysis of load curve fluctuation of charging pile

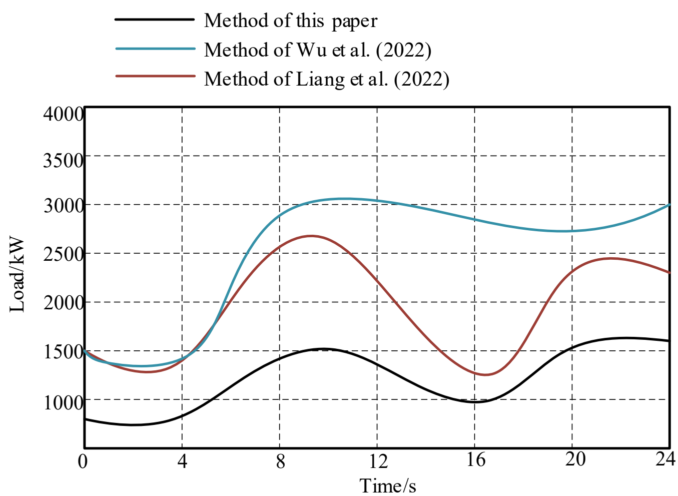
To reduce the difficulty of the experiment, only the load situation in the conventional charging mode was imaged in this experiment, as shown in Figure 2.

It can be seen from the analysis of Figure 2 that when the number of new energy vehicles is 50, the image drawn by the method of this paper is relatively close to that drawn by the other two methods. Under this number of vehicles, the load of the charging pile fluctuates slightly and is relatively stable as a whole. When the number of new energy vehicles is 100, the image drawn by the method of this paper and the other two methods changes. Under this number of vehicles, the load of the charging pile fluctuates significantly, but the image drawn by the method of this paper fluctuates slightly. When there are 300 new energy vehicles, the load of the charging pile drawn by the method of this paper fluctuates slightly, and the images drawn by the other two methods also show a decline. This image has roughly the same trend as the load variance of different numbers of new energy vehicles in the experimental area, which confirms the scientificity of the three methods in the experiment. On the whole, however, after the application of method of this paper, the load curve of the charging pile fluctuates slightly, indicating that the load control capability of method of this paper is relatively high.

Figure 2 Load curve of charging pile, (a) 50 new energy vehicles (b) 100 new energy vehicles (c) 300 new energy vehicles (see online version for colours)

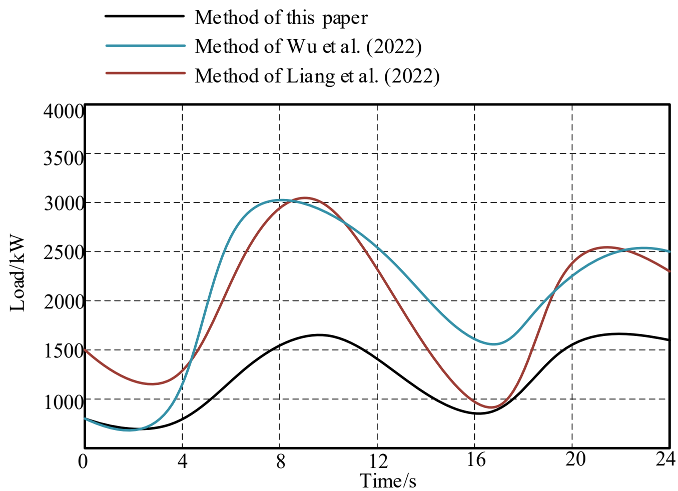


(a)



(b)

Figure 2 Load curve of charging pile, (a) 50 new energy vehicles (b) 100 new energy vehicles (c) 300 new energy vehicles (continued) (see online version for colours)



(c)

5.4.2 Analysis of load peak valley difference experimental results

On the basis of the load curve of the charging pile, use formula (18) to calculate the load peak valley difference. The specific experimental results are shown in Table 2.

Table 2 Peak valley difference of different quantities of new energy vehicles in the experimental area (kW)

No.	*Number of new energy vehicles*	*Method of this paper*	*Method of Wu et al. (2022)*	*Method of Liang et al. (2022)*
Zx-01	50	1.50	1.56	1.57
Zx-02	100	1.65	3.15	2.62
Zx-03	300	1.70	4.85	4.50

Analysis of the data in Table 2 shows that the method of this paper and the other two methods can control the load of the charging pile after application, but there are great differences between the three methods. After the method of this paper is applied, the load peak valley difference between charging pile is low, and the maximum load peak valley difference is only 1.70 kW, which indicates that the load of charging pile is relatively stable, and it is not easy to affect the power grid in this area. After applying two reference methods, the load peak valley difference between charging pile is relatively poor, and the load peak valley difference of method of Wu et al. (2022) is far more than that of method of Liang et al. (2022) and method of this paper. By organising the above experimental results, it can be determined that the application effect of method of this paper is superior to the other two methods.

6 Conclusions

The load coordination control method of new energy vehicle charging pile based on Markov chain has achieved remarkable results in reducing the load peak valley difference and improving the stability of load operation. Through the application of Markov chain theory, the state transition form of charging load of new energy vehicles is determined, and the charging duration of new energy vehicles is calculated. With the help of the least square method and the inverse linear regression equation, the load that the new energy vehicle charging pile needs to output is predicted. By constructing a load objective function and constraint conditions, precise control of charging load was successfully achieved. The experimental results validate the superiority of this method in load control. After the application of this method, the fluctuation of the load curve of the charging pile is significantly reduced. On the premise of meeting the charging demand, the peak to valley load difference can only reach 1.70 kW. This shows that the method can effectively ensure the operation stability of the charging pile, and provides a feasible solution for the reliable operation of the charging pile. In conclusion, the load coordination control method of new energy vehicle charging pile based on Markov chain shows obvious advantages in reducing the load peak valley difference and improving the stability of load operation. This method has good load control ability, and provides important reference and guidance for the operation management of new energy vehicle charging pile and power grid load regulation. Further research can further optimise this method and promote and apply it in practical applications.

Acknowledgements

This work was supported by State Grid Beijing Electric Power Company under Grant No. 52020420004Y.

References

Ding, C., Liu, C., Zang, Q. and Niu, Y. (2023) 'A class of small deviation theorems for Markov chains in bi-infinite random environment', *Communications in Statistics – Theory and Methods*, Vol. 52, No. 3, pp.693–701.

Dong, K., Cai, X., Cui, Y., Meng, Z., Yu, Z., Zhang, R. and Yu, Y. (2022) 'Aggregation modeling based on Markov chain and multi-mode control strategies of aggregated electric vehicles for frequency regulation', *Power System Technology*, Vol. 46, No. 2, pp.622–631.

He, J., Shi, C. and Wei, T. (2021) 'Adaptive power demand prediction model of energy storage based on Markov chain', *Transactions of China Electrotechnical Society*, Vol. 36, No. S02, pp.563–571.

Kim, S., Rasouli, S., Timmermans, H.J.P. and Yang, D. (2022) 'A scenario-based stochastic programming approach for the public charging station location problem', *Transportmetrica B: Transport Dynamics*, Vol. 10, No. 1, pp.340–367.

Li, X., Huang, Y., Hu, Y., Li, H. and Gao, Q. (2021) 'Multiple-feature power load forecasting based on PAU-LSSVM model', *Chinese Journal of Electron Devices*, Vol. 44, No. 2, pp.474–479.

Li, Y., Peng, J., Liao, W., Zou, B. and Cao, J. (2022) 'Research on an integrated model for electrical load forecasting based on time series', *Building Science*, Vol. 38, No. 10, pp.190–197.

Liang, S., Zhao, Q., He, J. and He, S. (2022) 'Optimization of community electric vehicle charging schemes with balanced load time distribution under shared charging hubs', *Application Research of Computers*, Vol. 39, No. 12, pp.3688–36933700.

Liu, D., Zhang, Y., Peng, X., Liu, M., Wang, W., Jia, H., Qin, G., Wang, J. and Yang, Y. (2021a) 'Clustering prediction of electric vehicle charging load considering similar days and meteorological factors', *Electric Power Construction*, Vol. 42, No. 2, pp.43–49.

Liu, X., Fu, J., Zhao, S., Zhong, K., Yang, X. and Li, X. (2021b) 'Location and capacity determination method of electric vehicle charging pilebased on bi-level programming and considering load forecasting', *Electrical Measurement & Instrumentation*, Vol. 58, No. 5, pp.144–150.

Mi, Y., Lun, X., Meng, F., Zhang, X., Ge, X. and Lin, S. (2021) 'Frequency coordinated control of a new energy power system based on a model-free algorithm and EV auxiliary regulation', *Power System Protection and Control*, Vol. 49, No. 24, pp.13–20.

Oladigbolu, J.O., Mujeeb, A., Imam, A.A. and Rushdi, A.M. (2022) 'Design, technical and economic optimization of renewable energy-based electric vehicle charging stations in africa: the case of Nigeria', *Energies*, Vol. 16, No. 1, pp.397–397.

Rubino, L., Rubino, G. and Esempio, R. (2023) 'Linear programming-based power management for a multi-feeder ultra-fast DC charging station', *Energies*, Vol. 16, No. 3, pp.1213–1213.

Su, J., Fang, S., Liu, B., Du, S., Shan, B. and Gao, T. (2021) 'Short term load prediction method based on modal combination', *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 37, No. 14, pp.186–196.

Suvvala, J. and Kumar, K.S. (2023) 'Implementation of EFC charging station by multiport converter with integration of RES', *Energies*, Vol. 16, No. 3, pp.1521–1521.

Usatenko, O.V., Melnyk, S.S., Pritula, G.M. and Yampol'skii, V.A. (2022) 'Information entropy and temperature of binary Markov chains', *Physical Review E*, Vol. 106, No. 3-1, pp.034127–034127.

Wu, D., Zhen, H., Lei, T., Chen, J., Qian, Y., Li, Q. and Zheng, L. (2022) 'Prediction method of electric vehicle charging pile operating state based on CNN and LSTM hybrid network', *Electric Machines & Control Application*, Vol. 49, No. 2, pp.83–89.

Yang, G. and Li, X. (2022) 'The short-term power load forecast in wide area learning system based on maximum information mining', *Electrical Measurement & Instrumentation*, Vol. 59, No. 3, pp.38–45.

Yu, H., Cai, G., Shi, S., Zhang, H., Peng, D. and Yin, S. (2022) 'Operation optimization method for microgrid with large-scale charging piles', *Proceedings of the CSU-EPSA*, Vol. 34, No. 1, pp.16–25.