



International Journal of Energy Technology and Policy

ISSN online: 1741-508X - ISSN print: 1472-8923

<https://www.inderscience.com/ijetp>

Online identification method of power grid load sensitivity based on adaptive Kalman filter

Hao Huo, Chao Kang, Ningrui Li, Bingbing Liu, Huifeng Zhang

DOI: [10.1504/IJETP.2025.10066453](https://doi.org/10.1504/IJETP.2025.10066453)

Article History:

Received:	25 April 2024
Last revised:	23 May 2024
Accepted:	08 July 2024
Published online:	05 February 2025

Online identification method of power grid load sensitivity based on adaptive Kalman filter

Hao Huo*, Chao Kang, Ningrui Li,
Bingbing Liu and Huifeng Zhang

State Grid Gan Su Extra High Voltage Company,
Lanzhou, 730070, China

Email: hao_sg@126.com

Email: chao_sg@126.com

Email: ningrui_123@126.com

Email: bbing_123@126.com

Email: hfeng2024@126.com

*Corresponding author

Abstract: In order to overcome the problems of large covariance, high deviation, and low sensitivity in traditional load sensitivity identification methods for power grids, this paper proposes an online identification method for power grid load sensitivity based on adaptive Kalman filtering. Firstly, construct a power grid load sensitivity identification architecture consisting of data layer, service layer, and application layer. Secondly, construct a discrete Kalman filter model, determine the time update formula, and design a Kalman filter. Then, the adaptive Kalman filter is used to verify the load node status of the power grid and identify the load data. Finally, based on the data identification results, the relay protection setting value is calculated and used for adaptive online identification of power grid load sensitivity. The experimental results show that the covariance of the method proposed in this paper is stable at 0.01, the sensor acquisition information error remains below 1%, the sensitivity index is high, and it has good robustness.

Keywords: adaptive Kalman filter; grid load; sensitivity; online identification.

Reference to this paper should be made as follows: Huo, H., Kang, C., Li, N., Liu, B. and Zhang, H. (2025) 'Online identification method of power grid load sensitivity based on adaptive Kalman filter', *Int. J. Energy Technology and Policy*, Vol. 20, Nos. 1/2, pp.110–124.

Biographical notes: Hao Huo received his Master's degree in Electrical Engineering and Automation from Xi'an Polytechnic University. He currently works for State Grid Gan Su Extra High Voltage Company. He is engaged in the operation and maintenance of ultra-high voltage converter station, mainly good at power system equipment operation fault diagnosis, power grid load sensitivity monitoring, reactive power compensation equipment and harmonic governance.

Chao Kang received his Master's degree in Electrical Engineering and Automation from Nanjing University of Posts and Telecommunications in 2011. He currently works at State Grid Gansu Extra High Voltage Company. His research interests include high voltage direct current transmission.

Ningrui Li graduated from North China Electric Power University, is currently engaged in the operation and maintenance management of ultra-high voltage converter stations, mainly conducting research on the principle structure, operating characteristics, and maintenance of ultra-high voltage direct current transmission equipment.

Bingbing Liu received his Master's degree in Electrical Engineering and Automation from School of Electrical Engineering of Henan Polytechnic University in 2012. He is currently an Engineer of Ultra-high Voltage Operation and Maintenance. He has been engaged in the converter station since started working, so he has rich experience in the field.

Huifeng Zhang received his BS degree in Automatic Engineering, and his MS degree in Communication. He is currently working as a Senior Engineer, and conducts research in converter station equipments and HVDC transmission technology.

1 Introduction

With the rapid development of power system and the increasing power demand, it is particularly important to accurately predict and manage the power grid load (Dong et al., 2022; Group, 2022). In order to better grasp the operation state of power system and adjust the control strategy in time to meet the real-time demand, it is of great significance to study the online identification method of power grid load sensitivity (Tan et al., 2021). In recent years, adaptive Kalman filter technology has attracted attention because of its superiority in dealing with parameter estimation of dynamic systems. Adaptive Kalman filter is a system identification method for real-time estimation and has been widely used in the field of power system load forecasting and control in recent years. Through real-time monitoring and analysis of power grid load data, we can better understand the influence of power grid load change on power system operation (Khatua and Mukherjee, 2021; Lakshminarayana et al., 2021) and provide corresponding control strategies. The realisation of this goal depends on accurate identification of power grid load sensitivity. Power grid load sensitivity is the sensitivity of power grid load to the changes of system parameters or variables under different operating conditions, which reflects the stability and reliability of power system operation and provides important reference information for power grid operators. Therefore, it is of great significance to accurately identify the load sensitivity of power grid for the operation and control of power system.

Chang and Zou (2022) put forward a method to identify the fragile lines of power grid based on the comprehensive sensitivity of branches. Firstly, the power transmission distribution coefficient is improved, and the influence of branch load rate is considered, and the branch power flow sensitivity index is proposed to reflect the sensitivity of branches to power flow transfer. Then the distribution factor of branch fracture is modified, and the sensitivity of branch fracture is constructed, which reflects the fragility of branch fracture from two aspects. Entropy weight method is used to allocate the weights of the two indicators, and the fragile lines in the system are screened out. The recognition results are compared with related literature, and finally the simulation is carried out by IEEE39 system. In this paper, three attack methods are used to attack, and the network transmission efficiency is used to reflect the impact of attack methods on the

system. The results prove the feasibility and rationality of this method. However, the covariance of this method is large, which affects the identification effect. Xue et al. (2022) propose a stochastic economic identification method considering voltage-sensitive load as backup. Firstly, the transmission and distribution voltage control model based on coordinated sensitivity is established, and the active power regulation boundary considering voltage stability is quantified. Then, based on the corresponding risks, a stochastic reserve decision model of power system considering VSL regulation ability is established. The example analysis of the improved IEEE RTS-79 system shows that this method can fully consider the influence of access point voltage on load power, change the power of VSL, and provide active power reserve for power system. This method can reduce the risk of wind and load rejection in the system, and improve the economy and flexibility of system operation. However, there is a big deviation between the measured value and the identification value, and the identification effect is not good. Fahmy and Paolone (2021) propose an identification method of power system sensitivity coefficient considering voltage-dependent injection. With the increasing demand for real-time regulation in power system, the power grid perceptual control framework relies more and more on sensitivity coefficient to formulate and effectively solve the optimal control problem. In practical control applications, the system state knowledge from the state estimation process allows the sensitivity coefficient to be calculated directly without power flow. The purpose of this paper is to put forward the analysis and derivation of node voltage sensitivity coefficients of all node types for power grid with general topology, phase number and voltage-related node power injection model. It also includes a detailed list of all other sensitivity coefficients that can be directly calculated by using the sensitivity coefficient of node voltage, the computational complexity analysis of the proposed method and the numerical benchmark. However, the total sensitivity, local sensitivity and high-order sensitivity of this method are all low, and the identification effect is limited.

In order to solve the above problems, this paper proposes an online identification method of power grid load sensitivity based on adaptive Kalman filter. Adaptive Kalman filter is a parameter estimation method based on Kalman filter theory, which can adapt to the change of system operation state and estimate and update the load sensitivity according to real-time data. By estimating and updating the load sensitivity of power grid in real time, accurate reference information is provided for power grid operators, which is helpful to optimise system operation and improve power supply reliability and economy. The main technical route of the article is as follows:

Firstly, the structure of power grid load sensitivity identification is constructed. Constructing an online identification framework of power grid load sensitivity, which consists of data layer, service layer and application layer;

Secondly, adaptive Kalman filter design. Based on this architecture, an adaptive Kalman filter is established, and the time updating formula of adaptive Kalman filter is used to verify the prior information of node state and identify data, thus realising the identification of heterogeneous data.

Then, the load sensitivity of power grid is identified online. The relay protection setting value is calculated, and the online identification of power grid load sensitivity is completed by using this setting value.

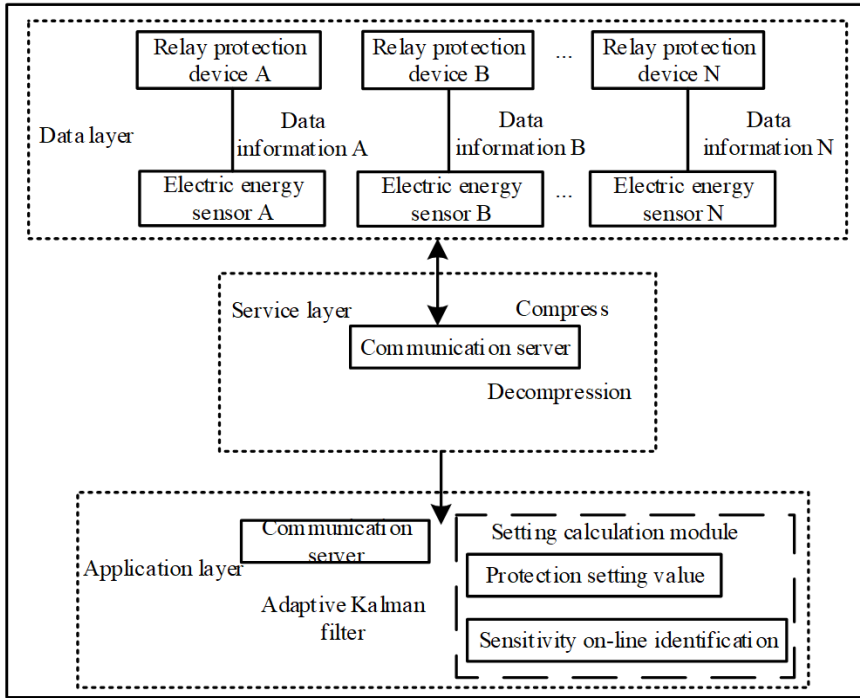
Finally, covariance, deviation and sensitivity are used as experimental indicators to verify and get the conclusion.

2 Online identification of power grid load sensitivity under adaptive Kalman filter

2.1 Online identification architecture of power grid load sensitivity

Online sensitivity identification is one of the main criteria to judge whether the power grid load is sensitive and reliable. Numerous sub-modules with distributed structure constitute the online identification architecture of power grid load sensitivity (Li et al., 2022; Hardan et al., 2022), which is composed of data layer, service layer and application layer. The architecture structure is shown in Figure 1.

Figure 1 Online identification system architecture of power grid load sensitivity



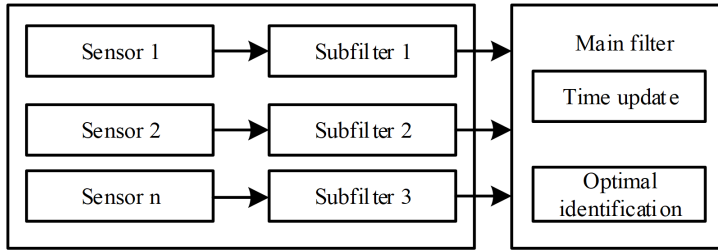
According to Figure 1, the data layer collects fault wave recording data of current, voltage, etc. in the power grid load protection device through the electric energy sensor (Korada and Mishra, 2022). In the service layer, the protection manager is responsible for compressing and decompressing the data collected by multiple power sensors to ensure that the communication server can transmit these data in real time. The communication and data exchange among all levels in the architecture are realised through the communication server, and the collected information will be transmitted to the application layer of the system through the communication server according to the different sequence and application objects. In the application layer, all the real-time data transmitted by the service layer communication server will be stored in the wave recorder. Then, the data collected by multiple sensors are fused by adaptive Kalman filter, so as to get the fusion result of power grid load. According to this fusion result, relay protection setting calculation is carried out. In the setting calculation module, the

protection setting value is calculated according to the calculation results, and the online identification architecture design of power grid load sensitivity is completed according to the obtained protection setting value.

2.2 Heterogeneous data identification based on adaptive Kalman filter

Based on the above-mentioned online identification system architecture of power grid load sensitivity, adaptive Kalman filter is used to identify heterogeneous data. Adaptive Kalman filter is a commonly used signal processing and system identification method (Ompusunggu, 2023; Mungufeni et al., 2022), which uses the principle of optimal estimation to estimate and predict the system state, so as to achieve the purpose of signal filtering and system identification. In the online identification method of power grid load sensitivity (Selvaraj and Kannan, 2022; Miret et al., 2023), adaptive Kalman filter can be used to estimate the state and parameters of power grid load change (Kussainov, 2021; Al-Hussein. and Haldar, 2022). Its core idea is recursive and iterative correction based on observation data, thus improving the accuracy and reliability of load estimation. The structure diagram of adaptive Kalman filter is shown in Figure 2.

Figure 2 Structure diagram of adaptive Kalman filter



The data processing process of adaptive Kalman filter is mainly divided into two processes: main filter and local sub-filter (Puri and Caverly, 2023). In the calculation, each sub-filter works independently, that is, the time update and the measured value update run separately.

The discrete model of the adaptive Kalman filter is expressed as:

$$Q_{AB} = F \times (\alpha \times A_a + \beta \times B_b) \quad (1)$$

In the formula, F represents the state value of the estimated target, α and β respectively represent the state transition values of target estimation, A_a represents the observation noise sequence of the a data, and B_b represents the noise sequence of the b -th data.

The time updating formula of adaptive Kalman filter is expressed as:

$$W_E = C_c \times \gamma \times \delta \times Q_{AB} \quad (2)$$

In the formula, C_c represents the estimated state value at the c time, γ represents the state prior estimation value, and δ represents the posterior covariance estimation parameter.

Verify the prior information of node state, and the formula is as follows:

$$R_Y = W_E \times \varepsilon \times \theta \quad (3)$$

In actual identification, each node can receive data from a subset of nodes (Chen and Zhao, 2023), and each node can send its own local posterior covariance U_O to the covariance matrix of adjacent nodes for data identification, and the obtained identification information is expressed as:

$$P_M = R_Y \times U_O \quad (4)$$

Repeat the above process until all data identification is completed. In this way, heterogeneous data identification based on adaptive Kalman filter is realised.

3 Realisation of online identification of power grid load sensitivity

The response ability of protection devices in power grid to faults or abnormal conditions in their protection areas is load sensitivity. Based on the results of heterogeneous data identification of power grid load, the relay protection setting value is calculated, and the online identification of power grid load sensitivity is completed by using this setting value.

3.1 Calculation of setting value of power grid load sensitivity protection

Protection setting value is a set value used to trigger the action of protection device in power system, which covers the setting parameters of impedance protection for multiple lines, and is used to monitor the abnormal situation in the system and take protective measures. In power system, in order to protect multiple lines from faults, setting impedance protection devices are usually used. Setting impedance protection is a protection method based on line parameters and fault characteristics, which is used to detect line faults and trigger corresponding protection actions (Karpov et al., 2022). When the phase-to-phase distance of the power grid line is a section, the setting is conducted to avoid the abnormality at the end of the line itself, and the expression of the setting impedance protection setting value is:

$$Z_I = P_M \times Z_a \times k_1 \quad (5)$$

In the formula, Z_I represents the setting impedance of the distance protection section, Z_a represents the positive sequence impedance of the protected line, and k stands for reliability coefficient.

When the phase-to-phase distance of the line is J section, according to the calculation of avoiding the other side bus of the adjacent transformer, the setting impedance protection setting value expression is:

$$Z_J = P_M \times Z_b \times k_2 \quad (6)$$

In the formula, Z_J represents the setting impedance of J section of distance protection, Z_b represents the positive sequence impedance of the adjacent transformer, and k_2 represents the boosting coefficient with the smallest value.

When the phase-to-phase distance of the line is z section, it should be set according to the load impedance when avoiding the maximum load of the line, because the distance z section is a directional impedance starting element, and its setting impedance protection setting value expression is:

$$Z_z = P_M \times Z_C \times k_3 \quad (7)$$

In the formula, Z_z represents the setting impedance of z section of distance protection, Z_c represents the minimum value of load impedance and k_3 stands for the return coefficient.

At this time, the fixed value result of power grid load sensitivity protection is obtained.

3.2 Realisation of online identification of power grid load sensitivity

Online identification of power grid load sensitivity is carried out according to the fixed value results of power grid load sensitivity protection obtained in Section 3.1. Check that the phase-to-phase distance of the line is the sensitivity of I section and the length of the protection range, so that the length of the protected line can reach 80%–85%. Line phase-to-phase distance J section and adjacent line phase-to-phase distance I section are combined, and the online identification expression of line phase-to-phase distance J section sensitivity is:

$$K_a = \frac{Z_J}{Z_I} \quad (8)$$

The expression of backup protection with the phase-to-phase distance of the line near the section is:

$$K_b = \frac{Z_J}{Z_I} \quad (9)$$

The expression of backup protection with the phase-to-phase distance of the line being far is:

$$K_{ab} = \frac{Z_Z}{Z_I} \times K_b \times Z \quad (10)$$

In the formula, Z represents the positive sequence impedance of the next line adjacent to z segment.

Collect the historical data of regional electricity consumption and related influencing factors, pre-process these data, establish the sensitivity identification model of regional electricity load according to the selected characteristic variables and electricity load data, and use this model to calculate the parameters of the model through training and optimisation methods. The accuracy and prediction ability of the model are verified by applying the calculated model to the new data set and verifying and evaluating it. The identification formula is:

$$H_{ab} = \frac{U_1 / P_a}{U_2 / P_b} \quad (11)$$

In the formula, the process of voltage change, U_1 and U_2 represent the voltage values of the first group and the second group respectively, and P_a and P_b both represent load power. According to the verification results, the model can be further optimised and adjusted to improve the identification performance of power grid load sensitivity, that is, the online identification of power grid load sensitivity based on adaptive Kalman filter can be realised.

4 Experimental analysis

4.1 Experimental Scheme

In order to verify the effectiveness of the online identification method of power grid load sensitivity based on adaptive Kalman filter, experimental analysis is carried out. Select a grid load connected in the traditional way, in which the traditional units are thermal power generating units and the new energy units are wind power generating units. The experimental scheme includes the following steps:

- Step 1 Determine the range of parameters involved in the experiment, such as power grid load, system state and external interference.
- Step 2 Use electric energy sensors, instruments and equipment to obtain data such as power grid load, system status, control signals and external interference. For each data type, we need to consider the acquisition accuracy, sampling rate and noise processing.
- Step 3 Observe the response of thermal power generator set and wind power generator set by adjusting power grid parameters or adding external interference.
- Step 4 According to the experimental results, the sensitivity of power grid load is evaluated and analysed, and the adaptive control algorithm is further optimised.
- Step 5 According to the analysis results of experimental data, evaluate the effectiveness and performance of the online identification method of power grid load sensitivity based on adaptive Kalman filter. The performance of the method is evaluated by using indicators and comparing experimental results, and relevant conclusions are given. According to the above process, the experimental scheme is set up.

According to the above experimental scheme, 500 different types of electric power metering equipment are selected as the research objects in this experiment, and all the research objects are in normal state in the initial state. A total of 250 samples in the research object were adjusted to abnormal state by man made destruction, and the other 250 samples remained normal state, which was used as the initial detection samples of the experiment. According to random distribution, the prepared samples of power metering equipment are divided into five groups, and the total number of samples in each group is the same, but the number of abnormal samples is different from that of normal samples. Connect the above test data to the MATLAB test platform for testing.

4.2 Performance index design

4.2.1 Covariance

In order to avoid the error of a single test, 80 tests are conducted, with covariance as the test index, and the calculation formula is:

$$\text{cov}(X, Y) = \frac{X_i + Y_i}{n} \times 100\% \quad (12)$$

In the formula, X_i and Y_i represent the i sample values of X and Y , respectively, and n represents the number of samples. The sample variable of this test is the number of each type of fault, and the fault detection results will be different when the number of samples is different. In general, the less the number of samples, the lower the covariance of detection, indicating that the better the online identification effect of power grid load sensitivity is.

4.2.2 Identification deviation

Identification deviation is the difference between the actual identification result and the estimated identification result, which can reflect the accuracy of sensitivity identification. The larger the identification deviation month indicates the lower the sensitivity identification accuracy, and conversely, the smaller the identification deviation month indicates the higher the sensitivity identification accuracy.

4.2.3 Sensitivity

4.2.3.1 Total sensitivity

Total sensitivity refers to the analysis method of the overall response change of a target variable relative to the input parameters in the system. By calculating the partial derivative of the target variable for each input parameter or other sensitivity indicators, it evaluates the correlation and influence degree between the target variable and the input parameters. The total sensitivity can help to understand the contribution of different input parameters in the system to the target variable, and determine which parameters have important influence on the system performance or output results. The calculation formula of total sensitivity is:

$$S_{MN} = \frac{V_{ar}(Y)}{V_{ar}(X)} \quad (13)$$

In the formula, (Y) represents the variance of the target variable Y for online identification of power grid load sensitivity, and $V_{ar}(X)$ represents the variance of input parameter X for online identification of power grid load sensitivity.

4.2.3.2 Local sensitivity

Local sensitivity: local sensitivity refers to the sensitivity of the target variable to the slight change of the input variable at a certain point or condition. It measures the changing relationship between the target variable and the input variable, and can help to

determine which input variables have the greatest influence on the target variable. The calculation formula of local sensitivity is:

$$S_M = \frac{d(Y)}{d(X)} \quad (14)$$

In the formula, $d(Y)$ represents the partial derivative of the target variable Y , and $d(X)$ represents partial derivative of the target variable X .

4.2.3.3 High-order sensitivity

High-order sensitivity: High-order sensitivity is the analysis of the response change of the target variable when the model is disturbed many times. It can provide more comprehensive and accurate information about the relationship between variables, including the influence of nonlinear effect and interaction. The calculation formula of high-order sensitivity is:

$$S_N = \frac{\partial(Y)}{\partial(X)} \quad (15)$$

In the formula, $\partial(Y)$ represents the expected value of the target variable Y , and $\partial(X)$ represents the expected value of the target variable X .

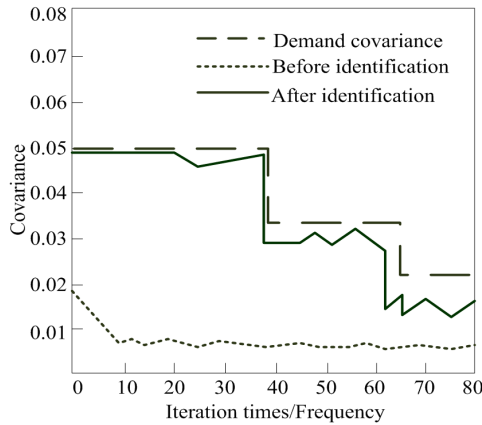
4.3 Test and analysis of performance index

4.3.1 Covariance of power grid load sensitivity

Electric energy sensors and instruments are used to obtain fault wave recording data such as power grid load, system state, control signal and external interference. After information is collected by single sensor and identified by multiple sensors, the information is identified online, and covariance is counted, which verifies the online identification effect of power grid load sensitivity under this method. Set the demand covariance of the power grid load, and compare the covariance of online identification before and after sensor information identification. The experimental results are shown in Figure 3.

According to Figure 3, the identification process of power grid load sensitivity has a significant impact on covariance curve. Before identification, the covariance curve showed an obvious downward trend, which was significantly different from the preset demand covariance curve, indicating that there was a big error in the information collected by the electric energy sensor before identification. After 10 iterations, the covariance of the protection setting is basically stable at about 0.01, which further indicates that the application performance of the information collected by the sensor is poor before identification. However, after identifying the load sensitivity data of power grid by this method, the downward trend of covariance curve is preserved, but its trend is closer to the preset demand covariance curve, which means that the identified sensor has less error in collecting information and higher application performance. The experimental results show that the identification method of power grid load sensitivity information proposed in this paper has a significant improvement in application effect.

Figure 3 Covariance of power grid load sensitivity before and after online identification (see online version for colours)



4.3.2 Identification deviation

Using the sensitivity identification model of regional power load created by this method, the sensitivity identification of per capita annual power consumption of 8 randomly selected power users is carried out, and the results are shown in Table 1.

Table 1 Sensitivity identification results of per capita annual electricity consumption of users

Power user number	Per capita annual electricity consumption/kW·h		
	Measured value	Identification value	Deviation/%
User 1	831.30	831.24	0.06
User 2	869.34	868.32	1.02
User 3	887.56	887.51	0.05
User 4	879.65	878.95	0.7
User 5	822.47	822.14	0.33
User 6	864.93	864.35	0.58
User 7	866.49	865.89	0.6
User 8	884.91	884.31	0.6

As can be seen from Table 1, in the sensitivity identification data of per capita annual electricity consumption of users, the measured value and identification value of each user are different, which is expressed as the percentage of deviation. It can be seen that the deviation between the measured values and the identified values of most users is small, all of which are below 1%. This indicates that the identification accuracy of power grid load sensitivity of this method is high, which can effectively reflect the power consumption of different power users and help to provide reliable guidance for regional power consumption and energy storage planning. Through the sensitivity identification of electricity consumption, the predictability of users' electricity consumption behaviour can be evaluated, and then the work of load regulation, energy management and planning of power system can be guided. This is because this article uses an adaptive Kalman filter to

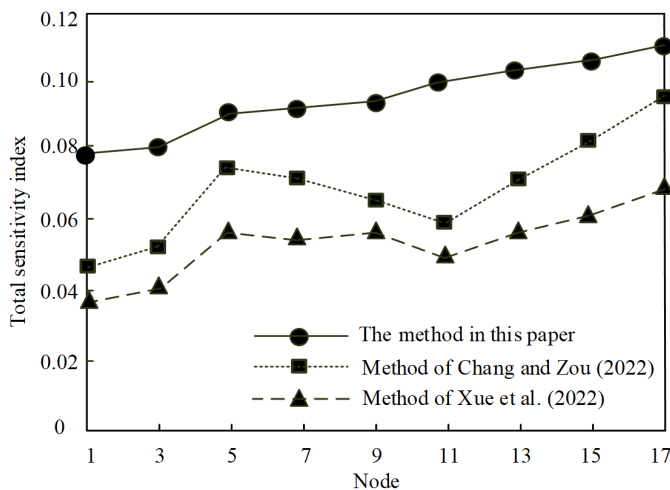
verify the state of power grid load nodes, and calculates relay protection settings based on data identification results, effectively improving the accuracy of the sensitivity identification results of this article's method.

4.3.3 Sensitivity contrast

In order to continue to measure the robustness of this method applied to online identification of power grid load sensitivity, comparative experiments were carried out by Chang and Zou (2022) method and Xue et al. (2022) method respectively. The total sensitivity, local sensitivity and high-order sensitivity indexes of power grid load output response at 25 nodes of the power grid were tested, and the results are shown in Figure 4.

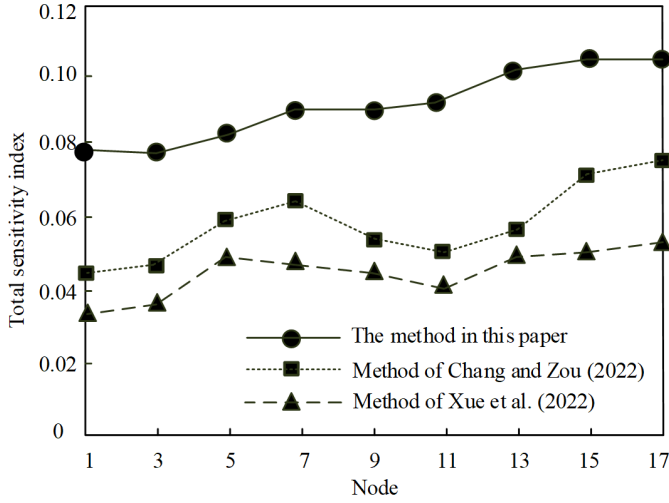
According to Figure 4, the method in Chang and Zou (2022) and the method in Xue et al. (2022) all show small values in terms of total sensitivity, local sensitivity and high-order sensitivity index of power grid load output response, and show an upward or downward trend. However, compared with the reference method, it is obvious that the output response of power grid load obtained by this method shows high values in total sensitivity, local sensitivity and high-order sensitivity, and shows an upward trend. This result fully shows that the sensitivity index obtained by this method can accurately reveal the dynamic law of the influence of the change of grid input uncertainty on grid load, thus verifying the good robustness of this method. This is because this article uses an adaptive Kalman filter to verify the state of power grid load nodes, identifies load data, calculates relay protection settings based on the data identification results, and uses these settings for adaptive online identification of power grid load sensitivity, effectively improving the robustness of the method proposed in this article.

Figure 4 Comparison results of sensitivity indexes under different methods, (a) comparison result of total sensitivity index (b) comparison results of local sensitivity indexes (c) comparison results of high-order sensitivity indexes

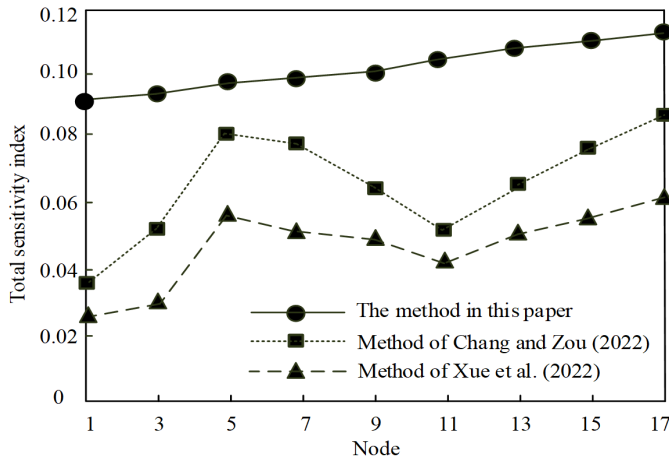


(a)

Figure 4 Comparison results of sensitivity indexes under different methods, (a) comparison result of total sensitivity index (b) comparison results of local sensitivity indexes (c) comparison results of high-order sensitivity indexes (continued)



(b)



(c)

5 Conclusions

This article studies an online identification method for power grid load sensitivity based on adaptive Kalman filtering. By introducing adaptive Kalman filtering technology, the online identification of power grid load sensitivity is achieved. After experimental verification, the following conclusions have been drawn in this article:

- 1 After identifying the sensitivity data of power grid load using the method described in this article, the covariance curve decreases, and the identified sensor has a smaller error in collecting information, resulting in higher application performance.
- 2 The deviation between the measured value and the identified value of the user is less than 1%, indicating that the sensitivity identification accuracy of the proposed method for power grid load is relatively high.
- 3 The sensitivity of the power grid load output response obtained by this method shows high values and good robustness.

In practical applications, the dynamic characteristics and uncertainties of power grid loads may be more complex, and further improvement of the adaptive Kalman filtering method is needed to adapt to a wider range of scenarios.

References

- Al-Hussein, A. and Haldar, A. (2022) 'Recent developments in unscented Kalman filtering for health assessment of large structural systems', *Recent Developments in Structural Health Monitoring and Assessment — Opportunities and Challenges*, Vol. 1, No. 1, pp.1–10.
- Chang, C. and Zou, Q. (2022) 'Identification method of vulnerable lines in power grid based on comprehensive sensitivity of branches', *Journal of Interconnection Networks*, Vol. 22, No. 3, pp.1–12.
- Chen, T.T. and Zhao, S.Z. (2023) 'Research on high-dimensional big data mining method considering fuzzy time series', *Computer Simulation*, Vol. 40, No. 3, pp.467–470.
- Dong, Y., Shan, X., Yan, Y. et al. (2022) 'Architecture, key technologies and applications of load dispatching in China power grid', *Journal of Modern Power Systems and Clean Energy*, Vol. 10, No. 2, pp.316–327.
- Fahmy, S. and Paolone, M. (2021) 'Analytical computation of power grids' sensitivity coefficients with voltage-dependent injections', *PowerTech 2021*.
- Group, A.P.M. (2022) 'Malawi adds 3.4MW to grid but faces longer periods of load shedding after Aggreko exit', *Africa Power Monitor*, Vol. 6, No. 347, pp.1–6.
- Hardan, F., Norman, R. and Tricoli, P. (2022) 'Control and operation of a ship AC/DC microgrid under transient propulsion and manoeuvring load conditions', *International Journal of Electrical Power & Energy Systems*, Vol. 139, No. 6, pp.1–12.
- Karpov, A.S., Fastiy, G.P., Yaroshevich, V.V. et al. (2022) 'Fault analysis of the 110 KV power grid with one-way power supply', *Electric Power Systems Research*, Vol. 206, No. 5, pp.1–12.
- Khatua, S. and Mukherjee, V. (2021) 'Application of PLC based smart microgrid controller for sequential load restoration during station blackout of nuclear power plants', *Annals of Nuclear Energy*, Vol. 151, No. 2, pp.1–16.
- Korada, D.M.R. and Mishra, M.K. (2022) 'Adaptive power management algorithm for multi-source DC microgrid system', *International Journal of Emerging Electric Power Systems*, Vol. 24, No. 3, pp.319–340.
- Kussainov, B. (2021) 'Stochastic dynamic systems' state estimation based on mean squared error minimizing and Kalman filtering', *Scientific & Academic Publishing*, Vol. 11, No. 1, pp.1–8.
- Lakshminarayana, S., Sthapit, S. and Maple, C. (2021) 'Data-driven detection and identification of IoT-enabled load-altering attacks in power grids', *arXiv e-prints*, Vol. 1, No. 10, pp.1–10.
- Li, Y.-Z., Sun, T.-L., Liu, Y. et al. (2022) 'Uncertainty characterization of power grid net load of dirichlet process mixture model based on relevant data', *Acta Automatica Sinica*, Vol. 43, No. 3, pp.747–761.

- Miret, J., Castilla, M., Velasco, M. et al. (2023) 'Maximum current injection method for grid-forming inverters in an islanded microgrid subject to short circuits', *IET Power Electronics*, Vol. 16, No. 6, pp.1028–1042.
- Mungufeni, P., Migoya-Orué, Y., Matamba, T.M. et al. (2022) 'Application of classical Kalman filtering technique in assimilation of multiple data types to NeQuick model', *Journal of Space Weather and Space Climate*, Vol. 12, No. 9, pp.1–9.
- Ompusunggu, A.P. (2023) 'Switching Kalman filtering-based corrosion detection and prognostics for offshore wind-turbine structures', *Wind*, Vol. 3, No. 1, pp.1–13.
- Puri, N. and Caverly, R.J. (2023) 'Coupled least-squares forward kinematics and extended Kalman filtering for the pose estimation of a cable-driven parallel robot', *International Journal of Mechanisms and Robotic Systems*, Vol. 5, No. 3, pp.270–289.
- Selvaraj, M. and Kannan, E. (2022) 'Enhancing power in a grid-connected system using unified power quality conditioner with black widow optimization-based floating photovoltaic system', *International Journal of Energy Research*, Vol. 46, No. 3, pp.3095–3114.
- Tan, K.M., Ramachandaramurthy, V.K., Yong, J.Y. et al. (2021) 'Experimental verification of a flexible vehicle-to-grid charger for power grid load variance reduction', *Energy*, Vol. 228, No. 1, pp.120560–120568.
- Xue, L., Niu, T., Huang, T. et al. (2022) 'A stochastic economic dispatch method considering a voltage-sensitive load as a reserve', *Electric Power Systems Research*, Vol. 205, No. 4, pp.1–11.