J Inf Process Syst, Vol.18, No.6, pp.784~793, December 2022
https://doi.org/10.3745/JIPS.04.0258

ISSN 1976-913X (Print)
ISSN 2092-805X (Electronic)

JOURNAL OF INFORMATION PROCESSING SYSTEMS JIPS

Electrical Automatic Control System Based on the Internet of Things

Jiyong Jin*

Abstract
Grid-connected distributed power generation has been widely used in green energy generation. However, due to the distributed characteristics, distributed power generation is difficult to be dynamically allocated and monitored in the electrical control process. In order to solve this problem, this research combined the Internet of Things (IoT) with the automatic control system of electrical engineering to improve the control strategy of the power grid inverter according to the characteristics of the IoT system. In the research, a connection system of the power grid inverter and the IoT controller were designed, and the application effect was tested by simulation experiments. The results showed that the power grid inverter had strong tracking control ability for current and power control. Meanwhile, the electrical control system of the IoT could independently and dynamically control the three-phase current and power. The given value was reached within 50 ms after the step signal was input, which could protect the power grid from being affected by the current. The overall system could realize effective control, dynamic control and protective control.

Keywords
Auto-control, Electrical Design, Internet of Things, Inverter

1. Introduction

As a kind of necessary energy for life and industry, electric energy is facing many problems with the great development of the current society. For example, the distribution of power generation is insufficient and power generation and power generation security monitoring is difficult. At present, with the continuous increase of power grid terminal products, it is necessary to timely collect power grid operation information to form dynamic control [1]. Dynamic control can improve the safety of power grid operation while preventing energy waste, exert a peak-cutting and valley-filling effect during power grid operation, and improve power stability [2]. The Internet of things has intrinsic advantages in networked automatic control. It can link devices through the network and collect the information from the devices to the processing platform for unified processing with cloud computing [3]. Therefore, intelligent automatic control of power grid by Internet of things is an inevitable trend in the development of dynamic power grid in the future. To solve the problem of dynamic automatic control of power grid can also provide users with a more reliable power environment [4].

Manuscript received April 29, 2022; first revision August 23, 2022; second revision September 19, 2022; third revision October 14, 2022; accepted November 6, 2022.

* **Corresponding Author:** Jiyong Jin (5803@zut.edu.cn)
School of Mechatronics Engineering, Zhongyuan University of Technology, Zhengzhou, China (5803@zut.edu.cn)

The main purpose of this research is to help solve the main problems existing in distributed generation. At present, distributed generation has the characteristics of wide distribution, so long-distance generation has certain instability and faces difficulties in supervision. Therefore, the research used the characteristics of the Internet of Things (IoT) to combine the distributed generation system with the IoT to achieve the automation of electrical control. In the control process, the single-phase inverter was used to realize the separated control of three items. By modulating the space vector in the inverter, the neutral line current could be reduced in the three-phase four wire system environment to achieve three-phase balance. The combination of IoT and the distributed generation system had great influence on the power system. The distributed power supply was integrated into the main network under the condition of standby power supply, which could share, alleviate, and solve the problems of overload and congestion in the main network, and it was conducive to the improvement of power margin of the grid. The voltage regulation of distributed power supply could support the voltage of the system and improve its overall level by adopting appropriate methods. As far as the voltage fluctuation was concerned, the output power of the distributed generation system could be positively correlated with the local load, which could suppress the voltage fluctuation of the system. Taking wind power generation as an example, the output power of wind turbines in wind power generation is related to the wind speed. When the wind speed is high, the power of the wind turbine generator is high, making it difficult for local loads to operate in coordination, thus causing large fluctuations in the system voltage. The distributed generation system can affect the output power to a certain extent, improve the efficiency and stability of power generation, and guarantee the normal power consumption of residents and social development. However, distributed generation has a certain degree of negative impact on power system protection. Distributed generation will reduce the sensitivity of line relay protection, and the speed protection cannot be quickly completed, thus the dead zone of line fault cannot be removed in time. In the distributed generation system, it is very common that the fault point is far away from the bus, so the protection device will detect that the fault current value is greater than the true setting value, resulting in the misjudgment of the relay protection. Electricity marketization is an important strategic reform in the power industry, in which distributed generation technology is an important technical reform. In the power market, distributed generation technology has a stronger adaptability as it provides users with more choices.

The novelty of this research lies in the combination of the distributed characteristics of grid connected distributed generation and the IoT as well as the integration of decentralized user power information which aims to achieve unified supervision, so as to help the grid more accurately meet user needs and provide power services. The control and tracking ability of the grid connected inverter was enhanced with better control ability. The control system was independent and real-time so the effect of automatic control could be achieved.

The structure of this paper is as follows. The second part includes the summary and analysis of the IoT, electrical control methods at home and abroad, and understanding of the effect of combining distributed power grid and the IoT on electrical automatic control. The third section introduces the control and design of the inverter based on the IoT, the overall effect of the inverter regulation on the controller and system voltage, and the cast-in-place process. The fourth section introduces the automatic control effect of the method in the simulation experiment. The fifth part summarizes the research methods, designed systems and experiments and points out the deficiencies.

2. Related Works

Based on the application status of 4G IoT, Milan et al. [5] proposed RL-IoT (reinforcement learning-Internet of Things), a system that explored automatic interaction with potentially unknown IoT devices. Utilizing reinforcement learning to understand the semantics of protocol messages and control devices to achieve a given goal while minimizing interactions, RL-IoT brought the opportunity of using reinforcement learning to automatically explore the interaction with IoT protocols with limited information and paved the way for interoperable systems. Zhu et al. [6] studied, with practical engineering experience, the automation transformation of a sewage treatment plant based on the IoT technology. A set of remote monitoring system of sewage treatment based on the industrial IoT was constructed to realize large-scale monitoring of sewage treatment with detailed introduction to on-site hardware systems, wide-area monitoring applications, management cloud platforms, and security technologies. Thakur and Sehgal [7] proposed a heterogeneous structure for smart cyber-physical system (SCPS) that integrated different electrical, pneumatic, and hydraulic processes to perform hybrid process dynamics based on IoT technology. The proposed structure was able to separate all aspects of process dynamics by estimating process disturbances, sensor delays, actuator delays, and transition delays. Computing embedded cores of distribute information to IoT was done through voltage-frequency islands with high modularity. All mapped process dynamics was optimized with dynamic voltage and frequency scaling.

In the direction of electrical control, Bernadic [8] proposed a switch logic control method for medium voltage power network based on the artificial neural network model. The control program was implemented by the Python tool TensorFlow. With the fault current and voltage samples, the back-propagation model based on the high-precision artificial neural network was used to control the digital relay protection device and implement switching control in the substation. Sheludko et al. [9] improved the naval electrical engineering and automation equipment, including the power generation and distribution system as well as the electric propulsion system. The advantages of different types of propulsion devices were incorporated to create a joint propulsion device. The experimental results reflected the effectiveness of using valve generator sets and transition to DC (direct current) power distribution. The current research used the advantages of the IoT to improve the electrical control to a more accurate level, but in the face of emergencies, it was difficult to be detected and adjusted. This study linked the IoT with electrical automatic control and utilized the characteristics of the IoT with rich remote information to expand the strategic scope for automatic control of the power grid and to help the power grid automatically adjust the power supply strategy with users' power consumption information. Compared with other studies, this study was more integrated and could help achieve automatic integrated control. It was also more practical and better conformed to the civil environment.

3. Design of Electrical Controller of Internet of Things

3.1 Inverter Control Mode Design

In the current smart grid environment, distribution of regulation information equipment is becoming more and more extensive, and information collection capacity has also been gradually enhanced. However, users' power consumption information is often scattering and huge. It is difficult for regulation centers to analyze users' power consumption characteristics and adapt the information for user regulation [10]. As the Internet based information acquisition and measurement technology, the IoT can put a variety of information into a unified information processing platform through digital transmission technology, find out the change law from relevant data, and ultimately realize control optimization and automatic control of things [11]. The Internet of things grid platform can integrate decentralized information to help smart grid more accurately describe users' needs, so as to achieve an automatic control effect.

With three-phase independent control strategy in the control process, the system realized separate control of the three phases by the control mode of the single-phase inverter, that is, changing the coordinates of the three-phase voltage, obtaining the voltage phase by phase-locked loop (PLL), and tracking each phase of the three phases. The PLL structure required the sinusoidal signal generator to convert the sinusoidal signal into the quadrature signal for the realization of phase tracking. The phase difference in *dp* coordinate system was the time interval between one wave leading or lagging behind the other, which was the distance between two waveforms. When it was 90°, it was phase orthogonal; when it was 180°, the phase was opposite. It was obtained that the phase difference between two waves was the phase angle error of the orthogonal signal, which can be expressed in mathematical coordinates as follows:

$$\varepsilon_{dp} = V\,sin(\omega t + \Phi)\,cos(\omega' + \Phi') - V\,cos(\omega t + \Phi)\,sin(\omega' t + \Phi') \tag{1}$$

Formula (1) can be simplified to formula (2) according to the cosine two angle difference formula.

$$\varepsilon_{dp} = V\,sin(\theta - \theta') \tag{2}$$

where $V\,sin(\omega t + \Phi)$ and $V\,cos(\,\omega t + \Phi)$ both represent a set of signals converted by the sinusoidal signal generator, that is, the virtual vector in the converted dp coordinate system, ω represents the rotation angular velocity of the virtual vector, and θ represents the angle in the converted coordinate system. When three-phase load was unbalanced, the system adopted three-phase independent control strategy, that is, combining the voltage formula of photovoltaic inverter obtained from Kirchhoff voltage law with formula (2), the AC (alternating current) voltage equation in grid connected current control is obtained below:

$$\begin{cases} \dfrac{di_d}{dt} - \omega i_q = \dfrac{1}{L}(-u_d + S_d U_{dc} - Ri_d) \\ \dfrac{di_q}{dt} - \omega i_d = \dfrac{1}{L}\left(-u_q + S_q U_{dc} - Ri_q\right) \end{cases} \tag{3}$$

where U_{dc} represents the output voltage; S_d and S_q both represent the output state of different phase bridge arms; and Ri_d and Ri_q represent the equivalent resistance of different currents. S_d and S_q are the switching function results of the coordinate system dp, respectively. L represents the current output, i_q and i_d represent the results of the transformation of different phase currents into the dp coordinate system, respectively. u_d and u_q represent the results of the transformation of power grid electromotive force into the dp coordinate system, respectively. Laplace transform formula (3), then:

$$\begin{cases} (sL + R)i_d(s) = \omega L i_q(s) - u_d(s) + u_{inv\_d}(s) \\ (sL + R)i_q(s) = \omega L i_d(s) - u_q(s) + u_{inv\_q}(s) \end{cases} \tag{4}$$

The inverter decoupled the coupling relationship between the output current on the axis d and the axis q to achieve independent control of the active and reactive components of the current. The current loop controller took the proportional integral (PI) controller commonly used in P/Q control strategy as the main controller, and the transfer function can be expressed as:

$$C_i(s) = K_{ip} + \frac{K_{ii}}{s} \tag{5}$$

where K_{ii} and K_{ip} represent the integral parameters and proportional parameters of current control, respectively and the open-loop transfer function is:

$$G_o = \frac{K_{\mathrm{ip}} \cdot s + K_{ii}}{s(T_1 \cdot s + 1)(sL + R)} \tag{6}$$

The calculation method of T_1 in the formula is:

$$T_1 = T_s + 0.5 \cdot T_s + T_{\hbar i} \tag{7}$$

where T_s represents the system control cycle, and T_{hi} represents the delay in the process of introducing the sampling link. In the power control during three-phase equalization, the IoT grid connected inverter realized the factor control of active and reactive power in light of the instantaneous power theory. In the instantaneous power theory, the instantaneous active power P can be expressed as:

$$P = \frac{3}{2}\left(u_d i_d + u_q i_q\right) \tag{8}$$

Instantaneous virtual power Q can be expressed as:

$$Q = \frac{3}{2}\left(u_q i_d - u_d i_q\right) \tag{9}$$

When the voltage vector coincides with the *d* axis, the rated output current of the inverter is:

$$i_{d\_ref} = \frac{2}{3}\frac{P}{U_d} \tag{10}$$

The corresponding open-loop transfer function of the system can be evolved into:

$$G_p = C_p(s) \cdot \frac{G_o}{1 + G_o} \cdot u_d \tag{11}$$

The main program flow chart of the controller is shown in Fig. 1.

3.2 Space Vector Modulation of IoT Inverter

This study analyzed the neutral point potential balance strategy of the three-wire system and the four-wire system. Because the IoT inverter designed in this study needed to be operated under two different grid balance conditions, i.e., three-phase balance and three-phase imbalance, it was necessary to modulate the space vector of the inverter so that the inverter could reduce the neutral line current in the three-phase four-wire system environment. According to the relevant theory of space vector modulation, the relationship that the system control cycle on different axes should reach is as follows:

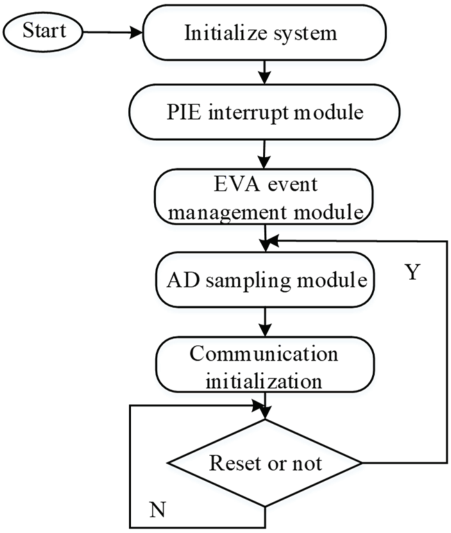


Fig. 1. Main program flow.

$$T_S = T_X + T_Y + T_Z \tag{12}$$

T_X, T_Y, and T_Z represent the system control cycles in three axes in the space, respectively. Under the constraint of this relationship, the three vectors closest to the reference vector in the axial direction are V_X, V_Y, and V_Z, respectively. After merging, the three vectors can become the reference amount shown in formula (13):

$$V_{ref} \cdot T_S = V_X \cdot T_X + V_Y \cdot T_Y + V_Z \cdot T_Z \tag{13}$$

Based on the space vector position relationship, according to the volt-second balance theory:

$$\left(V_{ref} - V_0\right) \cdot T_S = (V_1 - V_0) \cdot T_X + (V_2 - V_0) \cdot T_Y + (V_3 - V_0) \cdot T_Z \tag{14}$$

After the vector output sequence was calculated by the two-level calculation method, it was transformed into the three-level space and superimposed on the basic reference vector ONN to obtain the three-level output vector sequence, which can be expressed as ONN, PNN, PON, POO, PON, PNN, ONN. On this basis, the action time of each vector can be fully defined:

$$\begin{cases} T_{ONN} + T_{POO} = T_X \\ T_{PON} = T_Y \\ T_{PNN} = T_Z \end{cases} \tag{15}$$

where $\dot{I}_{cx}$ and $\dot{U}_x$ represent the current phasor and the voltage phasor of the three-phase power grid, respectively; $\dot{U}_{inv\_x}$ represents the output three-phase voltage phasor of the inverter; and L represents the equivalent inductance value of the power grid and the inverter. According to different output voltage requirements, the arm bridge of the inverter would present different states. Here, the two states were called state P and state N, respectively. Therefore, the maintenance time of state P in a switching cycle could be expressed as T_P, while the maintenance time of state N in a switching cycle could be expressed as T_N, and the three phases could be expressed as a, b, and c, respectively. The current calculation was the ratio of the AC voltage at both ends of the capacitor to the capacitance impedance. Capacitive impedance was resistance plus reactance. Considering the changes of current, voltage and impedance in a sinusoidal period, the average output current at the midpoint of capacitance in a single period can be obtained by integrating each subsection of the period:

$$\bar{\iota}_o = \int_{\theta}^{\theta+2\pi} \frac{(T_{Pa} + T_{Pb} + T_{Pc})\dot{U}_{dc1} - (T_{Na} + T_{Nb} + T_{Nc})\dot{U}_{dc2}}{j\omega L} d\theta = 0 \tag{16}$$

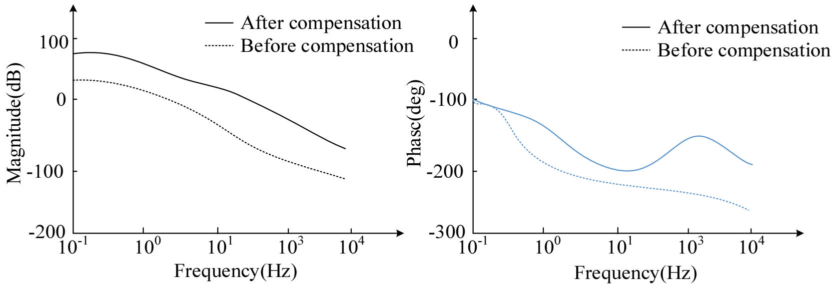
According to the Kirchhoff voltage law:

$$i_{c1} + \bar{\iota}_o = i_{c2} \tag{17}$$

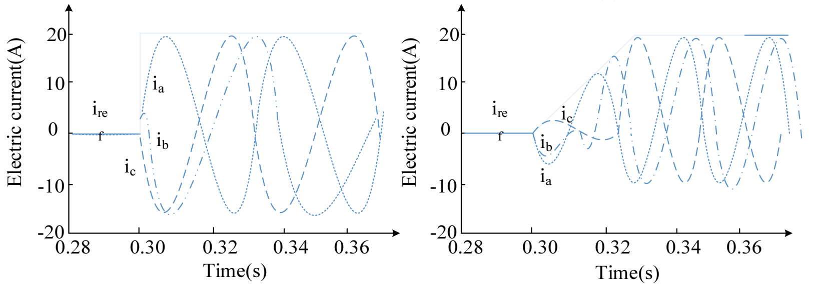
4. Effect Analysis of Electrical Automatic Control of IoT

4.1 Experimental Effect Analysis of IoT Inverter

This study used the form of simulation to analyze the control effectiveness and overall application effect of the designed electrical control system of the IoT, with the voltage and current wave forms generated by the system in the control process and the step response effect of the system being the focus. In the experimental environment of this study, the given bus voltage was 100 V (DC voltage) and the given sideline voltage was 50 V (AC voltage). In the modulation process, the given active power was 600 W in the active environment and the reactive environment, it was 0 W. Meanwhile, the input



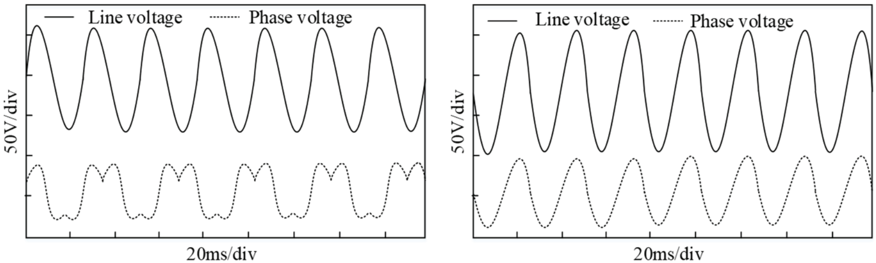
(a)Magnitude (b)Phasc



(c)Current inner loop step response (d)Current inner loop step response ramp input

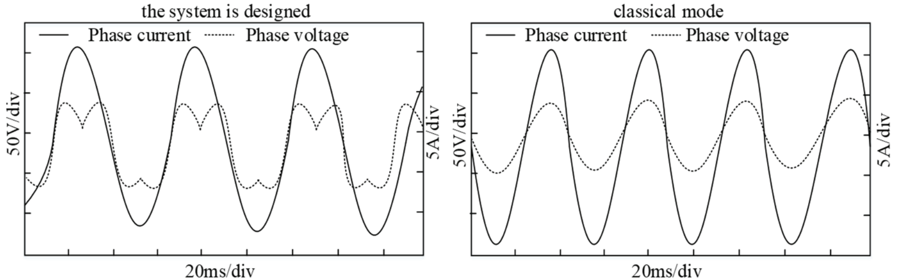
Fig. 2. Current control comparison: (a) magnitude, (b) phase, (c) current inner loop step response, and (d) current inner loop step response ramp input.

environment of the current loop in Fig. 2(c) was an idealized step signal environment, and the reference current was 20 A. The input environment of the current loop in Fig 2(d) was an idealized ramp signal environment, and the final reference current was still 20 A. It can be seen that under the ideal step signal environment, the system reached the predetermined current output value within 0.002 seconds, and after 0.3 seconds, the current inner loop still had strong tracking ability of the step signal.



(a)Voltage waveform of independent operation under the system is designed

(b)Voltage waveform of independent operation under classical mode



(c)Voltage waveform of grid connected operation under the system is designed

(d)Voltage waveform of grid connected operation under classical mode

Fig. 3. Voltage and current waveform comparison. Voltage waveform of independent operation under the designed system (a) and classical mode (b). Voltage waveform of grid connected operation under the designed system (c) and classical mode (d).

4.2 Analysis of Overall Application Effect of IoT on Electrical Control System

It can be seen that in the comparison of the effect of offline voltage and phase voltage in the isolated operation state, the phase voltage output by the electrical control system of the IoT was a saddle-shaped waveform formed by the superposition and cancellation of three-phase control (Fig. 3). The waveform contained three-phase harmonics of three-phase control. After the superposition and cancellation, the final line voltage was a sine wave of the state standard. In the control process of the classical electric control system, the phase voltage itself was a sinusoidal waveform, thus the corresponding line voltage was also a sinusoidal waveform. Through comparison, it could be seen that the control of the electrical control system of the IoT designed in this study was effective in the isolated operation state.

5. Conclusion

In order to solve the problems of the wide distribution of distributed power generation as well as difficulties in monitoring and control in time, this research improved the control strategy of the grid inverter according to the characteristics of the Internet of things system, so that the voltage and current control could be more dynamic under the premise of effective control. At the same time, the connection system between the grid inverter and the Internet of things controller was designed to realize remote monitoring, enrich information of the power grid and provide an information base for the automation and dynamic control of the system. The results showed that the saddle-shaped waveform formed by the three-phase control of the electrical control system of the Internet of things could achieve the same overall effective control as the classical electrical control system did. At the same time, the overall electrical control system of the Internet of things could realize independent dynamic control of the three-phase current and power. After the step signal was input, the given value was reached only after about 50ms. Although the electrical control system of the Internet of things was designed and tested and the experimental environment was ideal, unexpected conditions often occurred in the actual power grid operation. Therefore, it is also necessary to carry out more diversified application detection for the system, which is also the content to be studied in the future.

Acknowledgement

This research was supported by the China Textile Industry Federation Higher Education Teaching Reform Research Project (No. 2021BKJGLX505).

References

[1] B. Hu, Z. Chen, Z. Zhang, S. Liu, and W. Deng, “Model predictive flexible power control for grid-connected inverter under unbalanced network,” *IET Power Electronics*, vol. 13, no. 16, pp. 3580-3589, 2020.

[2] H. Tang, K. Lv, B. Bak-Jensen, J. R. Pillai, and Z. Wang, “Deep neural network-based hierarchical learning method for dispatch control of multi-regional power grid,” *Neural Computing and Applications*, vol. 34, pp. 5063-5079, 2022.

[3] H. Kim, J. Park, and H. Jung, “Automatic control system based on IoT data identification,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 3, pp. 1525-1532, 2020.

[4] A. H. Bagdadee, M. Z. Hoque, and L. Zhang, “IoT based wireless sensor network for power quality control in smart grid,” *Procedia Computer Science*, vol. 167, pp. 1148-1160, 2020.

[5] G. Milan, L. Vassio, I. Drago, and M. Mellia, “RL-IoT: reinforcement learning to interact with IoT devices,” in *Proceedings of 2021 IEEE International Conference on Omni-Layer Intelligent Systems (COINS)*, Barcelona, Spain, 2021, pp. 1-6.

[6] W. Zhu, Z. Wang, and Z. Zhang, “Renovation of automation system based on Industrial Internet of Things: a case study of a sewage treatment plant,” *Sensors*, vol. 20, no. 8, article no. 2175, 2020. https://doi.org/10.3390/s20082175

[7] P. Thakur and V. K. Sehgal, “Emerging architecture for heterogeneous smart cyber-physical systems for industry 5.0,” *Computers & Industrial Engineering*, vol. 162, article no. 107750, 2021. https://doi.org/10.1016/j.cie.2021.107750

[8] A. Bernadic, I. Brnadic, V. Grude, and Z. Leonowicz, “Impact of characteristics of block-transformers on inrush currents and voltage distortions at the connection point of wind parks,” in *Proceedings of 2012 11th International Conference on Environment and Electrical Engineering*, Venice, Italy, 2012, pp. 59-63.

[9] V. N. Sheludko, Y. V. Sentyabrev, and A. V. Grigoriev, “Electrical engineering strategy,” *Russian Electrical Engineering*, vol. 92, no. 3, pp. 123-128, 2021.

[10] R. Lu, N. Liu, D. Li, X. Luo, and Y. Fan, “Intelligent monitoring analysis of power grid monitoring information based on big data mining,” *Journal of Physics: Conference Series*, vol. 1992, article no. 032132, 2021. https://doi.org/10.1088/1742-6596/1992/3/032132

[11] S. Nakamura, T. Enokido, and M. Takizawa, “Information flow control based on capability token validity for secure IoT: implementation and evaluation,” *Internet of Things*, vol. 15, article no. 100423, 2021. https://doi.org/10.1016/j.iot.2021.100423

Jiyong Jin **https://orcid.org/0000-0002-8903-1780**

He received Engineering Master's degree form Lanzhou University of Technology in 2005. He is a lecturer in School of Mechatronics Engineering, Zhongyuan University of Technology, Zhengzhou, China. His major directions of research are as follows: vibration measurement, precision measurement, electromechanical control.