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Research Article

Design of a Substation Secondary Equipment-Oriented Error Prevention System Using Wireless Communication Technology and Edge Node Cooperation

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In order to solve the error prevention problem of secondary equipment in intelligent substations, this paper designs the Substation Secondary Equipment- (SSE-) oriented error risk Prevention, Control, and Management (P&C&M) system. Firstly, the basic principle of SSE error prevention is reviewed. The SSE model is expanded based on the existing microcomputer error prevention system's Substation Primary Equipment (SPE). Thereupon, the SSE status acquisition device is designed, and the overall architecture is implemented for SSE error prevention. Secondly, edge-node cooperation is analyzed along with the specific architecture of the edge gateway. Finally, the wireless communication network is designed based on the edge gateway. The delay and flow of different data streams are compared, and the error proof verification mechanism is introduced into SSE. The numerical results corroborate that when the Sampled Value (SV) traffic exceeds 32 Mbps, the maximum delay exceeds the specified delay (3 MS). The average flow of the Manufacturing Message Specification (MMS) message is 90 kbps, which can meet the requirements of the intelligent substation. The delay of star networking is higher than that of ring networking. Meanwhile, the proposed network analyzer has a measured flow closer to the calculated flow of SSE. In the 60-hour accuracy statistics, the proposed SSE-oriented error P&C&M system reaches an accuracy as high as 84%. Therefore, the proposed SSE-oriented error P&C&M has strong feasibility. The outcome provides a reference for the intelligent development of error prevention of secondary equipment in intelligent substations.

1. Introduction

With the rapid domestic economic development, Chinese substation construction is rapidly catching up [1]. The Power Grid System (PGS) relies on the crucial technical index and basic infrastructure for smooth operation [2]. Inevitably, misoperation accidents of Secondary Substation Equipment (SSE) also rise sharply with increasing substation construction [3]. Therefore, in recent years, the power industry has shifted its attention to strengthening the operation management of SSE to reduce the failure from misoperations [4]. In particular, nonstandard operations of substation staff, inadequate implementation of substation safety measures, and obvious problems of on-site information outlets will lead to SSE misoperations [5]. At present, there are still hidden dangers and disadvantages in the error Prevention, Control, and Management (P&C&M) system of domestic substations. For example, the error prevention function of SSE operation is imperfect, and the error prevention locking logic verification is not fully automated [6]. The information system in the error P&C&M system has not played its full role yet, so there are problems, such as data island and system isolation. Besides, error-proof terminals cannot operate online, such as ground wire locking units and error-proof computer keys. Thus, data cannot be returned in real time to realize comprehensive online verification [7].

The Opinions on Safe Production in 2021 issued by the State Grid Corporation of China puts forward the requirements of "strengthening the support of safety science and technology, promoting the digitization of safety management and control and accelerating the online five prevention." Also, the document puts forward further requirements for the digital management of the substation safety. China's State Grid Equipment Department includes the substation's comprehensive intelligent error prevention pilot in the operation inspection target in 2021. Wireless communication technology can effectively improve the cable layout difficulties caused by local and decentralized deployment. The protection device and station control layer equipment usually use cable media, such as optical cable or coaxial cable to realize the information exchange of equipment. A large number of optical fibers or cables need to be laid. Therefore, introducing wireless communication technology will provide a more convenient and effective information exchange means for networking intelligent substations. It can reduce the construction cost of intelligent substations. Edge computing is a common structure in the Internet of Things (IoT), which realizes the calculation process based on the edge nodes' deployment. Accordingly, the present work introduces edge computing to address low-voltage faults in substations. Thus, to solve the problems in the current error P&C&M in SSE, this paper combines the edge-node cooperation (ENC) and wireless communication to design an intelligent SSE-oriented error P&C&M system. Wireless communication technology helps intelligent SSE communicate with ease. The IoT-based ENC technology ensures the accurate control of error-proof terminals [8].

Based on the pitfalls in the intelligent substation, this paper is unfolded from three aspects. Firstly, the basic principle and architecture of SSE error P&C&M are analyzed. Secondly, edge gateway's technical requirements and framework are studied. The error P&C&M system is designed based on wireless communication and ENC. Finally, the real-time state transmission and online error prevention are solved for the SSE. The innovation of this paper is to propose an integrated SSE-oriented error P&C&M method. At the same time, an IoT-based ENC method is introduced for SSE error P&C&M to meet regional autonomy and multisource data access. The results improve the current substation operation inspection efficiency and improve the operation safety and error prevention effectiveness. The research conclusion will improve the intelligent level of error P&C&M.

2. Recent Related Work

Outside China, substations have seen much early development. They have been relatively saturated, with an overall higher level than domestic substations [9]. In particular, most of the substations in developed countries, such as Europe and Japan, have realized automation, and the fault treatment can be handled remotely through the dispatching center [10]. The first foreign substation based on the International Electrotechnical Commission (IEC) 61850 standard was practical in the early 21st century. Since then, IEC 61850 has become the only standard for substation engineering construction [11]. In 2006, domestic IEC 61850 standard software and products saw substantial growth. At the same time, digital substation information sharing became common practice [12]. Back in 2009, China saw its first intelligent substation construction. The intelligent substation uses network technology to replace the traditional secondary wiring to realize internal data exchange. The secondary equipment of the intelligent substation is more networked and more operable [13]. The current intelligent substation equipment adopts a three-tier and dual-network architecture according to the IEC 61850 standard. Specifically, the three-tier structure includes the process, station control, and bay layers. The dual-network refers to the station control and process layer networks [14]. It is believed that future intelligent substations will develop towards integration and decentralization [15]. Langston et al. obtained the network structure optimization scheme of the single two-tier network by comparing the cost-effectiveness of substations before and after optimization [16]. Meanwhile, the wireless communication network with simple laying steps, flexible networking, and low maintenance cost has become a hot research field for improving intelligent substations [17].

American researchers applied wireless communication technology in smart grids in 2009 [18]. Herzik and Bethishou concluded that the infinite heterogeneous network could meet the data transmission requirements of the smart grid. They analyzed the wireless transmission delay and reliability between primary and secondary distribution substations [19]. Long found that ZigBee wireless communication was market-proven successful technology for wireless monitoring and wireless temperature measurement [20]. By comparison, there is only sporadic domestic research on wireless transmission of secondary equipment in intelligent substations [21]. Kanabar et al. developed a Wireless Local Area Network- (WLAN-) compatible intelligent substation terminal to realize the communication of SSE in combination with Wireless Access Point (WAP) [22]. Stanelytė and Radziukynas used an IEC 61859-to-Wireless Highway Addressable Remote translator (WirelessHART) protocol convertible gateway to communicate between devices. They finally obtained a scheme to integrate WirelessHART into IEC 61850 [23]. Abdolrezaei et al. obtained a wireless test scheme for intelligent SSE by studying the data terminal of the test platform [24].

The above contents conclude that the domestic research on intelligent substations mainly adopts wired network transmission, and the interferences are commonly found in SSE data transmission. Therefore, this paper designs the SSE-oriented error P&C&M system combined with wireless communication technology. At the same time, the fault sensing part introduces the ENC mechanism. This study will suggest an improvement for the all-around MC of substation operation and offer a powerful reference for intelligent substation development.

3. Design of the SSE-Oriented Error P&C&M System

3.1. Basic Principle and Overall Structure of Error Prevention of SSE. The data basis for realizing the error prevention of

SSE is the logical relationship network among Substation Primary Equipment (SPE), bay, secondary instrument, and SSE [25, 26]. The secondary instruments in the bay match different types of SSE [27]. In the research on the error prevention risk of SSE, according to the requirements of relay protection operation regulations and dispatching operation procedures, this study summarizes the basic principles of error prevention of SSE, such as prohibiting the out-of-order SSE misoperation and forbidding unprotected operation of SPE. These principles lay the theoretical basis of error prevention of SSE in the present work. Then, the present work will use computer software to realize the error prevention and verification function of SSE [28].

Based on the SPE of the existing microcomputer- (MC-) enabled error P&C&M, this study expands on the SSE model, develops the SSE status acquisition instrument, studies the SSE error prevention verification rules, and designs the error prevention algorithm of the SSE. The SSE will eventually be included in the switching operation ticket [29] to help SSE prevent, control, and manage errors and smoothly link with SPE. As such, it can optimize and integrate the error P&C&M process and improve the efficiency of operation inspection. The SSE-oriented error P&C&M structure is shown in Figure 1.

In Figure 1, in the proposed SSE-oriented error P&C&M structure, the maintenance boundary is set to be isolatable and controllable. Doing so can prevent accidental collision or misoperation during the maintenance process. The status of SSE is acquired by the monitoring system that directly sends the data to the error P&C&M system [30]. The proposed error P&C&M system is adaptive to different operation modes of the power grid.

The SSE modeling is the basis for realizing the error prevention logic check. It includes establishing air switch, pressing plate, abnormal signal, handle data model, and SSE graphic model. More precisely, the modeling process defines the SSE as an object and describes the basic attributes of the SSE object to associate the SPE and the SSE [31]. The secondary signal model includes SSE name, type, category, and attribute. The hierarchical relationship between the SPE model and the SSE model is depicted in Figure 2.

As Figure 2 suggests, the secondary instrument is a bridge between the SPE object and the SSE object. The grid level structure of the SSE graphical model is illustrated in Figure 3.

As shown in Figure 3, the constructed power plant-level hierarchy is divided into four layers. The specific plant and station are responsible for recording the characteristics. The second layer is the equipment bay and the switch bay. The secondary instruments of the third layer are the equipment microunit. The fourth layer is the inseparable basic elements. Thereupon, this paper constructs the automatic graphing process of SSE, as drawn in Figure 4.

As shown in Figure 4, the equipment bay topology is analyzed and directly called. As a result, the topology scale in the automatic SSE graphing is reduced, and the automatic graphing efficiency is improved.

3.2. Technical Requirements and Framework of the Edge Gateway. IoT technology has been widely used in intelligent substations, and IoT-native edge equipment also plays a significant role. At present, the research on Industrial IoT (IIoT) focuses on security. For example, Lv researched the security of IoT-based edge equipment [32]. Lv et al. examined the reliability of the IIoT system [33]. For the sake of security, this paper introduces the ENC mechanism into the error P&C&M system. The edge devices will adopt the State Grid Common Information Model/Easy (CIM/E) specification during cross-regional safe transmission and multiple data interaction. The wireless convergence and access device in the error-proof terminal is based on the wireless networking protocol over IoT Power Transmission and Transformation Equipment (PTTE) edge nodes. It adopts the state cryptographic algorithm authentication, state grid encryption chip, secure access platform, computerized online key, and secure access of intelligent ground wire head. The technical capability requirements of edge IoT agents are demonstrated in Figure 5.

As shown in Figure 5, the edge gateway meets the unified access of multidiscipline and multitype terminals. Based on the mature and reliable rack type industrial computer, the error-proof edge IoT devices adopt the independent and controllable security operating system and database. It integrates software and hardware design. Meanwhile, it fuses communication technology into encryption authentication to meet security and reliability requirements through data encryption, ID card, and access control. The overall IoT architecture is sketched in Figure 6.

As shown Figure 6, the functional architecture of the edge gateway includes hardware, operating system, basic function, and edge service layers. The functions of the edge gateway include subequipment management, equipment configuration management, resource management, and system monitoring. Among them, the hardware layer incorporates unique equipment identification, trusted computing modules, and other functions. The operating system layer encompasses online system monitoring, security access, application isolation, trusted measurement, and other functions. The basic function layer covers subequipment access, object model management, message queue, and other functions. It supports system management through system application and realizes the edge computing framework. The edge service layer involves flow computing, rule engine, and other functions; it offers cloud edge collaboration of resources, data, intelligence, and application management.

Then, the edge service framework in the proposed SSE-oriented error P&C&M system is detailed in Figure 7.

As shown in Figure 7, the edge service framework includes cloud edge collaboration, intelligent services, edge computing, and application management. Edge nodes are connected through wireless communication to ensure the safe operation of the SSE-oriented error P&C&M system.

3.3. Design of the Error P&C&M System Based on Wireless Communication and ENC. Based on the previous theoretical basis, combined with edge gateway technology and wireless network communication technology, this paper will build

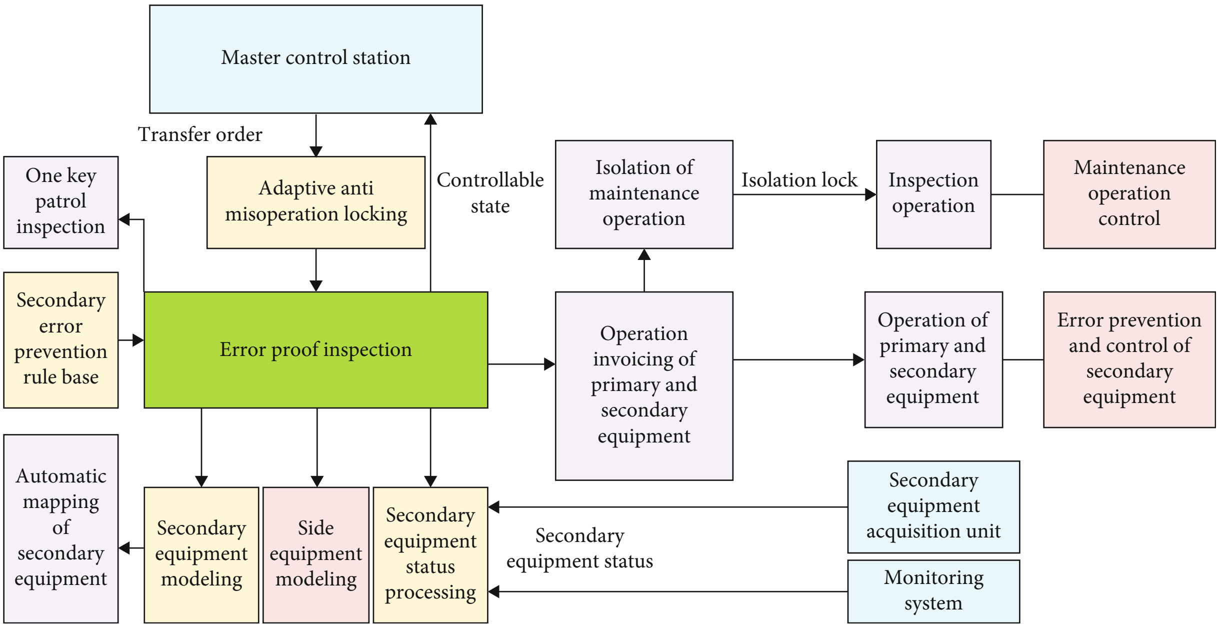


Figure 1: Structure of SSE-oriented error P&C&M.

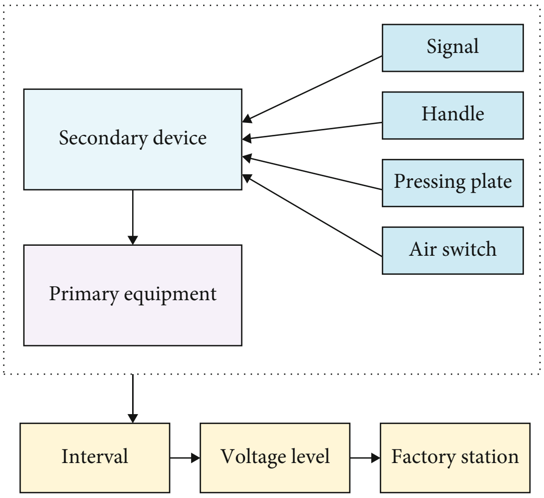


Figure 2: Hierarchical relationship of the equipment model.

an SSE-oriented error P&C&M wireless control edge IoT scheme based on multisource data access and regional autonomy. Since the SSE-oriented error P&C&M system must acquire equipment states to make the data transmission and acquisition intelligent and comprehensive, this paper introduces wireless communication technology and ENC [34]. The wireless sensor is the main resort for IoT to obtain information. The sensor's ability to collect information is affected by the information transmission and processing of the edge IoT agents' computing unit. The structure of the wireless sensor system is revealed in Figure 8.

As shown in Figure 8, wireless communication technology connects the proposed SSE-oriented error P&C&M system to the whole substation.

Multiple types of wireless sensors and edge nodes collect equipment parameters in real time and monitor the operating environment and equipment health. The error P&C&M belongs to the security part of the substation, and the electrical equipment protection sensor and production security sensor will be installed at the corresponding position. The data from sensors and edge IoT agents will be wirelessly transmitted following the state grid wireless transmission protocol. The edge IoT agent is connected through the Fourth-Generation Mobile Communication (4G) private network and optical fibers following the Message Queuing Telecommunications Transport (MQTT) protocol [35].

This paper follows the Q/GDW 12021-2019 Wireless Networking Protocol for PTTE IoT node, develops a safe wireless networking module, and uniformly aggregates the error data to the error-proof edge IoT agent for access and control and standardized management.

The communication network of intelligent substations has certain requirements for the reliability and delay of message transmission. Before introducing WLAN technology into intelligent substation automation systems, the wireless transmission delay and message reliability must be evaluated against the standard. The network transmission delay in wireless network design is calculated in equations (1)–(4) [36].

$$t_1 = \frac{p}{v}. \tag{1}$$

In equation (1), v, p, and t_1 represent the data transmission rate, the transmission distance, and the link transmission delay, respectively.

$$t_2 = \frac{q}{l}. \tag{2}$$

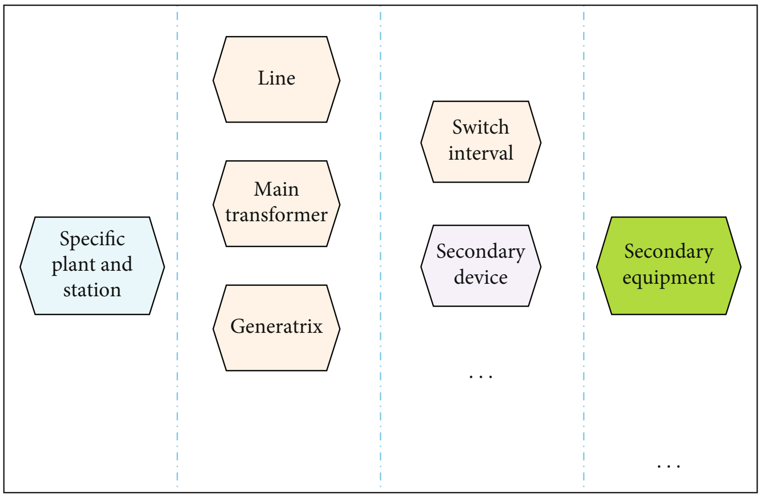


Figure 3: Graphical model of the SSE grid-level structure.

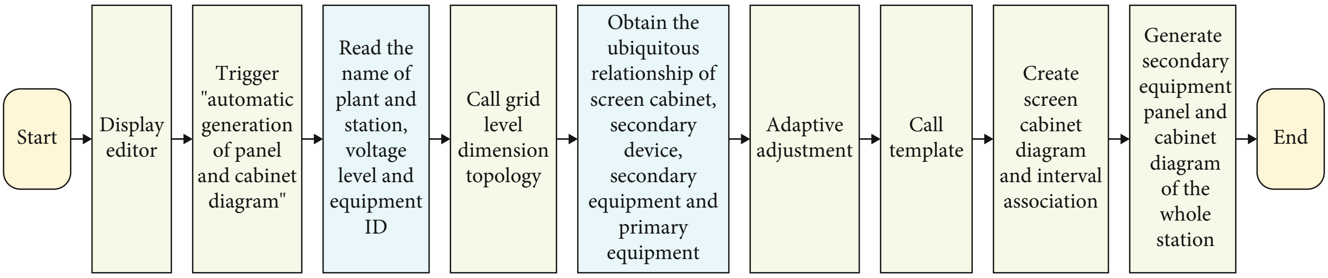


Figure 4: Automatic graphing of SSE.

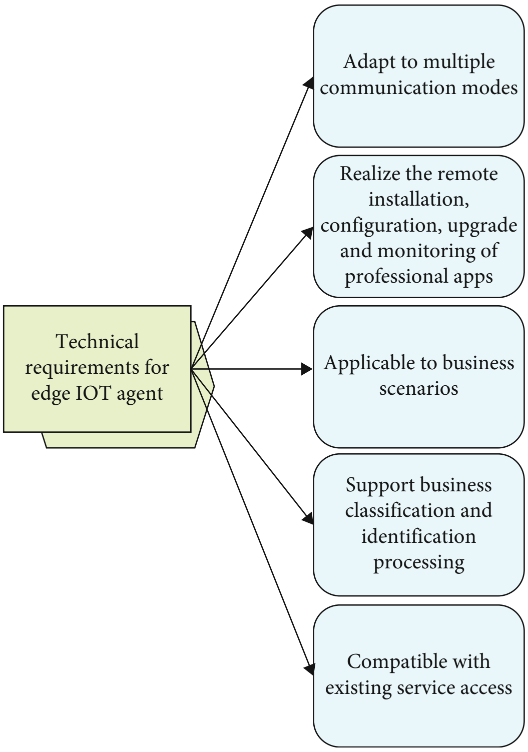


Figure 5: Technical requirements for the edge IoT agent.

In equation (2), t_2 indicates the storage and forwarding delay. L is the forwarding rate of network equipment, and q signifies the data frame length.

$$t_3 = t' \times t_p. \tag{3}$$

In equation (3), t_3 is the queuing delay. t_p stands for the time required to transmit Ethernet frames. t' denotes the load of network bandwidth.

$$T = t_a + t_b + \sum_{k=1}^{m} (t*+t_2 + t_3) + \sum_{j=1}^{n} t_1. \tag{4}$$

In equation (4), T means the time required for complete data transmission. $t*$ is the inherent delay, no larger than $10\,\mu$s. n and m are the numbers of communication links and intermediate nodes, respectively. t_b indicates the network transmission delay. t_a signifies the message transmission delay. K and j represent the numbers of intermediate nodes and the numbers of communication links, respectively.

Table 1 compares the performance of different wireless technologies [37].

Based on the consideration of the data transmission rate and security in intelligent substations, this section selects the industrial LAN of IEEE 802.11 AC standard, with a frequency band of 5 GHz.

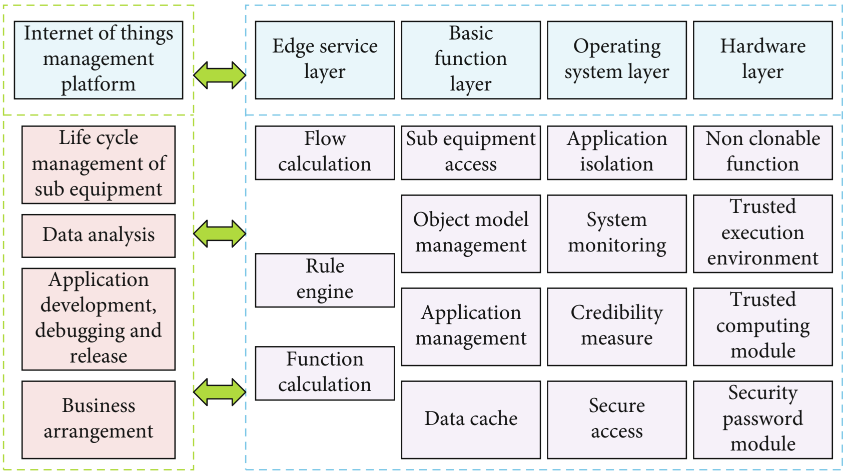


Figure 6: Functional architecture of the edge gateway.

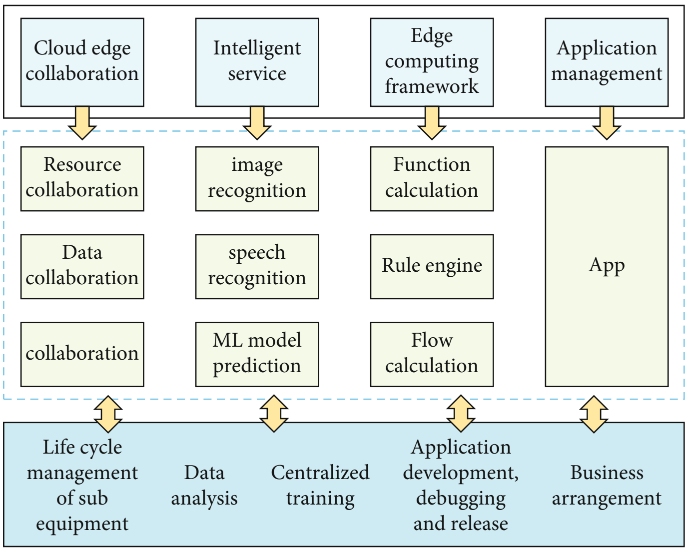


Figure 7: Edge service framework.

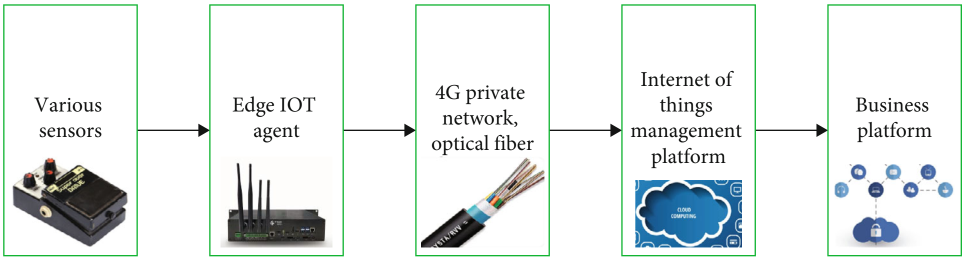


Figure 8: Wireless sensor system.

Then, the real substation environment in an area is selected for the wireless transmission test of information flow. A test node is set in the indoor substation together with a transmitting end and two receiving ends. The node end and transmitting end are bridged point-to-point. The switch adopts an intelligent substation private switch and an indoor private industrial Access Point (AP). Two network testers generate and receive messages, respectively. The first group generates 202 bytes messages of Generic Object-Oriented Substation Event (GOOSE), 512 bytes of Sampled Value (SV), and 1 KB of Manufacturing Message Specification (MMS). The second group receives the message.

When selecting the process and bay layers' communication network topology, this paper compares the delay of the

Table 1: Performance comparison of different wireless technologies.

Wireless technologies	Performance	Concrete content
Infrared technology	Working frequency	820 nm
	Data rate	115.2 kbps
	System power consumption	Counted by mW
Bluetooth technology	Working frequency	2.4 GHz
	Data rate	723.2 kbps
	System power consumption	1 mW~100 mW
ZigBee	Working frequency	2.4 GHz, 868 MHz, 915 MHz
	Data rate	20\40\250 kbps
	System power consumption	1 mW~3 mW
Wireless fidelity (Wi-Fi)	Working frequency	2.5 GHz, 5 GHz
	Data rate	1~1,700 Mbps
	System power consumption	10 mW~1 W

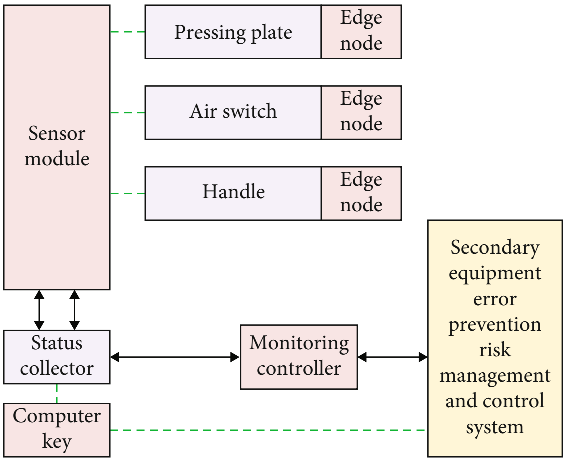


Figure 9: Principle of SSE status acquisition.

switch under different data streams from the ring and star network topologies. The scheme of network mining, network hopping, and the common network has a clear structure and fewer optical cables. It is conducive to network sharing [38] and, thus, has been selected by the present work.

The intelligent SSE flow is mainly analyzed after network construction, while the flow before network construction is not considered. Thus, this paper calculates the information flow distribution based on Substation Communication Data (SCD). The relationship matrix between the source port and the sent message in the SSE node model is reflected in [39]

$$S^i_{s\times z} = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1z} \\ s_{21} & s_{22} & \cdots & s_{2z} \\ \vdots & \vdots & \ddots & \vdots \\ s_{s1} & s_{s2} & \cdots & s_{sz} \end{bmatrix}. \quad (5)$$

In equation (5), z is the total number of messages. $S^i_{s\times z}$ indicates the relationship between the source port and the message. s is the total number of ports, and i signifies the port Serial Number (SN).

Here, the sink model expresses the relationship between sink port and subscription message by

$$R^i_{s\times z} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1z} \\ r_{21} & r_{22} & \cdots & r_{2z} \\ \vdots & \vdots & \ddots & \vdots \\ r_{s1} & r_{s2} & \cdots & r_{sz} \end{bmatrix}. \quad (6)$$

In equation (6), $R^i_{s\times z}$ indicates association.

The transmission frequency can be expressed as a matrix in

$$U^i_{z\times 1} = [u_1 u_2 \cdots u_z]^T. \quad (7)$$

In equation (7), i and u are the number of messages and the time, respectively.

Equation (8) calculates the message sending frequency of all source ports.

$$U_{z\times 1} = \sum_{i=1}^{s} U^i_{z\times 1}. \quad (8)$$

The message collection matrix C is obtained based on the above contents, as in

$$C_{s\times z} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1z} \\ c_{21} & c_{22} & \cdots & c_{2z} \\ \vdots & \vdots & \ddots & \vdots \\ c_{s1} & c_{s2} & \cdots & c_{sz} \end{bmatrix}. \quad (9)$$

Given that switch settings might incur redundant equipment idleness, this section optimizes the communication

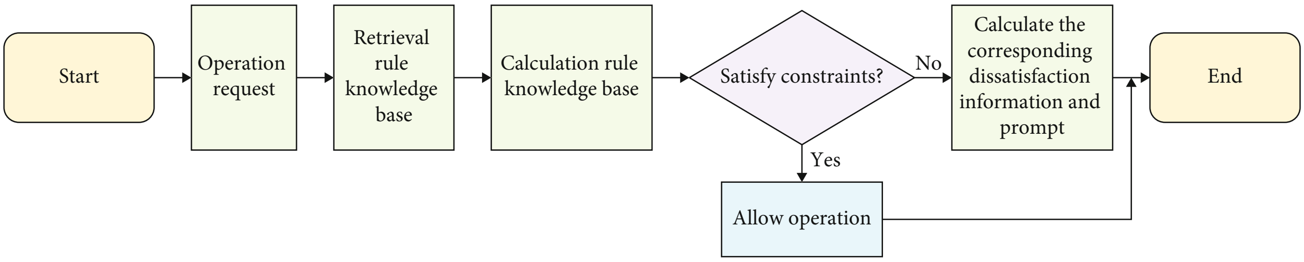
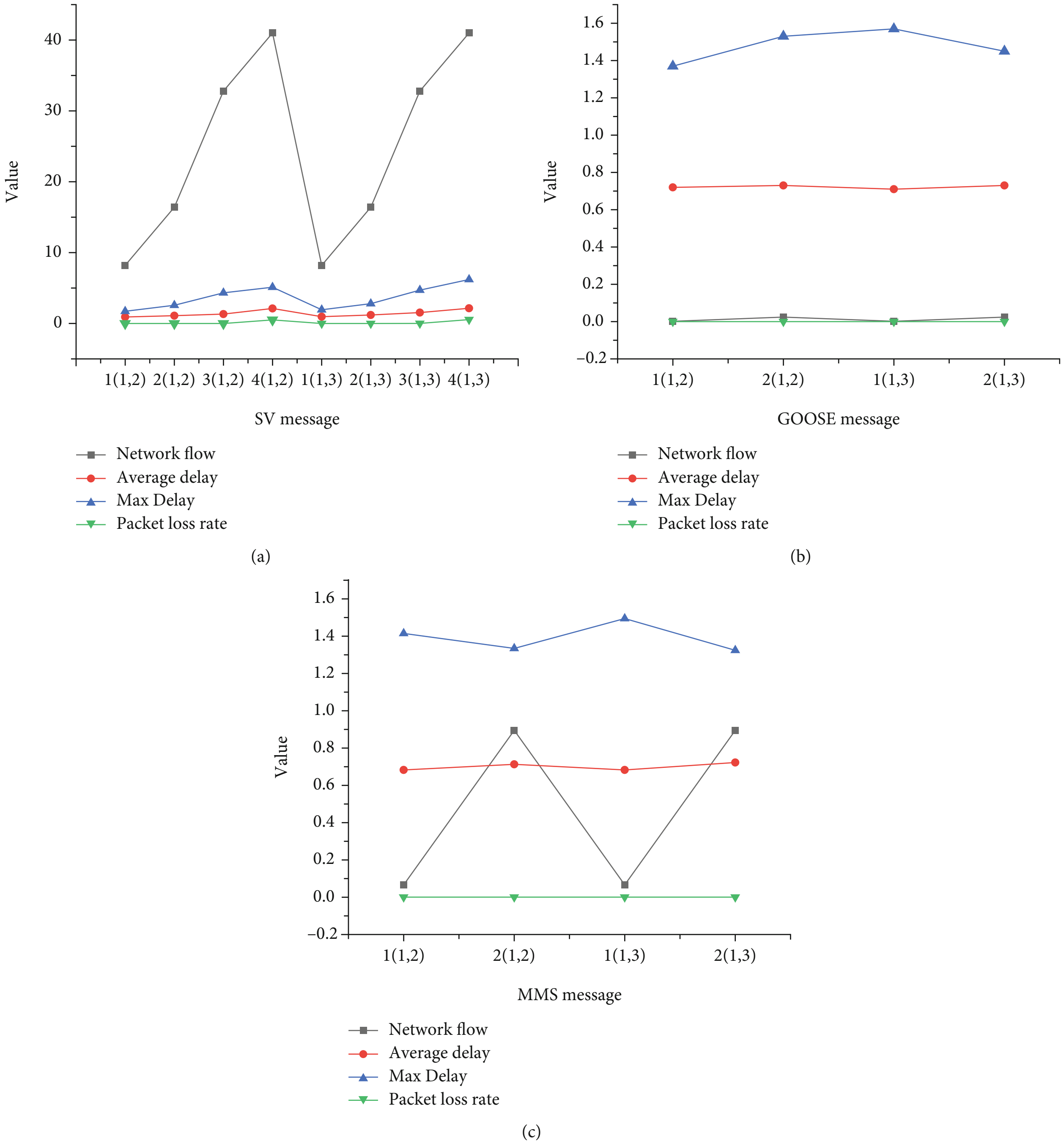


Figure 10: Error prevention verification of SSE.



(a)

(b)

(c)

Figure 11: Wireless platform test results: (a) SV message results; (b) the result of the GOOSE message; (c) the MMS message result.

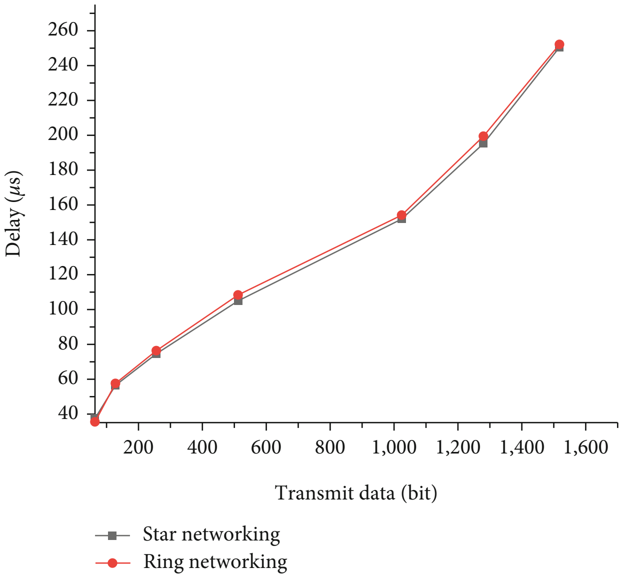


FIGURE 12: Delay results of data streams with different sizes.

network topology. Then, the switch traffic load w_i can be expressed as

$$w_i = \sum_{l=1,k=1,l\neq k,\text{path}\,(l,k)}^{M} D_{\min}(i = 1, 2, \cdots, m). \tag{10}$$

In equation (10), D is the traffic demand and M is the total number of switches.

Equation (11) counts the ideal conditions of switch load.

$$50\% \times C \geq w_i. \tag{11}$$

In equation (11), C represents the switch capacity.

Subsequently, a virtual LAN partition strategy is proposed based on the optimal path to suppress the message broadcast domain. The constraints of optimal path virtual LAN division mainly include the optimal path between the source and sink and the switch parameter configuration rules. Then, weight is introduced to find the optimal path using the alternating search of the logical connection matrix and the physical connection matrix of the intelligent substation.

During Virtual Local Area Network (VLAN) configuration, the verification functions of devices with subscription messages and without subscription messages are calculated by equations (12) and (13), respectively.

$$X_1 = \prod_{i=1}^{n} X_{1i} = \prod_{i=1}^{n} \frac{E_{1i}}{E_{2i}}. \tag{12}$$

In equation (12), n represents the total number of Intelligent Electronic Devices (IED). E is the number of subscribed messages. X refers to the adequacy of VLAN verification.

$$X_2 = \prod_{i=1}^{n} X_{2i} = \prod_{i=1}^{n} \frac{E_{3i}}{E_{2i} + E_{3i}}. \tag{13}$$

3.4. Status Acquisition and Error Prevention Verification of SSE. Combined with the content of the previous section, wireless communication technology and ENC will finally complete the SSE status acquisition. The acquisition principle is exhibited in Figure 9.

As shown in Figure 9, the SSE status acquisition realizes the centralized acquisition of the pressing plate, air switch, and handle status under ENC. The acquisition results will be transmitted to the SSE-oriented error P&C&M system over wireless communication technology.

The core of the proposed SSE-oriented error P&C&M algorithm includes SSE expert knowledge base, power system SPE bay identification, and SSE and SPE data model-oriented constraint extraction technology. Then, the error prevention verification is carried out, as unfolded in Figure 10.

As shown in Figure 10, the SSE error prevention verification loads the substation information and SSE error P&C&M rules, matches the bay, and obtains the SSE bay type as per system instructions. It makes the error P&C&M judgment and returns the system results.

Finally, the proposed SSE-oriented error P&C&M system is applied to 28 intelligent substations in the research area. Meanwhile, the proposed SSE-oriented error P&C&M system is compared with the conventional system. The comparison results are characterized by the accuracy of the SSE error prevention effect.

4. Results and Discussion

4.1. Wireless Network Platform Test Results. Based on the above content, Figure 11 analyzes the test results of the wireless network platform.

As shown in Figure 11, when SV flows >32 Mbps, the maximum delay exceeds the specified delay (3 MS) of IEC 61850. In the intelligent substation network, SV message flow accounts for over 90% and is transmitted by a frequency of 4,000 frames/s. Therefore, the Packet Loss Rate (PLR) of SV messages will rise when the substation network gets large. In that case, the wireless transmission of SV messages does not meet the requirements. Given that the bay and process layers are very close, the process layer adopts wired communication. The average flow of MMS messages is 90 kbps, meeting the requirements of the intelligent substation. The station control layer uses wireless communication.

Further, Figure 12 compares the delay results of the switch inputted with different sized streams under the ring and star network structures.

As shown in Figure 12, the communication delay of the star topology network is lower than that of ring topology. Except under 64-bit transmission data, the delay of star

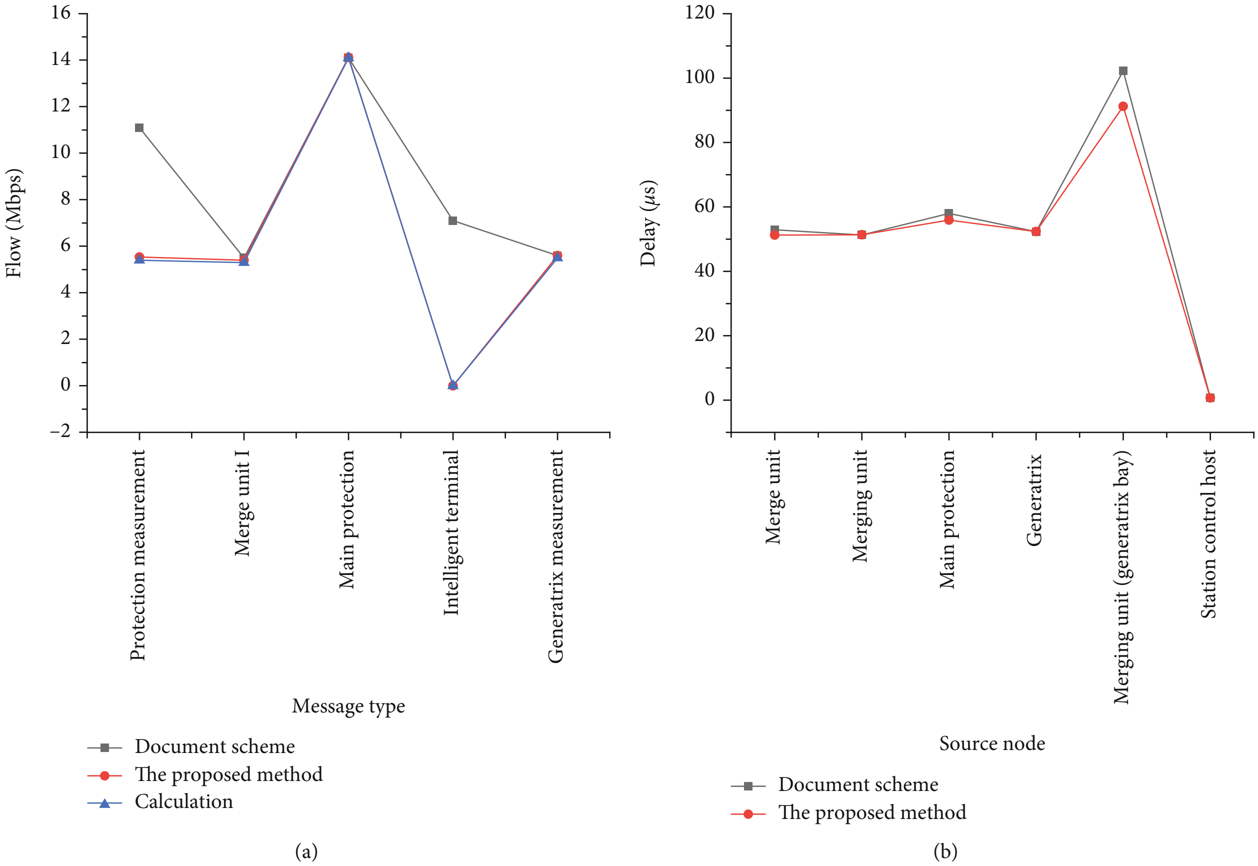


Figure 13: The comparison result of flow and delay: (a) for flow comparison; (b) for delay comparison.

networking is higher than that of ring networking. Under other data volumes, the black curve representing star networking is mainly below the red curve. Thus, the star network has better performance. Accordingly, this paper uses the star topology to communicate between the bay and the process layers.

Subsequently, Figure 13 comparatively analyzes the system message flow and delay under the steady-state operation.

There is a difference between theoretical and practical flow values, so a calculation flow (namely, theoretical value) is introduced in Figure 13(a); thus, three objects are in Figure 13(a). As shown in Figure 13, the measured flow of the network analyzer in the proposed scheme is closer to the calculated flow. By comparison, the measured flow of the literature scheme is quite different from the calculated flow. When the calculated flow of the intelligent terminal at the high voltage side of the main transformer is 0.001 Mbps, the measured flow of the literature scheme is 7.1 Mbps and the measured flow of the proposed scheme is 0.002 Mbps. In the literature scheme, the intelligent terminal at the high voltage side of the main transformer is in the same zone as other equipment in the main transformer bay, and the port will outflow. Overall, the delay of the proposed scheme is lower than that of the literature scheme.

4.2. Evaluation Results of the SSE-Oriented Error P&C&M System. Based on the previous research, the accuracy comparison of the SSE error prevention effect is plotted in Figure 14.

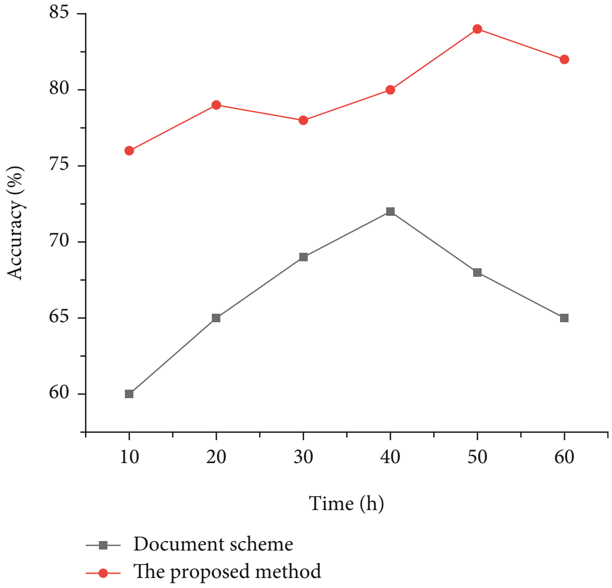


Figure 14: Comparison of accuracy of the SEE-oriented error P&C&M system.

As shown in Figure 14, in the 60-hour accuracy statistics of the SSE error P&C&M system, the accuracy of the proposed SSE-oriented error P&C&M system is higher than that of the literature system. The highest accuracy rate, 84%, happens at the 50th hour of system operation. In contrast, the highest accuracy of the literature scheme is 75%. Therefore, the proposed SSE-oriented error P&C&M system has strong feasibility.

5. Conclusion

This paper introduces wireless communication technology and ENC to design the SSE-oriented error P&C&M system. Specifically, it analyzes the research basis of SSE, compares the existing wireless technology, and designs the wireless network. Then, the ENC mechanism is added to the wireless network. The error prevention verification mechanism is introduced into SSE, and the SSE-oriented error P&C&M system is finally constructed. Subsequently, the feasibility of the proposed P&C&M system is verified. This paper creatively proposes an integrated SSE-oriented P&C&M method and an error-proof edge IoT method to meet regional autonomy and multisource data access. The research shows that the measured flow of the proposed network analyzer is closer to the calculated flow of SSE. In the 60-hour accuracy statistics, the proposed SSE-oriented P&C&M system reaches the highest accuracy of 84%. The findings offer a reference for the combined development of intelligent substations and wireless networks. However, there are still some shortcomings. Due to the limited time, the duration of this experiment is short so the results may have some limitations. Additionally, the error proof verification results of the SSE and the section handover of the maintenance operation state in the actual operation of the substation are not presented. Therefore, the experimental time will be increased, and more comprehensive experimental results will be excavated in the follow-up work. The model effect applied to the intelligent substation will be more comprehensively presented. This research will promote the popularization and application of error prevention of SSE and promote the intelligent development of error prevention of SSE.

Data Availability

All data are fully available without restriction.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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