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Review article

Research on the construction of a "full-chain" rapid response system for power emergencies

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ABSTRACT

A crucial industry for improving society's sustainable development is the power sector. To address issues with the ineffectiveness of electric power emergency response during emergencies and the unclear division of duty among emergency subjects. A prefecture-level city power supply company to respond to the "In-Fa" typhoon, for example, to build a "1 + N" two-level emergency rapid response unit. Furthermore, it is proposed from the emergency response, emergency coordination, emergency material reserves, etc., to build a "full-chain" type of power emergency quick reaction system. Case studies have revealed that the quick response system's emergency combat capability, catastrophe preventive and mitigation capability, and emergency security capability have all improved. The construction of a "full-chain" type of power emergency rapid response system specialized and standardized the power emergency response system and provided a reference basis for the power industry's emergency response.

1. Introduction

In recent years, the frequent occurrence of accidents and disasters has caused damage to the power system, posing a challenge to the power industry's emergency response [1]. In 2003, the "8·14" blackout in the United States and Canada, the "11·4" blackout in Western Europe in 2006, and the earthquake in Jiuzhaigou, Sichuan, in 2017, led to the paralysis of the power system, the obvious shortage of power supply, and other problems [2]. In 2021, the "7·20" rainstorm disaster in Zhengzhou, Henan Province, led to the disruption of the city's power supply system, water ingress in some substations, and severe damage to communications equipment. The occurrence of the aforementioned disasters has resulted in incalculable damages to society and people, compelling governments around the world to devote increasing attention to the research of emergency management of power systems.

By reviewing certain previous emergencies, it is discovered that both domestic and foreign countries have collected some experience in the development of electric power emergency management systems. From a national standpoint, the United States plays an important role in emergency response by coordinating efforts between the Department of Energy's Office of Electricity Delivery and Energy Reliability (OE), the Federal Energy Regulatory Commission (FERC), and the North American Electric Reliability Council (NERC). Canada has effectively addressed disaster situations by enacting emergency management legislation, establishing institutional frameworks, enhancing emergency response capabilities, and integrating regular exercises into its emergency preparedness measures. Australia has made significant contributions to post-disaster relief efforts, with a particular focus on safeguarding critical infrastructure and facilitating emergency recovery operations. In 2007, the State Electricity Regulatory Commission of China released a notification

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titled “Notice on Further Advancing the Emergency Management Efforts of Electric Power Enterprises”. This notification aimed to provide clarity on the responsibilities of emergency management and the development of emergency plans within the electric power sector. Subsequently, in 2016, the National Energy Administration issued the “Specification for the Assessment of Emergency Capacity Development in Electric Power Enterprises”. This specification aimed to enhance the establishment and evaluation of emergency response capabilities in electric power enterprises, thereby facilitating the expansion of the emergency management system within the power grid. Since then, China has established a comprehensive framework known as the “one case, three systems” approach, encompassing emergency planning, organizational structure, operational mechanisms, and legislative foundations for effective disaster management [3–7].

Furthermore, multiple researchers, both domestically and internationally, have researched the power emergency management system. Drabek described emergency management as an applied science devoted to the treatment and prevention of risks in 1991 [8]. The four phases of reduction, readiness, reaction, and recovery make up the 4R model, which was proposed by Health. Bussey et al., for remote areas, conducted in-depth excavation and exploration of the key factors affecting the emergency management system [9]. Kapucu, with Hurricane Katrina and other natural disasters as empirical evidence, discusses and reveals the existence of the problems and shortcomings in the United States of America emergency management joint agreement [10]. Francis et al. evaluated the resiliency of the power system in the event of emergencies and offered measures to improve its resilience [11]. Only with the occurrence of emergencies and the growth of the reform and opening-up policies have Chinese scholars begun to pay attention to emergency management. Fan et al. present a full overview of the purpose, substance, and components of the urban power supply emergency management system’s architecture [12]. Zhong et al. use the Sichuan Grid Degree Power Supply Company as an example to summarize the lessons and experiences learned during the emergency response procedure [13]. Tian et al. suggest developing a grid emergency response platform to improve power grid emergency management [14]. Yang et al. identify the instability indicator, key machine identification algorithm, and two-layer single-machine infinite bus equivalent structure as three essential technologies for real-time power system emergency control and accurate and speedy emergency schedule commencement [15]. Huang et al. developed a comprehensive and adaptable emergency response architecture to improve grid disaster resilience [16]. The power emergency management system is gradually improving thanks to the research of various professionals. At this point, China’s electric power emergency management system consists primarily of three components: the electric power emergency command platform, the electric power emergency rescue team construction, and the electric power emergency material reserve system, but its division of work, efficiency, function, and operability must be improved.

To address the shortcomings of the previous traditional emergency management system, such as unclear division of employment and low operability, and to increase the emergency response rate, the development of an efficient emergency quick response system has become critical. At the moment, the creation of an emergency quick response system is being used more prominently in the domains of earthquakes, transportation, and medical care, with improved outcomes. Kaveh et al. improved the post-disaster setup of the emergency management system for emergency response planning, evacuation, shelter, and equipment location [17]. Yu et al. suggested a quick response system for earthquake emergency response based on a seismic information data management system for emergency rescue and auxiliary decision-making [18]. Wen built a rapid response network to reduce accident losses and make emergency rescue more efficient using the current state of rescue operations in railway travel accidents [19]. Mankidy et al. investigated the impact of a nurse-led rapid response team and a professional physician-led medical emergency team on critical patients to reduce the rate of cardiac arrest and improve the expected effectiveness of the rapid response system [20]. Li proposed to ensure the smooth operation of emergency medical care by improving the emergency organization, consolidating the foundation of emergency supplies, and implementing measures such as monitoring and warning [21]. The practice has proven that the emergency quick response system may effectively increase the emergency disposal capability of all types of emergencies.

Among the numerous emergency response systems, there is no study connected to the building of an emergency quick response system in the electric power industry, and the majority of existing research focuses on the electric power emergency management system. Huang et al. used deep reinforcement learning to create adaptive emergency control algorithms to keep the power system running safely [22]. Li proposed measures such as improving the emergency plan system, perfecting the emergency protection work, conducting regular drills, and performing the emergency assessment to put power emergency management into practice [23]. To ensure the reasonable dispatching of emergency materials, Li et al. built a multi-objective mobile emergency material allocation model based on the affected area’s emergency material demand, solving the optimal solution of the electric power emergency material deployment path to decrease the cost of emergency material dispatching [24]. These initiatives, while providing theoretical references for reacting to various forms of emergencies, do not concretize the electric power emergency management system or establish more refined emergency disposal units. The “full-chain” type electric power emergency rapid response system is based on the three major parts of the current electric power emergency management system, and it has the advantages of clear emergency command, efficient emergency response, and adequate emergent response by adding a rapid response unit, improving the emergency command system, standardizing the management of the unit personnel, setting up the emergency disposal card, and other methods of construction.

As a result, this paper focuses primarily on the electric power industry emergency response system, proposing a “1 (city and county corporation emergency base team) + N (county power supply stations)” two-level emergency rapid response unit to change the emergency response to the time-consuming, messy emergency supplies reserve, unclear emergency command responsibility, and other issues. According to many measures, the integration of multiple resources through the establishment of grass-roots forces enhances the emergency management system, focusing on emergency pre-control, strengthens the construction of the power emergency response system, and constantly improves the power industry’s emergency response capabilities to protect social and economic development.

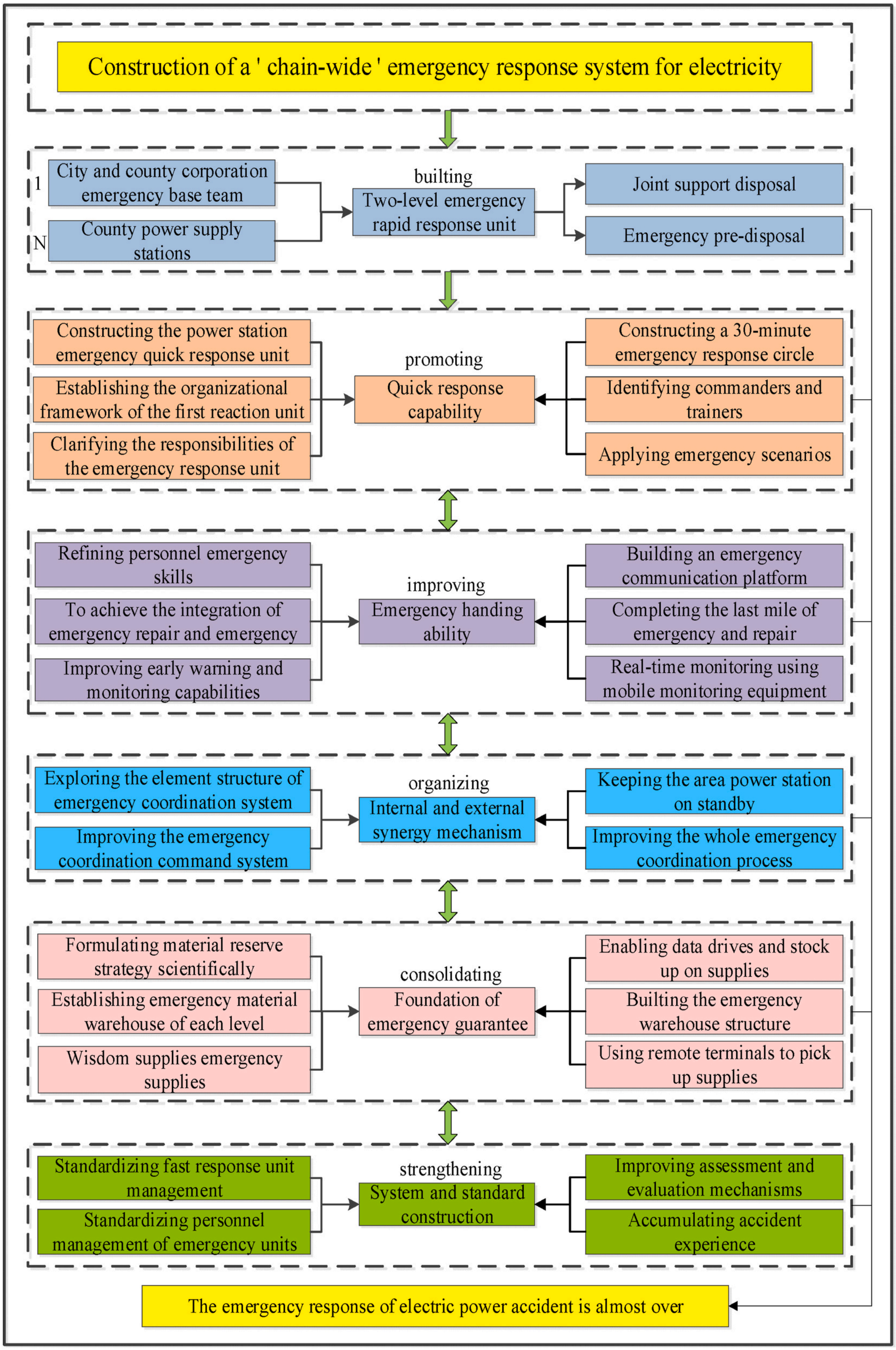

Fig. 1. "Full-Chain" power emergency response system.

2. A "full-chain" emergency response system

The power industry is a fundamental industry for the country. To improve the efficiency of power emergency rapid reaction and the capacity for power emergency disposal, the "full-chain" kind of power emergency quick reaction system depicted in Fig. 1 was built using five areas of power emergency management countermeasures research. The two-tier emergency rapid response system is described below.

(1) Construction of two-level emergency quick-response units: The two-level emergency quick-response units in the system were divided into emergency base teams of municipal and county companies and emergency quick-response teams of power supply stations, with the former accountable for linkage support and disposal in case of emergencies and the latter responsible for pre-disposal in case of emergencies.
(2) After completing the construction of the two-level emergency response unit, develop a 30-min emergency response circle by strengthening the organizational framework of the power supply emergency response unit and explaining the roles of each unit. Simultaneously, the commanders and trainers of the emergency fast response unit were identified, and countermeasures were provided in connection with the emergency reaction scenarios, thereby improving the emergency quick response capability.
(3) An emergency response communication platform was built to open up the last mile of emergency and emergency response, thereby improving emergency response capabilities by refining the emergency response skills of the fast-response unit's staff, integrating repair-emergency alignment work, and using mobile monitoring equipment for real-time monitoring.
(4) In-depth examination of the structure of emergency coordination elements, enhancement of the emergency coordination command system, and enhancement of the entire emergency coordination process to develop an efficient internal and external coordination mechanism.
(5) To have a reasonable amount of emergency materials on hand and be able to get them from a remote terminal, the foundation of emergency material security needs to be strengthened. This can be done by coming up with scientific strategies for emergency material reserves, setting up emergency material warehouses at the institute level, and smartly supplying emergency materials.
(6) Handling emergencies is improved by standardizing the management of quick-response units and accumulating and pooling experience with accidents. And then enter the emergency response cards into the application, establishing appropriate measures for each risk category to aid staff in decision-making. The construction of institutional systems is thus regulated.

Each link is properly coordinated and interlocked to form a chain-type emergency rescue system. Not only does it enhance the emergency response and combat capability, disaster prevention and mitigation capability, as well as emergency protection capability, but it also integrates the emergency response forces of all social parties and improves the hierarchical and graded emergency response coordination mechanism. Thinking from a multi-dimensional perspective, the emergency units are refined to form an emergency quick-response mechanism that is commanded from above, cooperated with at lower levels, and integrated by multiple parties. With the collaboration of the power industry and social emergency response forces, the continued deterioration of emergencies is strongly

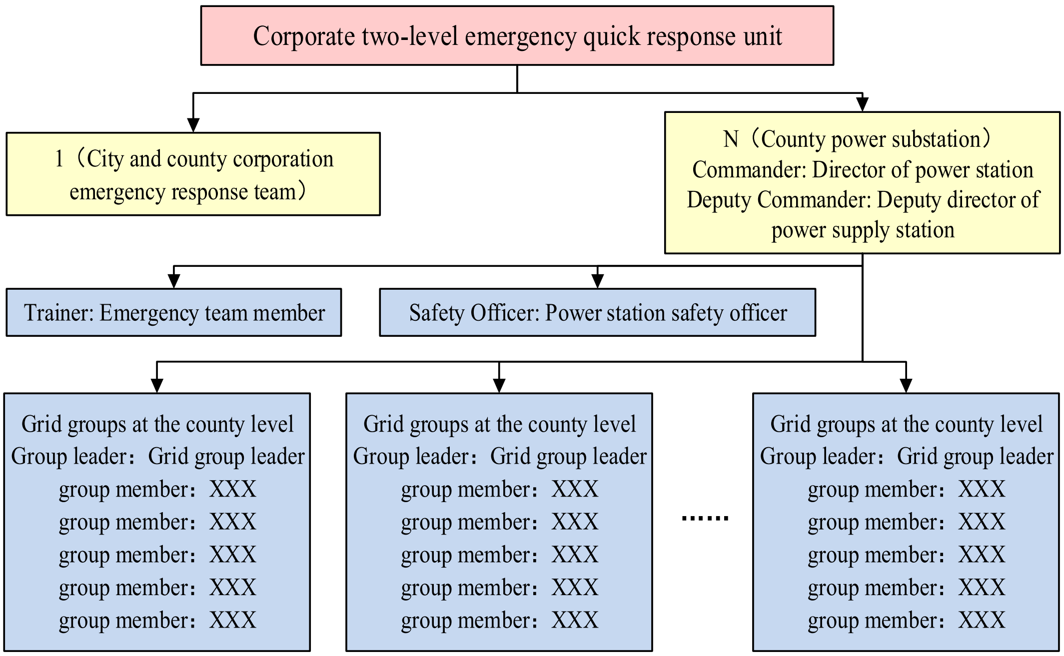

Fig. 2. The two-level emergency rapid response unit.

controlled.

3. Elements of an emergency rapid response system

3.1. Enhance emergency rapid response capability

(1) Build emergency rapid response units

The “1 + N” two-level emergency rapid response unit was constructed by refining the emergency operation team, efficiently preventing and resolving various safety risks, and improving the emergency rapid response capacity. Taking the emergency response system of a prefecture-level power supply company of the State Grid as an example, based on the city and county emergency base teams, it proposes to build “N” emergency quick-response units for power supply stations, which are divided into grid areas. Through the construction of the quick counter unit, the original emergency base team was developed into a “1 (city and county corporation emergency base team) + N (county power supply stations)” emergency quick counter system (as shown in Fig. 2). To ensure the correct operation of the two-tier emergency rapid response unit, it is clear that the commanders will be the director or deputy director, and the trainers will be emergency base team people. The construction of the Emergency Rapid Response Unit is put into practice through a specific and detailed division of responsibilities. In the event of an emergency, the emergency quick-reaction unit of the power supply station quickly assembles and arrives at the scene to carry out investigations, find out the existence of dangerous sources of accidents, the scope of accident hazards, and the degree of impact, make preliminary assessments of the nature and category of the emergency, and report them accordingly, effectively solving the “last mile” of disaster warning [25]. At the same time, the emergency response force is placed at the forefront of the war to achieve an efficient “30-min emergency response circle”. Based on comprehensive risk monitoring, adequate personnel strength, sufficient material reserves, and proficient operational skills, the impact of disasters can be mitigated or eliminated, providing a solid guarantee for the regular operation of the power supply after an accident.

(2) Clarify the responsibilities of the Emergency Response Unit

A defined division of tasks is required for coordination between the two levels of emergency response teams. In the face of emergency scenarios, the two levels of emergency rapid response unit duty boundaries are divided and defined in conjunction with the configuration of emergency materials and equipment and the skill level of the base team personnel in disaster rescue and relief and other actual situations (as shown in Table 1). In this way, it ensures that the two levels of emergency quick reaction units, by their advantages, fulfill their duties and play a real role in quickly controlling the scope of the impact of the disaster and guaranteeing the safety of the various emergency response personnel.

The fast response unit of the power supply office is the first to respond after a disaster. Simultaneously, as the first witnesses, they focused on the press and public opinion, revealing the truth about the crisis and its relief. Subsequently, any misinformation and uninformed guesses are banned at the source, in conjunction with the emergency services system (the Red Emergency Communication Mechanism and the Green Fast Track Mechanism) [26].

3.2. Improve emergency disposal capability

(1) Refine the emergency response skills of the rapid response team

The power industry works in areas of high risk, and improper handling of emergency response and rescue acts may cause further

Table 1
Responsibilities of the two-level emergency quick response unit.

Level	Designation	Advantage	Duty
Level 1	City and County Corporation Emergency Base Teams	Strong emergency response capability	①Responsible for the disposal of emergencies within the city and county linkage support. ②Complete limited space rescue, such as potholes in the jurisdiction within the capacity. ③To carry out the emergency power supply, flood control, emergency drainage, and crisis lighting, responsible for pylons, mountainous areas, and other regional rope rescues, water rescues, etc.
Level 2	County Power Supply Stations	Geographical and mobility advantages	①Take the lead in the pre-disposal of emergencies to reduce or even directly eliminate their impact. ②Act as a scouting station to accurately collect detailed information on emergencies and provide accurate data intelligence for subsequent linkage and disposal with the company's emergency base team, the rest of the power supply stations, and the government and social emergency forces to support disposal. ③Responsible for providing the emergency power supply, providing emergency drainage, emergency lighting, flood control and prevention, etc. within the scope of capacity, and linking disposal with township rescue teams and others.

expansion of accidents. To improve the efficiency of the two levels of emergency quick-response units for accident disposal, the grid division and rotation system are used for general emergency skills training. To change the usual emergency management model, the whole process of emergency response is studied from the perspective of accident scenarios [27,28], thus strengthening the concept of personnel risk prevention and control. In the context of scenarios such as "hill fire, demolition, and rescue", the practical effects of power emergency drills are improved, with emphasis on practice [29] and strengthening the linkage between government and enterprises to make emergency drills professional. To enhance the level of cross-regional coordination, it is necessary to actively learn from the valuable experience of many types of emergencies, to promote the basic members of each enterprise's emergency response to

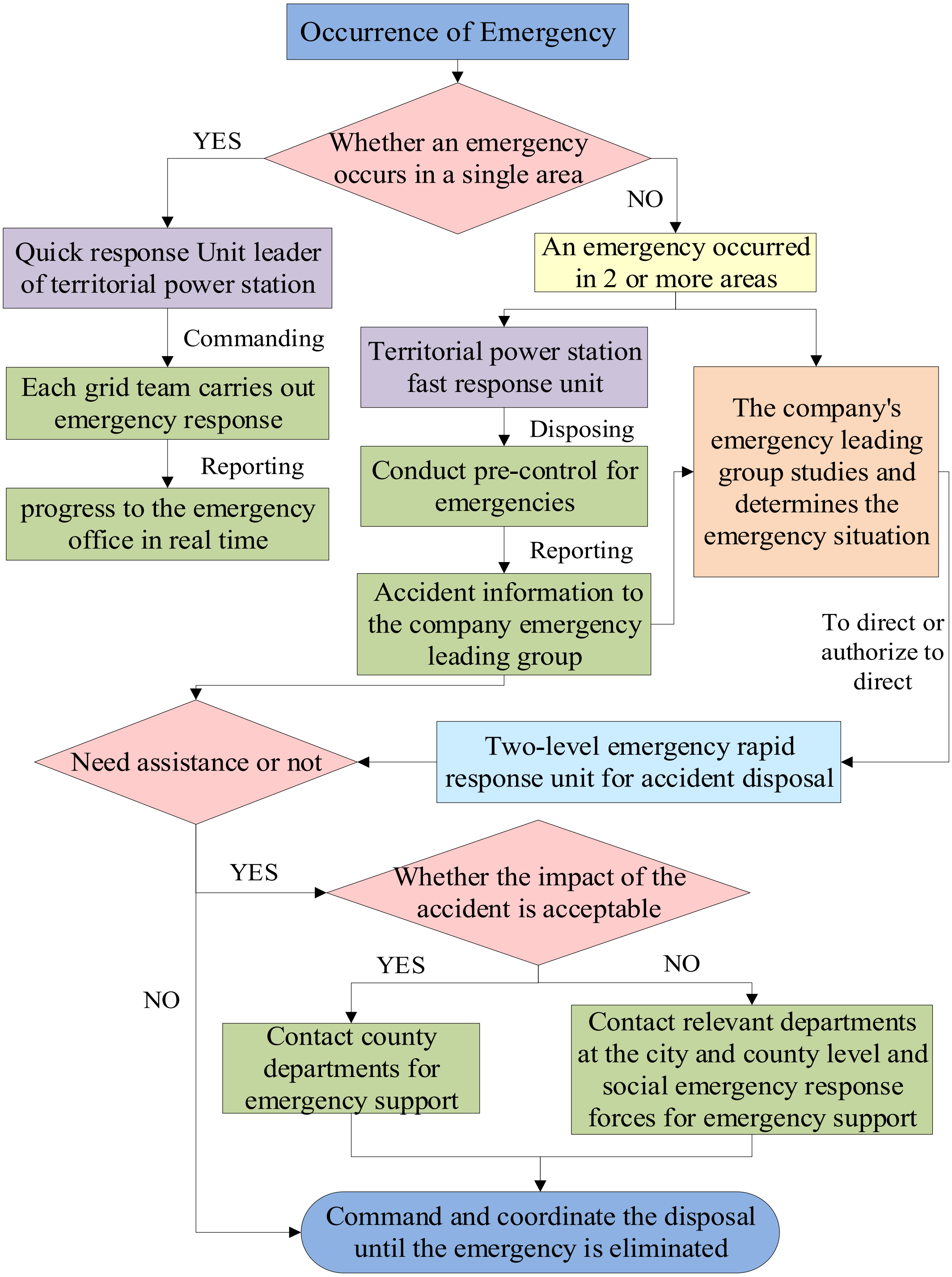

Fig. 3. Flow chart of emergency coordination command.

improve the level of emergency skills, and to better cope with flood control and typhoon prevention, power generation, lighting, and other emergency disposal work. To ensure the smooth development of emergency repair work, emergency quick-response units of power supply stations should be used to match emergency personnel to the needs of emergency tasks [30], so that quick-response teams with both emergency and repair capabilities can carry out rescue and fault repair work at the same time while reducing communication time. Simultaneously, the power emergency robot is used for optimal path planning based on hierarchical analysis and an upgraded A* algorithm, thereby replacing personnel to approach dangerous power scenes for rescue operations, improving emergency disposal safety and efficacy [31].

(2) Improve the timeliness of early warning monitoring

For typhoons, floods, hill fires, and other types of emergencies, traditional manual monitoring cannot accurately collect and transmit information. To improve the timeliness of early warning monitoring, enterprises use intelligent mobile monitoring equipment or technology, such as drones, video monitoring, and satellite remote sensing technology. Satellite remote sensing technology makes up for the harsh working environment on site, the low efficiency of emergency response, the difficulty in reaching personnel, and the poor adaptability by ensuring the safe operation of the power system [32]. During the extreme weather warning period, the weather monitoring and early warning system are applied to the main risk points, supplemented by the above intelligent equipment to monitor the risk factors in real-time, which promotes the modernization of the monitoring and early warning capabilities of various disasters [33]. At the same time, the application of cloud-assisted big data to grasp the key disaster information in the disaster area [34]. The terminal electronic equipment is used to view the monitoring data at any time to grasp the damage of the power equipment the first time, and to accurately locate the line fault problems such as disconnection and foreign body winding. When an emergency occurs, the use of geographic information systems (GIS) to launch the power emergency command work, and rapid access to emergency updates, for the subsequent development of the emergency disposal plan to provide data support, effectively reducing the loss of workforce and material resources, and improve the efficiency of emergency command [35].

3.3. Create internal and external synergy mechanisms

(1) Clarify the elements of emergency coordination

Using a prefecture-level city power supply company like State Grid as an example, build up the connection object within the company based on the power supply office-level emergency equipment library and emergency reaction force. On this basis, realizing the pre-disposal of fast-reaction units in the local power supply stations, the collaborative support of fast-reaction units in neighboring power supply stations, and the backup of fast-reaction units in other power supply stations. The local power supply station's quick reaction unit arrives at the scene for the first time, reports the incident situation quickly, and requests support from the nearby power supply station for emergency rescue forces and equipment and materials according to the needs of the incident disposal. When the on-site disposal exceeds the disposal capacity of the fast-reaction unit of the power supply station, the emergency base team of the county company should immediately provide support and request the emergency base team of the city company and other county and city companies for emergency support as needed.

In the face of emergencies, outside the emergency response system, there should be strengthened government-enterprise cooperation and the construction of an emergency rescue system complemented by social emergency response forces. Since then, the power company has signed emergency rescue and material linkage agreements with multiple parties (County Emergency Management Agency, County Water Bureau, County Construction Bureau, etc.). 5G technology is used to improve the level of smart grid information and the usage rate of existing equipment, thus opening up the sharing of emergency relief materials and information with townships [36]. In the face of power line failures in mountainous areas, call on the existing emergency supplies of other linked groups to guarantee the smooth progress of power repair work.

(2) Improve the emergency coordination command system

Comprehensively improving the emergency response capability and giving full play to the linkage effect requires the establishment of an efficient, synergistic, and interactive emergency response collaborative command system [37]. In this paper, in conjunction with the establishment of the second-level emergency rapid response unit, an emergency collaborative command system with closely linked subjects and a straightforward response process is formed (as shown in Fig. 3). When a single geographical emergency occurs in the jurisdiction, if the local power supply office can control the incident's progression, the head of its emergency rapid response unit will direct grid teams to carry out emergency response and will report to the Office of Emergency Response Leadership. When an emergency happens in two or more jurisdictional regions, the local power supply office's quick response unit will command and handle the emergency, as well as carry out pre-control. When the local power supply office requires assistance, the incident will be reported to the company's emergency response team, which will command or approve the preparation of the company's two-level emergency response unit and emergency equipment support. It should be noted that the adjacent power supply offices in the emergency support need to follow the "who leads, who commands" principle in unified compliance with the scheduling command of the supported party and with the integration of internal and external emergency rescue forces to complete the emergency disposal tasks. If the incident severely impacts and requires external support, contact the relevant city and county departments and teams for support and disposal until the emergency is eliminated.

3.4. Consolidate the foundation of emergency security

(1) Scientific planning of emergency supplies reserves

To optimize the stockpiling of emergency supplies, a management model for joint stockpiling of emergency supplies is proposed [38]. Based on the supply chain operation platform, real-time data on emergency supplies is collected to build a stockpile of emergency resources in power supply stations. Intelligent 5G technology is applied to improve the accuracy of emergency material reserve quotas to grasp the number of emergency materials in stock at each territory's power supply offices. To meet the logistics needs of the emergency rescue phase, the emergency supply network is used to carry out disaster relief within the affected area, and the scientific and reasonable planning of the material storage and transportation area is formulated [39]. Simultaneously, an emergency supply dispatching model is established to meet the relief needs of different disaster areas and to implement the priority of supply distribution to solve the problem of dispatching emergency supplies and save dispatching time and distribution costs [40]. In the event of an emergency, the online app's remote terminal dispatch mode is used, which is determined by a site survey and the number of material requirements. When obtaining materials from the closed power supply office, the back office will automatically register the data of the claim to realize dynamic material reserve and dispatch and reduce the time-consuming problem of material dispatch (as shown in Fig. 4). Furthermore, a novel disaster supply mode of transport using drones can be employed to overcome difficulties such as late distribution of materials due to rough road conditions in regions where emergencies occur. The UAV model is selected in conjunction with the characteristics of the accident site and the demand for supplies to ensure the supply of emergency supplies and buffer the tight rescue time. The power industry in Jinhua City, Zhejiang Province, has explored a new model of drone transport to increase the efficiency of transporting some supplies under complex geographical and environmental conditions by more than 50%.

(2) Accurate enhancement of power system stability

The strength of power system stability is correlated with the severity of disaster incidents. For example, the extraordinarily heavy rainfall disaster accident in Zhengzhou, Henan Province, caused a significant impact on the strength of the power system, resulting in a large-scale power outage due to the interruption of the city's power supply system. As a result, the Whale Optimization Algorithm (WOA) can be utilized to successfully propose emergency demand response strategies to ensure the stability of power system voltage operation [41]. Create a grid operation index system that takes maintenance risk into account to meet grid emergency dispatching work by combining qualitative and quantitative methodologies [42]. Finally, emergency rescue and restoration work is carried out through continuous and stable power to guarantee electricity for personnel in the emergency area.

3.5. Strengthen the standard construction of the rapid response system

(1) Standardize the management of quick-reaction units

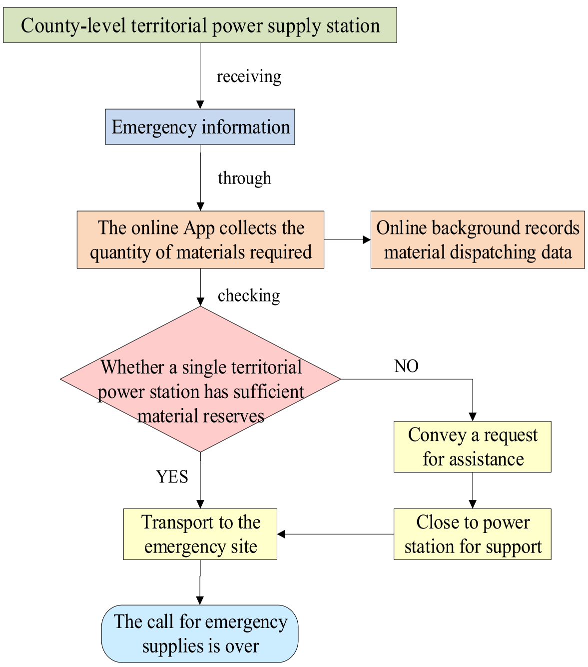

Fig. 4. Flow chart of emergency supplies scheduling.

Facing the two-level emergency quick reaction unit, the training, rehearsal, and emergency incident disposal of the emergency base team and the quick reaction team of the power supply office will be included in the assessment. To strengthen the capacity building and day-to-day management of the two levels of fast reaction units by establishing a sound rapid response unit appraisal system. Improve the drafting of special plans from the ground up to realize the reconstruction of the emergency plan system for the task's characteristics [43]. Evaluate existing power emergency plans, correct their one-sidedness, and optimize power emergency plan creation [44]. It accumulates relevant emergency rescue knowledge, reorganizes and simplifies the entire process of its early warning, response, safeguard, and summarization, and improves the practical ability to improve the on-site disposal scheme at the level of the power supply office based on the large database of electric power accidents. Simultaneously, to ensure the safe and stable operation of the power grid and in light of lessons learned from electric power accidents, it proposes scenario-based emergency response standards as well as improving the configuration of emergency personnel and materials for all types of similar disaster scenarios. Through the measures listed above, regional power supply offices' emergency preparedness will be improved, ensuring that emergency disposal and repair work is appropriately commanded and organized.

(2) Implementation of emergency unit staff management

Standardize staff roles to improve the efficiency of managers' decision-making. To maximize the effectiveness of emergency response operations, case-based reasoning (CBR) is extensively implemented to help staff make emergency dispatch decisions before grid emergencies brought on by catastrophic events [45]. It was discovered that the operability of emergency plans was generally subpar after thoroughly reviewing and analyzing the emergency management of incidents. Therefore, Zhang advocated that the post-emergency response card be used to aid personnel in decision-making and did so successfully to increase the emergency response capability [46]. The so-called emergency disposal card is an emergency knowledge card that guides the three questions of "who should do it", "what to do", and "how to do it" in an emergency, and it should cover the characteristics of an incident scenario, the emergency response responsibilities and processes of each role, scientific emergency resource deployment units, and the technical standards required for emergency response. For natural disasters, accidents, and catastrophes, emergency response cards are graded according to warning and response, and emergency unit managers and staff take corresponding measures according to different levels of warning information or warning response instructions, providing theoretical support for the standardization of emergency response. At the same time, in emergency management, the role of emergency volunteers is fully implemented and brought into play. Emergency rescue tasks are matched bilaterally with volunteers to provide a reference basis for emergency decision-making [47].

4. Study of cases

This study uses the response of the power supply company of a prefecture-level city, State Grid, to the "In-Fa" typhoon as an example to demonstrate the function of the "full-chain" kind of power emergency response system in practice.

4.1. Significant improvement in emergency response capability

The building of the emergency quick reaction unit has improved the emergency management of production safety and social emergency linkage and disposal capacity, as well as the level of training, rehearsal, and practical ability of the State Grid power supply company in a prefecture-level city. By expanding the number of emergency response forces at the grass-roots level, we have improved the speed of response and disposal and realized the decomposition and disposal of risk boards. In emergency response, there is a true 30-min circle of emergency response within the city and county and a one-hour circle of emergency response between the city and the city and between the county and the county.

According to the two-level emergency response unit's division of responsibilities, during the emergency "In-Fa" typhoon attack, the variable cable layer into the water mishap occurred in the Puyang River Basin. In the event of an emergency, the Pudong Power Supply and the Huangzhai Power Supply are the first to respond. Pudong power supply emergency quick reaction unit arrived at the scene in 16 min to begin emergency drainage disposal, and Huangzhai power supply emergency quick reaction unit arrived in 33 min to carry out coordinated disposal, respectively, compared to the emergency base team arriving at the scene in 46 min to improve 65.2% and 28.3%. As a result, the establishment of a two-level emergency response unit and the separation of responsibility for emergency response to accidents have yielded considerable functions, successfully serving as efficient rescue and risk reduction.

4.2. Substantial increase in disaster prevention and mitigation capacity

The construction of the two-level emergency rapid response unit integrates the emergency response resources of the government, society, and other parties. By setting up emergency coordinated command, the problems of scattered resources and lack of capacity have been solved. This has led to the implementation of an effective emergency coordinated system that includes prevention, resistance, and rescue. It provides a good guarantee for the safe and stable functioning of the electrical grid through accurate and effective monitoring, early warning, and prompt and efficient emergency response. Despite an increase in the number of severe weather catastrophes, the number of households affected each hour by emergencies such as extreme weather has dropped by nearly 2400 in 2021 compared to 2020. This demonstrates that an effective emergency coordination system gives a good guarantee for the power grid's safe and stable operation.

4.3. *Significant improvement in emergency support ability*

Reduced the duplicate stockpile inventory of 960,000 supplies through rational planning of emergency stockpiles. With the supply chain operation center coordinating emergency material deployment management, the average deployment reaction time has increased by more than 20%. The implementation of new technology and intelligent specialized warehouses improves the Efficiency of material-receiving activity while saving approximately 33% in human resource expenditure. During the "In-Fa" typhoon, the power company, through the supply chain operations center, coordinated the deployment in a total of 12 counties and municipalities to "zero delay delivery" (This includes 16 vehicles of distribution cables, low-voltage cables, overhead insulated conductors, emergency lights, water stoppers, and other supplies and equipment totaling $320,000). "Zero error" completed the "In-Fa" battle of emergency material protection, providing strong support for the power grid repair work.

Strengthening the integration and interconnection of the government's emergency response resources and forces through the enhancement of emergency response building capacity in terms of personnel, skills, and materials. The construction of the emergency quick reaction unit has realized the rapid response of emergency equipment resource sharing and efficient collaborative disposal of emergencies, made up for the shortcomings in equipment, and enhanced its own emergency response capability and disposal range. In the face of complex and uncontrollable emergencies, there can be a flexible response to ensure that the critical moment personnel team materials "pull out, use, win".

5. Conclusion

The complex structure of the power network and the significant electricity demand are the future development trends of the power industry. To prevent power failures caused by emergencies and improve the ability to rescue, a "1 + N" two-level emergency response unit has been constructed through the interplay of all links, forming a "full-chain" type of emergency response system for power.

(1) Divide the two-level emergency rapid response unit into emergency base teams of municipal and county companies and emergency rapid response teams of power supply stations, with the former responsible for linkage support and disposal in case of emergencies and the latter for pre-disposal in case of emergencies. To enhance the emergency rapid response capability through the standardization and refinement of the emergency response system.
(2) For the two levels of emergency quick-response unit teams, a grid division and rotation system are used to provide general emergency skills training. Based on scenario simulation, the concept of risk prevention and control of personnel is strengthened to ensure that rescue and repair work are carried out simultaneously by the two levels of emergency response unit teams. In addition, intelligent mobile monitoring facilities are used to grasp the location of faults and damage to power equipment in the first instance, as data support for the formulation of emergency disposal plans, and to improve emergency handling capabilities.
(3) When an emergency occurs within the emergency response system, if the local power supply station can control the accident, it will carry out pre-disposal of the accident. When the on-site disposal exceeds the disposal capacity of the power supply station's fast-reaction unit, support from the emergency base team of the city or county company will be sought as appropriate. Outside the emergency response system, strengthen the emergency linkage with multiple subjects, coordinate resources from all sides, and create an internal and external synergy mechanism.
(4) Construct a reserve of emergency resources for emergency quick-response units in power supply stations and apply intelligent online software to call supplies from remote terminals when emergencies occur to solve the problem of time-consuming material dispatch and communication and consolidate the foundation for emergency protection.
(5) Implement the application of emergency disposal cards and standardize the management of the responsibilities and decisions of emergency quick-reaction unit team personnel at both levels.

Shortcomings and prospects

Although this paper has achieved certain research results in electric power emergency response, due to geographical constraints, the preparation of emergency supplies in some remote areas may not be up to the ideal state, and the emergency cooperation ability is still to be improved, which can be taken as the focus of research in the future.

CRediT authorship contribution statement

Su Zhang: Conceptualization, Methodology. **Xiaolu Liu:** Investigation, Writing – original draft. **Jingui Wang:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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