Intelligent Fault Diagnosis and Response Method Based on GIS and IoT in Power Grid Planning

Hongda Zhao[1], Zhe Wang[1](✉), Mingxia Zhu[1], Zhongmin Shi[2], Zhen Wang[2], and Xianli Wu[2]

[1] State Grid Jiangsu Electric Power Co., Ltd. Economic Research Institute, 210024 Nanjing, Jiangsu, China
1242358522@qq.com, 10386057@qq.com, 1016744576@qq.com
[2] Xiamen Great Power GEO Information Technology Co., Ltd., 361000 Xiamen, Fujian, China
bigheadshi@sohu.com, ivenwz@163.com, 28860580@qq.com

Abstract. The intelligent fault diagnoses and responses of power grid planning are very important parts of the future power grid. This paper proposes an intelligent fault diagnosis and method based on GIS map and IoT. The method mainly includes the stage of automatic fault diagnosis and data analysis based on IoT sensor data, and the process of panoramic display and response optimization based on GIS. The system includes response management and control module, business development monitoring module and power outage analysis module. It can be used for panoramic map display of current response to resource distribution. Besides, it also can support automatic topology tracing and fault analysis to copy with trajectory real-time update and optimal scheduling.

Keywords: IOT · GIS · Fault analysis · Power grid planning

1 Introduction

With the rapid development of economy, people's demands for electricity are also increasing day by day, and the stability of power grid system becomes particularly important. It is necessary to maintain the stability of power transmission system, which is the closest link with users, and it is essential to provide users with reliable and high-quality electricity. However, in recent years, the development of distribution network based on Geographic information system (GIS) [1] and Internet of Things (IOT) [2] has brought new solutions to power system automation. GIS has been favored by most countries for its strong spatial data management ability and topological analysis ability, as well as its unique management advantages for pipeline network. Its technology has also been greatly developed. The distribution network GIS has developed from a simple equipment information management system at the beginning to now add a variety of

G. Wang et al. (Eds.): SpaCCS 2020, LNCS 12383, pp. 181–190, 2021.
https://doi.org/10.1007/978-3-030-68884-4_15

auxiliary decision-makings and analysis functions, and this development trend is bound to gradually replace the traditional manual management mode.

For many years by now, there are big defects in the way of household electricity fault repair. The fault repair process is tedious and long, and the fault cannot be repaired in time. Therefore, the user experience is poor. When the users report for repair, they need to know about some problems of the user's power failure. Due to some professional problems, most of them are not well understood by users and users only know that there is no power at home, which causes the power department not to know how to overhaul. This link reflects factors such as unprofessional and time-consuming handling of problems. Based on this situation and background, it is necessary to study and realize the power supply capability analysis of distribution network based on GIS space service and power Internet of things, so as to grasp the power supply capability of distribution network of the whole province in real time, improve the lean management level of distribution network, and provide decision-making basis for relevant business departments.

On the basis of power grid GIS platform, the professional applications of development planning are deepened. Automatic analysis, efficient design, intelligent decision-making and dynamic tracking are realized on statistical stage diagram, planning stage diagram and construction stage diagram, so as to construct and adapt to the development of different professional visualization work engines. Besides, the whole business processes of distribution network planning, such as simplification of supporting data collection and management, status analysis and diagnosis, load forecasting and checking, intelligent site selection and line selection, comparison and demonstration of planning schemes, and display of planning results, are realized too. Power network analysis and spatial analysis are deepened [3]. Moreover, the three-state management of grid resource information status, plannings and projects in all time and space are also realized; Finally, all-round supporting planning business, intelligent integration of full-space information, intelligent analysis and intelligent interaction are achieved [4–8].

In response to the above requirements, an intelligent autonomous fault diagnosis and method is provided here. The responders can know the fault problems and solve them in the first place based on GIS map and IoT intelligent address location. The method to build the system includes response management and control module, business development monitoring module and power outage analysis module through the construction of the high reliability electricity sensor network, which can realize automatic data collection terminal data, guarantee data integrity, reduce the loss of data, and carry out intelligent research and judgment response. In a word, it plays a supporting role in the distribution network intelligent planning.

2 Related Work

In the traditional power grid planning, the data collection methods were to make the drawing after the field investigation, which resulted in the time-consuming and low-precision situations, and prone to errors when the power grid planners prepare the specific schemes. Rapid changes in geographic graph data and poor real-time performance in traditional planning system make it difficult to draw and calculate survey data accurately, which requires repeated confirmation by planners, greatly increasing the workloads of personnel. The GIS geographic information system [9] contains diversified technical means, which can realize real-time analysis, collection, storage and management of geospatial information, etc. With the support of satellite navigation and positioning technology, the mapping accuracy in GIS application is improved, which is conducive to enhancing the utilization value of corresponding data information.

Using GIS technology based on the spatial location datas and information [10], it has management functions of spatial information with geographic graphics and spatial positioning functions. Moreover, It also integrates computers, geography, urban science, management science and space science, which provides geographical information and space to the management points that are in demand. The advantages of technology are its own information synthesis and evaluation skills. It can obtain important datas on the basis of conventional models, complete the simulation and prediction of geospatial process changes, and at the same time guarantee the scientific nature of the emergency scheduling command by relying on navigation information, so the existence of the GIS technology is very important for power grid planning [11].

The Internet of things [12] is an important part of a new generation of information technology. It means a huge network combined with all kinds of information sensing devices and Internet based on “the concept of Internet”, which extends its client to any of the items and items. All in all, it is a network concept for information exchange and communication. The Internet of things (IoT) is a network that enables all ordinary objects with independent functions to connect and achieve artificial intelligence management and control [13,14]. Based on Internet of things intelligent address location on the basis of grid GIS platform, it deepens the development plans for professional applications, covering development figure corresponding, connection mode recognition, vision of the load distribution, visualization of project situation display, site selection and line selection on the map. Besides, it also designs “one picture and three states” (planning state, planning state, current state) in accordance with the principles of “intelligent analysis, visualization of results, and graphical project” to realize automatic analysis on the statistical stage diagram, efficient design on the planning stage diagram, intelligent decision-making on the planning stage diagram, and dynamic tracking on the construction stage diagram. Finally, it constructs and develops visualization work for different specialties.

3 The Proposed Fault Diagnosis and Response Method

3.1 Proposed Fault Diagnosis Method

Combining GIS technology and Internet of Things technology, we propose a new fault diagnosis and method. The steps are as follows:

1. When the users call for fault repair, the user number shall be provided first. According to the user number, the GIS system will automatically inquire the address of the user's power supply fault and confirm with the user;
2. After confirming with the user, the GIS system will automatically report the power failure information (if the user reports a repair call, the account number is known, and the power failure is suspected to be 'multi-family/single-family'), and start the process of research and judgment and order dispatch;
3. If the GIS system automatically determines that it is a planned power failure (known plan/known fault), it will return to inform the customer that it is a known plan/known fault and no repair is required;

    Otherwise, we should continue analysis: In the case of an account number, it conducts a visual copy-through. If the copy-through succeeds, the meter has electricity and no repair is required; If the copy-through fails, it countinues to the next visual dispatch analysis;

    In the case of no account number, it continues to the next visual dispatch analysis without a copy-through;
4. Dispatch analysis is visualized. The nearest coping team is calculated. The map shows the shortest path and the distance of each material point from the closest coping team, and the time of arrival;
5. The response message will be pushed to the response team, and the response team will confirm and repair the message as soon as they see it.
6. GIS system will automatically read data, modify status, simulate bill of lading and dispatch documents; Then it will report repair notices (e.g. "repair calls from users have been recorded, sent to response team, and estimated time of arrival).

Through the panorama display technology of the power failure information based on GIS system, the power failure distribution and areas and users affected by the power outage can be visualized. Besides, the research on big data analysis can be carried out to realize the generation and analysis of the power failure electrothermal force diagram and visually demonstrate the weak links of the power grid. Moreover, The automatic voice warning technology of power failure event is studied to provide visual and rapid response technical support for power supply service command center.

3.2 Response Method

When the power is cut off due to an emergency, the emergency response vehicles and fault tasks should be allocated reasonably, so as to effectively improve the utilization rate of the response vehicles, repair the fault as quickly as possible, shorten the power outage time and reduce economic losses. Besides, the response efficiency can be improved by optimizing the organization of response vehicle teams and optimizing the economic loss of power failure. In the visual dispatch analysis, the optimization model of responding vehicle team includes internal collaborative load and external collaborative load. The internal collaborative load of responding vehicle team G_m is $N(m)$, indicating the cumulative number of responding vehicles assigned to the responding vehicle team

$$N(m) = \sum_{k=1}^{K} R_{G-P}(k, m) \tag{1}$$

$\sum_{k=1}^{K}$ is the sum of k distributions from 1 to k,

$R_{G-P}(k, m)$K for the Kth time, m for the response team id, R_{G-P} represents the algorithm function name of internal collaborative load, and the external collaborative load for vehicle team Gm is $W(m)$,which represents the cumulative load of the responding vehicle team in collaboration with other responding vehicle teams.

$$W(m) = \sum_{n=1, n \neq m}^{M} R(n, m, x_i) \tag{2}$$

$\sum_{n=1, n \neq m}^{M}$ n is the number of accumulations from 1 to M, m represents the id of the response team, and n is not equal to m;

$R(n, m, x_i)$ parameter n represents the nth accumulation, m represents the response team id, x_i represents the id of other response team, R is the name of the algorithm function to calculate the response team external collaborative load;

Therefore, in the case of a given fault, the adaptability measure of vehicle allocation should be

$$\alpha = \sqrt{\frac{1}{M} \sum_{m=1}^{M} [N(m) + W(m)]^2} \tag{3}$$

m is the number of cooperation, M is the total number of cooperation;

α for the team to deal with the vehicle total working load of RMS, while minimizing the response team vehicle mean and variance of total load. The goal is to reduce unnecessary collaboration between the response vehicle teams in troubleshooting (including cooperating with the internal coordination of vehicle teams and cooperating with the external coordination of vehicle teams in troubleshooting), improve the efficiency of troubleshooting. When the value is smaller, it shows the better effect and higher efficiency to deal with the vehicle allocation under current fault conditions.

Its constraints are as follows:

1) Each fault shall be assigned to at least one response vehicle team;

m is for the vehicle team $id.i$ is for the number of collaborations.M is for the total number of collaborations.R_{G-X}means that each fault is assigned to at least one algorithm function for constraints of vehicle team.

$$\sum_{m=1}^{M} R_{G-X}(i,m) \geq 1, \qquad i = 1, 2, ..., N \tag{4}$$

2) Each response vehicle can only be assigned to one response vehicle team;

$$\sum_{m=1}^{M} R_{G-p}(k,m) \geq 1, \qquad k = 1, 2, ..., K \tag{5}$$

k is the number of response vehicle teams.m is the number of coordination.M is the total number of coordination.R_{G-p} represents that each responding vehicle can only be assigned to an algorithm function that responds to the constraints of the vehicle team;

3) Constraints on resource capacity;

$$\sum_{m=1}^{M} R_{G-X}(i,m) r_{ml} \geq r_{il}, i = 1, 2, ..., N; m = 1, 2..., M; l = 1, 2, ..., L \tag{6}$$

i is the number of collaboration.m is the number of response team, l is the number of response vehicle.$r_{ml}$is for the response team and the response vehicle restraint.$r_{il}$is for the response vehicle restraint.$R_{G-X}$is the name of the algorithm function of response resource capacity constraints.

Optimization of economic loss of power failure in the visual dispatching analysis. The optimization objective is to reduce economic loss of power failure caused by power failure of distribution network, and the objective function in this stage is

$$f(x) = \sum_{i=1}^{N} T(x_i) \sum_{l=1}^{3} \omega_l L_l(x_i) - \sum_{j=1}^{N} T_j \omega_l L_j \tag{7}$$

$T(x_i)$ is the power failure time caused by fault point x_i; T_j is the power supply time of the emergency generator when the dual-power user loses power; ω_l for failure is caused by the power failure load rating coefficient; $L_l(x_i)$ is the power value of the load with grade l caused by power failure of fault point Xi; L_j is the load power value supplied by the emergency generator car;

Its constraints are as follows:

After fault response and switch operation, the distribution network should maintain a radial structure, that is, $gk \in GR$, gk is the network structure of the power supply recovery area; GR is to ensure the collection of radial networks; The wait time for collaboration failures should be met $\tau_(xi) \leq t^{\varepsilon}$, where t^{ε} is the maximum allowable cooperative wait time.

In the case of household number, we should search and analyze the situation according to the location of access point;

In the case of no household number, we should search and analyze the situation according to the address that can match the GIS address base, locate directly on the map, and then search the corresponding resources nearby. In this way, it is easy to locate, improve response efficiency and save time.

4 System Implementation and Deployment

4.1 System Description

We have deployed this system in Xiamen area, as shown in Fig. 1. The system comprises includes response management and control module, business development monitoring module and power outage analysis module.

The response management and control module is used to display the current response resources (stationary point, response team) and work order distribution in a panoramic way on the map. It can support automatic polling display of work orders in transit, automatic voice reminder of overtime and new work orders, automatic topology tracing and fault analysis, and respond to team trajectory real-time update and optimal scheduling to realize the intelligence of response command and quick response of service.

The business development monitoring module is used for the map integration of the open capacity of medium-voltage lines. According to the coordinates of the user's loading location, it automatically calculates the lines available within the set radius, generates alternative power supply access schemes and recommends the optimal access schemes. The map presents the progress of the on-line industry expansion plan in real time, improves the efficiency of formulating the plan for online acceptance of industry expansion requirements, and realizes efficiency improvement of the business development process management and control;

The power outage analysis module is used to display the power outage information overview, power outage distribution, and areas and users affected by the power outage on the geographic map. It also supports automatic voice reminders for power outage events and provides power outage visual and rapid response technical support for the power supply service command center. At the same time, it supports linkage with the large screen of the power supply service command center.

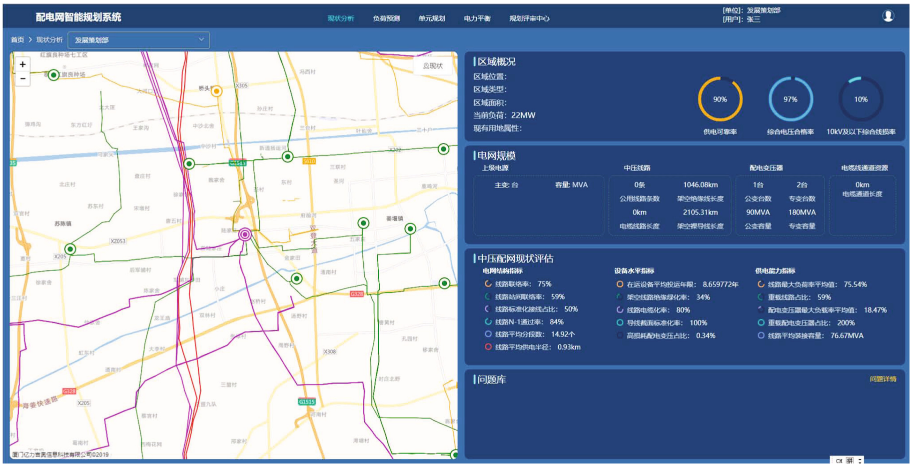

Fig. 1. Evaluation index

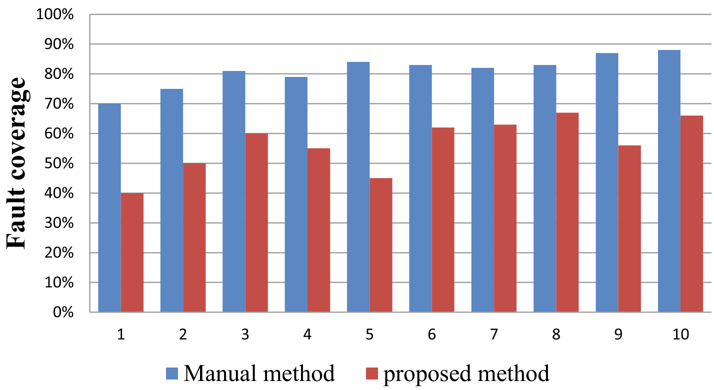

Fig. 2. Evaluation index

4.2 Performance Comparison

The previously undeployed and deployed fault diagnosis results (mainly including: fault location, fault type, elimination plan, etc.) are scored. The final test results are shown in Fig. 2. The index of fault coverage can be expressed as: fault coverage = number of identified faults/actual number of faults $\times$ 100%

5 Conclusion

In recent years, the development of distribution network GIS and Internet of Things technology has brought new solutions to power system automation. Geographical Information System (GIS) with its powerful spatial data management and topology analysis ability, as well as its management advantages for pipeline network unique won the favour of most countries. The technology has also got rapid development. The distribution network GIS has developed from a simple equipment information management system at the beginning to now add a variety of auxiliary decision-makings and analysis functions, and this development trend is bound to gradually replace the traditional manual management mode. Based on this situation and background, it is necessary to study and realize the power supply capability analysis of distribution network based on GIS space service, so as to master the power supply capability of distribution network of the whole province in real time, improve the lean management level of distribution network, and provide decision-making basis for relevant business departments.

In this paper, through the panorama display technology based on the power failure information in GIS system, the power failure distribution and the visualization of areas and users affected by the power outage are realized. The researches on big data analysis are carried out to realize the generation and analysis of the power failure electrothermal force diagram and visually demonstrate the weak links of the power grid; The automatic voice warning technology of power failure event is studied to provide visual and rapid response technical support for power supply service command center. Besides, it also provides a reliable and convenient method for intelligent address location and analysis in power grid planning and improves work efficiency.

References

1. Ueta, G., Okabe, S., Utsumi, T., et al.: Electric conductivity characteristics of FRP and epoxy insulators for GIS under DC voltage. IEEE Trans. Dielectr. Electr. Insul. **22**(4), 2320–2328 (2015)
2. Wang, T., Luo, H., Jia, W., et al.: MTES: an intelligent trust evaluation scheme in sensor-cloud enabled industrial internet of things. IEEE Trans. Ind. Inf. **16**(3), 2054–2062 (2020)
3. Marotta, A., Avallone, S., Kassler, A.: A joint power efficient server and network consolidation approach for virtualized data centers. Comput. Netw. **130**(JAN.15), 65–80 (2018)
4. Motepe, S., Hasan, A.N., Stopforth, R.: Improving load forecasting process for a power distribution network using hybrid AI and deep learning algorithms. IEEE Access **7**, 1 (2019)
5. Ma, Y., Sun, Yu., Lei, Y., Qin, N., Lu, J.: A survey of blockchain technology on security, privacy, and trust in crowdsourcing services. World Wide Web **23**(1), 393–419 (2019). https://doi.org/10.1007/s11280-019-00735-4
6. Wang, T., Jia, W., Xing, G., Li, M.: Exploiting statistical mobility models for efficient Wi-Fi deployment. IEEE Trans. Veh. Technol. **62**(1), 360–373 (2013)
7. Xiao, C., Liu, C., Ma, Y., et al.: Time sensitivity-based popularity prediction for online promotion on Twitter. Inf. Sci. **525**, 82–92 (2020)
8. Wu, Y., Huang, H., Wu, Q., et al.: A risk defense method based on microscopic state prediction with partial information observations in social networks. J. Parallel Distrib. Comput. **131**, 189–199 (2019)

9. Lu, G., Batty, M., Strobl, J., et al.: Reflections and speculations on the progress in Geographic Information Systems (GIS): a geographic perspective. Int. J. Geograph. Inf. Sci. **33**(1–2), 346–367 (2019)
10. Leite, J.B., Mantovani, J.R.S., Dokic, T., et al.: Resiliency assessment in distribution networks using GIS based predictive risk analytics. IEEE Trans. Power Syst. (2019)
11. Shu, J., Wu, L., Li, Z., et al.: A new method for spatial power network planning in complicated environments. IEEE Trans. Power Syst. **27**(1), 381–389 (2012)
12. Li, S., Xu, L.D., Zhao, S.: The internet of things: a survey. Inf. Syst. Front. **17**(2), 243–259 (2014). https://doi.org/10.1007/s10796-014-9492-7
13. Wang, T., Qiu, L., Sangaiah, A.K., et al.: Edge-computing-based trustworthy data collection model in the internet of things. IEEE Internet Things J. **7**(5), 4218–4227 (2020)
14. Wang, T., Wang, P., Cai, S., et al.: A unified trustworthy environment based on edge computing in industrial IoT. IEEE Trans. Ind. Inf. **16**(9), 6083–6091 (2020)