

ARCHITECTURE AND MODULAR DESIGN OF POWER EMERGENCY COMMAND SYSTEM BASED ON ASSOCIATION RULE ALGORITHM

QIAN WANG* AND MINGMING LIU

Abstract. In order to effectively obtain the electric power emergency command plan and reasonably dispatch emergency resources, the electric power emergency command system architecture based on association rule algorithm is designed according to the modularization idea. In the hardware part, the sensing layer is used to collect operation data, and the service layer is used to analyze and mine the data. The tool layer establishes the basic component library and the power industry component library. The network layer transmits relevant information to the application layer. The application layer realizes the three-dimensional simulation and visual operation of power emergency command such as resource scheduling and fault repair by calling the tool set. In the software part, the association rule algorithm combined with online analytical processing technology is used to mine the effective data in the collected data set to realize the analysis and processing of emergency command related work. Experiments show that the system can effectively command the output of the generator and obtain higher transmission margin when the fault occurs. And reasonably and evenly dispatch emergency resources to avoid resource waste.

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1. INTRODUCTION

In recent years, electric power safety accidents have often occurred. Electric power enterprises have major responsibilities in electric power production and emergency handling. Economic development leads to the increasing demand for electricity consumption [1–3]. The design of the electric power emergency command system can guarantee the safety of electric power production, accelerate the work efficiency of electric power enterprises, provide a basis for production decision-making of electric power enterprises, and strengthen their management level [4]. Electric power emergency command system is a command and dispatch platform built for a large area power failure caused by major electric power accidents and natural disasters. The electric power emergency command system can improve the speed of emergency repair and reduce economic losses [5]. Ziqiang *et al.* designed a power dispatching management system based on Mobile Ageo technology to accelerate data processing capacity, reasonably manage power resource dispatching, and improve the flexibility of power resource dispatching [6]. However, the system is not suitable for power resource scheduling when emergent faults occur. Hongsheng *et al.*

Keywords. Association rules, electric power emergency command, modular, component library, resource scheduling, spatial information service.

Shenzhen Power Supply Co., Ltd., Shenzhen, Guangdong 518000, P.R. China.

*Corresponding author: zhaoji37814@163.com

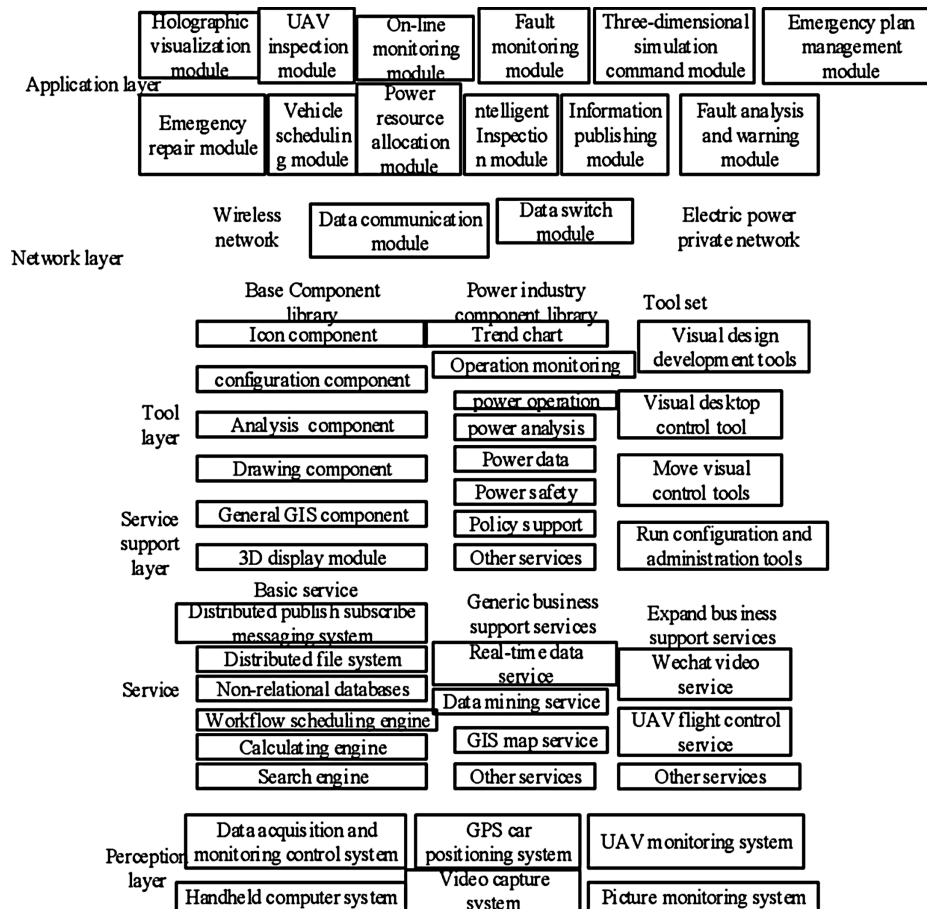


FIGURE 1. Overall system architecture.

designed an automatic power dispatching emergency system to improve the comprehensive capacity of power emergency dispatching by reducing the cost of emergency dispatching and improving dispatching efficiency [7]. The anti-interference performance of the system is poor in the process of power emergency dispatching when sudden faults occur, which reduces the effect of emergency dispatching. Association rules are a commonly used data mining algorithm, which can find valuable knowledge patterns in the database, complete data mining, and have the advantages of obtaining accurate mining results, supporting indirect data mining, and processing long data [8]. Therefore, the architecture of the power emergency command system based on the association rule algorithm is designed. When the power system fails, it can effectively command power resources, improve the quality of emergency repair and enhance the anti-interference ability of the system.

2. HARDWARE DESIGN OF ELECTRIC POWER EMERGENCY COMMAND SYSTEM

Based on the association rule algorithm, combined with the Internet of Things and spatial information technology, the power emergency command system is designed to provide analysis and command functions for power fault prevention and improve the reliability of power system operation. The overall architecture of the system is shown in Figure 1.

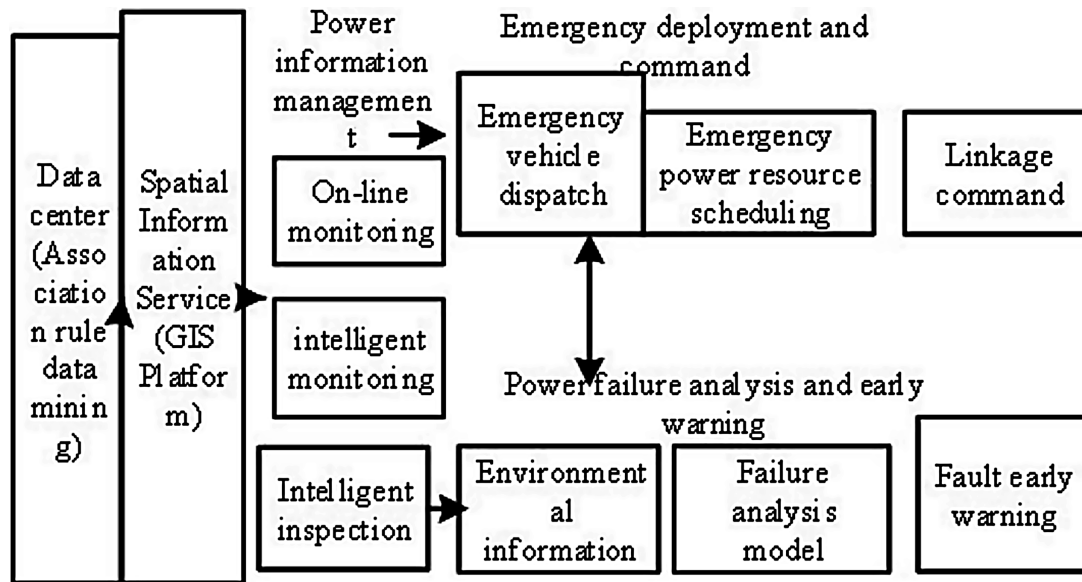


FIGURE 2. System functional architecture diagram.

The perception layer is responsible for monitoring transmission lines and distribution stations, etc., and is used to collect the operation data of each link of the power system and provide data support for the emergency command system. The perception equipment mainly includes an intelligent emergency terminal and a UAV.

In the service support layer, the service layer is responsible for providing data analysis and mining services, using the association rule algorithms to realize data mining, and providing more effective data for the upper application. Among them, UAV flight control services and other extended services can provide diversified services for upper applications. The tool layer establishes the basic component library and power industry component library according to the effective data obtained by the service layer and provides system management and visual operation tools.

The network layer is a bridge between the service support layer and the application layer and is responsible for transmitting the relevant information in the basic component library and the power industry component library to the application layer. The commands issued by the application layer are also transmitted from the network layer to the service support layer. The network layer has the function of two-way data transmission, which is realized by wireless network and power private network [9].

By calling the basic component library of the service support layer and the relevant information in the power industry component library, the application layer realizes the analysis and processing of the related work of the power emergency command. By calling the toolset of the service support layer, the three-dimensional simulation and visual operation of the power emergency command are realized, and the operation of the power system is monitored comprehensively. According to the spatial information service, the fault analysis and early warning module are built, and the emergency resources are allocated.

2.1. System functional architecture

The emergency command system is modularly designed from the perspective of functions, mainly consisting of four functional modules, and its functional architecture is shown in Figure 2.

Spatial information service has the power system spatial information analysis function. According to the power system emergency data and resource data, it builds the power system spatial data and environmental data and other data sharing service platforms to complete the power system emergency business service integration in

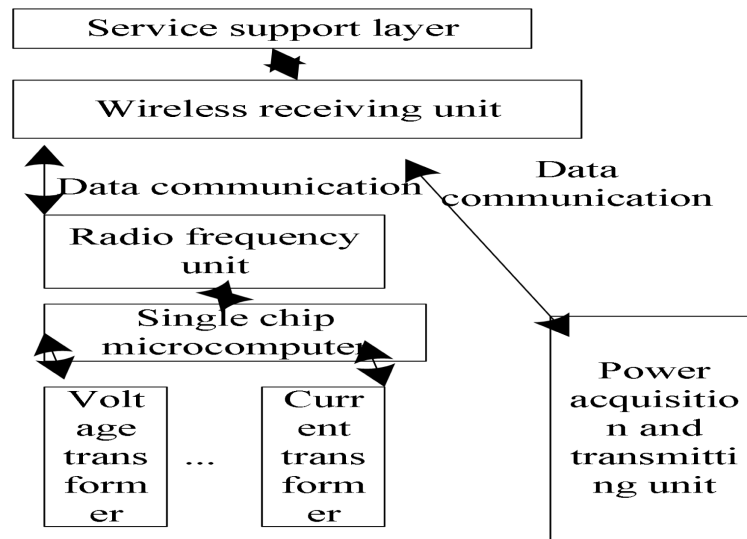


FIGURE 3. Data acquisition module.

GIS. In the process of emergency command, it has the functions of locating fault points and analyzing fault ranges.

Power information management is responsible for managing and using the effective power information mined and obtained by association rule algorithm as well as the relevant information in the basic component database and power industry component database in the service support layer, which provides effective data support for emergency command, including online monitoring and intelligent monitoring information [10].

Fault analysis and early warning are based on effective power system-related information. Combine with spatial information service to build fault analysis and early warning model, analyze the cause of power system failure, and timely send early warning information.

Emergency deployment and command is responsible for the implementation of power system emergency management and emergency time processing related business. Emergency vehicle scheduling is responsible for the scheduling and tracking of vehicles with GPS (Global Positioning System, satellite Positioning System) according to the spatial information service to obtain the real-time position and driving route of vehicles; in emergency power resource scheduling, GPS is used to obtain the real-time position and transportation state of power resources. The spatial information service and route decision model are combined to allocate emergency power resources reasonably. GIS is used to realize the graphical linkage command and dispatch of vehicles and materials.

2.2. Data acquisition module

The structural block diagram of the data acquisition module is shown in Figure 3.

A power acquisition and transmitting unit are installed in the monitoring position. A voltage/current transformer is used to collect the waveform. The microprocessor adopts an 8-bit single-chip microcomputer, which has the function of collecting, converting, analyzing, and storing waveform signals. Its internal serial communication interface can complete synchronous communication between the data receiving unit and the service support layer, and transmit real-time information to the service support layer for processing. The chip in the radio frequency unit contains a frequency synthesizer and modulator, etc., and has the advantages of low power consumption and strong anti-interference ability.

3. DATA MINING METHOD BASED ON ASSOCIATION RULE ALGORITHM

3.1. Association rule algorithm

Firstly, the attributes of power system-related data objects are analyzed. Then the On-Line Analytical Processing (OLAP) technology is introduced based on association rules to shape data cubes and improve the speed of data mining.

The main content of the association rule algorithm is transaction and support. Relevant definitions are as follows:

A transaction represents a known transaction data-base $Q = \{L_1, L_2, \dots, L_i, \dots, L_n\}$. A transaction in Q is $L_i = \{I_1, I_2, \dots, I_k, \dots, I_m\}$, $i = 1, 2, \dots, n$. T_i has only one identifier TID. Item is $I_k (k = 1, 2, \dots, m)$. The item sets $I = \{I_1, I_2, \dots, I_p\}$ belong to the set of all items in D . And a random subset of I is the item set of L . The set with k items is called k -item set. K is the number of items in I . L constitutes Q . One L has several items. I is only an item set for mining association rules of data in the power system [11–13]. Association rules represent the relationship between item sets X and Y . If X and Y conform to $X \subset Q, Y \subset Q, X \cap Y = \emptyset$, then the expression $X \Rightarrow Y$ is the association rule. X and Y represent the premise and conclusion of the rule, which indicates that if X exists in L , then Y also exists in L . The degree of support represents the proportion of L in Q where I is located. And the degree of support $X \Rightarrow Y$ represents the proportion of L in Q where there is an item set $X \cup Y$. The formula is as follows:

$$S(X \Rightarrow Y) = \frac{|X \cup Y|}{|Q|} \quad (1)$$

$|X \cup Y|$ is the number of $X \cup Y$ transactions in Q ; $|Q|$ is the total number of transactions in Q .

The confidence represents the percentage of both X and Y in Q , which belongs to the ratio of the number of X and Y in Q to the number of X in Q . $X \Rightarrow Y$ the confidence formula is as follows:

$$C(X \Rightarrow Y) = \frac{S(X \cup Y)}{S(X)} \times 100\%. \quad (2)$$

For $X \Rightarrow Y$, the value of C is proportional to the probability that Y appears in L where X exists.

Association rule mining $S_{\min}$ and $C_{\min}$ represents extracting strong association rules that meet the known threshold and within the known Q .

3.2. Association rule data mining method

OLAP is a method to analyze and process the data related to the power system acquired by the perception layer. The framework of association rule data mining method with OLAP technology is shown in Figure 4.

The specific steps of OLAP are as follows:

- Step 1.** Select the data to be analyzed from the power system related data obtained by the sensing layer;
- Step 2.** Create a corresponding data cube [14], which is called a work cube;
- Step 3.** OLAP work cube.

The specific steps of data mining method based on association rule algorithm are as follows:

- Step 1.** Create a data cube for the power system related data obtained by the perception layer by using OLAP technology, and use it as the input of the association rule algorithm;
- Step 2.** Initialization: $k = 1, I = \emptyset$;
- Step 3.** $k = k + 1$, form the candidate set B_1 and frequent set of 1-frequent set I_1 ;
- Step 4.** Repeat the operation I_{k-1} to form a k -frequent set B_k , and through B_k to generate a k -frequent set I_k , and then stop at $I_k = \emptyset$.

The process through B_k to generate B_k is as follows:

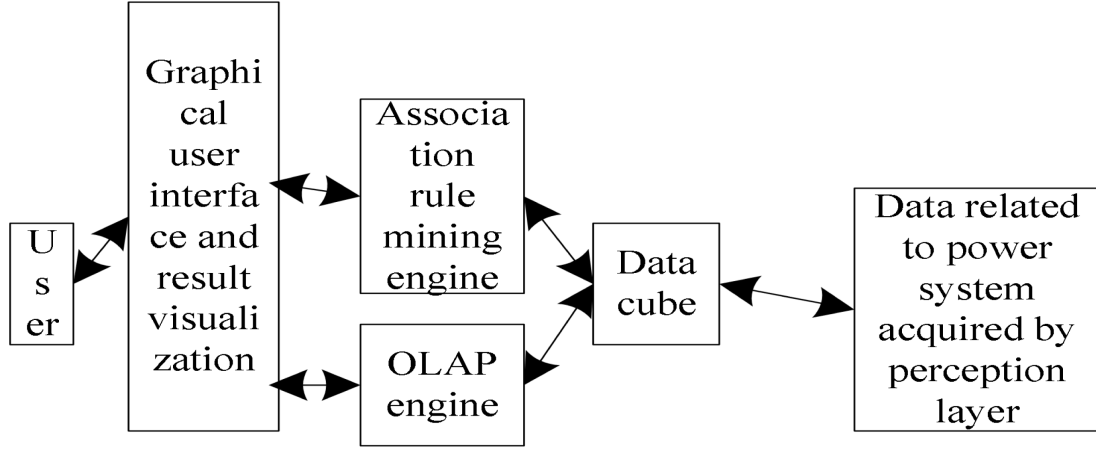


FIGURE 4. Framework of association rule data mining method.

Step 1. $B_k = \emptyset$;

Step 2. Repeatedly process the frequent sets within I_{k-1} and connect them in pairs. The connection condition is that the length is $k-2$, and there is $k-3$ frequent sets with the same item at the same time. Add the connection result B_k .

The process through B_k to generate I_k is as follows:

Step 1. Make $I_k = \emptyset$;

Step 2. Repeatedly process each candidate within B_k . Use OLAP engine to obtain the corresponding calculation value of each candidate, and judge whether each candidate meets $S_{\min}$ or not. If so, add to I_k .

When connecting two $(k-1)$ -frequent sets, if there is a common item $k-2$, then connect the two frequent sets to form k -frequent sets. Measure whether all subsets of k -frequent sets are I_k , and determine the candidate identity of each subset. If a subset is not I_k , then k -frequent set cannot be regarded as B_k . The formula for testing the number of subsets is as follows:

$$\sum_{k=1}^a (|I_{k-1} \otimes I_{k-1}| * (k-1)). \quad (3)$$

a represents the possible maximum number B_k ; $I_{k-1} \otimes I_{k-1}$ represents the number of k -frequent sets generated from $(k-1)$ -frequent sets; during the test, only subsets except $k-2$ th $(k-1)$ the two connected $(K-1)$ -frequent sets are tested, because the two connected $(K-1)$ -frequent sets are already frequent [15].

When scanning the data cube, the number of scans B_k can be obtained by solving the number of squares contained in each C , and the formula is as follows:

$$\sum_{k=1}^a (|B_k| * k * |R|). \quad (4)$$

$|B|$ represents the number of internal candidate items B_k ; $|R|$ represents the number of transactions in the data cube.

4. EXPERIMENTAL ANALYSIS

Taking an electric power company as the experimental object, the system in this paper is used to carry out the electric power emergency command of the electric power company, which is to test the power resource scheduling

TABLE 1. Generator output command results.

Generator node	Generator initial output/MW	The generator output of the system after emergency command/MW
29	660	660
30	665	665
31	659	659
32	632	659
33	618	634.7
34	559	574
35	569	584
36	549	549
37	539	539
38	866	866.2

TABLE 2. Actual power of two sections, TTC and TRM.

	Section	Active/MW	TTC/MW	TRM/%
Section 1	The initial value in normal condition	988.7	1200.6	11.24
	After system emergency command	1139.9	1199.7	10.48
Section 2	The initial value in normal condition	890.7	1153	15.3
	After system emergency command	930.5	1175.8	14.5

situation of the system in the case of failure and verify the effectiveness of the electric power emergency command of the system in this paper.

Taking the power system of the power company as the prototype, the simulation experiment is carried out through the New England 10-machine 38-node system. The experimental settings are as follows:

- (1) The power system consists of two sections, one consisting of 16–26 node lines and 24–25 node lines, and the other consisting of 8–38 node lines, 2–3 node lines, and 14–15 node lines.
- (2) Two emergencies are set for two sections. One is a failure in section one, and the maximum power of the line is greater than 650 MW. The second condition is a failure in section two, and the maximum power of the line is greater than 650 MW.

A load of each node in the power system is increased. The total load of the power system is increased by 110.72 MW. The load lifting operation is completed after the power system runs for 6min. All the generators except the 38-node generators are deployed for emergency power dispatching to ensure that the power system can reach balance after the load lifting. The generator output command results of the system in this paper when two conditions occur simultaneously are shown in Table 1. The actual power, Total Transmission Capacity (TTC), and Transmission margin of the two sections are shown in Table 2. Transmission Reliability Margin (TRM) represents the Transmission capacity required to ensure system security when the power system is in trouble. When TRM exceeds 10%, the security of system operation can be ensured.

Based on the comprehensive analysis of Tables 1 and 2, it can be seen that the generator output after the emergency command of the system in this paper has a small gap with the initial output of the generator. The maximum output gap is only 27 MW, indicating that the power system can operate safely after the emergency command of the system in this paper in case of failure. Section of a failure, after using the emergency command system in the actual power compared to the initial power of the cross-section a slightly ascending, TTC and initial TTC slightly lower after the emergency command. Emergency command after initial TRM fell by only 0.76%, which compared to the TRM system in this paper. It indicates that after the emergency operation to

TABLE 3. Minimum requirements for emergency resources for troubleshooting.

Emergency	The fault object	Minimum emergency resource requirements
State 1	Low pressure branch box Z_1	5 personnel, 2 vehicles, 15 tools
	Low voltage metering equipment Z_2	3 personnel, 2 vehicles, 7 tools
	Low voltage distribution box Z_3	5 personnel, 2 vehicles, 15 tools
	Low voltage line Z_4	7 personnel, 4 vehicles, 30 pieces of tools
	Into the door device Z_5	5 personnel, 2 vehicles, 7 tools
State 2	Internal customers Z_6	3 personnel, 2 vehicles, 9 tools
	Transformer Z_7	7 personnel, 4 vehicles, 46 pieces of tools
	Medium voltage cable line Z_8	11 personnel, 4 vehicles, 55 pieces of tools
	Medium voltage overhead line Z_9	11 personnel, 5 vehicles, 60 pieces of tools
	Column on the equipment Z_{10}	9 personnel, 4 vehicles, 25 pieces of tools

TABLE 4. Emergency resource scheduling results of three emergency teams.

Emergency response team	Repair the faulty object	Personnel/number	Vehicle/number	Tools/pieces
Group 1	Z_1, Z_2, Z_3	20	7	40
Group 2	Z_4, Z_9, Z_{10}	30	14	120
Group 3	Z_5, Z_6, Z_7, Z_8	30	13	120

ensure the system security needs of transmission capacity is still in accord with a standard, which ensures the safety of power system operation. When a fault occurs in Section 2, there is little difference between the actual power and TTC after emergency command and the power and TTC in the initial state. Compared with the initial TRM, the TRM after emergency command only decreases by 0.8%, which also meets the standard of transmission capacity required to ensure system security. Experimental results show that the system can effectively command the generator output under different power conditions, which ensures that the TRM of the power system meets the operation standard, and also ensures the safety of the system.

Each of the two emergencies contains five fault objects. Table 3 lists the minimum emergency resource requirements of each fault object.

When two situations occur at the same time, the system in this paper designs an electric power emergency command plan according to the emergency repair time and the emergency resources needed, and conducts emergency resource scheduling for each fault object to complete the emergency repair work. The scheduling results of electric power emergency resources designed in this system are shown in Table 4.

According to Table 4, when various faults occur in the power system, the system in this paper can effectively design the power emergency command plan, reasonably schedule the power emergency resources, and reasonably allocate personnel, vehicles, and tools to the three emergency teams. The resource scheduling results are slightly higher than the minimum requirements of each failure object. At the same time, each team personnel scheduling results with minimum personnel demand differs 4, 3, and 4, respectively. The actual vehicle scheduling results with the minimum requirements of both differ 1 vehicle. Practical tool machine scheduling results differ with the minimum requirements are 3, 5, 3 pieces. This article system for electric power emergency resource scheduling can even schedule various kinds of emergency resources. At the same time, it can also avoid the waste of emergency resources and improve the quality of the emergency repair.

To verify the anti-interference performance of the system in conducting electric power emergency commands in this paper, a total of 80 interference samples were added to the power system. The interference samples were

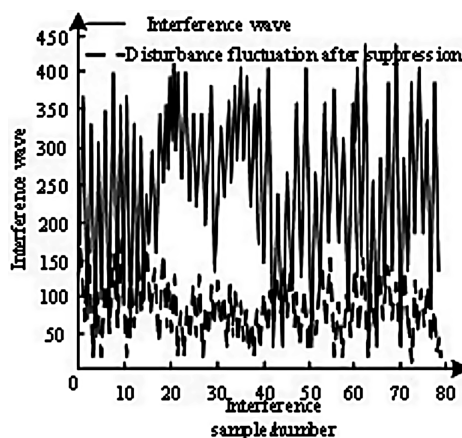


FIGURE 5. Anti-interference test results.

suppressed by the system in this paper. The interference fluctuation in the power system should be controlled within 200 dB. The anti-interference test results of the system in this paper are shown in Figure 5.

According to Figure 5, the system in this paper can effectively suppress the interference fluctuation in the power system. Compared with the actual interference fluctuation, it shows a very significant downward trend and keeps the interference fluctuation within 200 dB, which does not exceed the interference fluctuation demand of the power system. The reason is that the data acquisition module designed in the system in this paper has strong anti-interference ability, which can effectively suppress the interference fluctuation in the collected data and ensure that there is no interference fluctuation in the data required by the subsequent system emergency command.

5. CONCLUSION

Electric power emergency command system belongs to the emergency command system in the specific application of the electric power industry, which is to effectively integrate information resources in the power system. Obtain emergency command plan, ensure the safe operation of power system, and design electric power emergency command system based on association rules algorithm architecture. In power system failure, it is suggested to effectively design emergency command plans, reasonably scheduling of emergency resources, improving the quality of emergency repair, and reduce economic losses. Due to the time limit, the power emergency command system designed in this paper can be further improved. The system functions can be further expanded in the future. The power emergency command system can predict power emergent faults according to the relevant data of the power system, and improve the power emergency command system's ability to deal with sudden faults.

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