Research on substation intelligent monitoring scheme under big data environment

Peng Lu, Feifei Zhang, Shichao Fan
State Grid Hebei Electric Power Supply Co., Ltd. Shijiazhuang, China.

***Abstract*—With the comprehensive implementation of 500kV unattended substation, centralized monitoring information is growing. For the requirement of fast treatment of monitoring information and data, big data theory has been gradually introduced in the field of power system. In this paper, the substation intelligent monitoring scheme under big data environment is investigated. Firstly, the substation centralized monitoring mode and present condition are introduced. Secondly, based on the theory of big data and the intelligent analysis algorithm, intelligent monitoring scheme is studied. The scheme mainly includes four aspects: intelligent inspection plan, signals intelligence surveillance, technical support of rapid fault treatment and auxiliary decision function. The implementation process of each functional module is analyzed and established, respectively. Finally, the actual operation interface of the intelligent monitoring system is presented. The scheme proposed in this paper can assist the monitor to fully understand the meaning of alarm signals, lighten the load of substation attendant and improve the accuracy and speed of the treatment in abnormal or accident circumstances, so as to guarantee the safe operation of power grid.**

***Index Terms*—big data, centralized monitoring, intelligent monitoring, unattended operation**

I. INTRODUCTION

WITH the comprehensive implementation of 500kV and below voltage level unattended substation， the monitoring responsibility of the substation is transferred to the dispatching and control center at all levels. With the rapid development of power grid in recent years, centralized monitoring information is growing. Although the remote monitoring and alarm system is constantly upgrading and optimizing [1], the operation of substation inspection, alarm signal processing and fault disposal judgment still need manual operation, which is highly dependent on the level of the monitor. Therefore, it is urgent to integrate more automation technologies on the basis of existing monitoring systems to help monitors to carry out business. The monitoring information of substation has the following characteristics: 1) large scale of data and high requirement for processing time; 2) variety of data types, including semi-structured and unstructured data, etc. which the traditional data processing technology cannot meet the requirements; 3) the source data shall be processed [2]. Therefore, the monitoring information has the '5V' characteristics of big data, such as volume, velocity, variety, veracity and value [3]. For the requirement of fast treatment of information and data, big data theory has been gradually introduced in the field of power system, which can significantly improve the level of intelligent analysis of monitoring business.

The newest technical specifications about power gird real time supervisory control & early warning(GB/T 33697-2017, DL/T 1709.4-2017) [6-7] give the general requirement of power grid monitoring system, which is the standard to be followed in big data monitoring modelling. The corresponding standards for real-time monitoring and early warning of the power grid are interpreted in literature [8-9].The overall design of the big data monitoring analysis system is described in literature [10], and the visualization technology for power grid real-time monitoring is studied and analyzed in literature [11].

The rest of the paper is organized as follows: Section 2 analyzed the current situation and problems of substation centralized monitoring, on this basis, the demand for improvement is proposed; in Section 3, based on the theory of big data, an intelligent monitoring scheme for substation under big data environment is proposed, which include 4 parts: intelligent inspection plan, signals intelligence surveillance, technical support of rapid fault treatment and auxiliary decision function, then the implementation process of each functional module is analyzed and introduced, respectively; in Section 4, the actual operation interface of the intelligent monitoring system is presented; and conclusions are drawn in Section 5.

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Peng Lu is with the State Grid Hebei Electric Power Supply Co., Ltd. Shijiazhuang, China. (e-mail: lup@he.sgcc.com.cn).
Feifei Zhang is with the State Grid Hebei Electric Power Supply Co., Ltd. Shijiazhuang, China. (e-mail: 648979885@qq.com).
Shichao Fan is with the State Grid Hebei Electric Power Supply Co., Ltd. Shijiazhuang, China. (corresponding author, phone: 18000319169; e-mail: fsc25598@126.com).

II. THE CURRENT SITUATION AND PROBLEMS OF SUBSTATION CENTRALIZED MONITORING

A. The monitoring tasks of substation

The monitoring tasks of substation can be divided into two parts: routine monitoring tasks and rapid disposal after fault. The routine monitoring tasks includes two parts: intelligent inspection plan and signals intelligence surveillance. The rapid disposal after fault mainly includes the accurate report about action information of the equipment and the protection after the fault and the judgment of whether the transmission line meets the requirement of remote resume of power delivery. The specific monitoring tasks are shown in table 1.

TABLE 1
CLASSIFICATION TABLE OF SUBSTATION MONITORING TASKS

Task classification		Specific monitoring content
Routine monitoring tasks	**Intelligent inspection plan**	**Remote measuring :** Switch and line three phase current, three phase voltage, bus voltage, transformer oil temperature, system frequency ,etc.
		Alarm window: substation public signal, interval signal and DC signal.
		Remote communicating: Whether the display state of the monitor screen is consistent with the actual state
		Equipment load monitoring: monitoring the risk of overloading
	Signals intelligence surveillance	Real-time monitoring of four types of information: **accidents, anomalies, over-limits,** and **displacements**.
The rapid disposal after fault	**Accurate report about action information after the fault**	Accurately and timely summarize fault related information and report it to the related dispatchers
	Judgment of remote resume of power delivery	Based on the 5 rules of condition discrimination about the fault outage line.

B. Analysis of substation monitoring problems

With the development of power grid and the rapid growth of the number of substations, the daily inspection time is increasing, and the security monitoring task of the power grid will become more difficult. As a result of this, the following problems may exist:

1) **Insufficient inspection**. The inspection work requires the monitor to concentrate on completing. With the increase of the inspection workload and the extension of the time consuming, the omission inspection and wrong inspection may occur, which may cause a hidden danger for the safety of the power grid. If automatic inspection can be realized and the inspection result can be reported automatically, and it will significantly improve this problem.

2) **Monitoring alarm information is monotonous.** At present, the monitoring alarm signal contains only the signal alarm information, and the related information such as the signal interpretation, alarm causality, equipment information, and historical information can't be sent synchronously, which is not good for the monitors to make the monitoring inspection plan quickly.

3) **Lack of technical support during fault treatment.** At present, the large and scattered alarm information sent out by the system after the fault is not good for the monitors to analyze and report the fault timely.

4) **Lack of alarm information statistics and recording functions.** If the history information such as the number of reporting, processing method and recovery time of the same signal can be recorded and counted, it can not only provide reference for the monitors when making signal disposal scheme, but also can provide data support for the research of monitoring information.

C. Real time monitoring and warning standard

The newest technical specifications about power gird real time supervisory control & early warning (GB/T 33697-2017, DL/T 1709.4-2017) give the general requirement of power grid monitoring system, which is the standard to be followed in big data monitoring modelling. Due to the limitation of space, this paper will not repeat it.

III. INTELLIGENT MONITORING SCHEME UNDER BIG DATA ENVIRONMENT

A. Overall structure

The intelligent monitoring scheme proposed in this paper realizes standardized data access to various forms of data, integrating D5000 real-time data, OMS, PMS, fault recording system, condition monitoring, weather and lightning location systems and other data sources.

By means of the verification rules engine and the data extraction transformation loading (ETL) tool, the extraction data is cleaned and standardized. This data access method ensures the comprehensive, unified and high quality of the relevant data, which lays a foundation for the upper data storage.

In the big data modeling and analysis module, four main functions of intelligent monitoring are realized through the big data causality analysis, principal component analysis, clustering analysis, neural network and so on. The intelligent inspection plan, signals intelligence surveillance, technical support of rapid fault treatment and auxiliary decision functions are realized. These four functions will be described in detail below.

Finally, a comprehensive display of the above intelligent monitoring results is realized through a visual display application platform. The overall structure diagram of the above intelligent monitoring scheme is shown in the Fig.1.

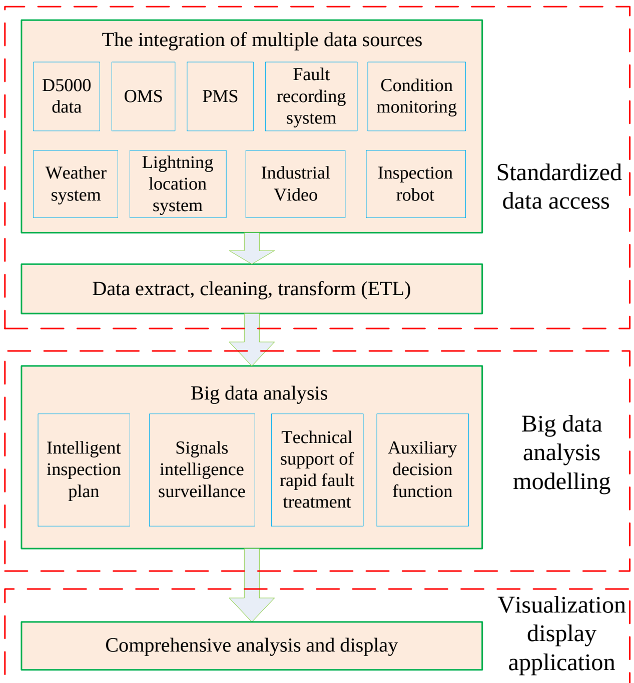

Fig.1 Overall structure diagram of the intelligent monitoring scheme

B. The intelligent inspection plan

The intelligent inspection plan has the function of one-key automatic inspection and uploading inspection results. When the monitor clicks the automatic inspection button, it can realize the automatic inspection of the controlled station and report the inspection results. The implementation process includes three steps: source data extraction and storage, data processing and storage, and display of inspection results. The data processing flow of the intelligent inspection plan is shown in the Fig.2.

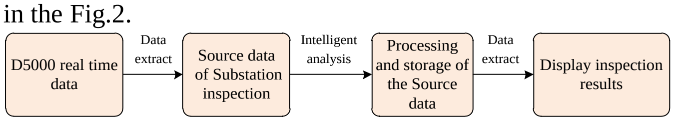

Fig.2 Data processing flow of intelligent inspection plan

a) Source data extraction and storage

The data required for substation inspection is extracted from the D5000 system and stored as inspection source data, such as three-phase current of breaker, bus voltage and transmission line load data, etc.

b) Data processing and storage

In order to realize automatic inspection, the source data should be processed, and the required data should be selected for storage, providing data for display of inspection results. The methods are as follows:

(1) Data processing of the breaker current

Principle of the breaker off phase: 1）In the three-phase, the one-phase current is zero and the other two phases have the current; 2) In the three-phase, the two phases current is zero and the other one phase has the current; 3) the switch is in the closed position, and the three-phase current is zero.

According to the above criteria, the three-phase current of a breaker is diagnosed. If one of the above conditions is satisfied, the relevant data (substation, interval, name, number and three-phase current value of the equipment) will be stored.

Three phase deviations of current. According to the collected current data, the maximum deviation ratio is calculated according to equation (1), and the specific data of the breaker whose deviation ratio is greater than 50% is stored.

$$\sigma_{\max} = \frac{I_{\varphi\max} \text{-} I_{\varphi\min}}{I_{av}} \times 100\% \tag{1}$$

where the $\sigma_{\max}$ is the maximum deviation ratio; $I_{\varphi\max}$ is the maximum phase current; $I_{\varphi\min}$ is the minimum phase current; I_{av} is the three phase average current.

(2) Bus voltage automatic inspection

Compare the source data of bus voltage with the upper and lower limits of bus voltage operation curve, and store the specific information of over-limit equipment. The calculation formula is as follows:

$$\alpha\% = \frac{U_0 \text{-} U_{\text{limit}}}{U_{\text{limit}}} \times 100\% \tag{2}$$

where the $\alpha\%$ is the over-limit ratio of bus voltage; U_0 is the actual voltage; U_{limit} is the limit value of the bus voltage.

(3) Inspection of the equipment load

Calculate load rate of power equipment and store equipment data when the load rate greater than 90%. The calculation formulas of the load rate of transmission line and transformer are respectively shown in equations (3) and (4).

$$\eta_{\text{line}} = \frac{I_0}{I_n} \times 100\% \tag{3}$$

where η_{line} is the load rate of transmission line; I_0 is the actual current of line; I_n is the rated current of line.

$$\eta_t = \frac{P_0}{P_n} \times 100\% \tag{4}$$

where η_t is the load rate of transformer; P_0 is the actual active power of transformer; P_n is the rated active power of transformer.

(4) Intelligent inspection of alarm windows

The status of the substation alarm windows has two states of

"1" and "0", the alarm state is "1" and the normal state is "0". Therefore, the optical characters with state of "1" can be retrieved and stored from the D5000 information library, removed from the constant brightness alarm message, and displayed in a centralized way.

(5) Automatic inspection of remote communicating

Collect the breaker position status information π (1 in the closed position, 0 in the open position.) and the three-phase current value I (when the three-phase current existed, the value is "1", conversely the value is "0"). Make a judgment according to equation (5) and (6).

$$\begin{cases} \pi = 1 \\ I = 0 \end{cases} \tag{5}$$

$$\begin{cases} \pi = 0 \\ I = 1 \end{cases} \tag{6}$$

If the breaker state satisfies one of equation (5) or (6), the remote communicating value is wrong, and the relevant data will be stored.

c) Display of inspection results

(1) The visual display

The visual display can be used for large-screen display, and the most serious of the various inspection results are displayed on the graph. For example, the visual display of the three-phase deviation of the breaker off phase and the current is shown in the Figs.3 and 4. Other visual displays are similar to this kind of display form, and will not be repeated in this paper.

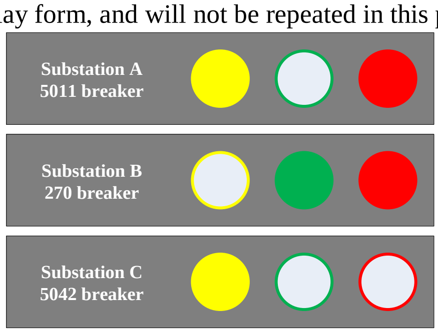

Fig.3 Visualized diagram of breaker off phase

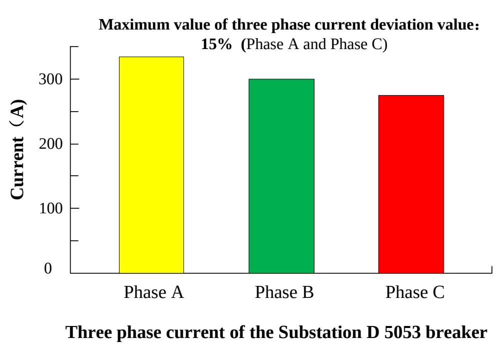

Fig.4 Visualized diagram of three phase current deviation value

(2) The table display

The results of automatic inspection will be shown in the form of a table. The results of breaker three-phase current inspection are shown in table 2. The rest of the inspection results are similar and will not be repeated.

TABLE 2
RESULTS OF BREAKER THREE-PHASE CURRENT INSPECTION

Category	Substation name	Equipment number	I_a(A)	I_b(A)	I_c(A)	Fault phase
Off phase	Substation A	5013	189	187	0	Phase C
	Substation name	Equipment number	I_a(A)	I_b(A)	I_c(A	Maximum deviation
Current deviation	Substation E	212	600	300	580	60.9%

C. Signals intelligence surveillance

Complete data and large amount of information are the main characteristics of the signals intelligence surveillance scheme, and the establishment of alarm database is the premise of the function.

***a)* Establishment of alarm database**

The alarm database include four parts: signal interpretation database, alarm causality database, equipment information database and historical database.

(1) Signal interpretation database.

The signal interpretation database should contain all the interpretation of alarm signal. Signal interpretation refers to the description of the specific meaning of the alarm signal. Such as the alarm signal “×× breaker low pressure alarm of SF_6” means monitoring the SF_6 value of the breaker body, reflecting the internal insulation condition of the breaker. Due to SF_6 pressure reduction, the pressure relay takes action.

(2) Alarm causality database.

This database should contain the possible causes and possible consequences of all kinds of alarm signals. For example, the cause of the signal "××breaker low pressure alarm of SF_6" are as follows: 1) circuit breakers have leaking point, pressure drop to alarm value; 2) pressure relay damage; 3) loop fault; 4) according to the pressure temperature curve of the SF_6, the SF_6 pressure value changes when the temperature changes. The possible consequences are as follows: if the SF_6 pressure continues to decrease, the breaker is locked up.

If the equipment related to the breaker is faulty at the time, the breaker refuses to move, the failure protection of circuit breaker has to take action to cut the fault, as a result of this, the accident range is expanded.

(3) Equipment information database.

The equipment information database should contain the model, type and related data requirements of all controlled equipment. For example, model and operating mechanism of

×× circuit breaker: LW12-500, hydraulic disc spring, and SF_6 related values of ××circuit breaker body: SF_6 rated pressure: 0.5Mpa; SF_6 alarm pressure 0.45Mpa; SF_6 locking pressure 0.4Mpa, etc.

(4) Historical database. The historical database should contain information such as the time and cause of the alarm signal and the disposal process of the signal.

***b)* Implementation process of signals intelligence surveillance**

When there is an alarm signal (which does not return within 30s, many signals will alarm and return for a short time due to system interference and other reasons), according to the signal content, relevant data will be searched from the above database automatically, and the data will be extracted and stored. If the monitor needs it, the stored data can be opened for inspection. Meanwhile, the monitor can record the disposal process of the alarm signal and update it to the historical database. The specific flow chart is shown in the Fig. 5.

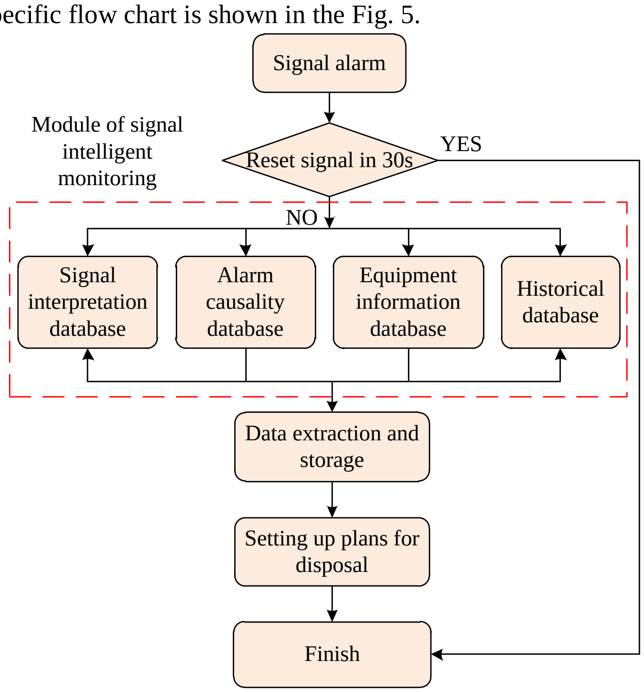

Fig.5 Diagram of signals intelligence surveillance

D. Technical support of rapid fault treatment

After the fault of power equipment, the monitor is required to make a preliminary analysis and judgment of the fault through the relevant alarm information at the first time and accurately report it to the corresponding dispatchers. Meanwhile, for the fault of transmission line, it is also required to report whether the transmission line meets the requirement of remote resume of power delivery as soon as possible.

In the existing monitoring system, the source of each signal data is relatively scattered. After equipment fault, the monitor needs to check the alarm window of D5000, fault equipment interval, fault recording system, industrial video and other systems one by one to comprehensively grasp the equipment fault information, and then decide whether the transmission line meets the requirement of remote resume of power delivery. When multiple faults caused by bad weather and other factors occur in the power grid, the existing working mode poses a severe challenge for the monitor to accurately analyze and report the fault information. In view of the shortcomings of the existing working mode, the following technical support of rapid fault treatment is proposed in this paper, and it is shown in the Fig. 6.

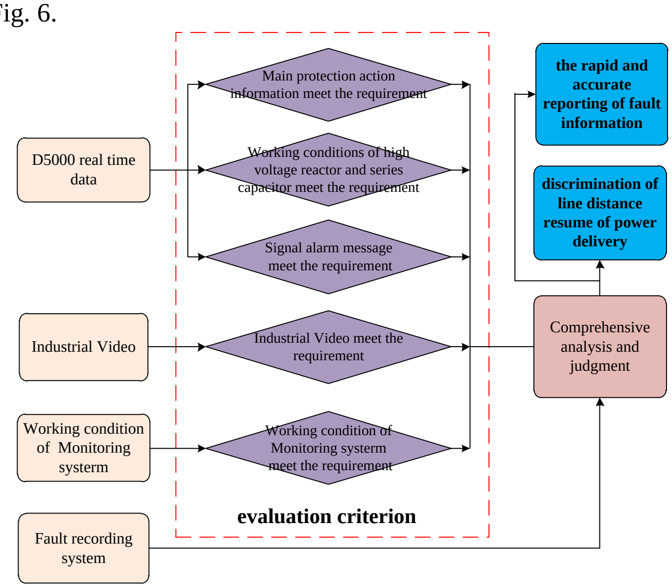

Fig.6 Diagram of technical support of rapid fault treatment

The module reads the standardized D5000 real-time data, industrial video, working condition of monitoring system, fault recording information, and analyzes whether the fault information meets the requirement of remote resume of power delivery through big data causal analysis, image recognition and other intelligent analysis methods. The evaluation criterions are judged one by one, and the judgment results are output after the comprehensive analysis. Moreover, the fault information is also intelligently summarized, which can better meet the time limit requirement of fault reporting.

E. Auxiliary decision function

The existing monitoring auxiliary systems are mostly scattered and isolated systems due to technical conditions and other reasons. The auxiliary decision function proposed in this paper mainly supports equipment monitoring from two aspects: bad weather warning and substation equipment condition monitoring, and it is shown in the Fig.7.

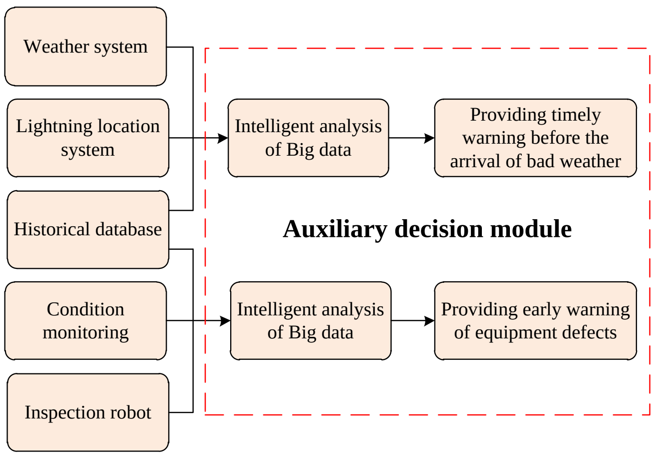

Fig.7 Diagram of auxiliary decision function

The weather warning module of bad weather reads the standardized data of weather system, the real-time data of lightning location and the historical database. Through the principal component analysis and the causality analysis processing algorithm in the big data analysis module, the weather conditions in various regions are prejudged for a period of time, especially for the extreme weather. The auxiliary decision function will give a clear warning of the bad weather, so that the monitor can anticipate the accident ahead of schedule.

For the substation equipment monitoring auxiliary support, reading the real-time and historical data of the standardized access condition monitoring system and the inspection robot to get the analysis data. Through the modeling of the big data analysis platform, the potential hidden danger of the equipment is discovered in advance. It can also give advice on strengthening equipment monitoring, so as to better monitor and control the operation of equipment.

IV. DISPLAY OF SYSTEM OPERATION

At present, the big data platform based on the operation data of the whole power grid has been constructed in the OMS system of Hebei Electric Power Supply Company, and it has realized the function of visual display. The display of system operation is shown in the Fig. 8.

The intelligent monitoring system proposed in this paper is based on the big data platform of the whole power grid operation, which can realize the intelligent operation of the monitoring business. It is of great significance to reduce the workload of the monitors, improve the accuracy and speed of accident and abnormal treatment, and guarantee the safe operation of the power grid.

Fig.8 Display of system operation

V. CONCLUSION

In this paper, the intelligent monitoring scheme under big data environment is analyzed and established. The monitoring scheme has the following advantages: 1) the combination of computer automatic inspection and manual inspection ensures the correctness and comprehensiveness of the inspection results. 2) Effectively reduce the workload of the monitors. 3) Significantly improve the accuracy and speed of the treatment in abnormal or accident circumstances.

Next, the big data platform and intelligent analysis algorithm will be further investigated and improved to increase the level of intelligent monitoring.

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Peng Lu received the B.S. degree from North China Electric Power University, Baoding, China, in 2003. Presently, he is a Senior Engineer in State Grid Hebei Electric Power Supply Co., Ltd. His research interests include power systems analysis, smart dispatching and security analysis.
Email: lup@he.sgcc.com.cn

Feifei Zhang received the M.S. degree from North China Electric Power University, Beijing, China, in 2013. Presently, he is an Engineer in State Grid Hebei Electric Power Supply Co., Ltd. His research interests include power systems analysis, smart dispatching and security analysis.
Email: 648979885@qq.com

Shichao Fan received the M.S. degree from Harbin Institute of Technology, Harbin, China in 2016. Presently, he is an assistant engineer in State Grid Hebei Electric Power Supply Co., Ltd. His research interests include power systems analysis, smart dispatching and security analysis. (Corresponding author)
Email: fsc25598@126.com