Intelligent Research and Judgment System for Power Grid Outage Fault Based on Abnormal Signal Situation Perception

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ABSTRACT.

With the rapid development of the social economy and the continuous improvement of living standards, the demand for load is growing rapidly. Medium and low voltage users, especially high-risk and important users, have increasingly high requirements for power supply reliability and reducing power outage time. When a power grid failure occurs and power outage occurs, it is crucial to promptly determine the fault location, minimize fault repair time, restore power supply, and reduce user power outage time, improve power supply reliability, and user satisfaction. This system is based on the enterprise level real-time measurement center to obtain the switch SOE signals actively reported by secondary monitoring devices such as concentrators, FTUs, DTUs, and fusion terminals. After signal cleaning and filtering, the system aggregates, classifies, analyzes, and determines the event of switch tripping or resetting. Then, it is associated and matched with a device network to generate power outage events for high and medium power lines in the power grid. The high-voltage lines are accessed through marketing data to determine the affected high-voltage and important users, and the number of transformers and low-voltage users is determined for medium voltage lines. The power outage scope is accurately determined, and corresponding fault power outage events and affected equipment are pushed in real time to support power outage monitoring, proactive repair, and other work.

Keywords: Security abnormal signal situational awareness; Fault analysis and judgment; Power outage analysis and judgment; Intelligent research and judgment;.

1. INTRODUCTION

Based on the increasingly higher requirements for power supply systems[1], In related applications such as power supply service command systems, fault analysis and judgment business construction has been carried out. At present, the main research methods for fault location in distribution network include traveling wave method[2], location method based on perturbation method[3], method based on signal injection[4-5], etc. However, there are problems such as incomplete data collection, low real-time performance, lack of and inaccurate source data, and real-time power grid topology. In particular, the low-voltage user collection coverage and frequency are insufficient, which affects the accuracy of power outage event analysis and judgment[6]. There are problems such as long troubleshooting time, high risk of customer complaints and many safety hazards[7]. There is an urgent need to improve distribution network fault analysis and judgment strategies, improve the timeliness of fault repairs, and ensure the quality and efficiency of repairs. Therefore, it is necessary to address the above problems and provide a main distribution network fault location research and judgment system that can quickly sense the operating status of the power grid to ensure rapid discovery and rapid recovery after a power grid failure. Through the optimization of power grid fault analysis and judgment strategies, real-time analysis and judgment of effective power outage events improves the accuracy and timeliness of fault analysis and judgment. At the same time, corresponding medium and low voltage fault events are pushed in real time to support the development of related work such as power outage information reporting, proactive repairs, and reliability management. Improve power supply service levels.

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2. GENERAL IDEA OF RESEARCH AND JUDGEX

The enterprise-level real-time measurement center gathers the switch displacements and power-off events pushed by the source collection system. After the measurement center model conversion, all sources of power outage events are disassembled into transformers or user power outages. After completion and repair according to the transformer or user's power outage, they will be merged according to the line and switch to which the transformer belongs, the meter box and station area corresponding to the user, and at the same time according to the power outage time range (medium voltage power outage time difference is 45 minutes, low voltage 15 minutes), Form a unified collection of power outage events. It is divided according to elements such as the scope of impact of the power outage event equipment, the nature of the power outage, etc., without too many business attributes. The process is shown in Figure 1:

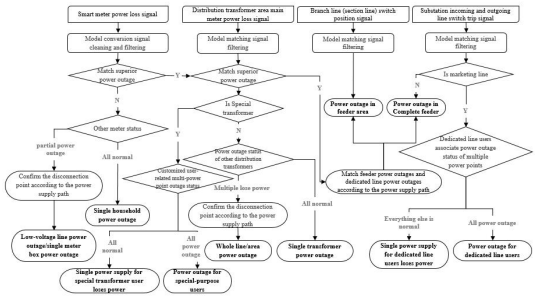

Figure. 1 The overall process of comprehensive research and judgment of main distribution network

3. MAINNET SWITCH SOE SIGNAL ANALYSIS MODULE

The main network research and judgment is based on SOE signal analysis, including three processes of data acquisition, data cleaning and data analysis. Among them, the data analysis process first groups and sorts substations, and then conducts a general analysis and judgment of interval accidents based on the status of the last data in the group and whether there is a record of non-resumption of power. The total accident data of the whole station can be converted into the total interval accident data for research and judgment. The process is shown in Figure 2:

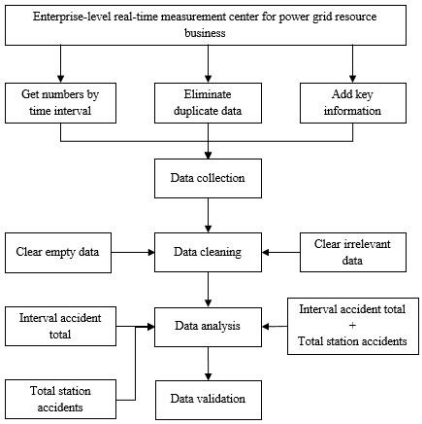

Figure. 2 Main network research and judgment process based on SOE signal analysis

3.1Data acquisition and processing

The switch SOE signal analysis is connected to the total station accident and interval accident total signals through the measurement center, combined with the power outage plan of the business center, to eliminate planned power outages and other power outage events, and use real-time load data to determine the effectiveness of the final synthetic fault. First, preprocess the total accident signal of the switch, retrieve the switch name and fault description information, and filter out the information containing capacitor, reactor, energy storage battery, battery pack, bus coupler, test, local control, segmentation, bus denominator, Recording of 21 types of information such as reactive power, isolating switches, voltage transformers, arc suppression coils, etc., because this type of data is large in volume and cannot be used as a basis for switch tripping. At the same time, some dirty data is filtered out, such as signals without switch IDs and event identifiers. After that, the signal is filtered twice, and the fault content includes "protection action reset", "zero sequence

I section action reset", "zero sequence II section action reset", "reclosing action reset", "reclosing reset", " Recloser outlet reset" and other related information are considered to be secondary equipment resets and are filtered out without processing.

3.2 Data analysis

The total accident signals are grouped into substations, and the switch signals in the same station are analyzed uniformly. The inspection signal is judged after the substations are grouped. If there is an inspection signal in a certain substation group, the substation is considered to be in an inspection state. Since the signals are relatively dense, the signals under the same station are segmented and processed at intervals of 30 seconds. It is divided into three situations: pure total signal processing for interval accidents[8], pure total signal processing for all-station accidents[9], and total mixed signal processing for all-station and interval accidents.

For interval accidents, if the interval between two accidents does not exceed 30 minutes, they can be merged. Using the switch as the key object for retrieval, the end time of the previous fault and the start time of the new fault, which do not exceed 30 minutes, can be merged.

3.2.1 Interval accident total signal processing

Read the status of the earliest time and latest time of each switch in turn.

If the status of the read interval accident total signal is on, search the power outage and restoration record table. If there is no record of unrestored power, create a new power outage and restoration record, write the trip information; and update the switch status and time; If there is a record that has not been restored, it is determined that the record is in an intermediate state and discarded. And update the switch status and time.

If the read total signal status of the interval accident is a reset signal, retrieve the power outage and restoration record table. If there is a record of unrestored power, write it into the power outage and restoration record table, and update the switch status and time at the same time; and calculate the power outage duration. If the power outage lasts less than 1 minute, a short-time power outage record mark will be marked. Replace the 30-second segment interval with the duration of the power outage, and execute the SOE record of the substation again. Theoretically, the power outage and restoration records will no longer appear. If there is a power outage and restoration record of power restoration, retrieve the power restoration time. If the difference between the power restoration time of the latest power outage restoration record and the new power restoration signal time is within 4 hours, update the power restoration time of the record; If the time difference exceeds 4 hours, a new power outage and restoration record is created, but this record does not have a trip time.

3.2.2 Total station accident signal processing

First perform fault description switch fuzzy matching. The method is to retrieve all the switches under the substation, and use the switch code, switch name, switch name and line in order to match the fault description.

If the matching is successful, it is considered that all station accidents in this time segment always point to this switch, thus converting the total station accident total into the interval accident total of this switch. Then conduct research and judgment on whether the total station accident recovery signal is true or false. That is, query the latest record in the time segment, and use the obtained switch ID to query the switch position at the corresponding moment. If the switch position is closed, the reset signal is true; if the switch position is open, the reset signal is false. The false signal is discarded, and the true signal confirms that the switch is closed and restored; then the pure interval accident total signal processing method is implemented.

Failure to match means that the content of the signal does not include switch coding, and the full-station switch displacement matching method needs to be used. That is, use all the switch IDs of the substation to access the switch position interface. If a switch changes position at the corresponding moment, the switch ID is written into the record. A station-wide accident may always result in multiple switches tripping at the same time. In this way, the total station accident total can be converted into an interval accident total.

When the switch displacement matching of the whole station is successful, the 12-second analysis method is used to determine whether the latest record is true or false. That is, query the latest record in the time segment (an action and a return signal may exist at the same time at one moment). If the latest record is a station-wide action, the signal is considered to be a true signal; If there is a total station reset record, when the total station reset time minus the latest full station action time is less than or equal to 12 seconds, the full station reset signal is judged to be a false signal. False signals are discarded and true signals are retained. Then execute the interval accident total signal processing method. If

the switch displacement matching of the whole station fails, a fault will be detected, and the switch information is "unknown switch".

3.2.3 Total mixed signal processing for total station and interval incidents

First perform the switching transition.

If only there was one switch. Assign the switch ID to the total station accident record, and convert the total station accident total into an interval accident total, thus converting it into a simple interval accident total. Then perform the logical judgment of the full station return signal to determine whether the latest record is true or false; finally, implement the pure interval accident total signal processing method.

If there are multiple switches. Split the total fault actions of the entire station into multiple interval accident total records according to the number of switches, and then judge whether they are true or false. Obtain the record with the latest time. If it is a reset signal and the corresponding switch displacement signal is opening, then the record is false and discarded. If the corresponding switch displacement signal is closing, the record is true and the pure interval accident total signal is executed. Approach. If it is an action signal and the corresponding switch displacement signal is closing, then the record is false and discarded. If the corresponding switch displacement signal is open, the record is true and the pure interval accident total signal processing method is implemented.

4. FAULT CLASSIFICATION RESEARCH AND JUDGMENT MODULE

Based on the analyzed switch tripping signal as a fault event, further fault classification research and judgment is carried out.

4.1 Dedicated line power outage research and judgment

For dedicated line power outages, the tripping of the incoming and outgoing line switches of the dedicated line is monitored. According to the D5000 system switch trip signal and protection action signal, the dedicated line equipment resources are obtained through the matching dedicated line incoming and outgoing switch ID, and the dedicated line power outage event is determined. Based on the relationship between the marketing line and the user, combined with the multi-power status of the special change user, the power outage of the users affected by the special line is determined. The process is shown in Figure 3:

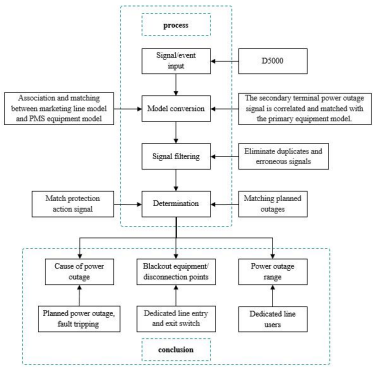

Figure. 3 Dedicated line power outage research and judgment process and conclusion

4.2 Research and judgment on power outage of entire feeder line

In view of the power outage of the entire feeder line, the direct acquisition of the line outlet switch trip signal and the summarization and merging of distribution transformer power outage events are realized. The two research and judgment results serve as the basis for mutual verification, and the merger of the research and judgment results can be achieved. The process is shown in Figure 4:

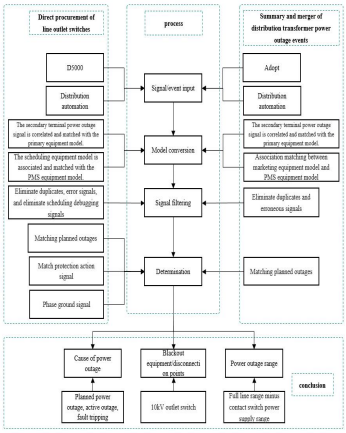

Figure. 4 Research and judgment process and conclusion on complete power loss of feeder line

Direct procurement of line outlet switches

Obtain the outgoing switch trip signal and protection action signal to directly determine the main line trip. For example, the obtained outgoing switch and trip signals do not have corresponding protection action signals, and are judged to be active outages. Based on the different signal types received, the cause of the power outage is determined to be outgoing tripping. Subsequently, based on the topological relationship of the power grid and the operating status information of the contact switch, the power outage area affected by the fault is analyzed from top to bottom.

Summary and merger of distribution transformer power outage events

The power outage information of multiple transformers under the main line is summarized and merged, combined with the operating status of the contact switch, to trace the power points from bottom to top. Obtain the common trunk line switches belonging to multiple power-off transformers during the same period, and then use the trunk line switch as the starting point to conduct grid topology analysis from top to bottom to generate a power outage area. Once it is determined that the switch belonging to the distribution transformer is the feeder outlet switch, it is determined that the entire feeder line is out of power.

4.3 Research and judgment on power outage of feeder area

For power outages in feeder area, it can be achieved through direct acquisition of branch line/section line trip information and summary and merger of distribution transformer power outage events. The two research and judgment results serve as the basis for mutual verification, and the merger of the research and judgment results can be achieved. The process is shown in Figure 5:

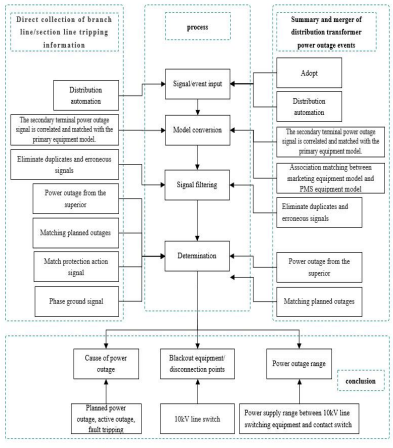

Figure. 5 Research and judgment process and conclusion on power outage of feeder area

Direct collection of branch line/section line tripping information

According to the fault trip signal fed back by the distribution automation system (FA strategy action is completed), it is determined to be a branch line. Based on the grid topology relationship and the contact switch operating status information, the power outage area affected by the fault is analyzed from top to bottom.

Summary and merger of distribution transformer power outage events

After receiving the power loss alarm information of multiple distribution transformers, trace the power points from bottom to top to obtain the public branch line switches of multiple distribution transformers in the same period, and then use the public branch line switches based on the status information of the branch line switches and contact switches. Taking the branch switch as the starting point, the grid topology is analyzed from top to bottom to generate the power outage area.

4.4 Research and Judgment on Distribution Transformer Loss of Power

For distribution transformer power outage, the distribution power outage event can be analyzed and judged by using the station area main meter power outage signal reported by the collecting device or the special transformer terminal, and the distribution transformer main open position change signal reported by the distribution transformer. The two research and judgment results can be used as a basis for mutual verification, and the merger of the research and judgment results can be achieved. The process is shown in Figure 6:

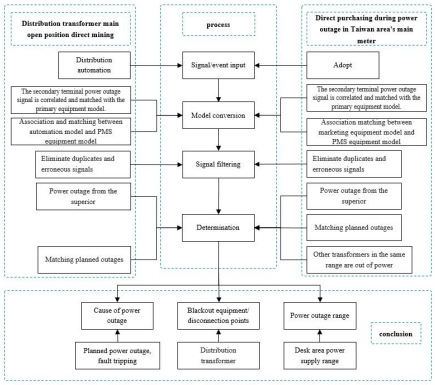

Figure. 6 Distribution transformer power loss research and judgment process and conclusion

Distribution transformer main open position direct mining

Through the power distribution automation system, the switch position signal of the station area's main switch and the power outage signal of the station area's main meter are collected, and the power outage events on the low-voltage side of the station area are analyzed through primary and secondary equipment correspondence. Supplemented by the switching voltage collected by TTU to determine the authenticity of the final power outage event. It is estimated that there will be a power outage in desk area.

Direct procurement during power outage in desk area main meter

Through the electricity consumption information collection system, the power outage signal of the desk area main meter is collected. Through marketing and PMS equipment model correspondence, the desk area transformer power outage event was analyzed. If only one transformer under this line has a power outage, it is a power outage in the desk area.

4,5 Research and Judgment on Low Voltage Line Outage

For low-voltage line power outages, the low-voltage line switch opening signal and HPLC low-voltage household meter power outage events can be summarized and combined for research and judgment. The two research and judgment results can be used as a basis for mutual verification, and the merger of the research and judgment results can be achieved. The process is shown in Figure 7:

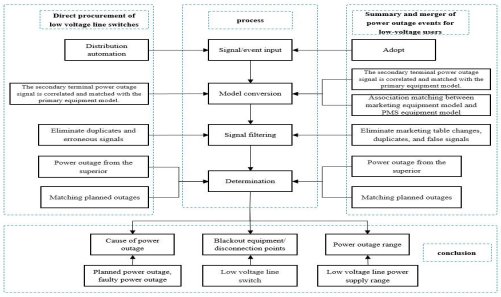

Figure. 7 Low-voltage line power outage research and judgment process and conclusion

Direct procurement of low voltage line switches

The opening signal of the low-voltage outlet switch is received through distribution automation and is directly determined to be a power outage on the low-voltage line. If a low-voltage branch line switch trip or low-voltage collector power-off alarm message is received, the power supply point will be traced from bottom to top. Obtain the status information of public low-voltage branch line switches and tie switches during the same period, conduct grid topology analysis from top to bottom, and generate power outage areas.

Summary and merger of power outage events for low-voltage users

By receiving the power outage information reported by multiple HPLC meters under the distribution transformer, and combining the connection relationship between the metering box and the user, it can determine the power outage status of other household meters under the meter box and the power outage status of other meter box users under the same distribution transformer. The power outage events are classified into single meter box power outage, multiple meter box power outage, and low-voltage line power outage.

5. KEY ALGORITHMS FOR FAULT ANALYSIS AND JUDGMENT

5.1 Data model transformation

The enterprise-level real-time measurement center uses stream processing to consume message queue data in real time, and combines the archive data and topology data in the cache to perform model conversion.

The collected subject data (switch protection action, switch status, switch current and voltage, switch trip signal) are associated with the transformer and switch relationship data through the switch ID to obtain the resource ID. Then, it is associated with the distribution and transformation account data through the resource ID together with the power outage signal data in the station area, and the resource name, affiliated feeder, power supply unit, affiliated city, affiliated district and county, and maintenance team are obtained. Action time, power outage event source, and action type are obtained from real-time collected data. The source of the power outage event is the topic in the message queue. The above results form medium voltage measurement data information.

The low-voltage side signal data is associated with the low-voltage user access point data through the resource ID to obtain the resource name, meter box, station area, power supply unit, affiliated city, affiliated district and county, and maintenance team. Action time, power outage event source, and action type are obtained from real-time collected data. The source of the power outage event is the topic in the message queue. The above results form low-voltage measurement data information.

Store the medium-voltage measurement data and low-voltage measurement data generated after model conversion into the collection library.

In the early morning of the next day, all the measurement data of the previous day will be pushed to the data center and entered into the history database.

5.2 Outage event compression

For power outage events from different event sources for the same device, the power outage events within 30 minutes between the power restoration time of the last power outage event and the power outage time of this power outage event can be merged into one power outage event. Single point power outage event compression algorithm is shown in Figure 8:

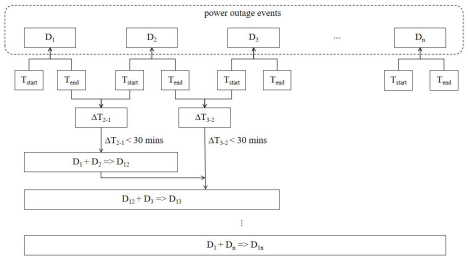

Figure. 8 Single point power outage event compression algorithm

Where D represents the power outage event source, n represents the sequence number of the power outage event source, sorted by the event source start time, Tstart and Tend represent the power outage and restoration time of each event source, and ΔT represents the difference between the power outage time of the latter event and the restoration time of the previous event. After executing the power outage event compression algorithm, n independent power outage events are compressed into one valid power outage event, which not only reduces the complexity of power outage event analysis, but also lays a solid foundation for the accuracy of power outage event judgment.

5.3 Judgment of effectiveness of power outage events

Mark each power outage event to see if it is a valid power outage event. If the power outage time is not empty, it will be considered valid if the power outage is longer than 10 minutes, otherwise it will be invalid; If there is power on but no power outage event, and there is no power outage signal within 24 hours, it is judged as invalid; There is a power outage time but no power on time and it is judged as valid. If the number of power outages exceeds 6 times within 24 hours, it will be deemed invalid for that day. The process is shown in Figure 9:

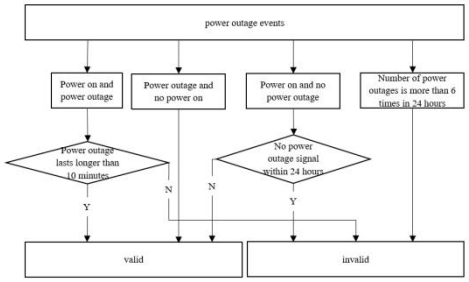

Figure. 9 Judgment of effectiveness of power outage events

5.4 Merge power outage events in the same area

Group the power outage events according to the area they belong to, and determine whether the superior level of the power outage equipment has a power outage. All sources of power outages are split into transformers or user outages. After completion and repair according to transformers or user outages, they are merged according to the line and switch to which the transformer belongs, and the corresponding meter box and station area of the user. At the same time, they are merged according to the time range of the outage. Form a unified collection of power outage events for use by other businesses. The merging rules are as follows.

Non-user power outage event synthesis is used to determine the switch and line to which the transformer belongs based on the transformer outage. If the power outage time of the transformer under the switch of the same line is within 45 minutes, and there are more than two power outage transformers (at least one public transformer), it will be determined as a line side power outage. The power outages are collected according to the line, and the earliest transformer power outage time and the latest power outage time are taken as the start and end time of the power outage event.

The user power outage event synthesis is based on the user's power outage and searches the meter box and station area it belongs to. If the user power outage time is within 15 minutes under the same meter box in the same station area, and there are more than two users, it is determined to be a single meter box power outage. If the power outages for different meter boxes are collected according to the station area, the earliest power outage time and the latest power outage time are taken as the start and end time of the power outage event.

5.5 Distribution network fault due to sudden drop in feeder load

After a fault occurs in the distribution network, because the fault current is greater than the line switch protection setting, the upstream line switch closest to the fault point will trip. All distribution transformers and their loads downstream of the switch are cut off, resulting in a sudden drop in power at the feeder outlet. When line losses are ignored, the feeder load sag is equal to the load proportion of the trip switch. Therefore, if the load proportion of each switch before the fault can be calculated, the authenticity of the fault trip switch can be determined by comparing the feeder load sag and the load proportion of each switch after the fault. So, after a fault occurs, the historical load data of each distribution transformer can be extracted immediately from the purchasing system, and the active load of each distribution transformer can be predicted at the time of the fault using load forecasting. Then combined with the topological relationship of "substation-line-switch-distribution transformer", the distribution transformer load prediction values downstream of each switch on the line are accumulated to obtain the load proportion of each switch at the time of the fault. Finally, fault analysis and judgment are carried out based on the load sag[10] and the load proportion of each switch.

6. SUMMARY

In view of the problems of inaccurate and timely analysis of power outage events in the fault analysis and judgment business carried out in the power supply service command system in the early stage. This system accesses the switch SOE signal through the measurement center, groups the signals, analyzes and processes them, and generates standardized switch signals. Based on the analyzed switch tripping signal as a fault event, further hierarchical research and judgment is carried out. Real-time analysis and judgment of effective power outage events to improve the accuracy and timeliness of fault analysis and judgment. At the same time, corresponding medium and low voltage fault events are pushed in real time to support power outage information reporting, proactive repairs, reliability management and other related work. Improved power supply service level.

7. REFERENCES

[1] HUANG Jianyong, MENG Qibin, WU Shunchao, et al. Operation state evaluation of distribution network based on attribute mathematics[J]. Electric Power, 2019, 52(2): 104-110, 118.

[2] DENG Feng, LI Xinran, ZENG Xiangjun, et al. A novel multi-terminal fault location method based on traveling wave time difference for radial distribution systems with distributed generators[J]. Proceedings of the CSEE, 2018, 38(15): 4399-4409, 4640.

[3] CHAI Peng, ZHOU Hao, ZHANG Yu, et al. Short-circuit fault location for power cables based on improved two-terminal traveling wave method[J]. Electric Power, 2020, 53(11): 168-174.

[4] BAO Xiaofeng, XIAO Kaiwei, YANG Jun, et al. Single-phase grounding fault location method based on active signal injection method[J]. Electrical Technology, 2018(17): 135-137.

[5] QI Zheng, ZHUANG Shuyi, LIU Zifa, et al. Fault location method analysis of distribution network based on shunt resistance disturbance signal[J]. Automation of Electric Power Systems, 2018, 42(9): 195-200.

[6] CHENG Yunxiang, LI Yang, LU Fang, et al. Fault-section location for active distribution networks assisted by multi-source information[J]. Power System Protection and Control, 2020, 48(17): 147-154.

[7] YAO Qiang, MA Qun, MU Kun, et al. Realization of initiative repair of power distribution network based on power failure information for power user electric energy data acquire system[J]. Jilin Electric Power, 2019, 47(1): 5-6, 56.

[8] Liu Zhen, DIAO Shoubin, XU Miao. Integrated Accident Circuits Improvement in Intelligent substations [J]. Shandong Electric Power, 2015, 42(12): 75-77.

[9] ZHENG Zhixin. Analysis of Total Synthesis Method of Substation Accident Based on CSM300E Telecontrol System[J]. Electric Engineering, 2022(2): 83-85.

[10] YANG Chenxi, MA Jie, YANG Wei, et al. Distribution network fault location method based on the sudden drop ratio of feeder active load[J]. Power System Protection and Control, 2022, 50(2): 144-151.