Approach for Provincial distribution automation system in Outage analysis

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Abstract—People's lives are becoming more and more inseparable from electricity, and the requirements for the quality of power supply are getting higher and higher. Because of most of the faults in the power system originate from the distribution network, the need to standardize the management of power outages and improve the efficiency of research and judgment has become more and more significant. However, in China, the differences in the development of automation construction in various places and the outage information of different departments require that power outage business applications should try to achieve accurate analysis of outage information under different scenarios. This paper designs a power outage analysis approach, which comprehensively analyzes distribution network data such as substations, lines, and meters, and establishes a signal credibility image, which flexibly mines and analyzes outage events from multiple dimensions and effectively improves the fault tolerance of fault location.

1. Introduction
The distribution network is the final link of power transmission in the power system which directly affects the power quality of users. Because there are many barriers between sharing data and integration of business systems, there is still a lot of room for improvement in the efficiency of fault repairs and the implementation quality of planned power outages in the related business of power outages in the distribution network. Up to now, the coverage of distribution network terminal equipment in most areas is limited, and many lines have not yet been automated in China. Even in the same area, automated construction will also receive differential investment. These caused a lot of difficulties and problems such as spending a lot of time on site surveys, repeating maintenance of information in different systems and difficulty in aggregating information.

In the field of distribution network fault location technology, most researches focus on fault location methods based on terminal signals such as monitoring Feeder Terminal Unit (FTU) and Distribution Terminal Unit (DTU). The common methods are artificial intelligence algorithms such as genetic algorithm and ant colony algorithm. Due to the complexity of the distribution network that it is not only necessary to realize the discrimination of wrong information, but also to make probability inferences on the basis of incomplete information, the algorithm selection needs to be fully considered[1-3]. DS evidence theory is very effective for probabilistic reasoning. Compared with traditional probability theory methods, it can better grasp the uncertainty of the problem by fusing
evidence from multiple sources of evidence, and has achieved good results in many current fields. Compared with traditional power outage analysis applications, the power outage analysis approach in this paper adopts a hierarchical and hierarchical research and judgment mechanism, and the configuration of power outage sensing conditions is more flexible. On this basis, an improved strategy is proposed, which combines signal credibility profile and d-s theory algorithm Perform fusion judgments, while studying and judging logic to take into account multiple types of scene conditions, it also solves the problem of inaccurate fault location when the signal is abnormal or conflicts[4].

2. Overall Design
Even in more developed areas in China, the construction of distribution automation is still in the large-scale pilot stage. The core point is to better complete fault repairs under existing conditions, and to transform the weak points of the grid to achieve Reasonable deployment of resources[5-8]. This requires that the design of power outage analysis applications not only ensure the timely accuracy of real-time fault perception to improve the efficiency of emergency repairs, but also need to rely on data analysis and verification to improve the reasonable standardization of power outage management from the side, and to explore and analyze weak links to support accurate investment in the project.

Provincial power grid companies already have relatively stable business systems in the fields of dispatching, operation inspection and marketing. The main problem is that the same type of data comes from different systems. Too many repetitive and conflicting invalid data increase data processing risks and screening costs. On the other hand, part of the data is only used at a single professional level that the data sharing is insufficient. The provincial deployment architecture of the distribution automation master station application has advantages in terms of construction costs and data fusion and other sharing aspects. It is easier to achieve standardized management of data aggregation, and it is more convenient to carry out benchmarking in the same industry.

The information of the distribution network can be divided into static information and dynamic information. The static information mainly includes the topology information of the distribution network line and the relationship between primary and secondary equipment. The dynamic information covers the distribution network operation data, including the substation signal, the line signal and the courts signal.

3. Hierarchical Grading Judgment
The fault location of the distribution network and analysis of the suspected fault zone are the most important part of the power outage management function. Power supply companies with a high level of automation will install a large number of intelligent detection terminals, which can obtain a large number singals of teleindication and telemetering. Even if some signals are mishandled or missed, the automation master station can also combine other signals and fault record information, or use DTU, FTU to send signals for offline fault analysis. Almost all fault location methods that rely only on a certain type of distribution network line signal have their limitations, resulting in a greater possibility of misjudgment, and it is not easy to analyze the nature and scope of the outage. In this case, if the fusion analysis of the signals in the EMS station or the distribution transformer signals is combined, not only the research and judgment rules can be enriched, but the reliability of the analysis results can be ensured to a large extent. This chapter mainly introduces the resource integration methods between the various systems of the distribution network, and elaborates key technologies such as main distribution network model splicing and fault research and judgment rules[9-12].

3.1. Rules of Hierarchical Grading Judgment
The fault signal source includes multi-level alarm information of substation-line-transformer-user. The primary problem of the entire fault analysis process is how to effectively and accurately analyze the nature of the power outage based on the multi-source fault alarm information, locate the fault zone, and select the most suitable topological search starting point.
This paper divides power outage events into deterministic and non-deterministic events, and analyzes and judges power outage events by hierarchical priority. Deterministic power outage events refer to faulty power outages, planned power outages, temporary power outages, etc., and deterministic events are placed at the top of the research and judgment logic. This logic is not actively associated with the results of the underlying research and judgment, but is only positioned for passive association. Non-deterministic power outage events include the power outage events associated with the real-time power outage signal in the courts and the work order reported by the user. The system can quickly match according to incomplete information, automatically find the most relevant power outage event, suspected event from the power outage event pool, and determine whether the signal is a related sub-signal in a certain deterministic event. The signal priority is designed such that the signal alarm information in the substation has priority over the line, and the line alarm information has priority over the courts. The distribution transformer signal with higher reliability at the station area level has priority over the user-level fault information. For example, when the system can complete the fault diagnosis and judgment by combining the substation-level and feeder-level alarm information, there is no need to consider the accuracy of the court-level information. When the qualitative event is completed, the theoretical station area power loss signal set and the actual station power loss signal set are checked to support the courts signal remediation and credibility portrait modeling. The processing logic of hierarchical research and judgment runs relatively independently. According to the level and priority, the lower-layer research and judgment analysis needs to consider the upper-layer research and judgment results, and when the signal is relatively complete, the upper-layer research and judgment does not need to consider the lower-layer signals or the judgment results. Cooperate with each level to check, and analyze the nature of the power outage and the fault interval according to the priority of the criterion.

3.2. Process Of Power Outage Research And Judgment
When the graphic model data is complete and reliable, the fault location uses the fault time point alarm information uploaded from information sources at all levels to confirm the approximate location of the device and the starting point of the topology search, and then complete the device location based on the topology analysis. This method usually requires the combination of better quality graphics and model data. If the data signal quality is guaranteed only, the research and judgment logic can be simplified to first query whether there are related signals at the level according to the discrete power failure signal, and then group the signals according to the feeder and branch lines, and first determine whether the entire line is out of power or the branch line is out of power, then analyze the most likely trip position, and then locate the fault area.

When the signal is missing in the substation or the feeder signal is missing, or the line has not yet realized the automatic terminal coverage, it will directly lead to the failure to be associated with the deterministic power outage event, and the complete logic power outage event research and judgment cannot be completed. At this time, the most likely trip position can only be inferred through the court-level signal, combined with the topological analysis of the static correlation relationship between the branch line and the distribution transformer. In some extreme cases, it is necessary to manually verify the authenticity of non-deterministic events and the nature of power outages. If a branch line fails and there is no circuit breaker upstream, it will cause the entire line to fail. This event will be classified as a power failure of the entire line. In addition, in order to ensure that the accuracy of the station-level signal reverse analysis is not affected by signal misreporting, it is necessary to combine real-time telemetry data to assist in research and judgment[13-19].

Due to the different construction conditions of multiple systems in different regions, there are differences in signal delay and accuracy. The fusion of multi-level data brings more logical directions for research and judgment, and may also have a negative impact on the results of research and judgment. For example, when logic conflicts occur at different levels, additional algorithms are needed to reduce the coupling of signals. As an uncertain reasoning method, d-s evidence theory is suitable for...
fusing multiple evidences and comprehensively considering multiple evidences to make decisions to improve the reliability of failure analysis.

4. Closed-loop checking method of fault signal based on d-s theory

4.1. Signal quality analysis
In areas with a high degree of distribution network automation, a large number of fault signals can be obtained when the distribution network fails. According to the rules of hierarchical grading judgment described in the previous chapter, the automation system can accurately and quickly locate the fault zone. However, currently in many areas with low automation or rural distribution networks, intelligent monitoring terminals such as DTU and FTU are usually not installed, and their automated construction and operation and maintenance schemes mostly use complete sets of switches as the mainstay, supplemented by fault indicators. The fault indicator will cause signal false alarm or signal loss due to the diversity of the environment and the operation mode of the distribution network. These poor signal quality will cause erroneous analysis of fault research and judgment.

In addition to DMS systems, systems in other fields such as EMS systems, PMS systems, SG186 systems, and electricity consumption information collection systems also provide data related to the distribution network. Each system data has real-time mismatch and accuracy problems. For example, the sampling frequency and real-time performance of the courts data of the electricity consumption information collection system cannot accurately match the real-time performance of the EMS system, and there are also a large number of signal quality problems such as false alarms, false alarms and non-reports in the power outages of the courts. In this case, the traditional fault location method is very likely to be misjudged, causing repair personnel to be unable to accurately locate the fault section, reducing the efficiency of fault repair and the reliability of power supply.

Some of these signal quality problems can be identified through anti-calibration analysis. For example, the signal in the substation has a protection signal, but there is no circuit breaker action signal. At the same time, the DTU/FTU has a switch action signal and a short-circuit accident total signal. Or if the fault indicator has an over-current flop action, it is inferred that the circuit breaker action signal in the station is missed, which is a clearly identifiable signal missed problem. In another part of the situation, both false positives or false negatives may occur. For example, the fault indicator on the branch line has an overcurrent flop action, but there is no power failure signal sent in the downstream courts. It may be the fault indicator malfunctioning, or the distribution transformer signal may be lost. These signal quality problems cause that it is not easy to analyze according to logical rules.

4.2. Evidence Theory Algorithm Based on Probability Secondary Distribution
When the distribution network fails, multi-source fault information can be obtained. If each type of fault alarm information is independent and correct, they can determine the fault area. However, the actual alarm information has a chance of false positives and missed reports, which makes the fault area identified by each type of fault information have the possibility of error. As an uncertain reasoning method, d-s evidence theory is suitable for fusing multiple evidences and comprehensively considering multiple evidences to make decisions to improve the reliability of failure analysis. Its main characteristics can be summarized as follows: it satisfies weaker conditions than Bayesian probability theory, does not need to know the prior probability, can well represent "uncertainty", and is widely used to deal with uncertainties such as information fusion and intelligence cases. In d-s evidence theory, the recognition framework \( U \) is a complete set composed of mutually exclusive and limited research objects.\( m \) is the basic probability assignment function of \( U \), \( m:2^U \rightarrow [0,1] \), and satisfies:

\[
m(\emptyset) = 0 \quad (1) \\
\sum_{A \subseteq \emptyset} m(A) = 1 \quad (2)
\]
m(A) is the basic credibility of A, formula (1) indicates that the credibility of the empty set is always 0, and formula (2) indicates that the sum of the credibility of all propositions is 1.

Assuming that n pieces of evidence are obtained from n information sources, the basic probability distribution is $m_1, m_2, m_3, \ldots, m_n$. If they are independent of each other, then formula (3) can be used to express the synthesis rule of multiple evidence bodies.

$$m(A) = \begin{cases} 0, & A = \emptyset \\ 1 - k \sum_{A_1=\emptyset}^{A_{i}=\emptyset} \prod_{i=1}^{n} m_j(A_i), A \neq \emptyset \end{cases} \quad (3)$$

The evidence conflict coefficient is formula (4).

$$k = \sum_{A_1=\emptyset}^{A_{i}=\emptyset} \prod_{i=1}^{n} m_j(A_i) \quad (4)$$

k reflects the degree of conflict between the various evidences, between 0 and 1. The larger the k, the higher the degree of conflict.

When there is no conflict between the evidences, after the fusion of evidence theories, the trustworthiness of high-trust targets can be further strengthened. But if the fault information is falsely reported, the evidence generated by the falsely reported signal may conflict with the evidence obtained from other correct information. When the degree of conflict of evidence is large or even completely conflicted, there will be results that are contrary to the actual situation. At this time, the possibility of misjudgment is very high, so further improvement is needed to adapt to the actual operating conditions of the distribution network.

In the description of signal quality mentioned earlier in this article, it is very likely that one piece of evidence will completely negate another piece of evidence in such situations as refusal to move, false positive, and underreport. Therefore, this article adopts a method which pre-processes each branch evidence and then assigns weight values according to the degree of relevance between the evidences, and analyzes and calculates according to the new distribution probability. What needs to be explained here is that the results after the redistribution probability and the results before the allocation will change in value, but the relative probability of each element of the fusion result remains the same.

4.3. Closed Loop Check of Differentiated Failure Analysis

When counting the actual false signal data on site, the analysis shows that signal false alarms and omissions are generally regular and repeatable. Based on the massive historical data of power equipment, including false alarms, false alarms, refusal to move, and other error information, this paper establishes a data warehouse for the credibility of fault signals. Take court signals as an example. At present, most of the on-site station area power outage signals and power recovery signals in China are temporarily forwarded by the use and acquisition system. Its data quality is characterized by low real-time signal accuracy, but its historical data accuracy rate is over 90%. By checking real-time data and historical data, doing probability statistics from dimensions such as time and data defects, and establishing a multi-level mapping of equipment-time-signal type-defect type-event probability, the logical conflicts between multi-source data can be reduced.

After a fault occurs, the system preprocesses the fault signal according to the hierarchical and hierarchical judgment logic. If the priority judgment rule is met, the decision result can be directly given through the hierarchical and hierarchical judgment rule. If the priority judgment rule is not met, the system needs to generate multiple judgment evidences based on the fault information and the network topology to construct a set of suspicious fault areas. Then, the suspected failure area obtained from various types of failure information is combined with equipment credibility data, and a new probability value is calculated according to certain rules to give evidence, and the fusion calculation is carried out through the improved d-s evidence theory, and finally the decision result is obtained. According to the decision result and the static topological relationship of the line, the theoretical signal set can be analyzed. Comparing with the actual signal set, the whole link can realize closed-loop processing, and the processing flow is shown in Fig.1.
5. Case Analysis

The example given in this article is a feeder automation distribution network based on the cooperation of circuit breakers and section switches. This kind of distribution network line is generally relatively simple, mainly divided into a radial network structure and a ring network structure. In addition to the main components of the normal distribution network, in order to facilitate the location of the fault area, a fault indicator with remote signaling function is generally installed at an important location of the feeder. Take a radial network structure line as an example. As shown in Fig.2, CB represents a circuit breaker, F represents a fault indicator, S represents a sectional switch, and T represents a distribution transformer station area.

For example, short-circuit fault occurred in the S1-S2-S3 trunk line area. According to the hierarchical classification rules, if the signal is complete, the fault area (S1, S2, S3) can be analyzed by
combining the signal in the substation and no teleindications of F2. When a malfunction of F2 happens, the system receives fault-related signals such as circuit breaker CB opening and closing, overcurrent protection signal, F2 overcurrent flop action, and power outage signals in T1, T2, T3, T4, T5 and T6 courts. Afterwards, we successively received the repetition signals from all courts except T4 and T5, and users in the T4 reported failure signals. The fault area inferred from the outgoing circuit breaker and the fault indicator signal is (S3, S4), the inferred range is (S1, S2, S3) based on the power loss signal of T4, and the inferred range is (S3) based on the P5 power loss signal. The range inferred based on the user's failure signal is (T4), (S1, S2, S3). According to the traditional fault research and judgment method, when a false alarm occurs in F4, the research and judgment result will be a fault in the downstream area of F4, namely (S3, S4), which will cause the application to capture the fault, but the fault area is not correctly located.

According to historical statistics, the ratio of line faults to courts faults on this line is about 6 to 1, so:

\[
\begin{align*}
M_1\{(S_3, S_4), (P_4)\} &= \left\{ \frac{6}{7}, \frac{1}{7} \right\} \\
M_2\{(S_1, S_2, S_3)\} &= 1 \\
M_3\{(S_3, S_4)\} &= 1 \\
M_4\{(S_1, S_2), (P_4)\} &= \left\{ \frac{6}{7}, \frac{1}{7} \right\}
\end{align*}
\]

The substation signal is generally very reliable. The false alarm rate of the T5 signal is 70%, the false alarm rate of the T4 signal is 20%, the false operation probability of F1 is 10%, the false operation probability of F2 is 40%, and the accuracy probability of the fault indicator signal is 54%, the T5 signal is accurately sent with a probability of 30%, and the user reporting a failure is a non-deterministic event. The correction factor can refer to the signal accuracy rate of the station area to be 0.8. After the second treatment, the improved evidence is shown in formula 6:

\[
\begin{align*}
M'_1\{(S_3, S_4), (T_4), \emptyset\} &= \{0.46, 0.08, 0.46\} \\
M'_2\{(S_1, S_2, S_3), \emptyset\} &= \{0.8, 0.2\} \\
M'_3\{(S_3, S_4), \emptyset\} &= \{0.4, 0.6\} \\
M'_4\{(S_1, S_2, S_3), (T_4), \emptyset\} &= \{0.69, 0.11, 0.2\}
\end{align*}
\]

The four pieces of evidence are fused by formula (3). According to formula (4), the calculation result is 0.81, which is substituted into formula 7:

\[
\begin{align*}
M\{(S_3, S_4)\} &= 0.029 \\
M\{(S_1, S_2, S_3)\} &= 0.937 \\
M\{(P_4)\} &= 0.0012 \\
M\{\emptyset\} &= 0.067
\end{align*}
\]

According to the fusion result, it can be judged that in the case of signal false alarm or incomplete terminal coverage, the decision result of the fault area of the evidence theory algorithm combined with the secondary distribution of probability is (S1, S2, S3). The result is consistent with the original setting, and the influence of signal quality on the result is well avoided.

6. Conclusion
This paper closely combines the concerns of various professionals on power outages, and conducts detailed analysis and research on the fault location methods of the distribution network, and realizes a wider monitoring range and more precise description of power outage information under differentiated conditions. The method of constructing a structured power outage information resource pool provides ideas for further accumulating the value of enterprise data and enhancing the effectiveness of data sharing. At the same time, it also provides a foundation for building a data center with open data and shared ecology. With the automatic transformation of medium-voltage lines and the vigorous advancement of TTU, the monitoring range of the system will be extended to low-voltage branch circuits and meter boxes, and the accuracy and completeness of signals at all levels will be
This will provide a strong data guarantee for the further improvement of the quality of power supply services.

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