Application Research of Multi-source Information Fusion Technology in Power Network Fault Diagnosis

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Abstract. In this paper, a power grid fault diagnosis method based on multi-source information fusion technology is proposed for grid faults. Firstly, the wavelet transform is used to analyze the electrical quantity information of the fault recorder and PMU, and the three fault reliability characterizations of the components are obtained. Secondly, the information fusion based on the improved D-S evidence theory is carried out for each fault characterization, and the comprehensive fault credibility of the components is obtained, and the fault criterion is given. Finally, the fuzzy C-means method is used to make the diagnosis decision of the faulty component, and the final diagnosis result is obtained. The simulation results show that the method combines the electrical quantities of the fault recorder and the PMU to obtain accurate fault diagnosis results, which can effectively reduce the impact of protection and switch refusal misoperation on power grid fault diagnosis. This method has a good application prospect in power system fault diagnosis.

1. Introduction

In the event of a grid failure, the dispatch center will receive a large amount of fault information, including switching quantities and electrical quantities [1]. At present, the power grid fault diagnosis method is mainly based on the switch quantity information, including expert system, neural network, Bayesian network, Petri net, analytical model, etc [2]. For example, Zaihua Li combines expert system and data mining technology, and designs the mining models for simple faults and complex cascading failures in literature [3]. Mingwei Sun uses the temporal Bayesian knowledge base theory to diagnose the power grid fault, which effectively solves the problem of high fault probability value of non-faulty components in literature [4]. The above papers make fault diagnosis based on the switch quantity information, and achieve certain effects, but in the event of actual faults, the protection and circuit breakers may be mis-moved and rejected, and sometimes it is difficult to obtain accurate results based on the fault diagnosis of the switch information [5]. At present, power grid fault diagnosis for electrical quantity and multi-source information fusion technology has become a research hotspot at home and abroad.
In summary, this paper obtains the current information and voltage information of the component from the fault recorder, obtains the voltage information of the component from the PMU measurement point, and uses the wavelet transform to analyze the three faultworthiness of the component. Then the improved D-S evidence theory is used to integrate the information, and the comprehensive fault credibility of each component is obtained. Finally, the fuzzy C-means method is used to make the diagnosis decision of the faulty component, and the final diagnosis result is obtained.

2. Electrical quantity feature extraction
This paper analyze and process voltage and current information from the recorder and analyze and process voltage information from the PMU.

2.1 Extracting the moment of failure
The recorded data obtained by the power grid dispatching center is with the fault moment. For the simulated data, in order to accurately obtain the fault time, the fault current of the fault phase is processed by db3 wavelet[6]. This paper uses the high frequency coefficient on the first scale of db3 wavelet to find the corresponding modulus maxima, and the corresponding sampling point as the fault moment. Figure 1 shows the fault phase current data obtained from the power grid dispatching center, and the fault time is extracted by the above method. The time at which the fault occurred (signal abrupt moment) is the 173th sampling point, which is very close to the 175th sampling point marked by the recorder, indicating that the method is valid.

![Figure 1. The Fault current Diagram collected by Power Network Recorder](image1.png)

![Figure 2. The waveform diagram of wavelet decomposition for fault current](image2.png)

2.2 Energy credibility
Wavelet transform and coefficient reconstruction of the fault signal, let \( E_1, E_2...E_z, E_{Z+1} \) be the wavelet energy distribution of the signal on \( z \) scales.

Assume that the fault signal of the \( i \) (\( i = 1,...,m \)) th line is \( x_i(n) \) when a fault occurs. Find the total wavelet energy of a waveform period after the recorder current signal fails. Take the maximum value of its three phases as the result \( E_i \). Define energy credibility \( E_i = (e_1,e_2,...,e_m) \), Its elements represent the relative level of support for each line fault.

\[
e_i = \frac{E_i}{\sum_j E_j}
\] (1)
2.3 Singular credibility

Singular Value Decomposition: The singular value decomposition of any $m \times m$ order matrix $A$ can be expressed as $A = U \Lambda V^T$, Where, $U$ and $V$ are $m \times m$ order and $n \times n$ order orthogonal matrices; $\Lambda = \text{diag}(\lambda_1, \lambda_2, ..., \lambda_t)$ is diagonal matrix, $t = \min(m, n)$. Its non-negative diagonal elements are arranged in descending order, which is the singular eigenvalue of $A$.

When the grid fails, the obtained voltage signal is subjected to 3-layer wavelet decomposition using db4 wavelet, and three reconstruction coefficients are respectively obtained, and the three reconstruction coefficients are formed into a matrix to reflect the detailed information of the voltage signal. Then singular value decomposition on this matrix is performed, Let $\Lambda_i = \text{diag}(\lambda_1, \lambda_2, ..., \lambda_k)$ be the singular feature matrix of the $i$-th component of the system. Let $S_i = \sum_{i=1}^{k} \lambda_i / t$. Define singular credibility $S^i = \left( s_1, s_2, ..., s_n \right)$. Where, $s_i$ is obtained in a similar way to equation (1). The singular credibility of the entire voltage signal of the recorder is calculated, and participate in information fusion as a body of evidence.

2.4 Energy Distortion Credibility

After the grid fails, the magnitude of the fault line voltage changes more obviously than the non-fault line, reflecting this characteristic with the energy distortion credibility. The total wavelet energy of one waveform period before and after the fault on the voltage signal obtained by the PMU is calculated. Let the total energy of the wavelet before the line fault be $E_b$, and the total energy of the wavelet after the fault be $E_a$, define the energy distortion:

$$D_i = \frac{E_b}{E_a}$$

(2)

The maximum value obtained by the voltage of each phase of the line is taken as the energy distortion of the line. Define the energy distortion confidence $D^i = \left( d_1, d_2, ..., d_n \right)$. Where, $d_i$ is obtained in a similar manner to equation (1). Indicates the degree of support for each line failure.

3. FAULT FEATURE INFORMATION FUSION

In practical applications, D-S evidence theory has many shortcomings, such as Zadeh paradox, one-vote veto, robustness and fairness. In this paper, energy credibility, singular credibility, and energy distortion credibility are used as evidence bodies. According to the degree of conflict between evidences, the evidence with weak conflicts is fused with Dempster synthesis rules. Evidence of strong conflicts is fused by using the mean weighting method below to improve the D-S evidence theory. At the same time, according to the reliability of the three faultworthiness defined, the credibility is taken as 0.9, 0.85, and 0.8.

Mean weighting method to improve D-S evidence theory belongs to the improvement of synthesis rules between evidences. For evidence of conflict, Temporarily do not consider the conflict between the two pieces of evidence, and wait until the next piece of evidence comes, then continue to merge [7]. Proceed as follows:

Step1: Read two pieces of evidence m1 and m2;
Step2: Calculate the conflict factor $K$ to determine whether there is a conflict. If it is conflict evidence, go to Step 4. Otherwise, proceed to the next step;
Step3: According to the Dempster synthesis rule, the evidence is merged, and the process proceeds to Step 5;
Step4: Process the conflict evidence according to the mean weighting method, and proceed to the next step;
Step 5: Make a decision;
4. Diagnostic decisions and diagnostic procedures

4.1 Diagnostic decision based on fuzzy C-means clustering
The improved D-S evidence theory was used to obtain the comprehensive fault reliability of the line. On this basis, in order to determine the faulty line, the obtained comprehensive fault credibility is processed by a classification algorithm-fuzzy C-means clustering method (FCM).

This article divides the line into fault and non-fault 2 categories and sets the FCM class membership threshold to 0.5. Since the reliability of the comprehensive fault is classified, the center value of V is large as the fault class. Whether the line is determined to be faulty in the fault class depends on the comparison of the \( u_{ij} \) in the U with the class membership threshold, and the greater than the class membership threshold is determined as the final fault line.

4.2 Grid fault diagnosis process
As mentioned above, the specific steps of the multi-source information fusion technology used in power grid fault diagnosis are as follows.

Step1: The voltage and current recording data collected by the fault recorder after the fault occurs from the protection fault information management system (RPMS) is obtained, and the voltage recording data from the PMU measuring point is obtained;

Step2: Based on wavelet transform and energy spectrum analysis, the reliability characterization of electrical faults is obtained, including energy credibility, singular credibility, and energy distortion credibility;

Step3: The above three credibility levels are constructed as evidence bodies, and information fusion is performed on them by using improved D-S evidence theory;

Step4: Perform fuzzy C-means clustering analysis on the fusion results;

Step5: Obtain the final grid fault diagnosis result;

5. Example calculation
The IEEE39 node system is simulated with PSCAD (as shown in Figure 3). The example analysis is based on the following four assumptions.

1) In the PSCAD simulation model of the IEEE39 node system, the line length is taken as 100 km.
2) PMU configuration: The PMU is configured at sections 3, 8, 10, 16, 20, 23, 25, 29 using the method proposed in literature[8] to achieve complete observability of the power system state.
3) The class membership value of FCM is taken as 0.5.
4) Multi-resolution wavelet transform for processing electrical quantities is performed using MATLAB "db4" wavelet.

The simulation duration is 2s. The single-phase ground fault occurs on the line at 1s, and the fault duration is 0.2s. In order to see the clarity, Figure 4 shows a section of the fault signal intercepted.
Assume that line $L_{9-39}$ ($L_{9-39}$ is the line between node 9 and node 39) has a single-phase short-circuit fault. Using the method of this paper for fault diagnosis, all lines in the system should be processed. Due to the large number of lines, select 10 representative lines ($L_{9-39}$, $L_{3-8}$, $L_{5-18}$, $L_{16-17}$, $L_{6-11}$, $L_{19-33}$, $L_{28-29}$, $L_{22-23}$; these 10 lines correspond to the 1-10 numbers in Table 1), Due to the limited space, the three-phase voltage and current waveforms of $L_{9-39}$ and $L_{1-39}$ are selected as shown in Fig. 4. From top to bottom respectively $L_{9-39}$ current, $L_{9-39}$ voltage, $L_{1-39}$ current, $L_{1-39}$ voltage.
Energy credibility, singular credibility, and energy distortion credibility for 10 lines is evaluated (Corresponding to T1, T2, T3 in Table 1, respectively). The maximum value of the three phases is taken as the desired result. As shown in Table 1.

### Table 1. The Line information fusion results

| line | Fault feature extraction | Fusion result | diagnostic result |
|------|--------------------------|---------------|-------------------|
|      | T1  | T2  | T3   | T1  | T2   |
| 1    | 0.4351 | 0.1919 | 0.8499 | 0.8645 | 1    |
| 2    | 0.1532 | 0.1712 | 3.47×10⁻³ | 0.0464 | 0.0085 |
| 3    | 0.0515 | 0.0235 | 5.24×10⁻⁶ | 0.0087 | 2.72×10⁻⁴ |
| 4    | 0.0066 | 0.0780 | 4.39×10⁻⁶ | 0.0061 | 6.19×10⁻⁴ |
| 5    | 0.0131 | 0.0476 | 5.18×10⁻⁶ | 0.0050 | 7.77×10⁻⁴ |
| 6    | 0.1410 | 0.0544 | 6.59×10⁻⁶ | 0.0259 | 0.0021 |
| 7    | 0.0176 | 0.0416 | 4.02×10⁻⁶ | 0.0053 | 7.35×10⁻⁴ |
| 8    | 0.0272 | 0.0627 | 3.74×10⁻⁶ | 0.0084 | 3.03×10⁻⁴ |
| 9    | 0.0265 | 0.0618 | 4.87×10⁻⁶ | 0.0082 | 3.26×10⁻⁴ |
| 10   | 0.0280 | 0.0673 | 6.94×10⁻⁶ | 0.0089 | 2.47×10⁻⁴ |
| μ    | 0.1  | 0.15 | 0.2  | 0.0125 |

For the fusion result T1, the fuzzy C-means method is used for the diagnosis decision, the iteration stop error is set to 10⁻⁵, and the number of iterations is 100 times. The first type of center value is 0.0123, the second type of center value is 0.8636, and the second type is selected as the fault set. The diagnosis result T² in Table 1 is the membership degree of the line for the second category. After the membership degree is compared with the threshold value, it can be determined that L₉₋₁₀ has a fault.

In this paper, the electrical quantity information before and after the fault is used to determine the faulty line. If the switch quantity information is considered, the other line may be diagnosed as a faulty component if the circuit breaker refuses to move. Therefore, the direct use of electrical quantity information, the use of its directness and accuracy, in the grid fault diagnosis has a certain advantage over the switch.

### 6. Conclusion

1. This paper uses the directness and timeliness of electrical quantity to analyze the grid fault, and analyzes the electrical quantity data collected by the fault recorder and PMU. Starting from the change of voltage and current before and after the fault, three kinds of fault support credibility for the line are proposed, which are energy credibility, singular credibility and energy distortion credibility.

2. This paper combine the three fault support credibility on the basis of improving the D-S evidence theory, and obtain the comprehensive fault support credibility of the line fault. Finally, the fuzzy C-means method is used for diagnosis decision. Based on the PSCAD simulation example, the method effectively diagnoses the faulty line.
References
[1] Cheng Xuezhen, Lin Xiaoxiao, Zhu Chunhua, et al. Power system fault analysis based on hierarchical fuzzy Petri net considering time association character[J]. Transactions of China Electrotechnical Society, 32(14):229-237(2007)
[2] Guo Chuangxin, Gao Zhenxing, Liu Yi, et al. Hierarchical fault diagnosis approach for power grid with information fusion using multi-data resources[J]. High Voltage Engineering, 36(12):2976-2983(2010)
[3] Li Zaihua, Bai Xiaomin, Zhou Ziguan, et al. Method of power grid fault diagnosis based on feature mining[J]. Proceedings of the CSEE, 30(10): 16-22(2010)
[4] Sun Mingwei, Tong Xiaoyang, Liu Xinyu, et al. A power system fault diagnosis method using temporal Bayesian knowledge bases[J]. Power System Technology, 38(3): 715-722(2014)
[5] Gu Xueping, Liu Daobing, Sun Haixin, et al. Acquisition of power system fault diagnosis information from SCADA System[J]. Power System Technology, 36(6): 64-70(2012)
[6] Zheng Huazhen, Yue Quanming, Yu Weiyong, et al. Location of fault moment by wavelet in ultra-high-voltage network based on fault record data[J]. Power System Technology, 29(19): 33-38(in Chinese)(2005)
[7] Lv Yuejing, Song Xiangbo, Zhang Lei, et al. A weighted improved D-S evidence reasoning algorithm[J]. Computer Application and Software, 28(10): 30-33(2011)
[8] Peng Chunhua. Optimal PMU placement based on immune BPSO algorithm and topology observability[J]. Transactions of China Electrotechnical Society, 23(6): 119-12(2008)