Research on fault diagnosis method of 750kV substation based on Bayesian network and fault recording information fusion

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Abstract. Aiming at the complexity of the 750kV substation system and the uncertainty of the fault information, this paper studies the fault diagnosis method of Bayesian network and fault recording information. In order to solve the problem of single-source, DS evidence theory is used to fuse the two diagnosis results. Through case analysis, it is proved that the method can effectively improve the accuracy of fault diagnosis.

1. Introduction

750kV substation system is a part of 750kV transmission and substation demonstration project in Northwest China. As a hub of a power network, it plays an important role in ensuring the safety and stable operation of the entire power network. Therefore, it is particularly important to improve the level of intelligent fault diagnosis in substations. Literature \cite{1} introduced the fault recorder system and the Bayesian network model of the power transmission network. This method improves the efficiency of power grid fault handling. Literature \cite{2} introduced a multi-source information fusion fault diagnosis method based on the Bayesian network and Hilbert-Huang transform. The case proves that the method is effective. Considering the complexity of the substation system and the uncertainty of fault information, this paper proposes the DS evidence theory method, which combines the BN fault diagnosis method and fault recording diagnosis method, solves the single-source problem, and improves the effectiveness and fault tolerance of diagnosis.

2. 750kV substation system

Lanzhou DongWusheng 750kV substation is a pivotal substation of the northwest power grid. The simplified diagram of electrical main wiring of the system is shown in Figure 1. It is composed of three voltage levels, among which 750kV and 330kV adopt 3 / 2 main wiring form and 66kV adopts single bus section form. The design of the system circuit is more flexible.
The substation automation system is designed according to IEC61850 standard. It adopts the open structure of "three layers and two networks", which is layered and distributed. In the substation, high-speed Dual Ethernet communication is used to realize information sharing and redundancy. According to the principle of dual configuration, different types of protection devices from different manufacturers are used in the substation.

3. Fault diagnosis of 750 kV substation based on Bayesian network

In this paper, the BN (Bayesian network) method is used for fault diagnosis according to the situation of maloperation, misoperation and information loss of 750 kV substation system fault information. BN is represented by a two tuple $B < G, P >$, in which $G$ represents its network structure and $P$ is probability. For the 750kV substation system with double network and double protection configuration, the BN fault diagnosis model is divided into the main network and redundant network [3]. It makes the diagnosis result have high fault tolerance. The BN fault diagnosis model of suspected fault elements is shown in Figure 2, where the nodes represent fault elements, corresponding protection or circuit breakers, etc.

In Fig. 2, $FE$ is Fault element; $CB_{NL}$ and $CB_{MS}$ are circuit breakers; $L$ and $S$ represent the number of circuit breakers; $R_{mi}^l$, $R_{ri}^l$, $R_{mi}^r$, $R_{ri}^r$, $R_{NL}$ and $R_{NL}$ represent system protection; the subscripts $m$ and $r$ represent the two network models, that is, the main network and the redundant network; $i (= z, j, y)$ represents the protection configuration of elements, in which $z, j$ and $y$ represent the main protection, near backup protection and far backup protection respectively; $i$ is remote trip protection; $f$ is breaker failure protection; $k$ can be 1 or 2, indicating the first set of protection and the second set of protection respectively.

In literature [4], according to the joint information entropy theory and the maximum discrete entropy theorem, the initial probability $P(a_{nl}b_{nr})$ of the root node in BN is obtained. According to the action logic relationship among the nodes, the conditional probability $P(a_{nl}/b_{nr})$ and joint probability
\[ P(a_1, a_2, \ldots, a_m) \] of the associated nodes are determined. The fault probability of every suspicious fault element is obtained by the converse reasoning of Bayesian theory, as shown in equation (1).
\[
P(a_1, a_2, \ldots, a_i, \ldots, a_m) = \frac{P(a_1, a_2, \ldots, a_i, \ldots, a_m)}{\sum P(a_1, a_2, \ldots, a_i, \ldots, a_m)}
\]

According to the BN fault diagnosis decision rule, the final fault element is determined after the comprehensive judgment of the diagnosis results. The case shows that the BN fault diagnosis method has better fault tolerance and effectiveness.

4. Fault diagnosis method based on fault record information
With the development of intelligent substation system, fault recording device has become an important part of substation integrated automation system. It describes the process of fault evolution by recording the changes of voltage, current, waveform and other indicators before and after the fault, and provides accurate and reliable data for fault analysis. With the development of intelligent technology of power grid, fault recording software uses an intelligent analysis method to screen and compress the recorded information. Among them, the wavelet transform algorithm is one of the most commonly used processing methods. The wavelet transform theory is applied as follows.

After the wavelet transform of the originally recorded signal \( y(k) \), the high-frequency component coefficients \( cG_i(k) \) and low-frequency component coefficients \( cD_j(k) \) are obtained at the \( j \)-th \((j=1, 2, \ldots, m)\) decomposition scale at \( k \) time, and then \( G_i(k) \) and \( D_j(k) \) are obtained after a single reconstruction. For the convenience of expression, set \( D_j(k) = G_{j+1}(k) \). Then the original recording signal \( y(k) \) can be expressed as:
\[
y(k) = G_1(k) + D_1(k) = G_1(k) + G_2(k) + D_2(k) = G_1(k) + G_2(k) + \ldots + G_{m+1}(k)
\]

When the substation fails, the signal of the \( i \)-th suspected fault element is \( y_i(k) \). Suppose the sampling point of the signal is \( l \), the component after wavelet transform is \( \{G_{il}, G_{i2l}, \ldots, G_{il}\} \), in which \( \{G_{il}, G_{i2l}, \ldots, G_{il}\} \) is the transform component corresponding to the signal before fault and \( \{G_{i(k+1)l}, G_{i(k+2)l}, \ldots, G_{il}\} \) is the transform component corresponding to the signal after fault. Let
\[
\begin{align*}
F_{G_l} &= \max (G_{il}, G_{i2l}, \ldots, G_{il}) \\
F_{D_l} &= \max (G_{i(k+1)l}, G_{i(k+2)l}, \ldots, G_{il})
\end{align*}
\]

Then the fault degree of suspected fault elements is defined as:
\[
y_i = \frac{F_{G_l} - F_{D_l}}{\max (F_{G_l}, F_{D_l})}
\]

Therefore, the wavelet transform algorithm is used to decompose and reconstruct the recorded data to obtain the fault degree of the signal. Then, according to the principle of maximum selection of fault probability, the suspicious fault element with the largest fault probability is determined as the fault element [5].

5. Fault diagnosis method based on DS evidence theory fusion
Based on the complexity of the power grid system, the fusion of multiple intelligent methods in power grid fault diagnosis has become a hot spot of current research [6]. DS evidence theory has advantages in information fusion processing.

5.1. DS evidence theory synthesis rule
Suppose that \( \{A_1, A_2, \ldots, A_k\} \) and \( \{B_1, B_2, \ldots, B_l\} \) is the corresponding focal elements of two basic confidence assignment functions \( h_1 \) and \( h_2 \) in the same recognition framework, \( k \) is the inconsistency factor of each evidence. If \( k < 1 \), the DS evidence combination rule of \( A \) and \( B \) is
\[
h(G) = \begin{cases} 
\frac{\sum_{i,j} h_1(A_i) h_2(B_j)}{1-k} & (\forall G \in U, G \neq \phi) \\
0 & (G = \phi)
\end{cases}
\]

(5)

In (5), if \( k \neq 1 \), then \( h \) is a basic probability assignment; otherwise, \( h_1 \) and \( h_2 \) are contradictory and cannot be fused according to this rule [7-8].
5.2. Fault diagnosis process based on DS evidence theory

The DS evidence theory fault diagnosis process of the 750kV substation system is as follows.

a. Determine the identification framework. The set of suspicious fault elements obtained from the BN fault diagnosis method and fault recording information diagnosis method is \( U = \{A_1, A_2, \ldots, A_n\} \). The elements in the framework are not compatible with each other.

b. Confirm the evidence body. The evidence bodies corresponding to the two different diagnosis methods are \( E_1 \) and \( E_2 \) respectively. The corresponding recognition framework of two evidence bodies is \( U = \{A_1, A_2, \ldots, A_n\} \). In the recognition framework, the uncertainty \( \Theta \) is used to replace the power set element composed of two or more fault elements.

c. Establish the basic reliability distribution of each evidence body. According to the reference [3], the basic reliability functions \( h(A_i) \) and \( h(\Theta) \) under different evidence bodies are calculated according to the failure probability \( P(A_i) \) of suspicious fault elements obtained by different fault diagnosis methods.

d. Calculation function \( BEL(A) \) and \( PL(A) \). The degree of uncertainty of \( A \) described in the confidence space \( (BEL(A), PL(A)) \) is determined.

e. Evidence synthesis. The reliability of the fusion of two fault diagnosis methods is obtained by using DS evidence theory synthesis rules.

f. Get the diagnosis result. According to the rule of maximum trust degree, the element with the greatest trust degree is determined as the faulty element.

6. Case analysis

In the 750kV substation system, when the Wuhai I line fails, the collected information is as follows:

The current differential protection of one set of protection device completes the action; the longitudinal protection of the other set of protection device completes the action; the phase C of circuit breaker switch 3372 trips, and its reclosing action at the same time; the phase C of circuit breaker switch 3370 trips, and its reclosing action at the same time.

The fault diagnosis process of the 750kV substation system is as follows.

a. Through the BN diagnosis method and fault recording information diagnosis method, four kinds of suspicious fault elements are obtained, which respectively expressed by letters \( A, B, C \) and \( D \). \( \{A, B, C, D\} \) is the recognition framework.

b. Determine the distribution result of the basic credibility of the evidence body, as shown in Table 1.

| Evidence body            | Fault A | Fault B | Fault C | Fault D | Uncertainty |
|-------------------------|---------|---------|---------|---------|-------------|
| BN Diagnosis            | 0.92    | 0.02    | 0.02    | 0.01    | 0.03        |
| Fault recording diagnosis | 0.88   | 0.02    | 0.01    | 0.04    | 0.05        |

c. According to the synthesis rules of DS evidence theory, the reliability of fusion is obtained, as shown in Table 2.

| Fault A | Fault B | Fault C | Fault D | Uncertainty |
|---------|---------|---------|---------|-------------|
| 0.9681  | 0.0010  | 0.0006  | 0.0007  | 0.0296      |

According to the decision rule of DS evidence theory fusion, it can be concluded that the actual fault element is fault A, that is, the fault of the Wuhai I line. It can be seen that DS evidence theory improves the reliability of actual fault elements, reduces the reliability of no-fault elements and the uncertainty of information. Compared with a single diagnosis method, the accuracy of diagnosis results is improved.
7. Conclusion
In view of the complexity of the 750 kV substation system, when the information is uncertain and incomplete, the BN fault diagnosis method and fault recording information diagnosis method are used to study the system respectively. At the same time, DS evidence theory is used to fuse the two diagnosis results in diagnosis decision-making. This method not only solves the problem of a single source but also makes the diagnosis result more accurate.

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