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Substation Fault Diagnosis Based on Time Sequence Fuzzy Petri Net

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Abstract

As the 750kV substation has the characteristics like timing inconsistency, dual protection configuration and uncertain diagnosis result, a fault diagnosis method of substation with redundant protection configuration based on time sequence fuzzy Petri nets is proposed. In this method, redundant knowledge about fault component is represented by using two sets of protective information. On that basis, component redundant diagnosis-model based on time sequence fuzzy Petri net is constructed, which can be decomposed into main and redundant subnet-model, in which initial-information credibility is determined by using information-entropy, the time sequence constraint is checked and initial-information credibility is corrected by using the relationship between the acted protection and breaker. Compared with fuzzy Petri net diagnosis method taking no account of time sequence factor, the proposed method can not only identify the malfunction information, but also obtain a certain result.

Keywords: 750kV substation, redundant protection, fault diagnosis, redundant knowledge representation, time sequence fuzzy Petri Net

1. Introduction

The 750kV grid is an important delivery channel of wind power and solar power in Gansu and Xinjiang, so the safety and reliability of substation is of great significance to ensure its stable operation. In 750kV grid, dual protection configuration is used, in other words, two sets of protection are in parallel operation and redundant [1-2]. The station level and the bay level communicate by means of dual Ethernet. Moreover, the 750kV substation with 750kV, 330kV and 66kV line plays an important role in 750kV grid. Due to the complexity of line, huge alarm information is sent to control center once a fault occurs. So it is very necessary for an operator to detect the fault quickly and accurately, locate and recover it. Hence, it is very important to study fault diagnosis system of substation in safe and stable operation of grid.

At present, foreign and domestic scholars have done a lot of work in fault diagnosis. For instance, the introduction of information theory solves the uncertainty, which turns diagnosis problems into combinatorial optimization of the minimum information loss [3]. In [4-5] the concept of dynamic association path has been put forward, so a new analytical model of fault diagnosis taking full advantage of time sequence information, which can describe reasonably time sequence relationship between the protection and breaker under the complex protective configurations, is constructed. This model can not only analyze specific events like the alarm generated and time interval, but also identify abnormal or omissive alarm messages. In [6], a time sequence constraint and abductive reasoning method based on alarm information is proposed to describe time sequence and logical relationship among the alarm information, which can identify breakpoint alarm, mistaken alarm and missing alarm information, and reduce the uncertainty of alarm result. Afterwards, the data structure and algorithm of extended time Petri net (ETPN) is studied in [7], which used ETPN to simulate action process of relay protective device. In [8], the characteristics of the power system fault diagnosis model based on time sequence fuzzy Petri net (TSFPN) are analyzed, which given a rapid correction method of model changes with grid topology structure and taken advantages of time sequence property of protection and breaker action information. However, there are still some limitations: 1) The studies of substation system used only single-net single-configuration; 2) Only considered the action priority of the protection and breaker; 3) The models were not well employed the time

sequence information of the protection and circuit breaker, which can lead to more similar diagnosis result.

So the further research works in this paper are listed as follows: 1) It is necessary to research substation system with dual-net dual-protection configuration; 2) In the proposed model, the alarm information is taken full advantages and the information entropy is used to determine initial information credibility; 3) Check time sequence constraint and correct initial-information credibility by using the relationship between the acted protection and breaker, which obtains a certain result. On that basis, the TSFPN diagnosis method is proposed for substation with dual-net dual-protection configuration. The result shows that the proposed method is feasible and effective.

2. Research Method
2.1. The Definition of Time Sequence Constraint
2.1.1. Time Interval Constraint

t_i is the occurrence time of event p_i, which can be decomposed into definite time point and indefinite time point. The latter can be defined as $T_C(t_i) = [t_i^-, t_i^+]$, which denotes the occurrence time of event. It satisfies time interval constraint, that is, $t_i \in T_C(t_i)$, otherwise, it does not. When $t_i^- = t_i^+$, t_i becomes a definite time point [9-11].

2.1.2. Time Distance Constraint

t_i and t_j are the occurrence time of events p_i, p_j, respectively. $d(t_i, t_j)$ denotes time distance between two time points, which can be defined as $d(t_i, t_j) = t_j - t_i$. The time distance can be decomposed into definite time distance and indefinite time distance. The latter $d(t_i, t_j)$ can be defined as $D(t_i, t_j) = [\Delta t_{ij}^-, \Delta t_{ij}^+]$. It satisfies time distance constraint, that is, $d(t_i, t_j) \in D(t_i, t_j)$, otherwise, it does not. Where, Δt_{ij}^- and Δt_{ij}^+ are the lower and the upper bounds of $D(t_i, t_j)$, respectively. When $\Delta t_{ij}^- = \Delta t_{ij}^+$, $d(t_i, t_j)$ becomes a definite time distance [9-11].

2.1.3. Time Sequence Constraint Calculation

Suppose that events p_i, p_j and p_k happen one after another at t_i, t_j and $t_k (t_i < t_j < t_k)$, then the three constraint calculations [9-11] concerned time interval constraint and distance constraint can be obtained as follows.

1) The time interval constraint for the forward event.

Given $T_C(t_i) = [t_i^-, t_i^+]$ and $D(t_i, t_j) = [\Delta t_{ij}^-, \Delta t_{ij}^+]$, from Figure 1(a), the time interval constraint is denoted by $t_j = t_i + d(t_i, t_j)$, which can be obtained as:

$$
\begin{aligned}
T_C(t_j) &= T_C(t_i) + D(t_i, t_j) \\
&= [t_i^-, t_i^+] + [\Delta t_{ij}^-, \Delta t_{ij}^+] \\
&= [t_i^- + \Delta t_{ij}^-, t_i^+ + \Delta t_{ij}^+]
\end{aligned}
\tag{1}
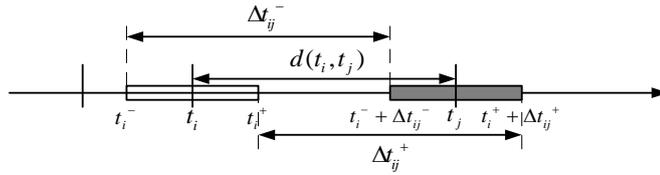$$

2) The time interval constraint for the backward event.

Given $T_C(t_j) = [t_j^-, t_j^+]$ and $D(t_i, t_j) = [\Delta t_{ij}^-, \Delta t_{ij}^+]$, from Figure 1(b), the time interval constraint is denoted by $t_i = t_j - d(t_i, t_j)$, which can be obtained as:

$$
\begin{aligned}
T_C(t_i) &= T_C(t_j) - D(t_i, t_j) \\
&= [t_j^-, t_j^+] - [\Delta t_{ij}^-, \Delta t_{ij}^+] \\
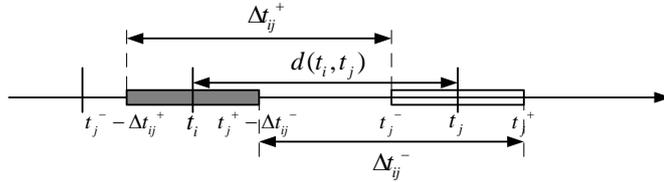&= [t_j^- - \Delta t_{ij}^+, t_j^+ - \Delta t_{ij}^-]
\end{aligned}
\tag{2}
$$

3) The sum of two time distance constraint for multiple events.

Given $D(t_i,t_j)=[\Delta t_{ij}^{-},\Delta t_{ij}^{+}]$ and $D(t_j,t_k)=[\Delta t_{jk}^{-},\Delta t_{jk}^{+}]$, from Figure 1(c), the time distance constraint is denoted by $d(t_i,t_k)=d(t_i,t_j)+d(t_j,t_k)$, which can be obtained as:
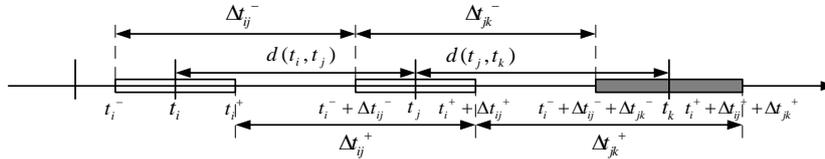
$$
\begin{aligned}
D(t_i,t_k) &= D(t_i,t_j)+D(t_j,t_k) \\
&= [\Delta t_{ij}^{-},\Delta t_{ij}^{+}]+[\Delta t_{jk}^{-},\Delta t_{jk}^{+}] \\
&= [\Delta t_{ij}^{-}+\Delta t_{jk}^{-},\Delta t_{ij}^{+}+\Delta t_{jk}^{+}]
\end{aligned}
\tag{3}
$$

(a) The time interval constraint for the forward event

(b) The time interval constraint for the backward event

(c) The sum of two time distance constraint for multiple events

Figure 1. Time Sequence Constraint Calculation

2.2. Redundant Knowledge Representation

Redundant knowledge of fault component is represented by using protection and breaker action information obtained from SCADA, as well as its time sequence property. For 750kV substation with dual-net dual-protection configuration, the redundant TSFPN of fault component can be defined as a ten-tuple $\text{TSFPN}=(P,T,T_C,D,I,O,M,u,W,\lambda)$. While TSFPN can be decomposed into two subnets: TSFPN_m and TSFPN_r with $\text{TSFPN}_m \cup \text{TSFPN}_r=\text{TSFPN}$ by using the dual-net characteristics. So $\text{TSFPN}_m=(P_m,T_m,T_{Cm},D_m,I_m,O_m,M_m,u_m,W_m,\lambda_m)$ is the main network and $\text{TSFPN}_r=(P_r,T_r,T_{Cr},D_r,I_r,O_r,M_r,u_r,W_r,\lambda_r)$ is the redundant.

Where:

(1) $P_i=\{p_{i1},p_{i2},\cdots,p_{in}\},(i=m,r)$ is the finite set of fuzzy places in the main network and redundant network, where n is the number of place, and $p_{ij1},p_{ij2}(j=1,2,3)$ are primary protection, local backup protection and remote backup protection corresponding to the first set of protection and the second set of protection of component respectively.

(2) $T_i = \{t_{i1}, t_{i2}, \cdots, t_{in}\}, (i = m, r)$ is the finite set of fuzzy transitions in the main network and redundant network, where n is the number of transition.

(3) $T_{Ci} = \{T_{Ci1}, T_{Ci2}, \cdots, T_{Cin}\}, (i = m, r)$ is the state-information time of original place in the main network and redundant network, which is time interval constraint corresponding protection action and breaker tripping time, where n is the number of original place.

(4) $D_i, (i = m, r)$ is the time distance constraint between any two events in the main network and redundant network, which includes three kinds: 1) the occurrence time of component and the action time of protection; 2) protection and its corresponding breaker; 3) primary protection and local backup protection or local backup protection and remote backup protection.

(5) $I_i : P_i \times T_i \rightarrow \{0,1\}, (i = m, r)$ is the input function of the main network and redundant network. $I(p_{ij}, t) = 1$, if there is a directed arc from p_{ij} to t.

(6) $O_i : T_i \times P_i \rightarrow \{0,1\}, (i = m, r)$ is the output function of the main network and redundant network. $O(t, p_{ij}) = 1$, if there is a directed arc from t to p_{ij}.

(7) $M_i(i = m, r)$ is the marking value of P_i in the main network and redundant network. $M(p_{ij})$ is the credibility of place in $p_{ij} \in P_i$, which describes the uncertainty.

(8) $u_i(i = m, r)$ is the credibility of the rule in the main network and redundant network associated to transition $t_{ij} \in T_i$, which describes the uncertainty.

(9) $W_i = \{w_{i1}, w_{i2}, \cdots, w_{in}\}(i = m, r)$ is a weight matrix of the main network and redundant network, which denotes the truth degree of the initial place with respect to the conclusion, where, W_i is an $1 \times n$ matrix.

(10) $\lambda_i(i = m, r)$ is the confidence threshold of the main network and redundant network in transition.

2.3. Redundant Diagnosis Model

The protective device associated with component has the setting value of time in substation, which can be integrated into the fuzzy Petri net. Consequently, the TSFPN diagnosis model of substation with dual-net dual-protection configuration is constructed according to 3.1 redundant knowledge representations.
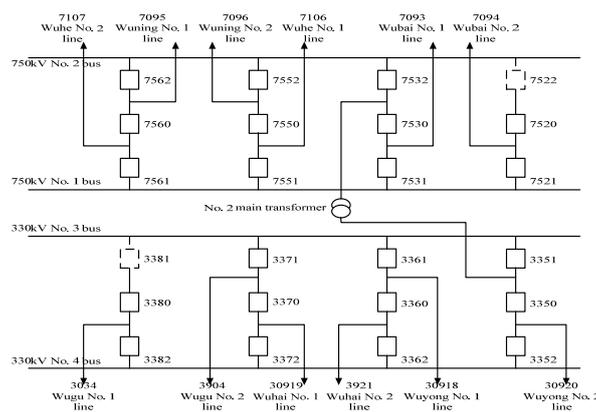

Figure 2. Local Main Electrical Connection Scheme of 750kV WuSheng Substation

Compared with fault diagnosis of single-net single-configuration, the characters of fault diagnosis for dual-net dual-protection configuration are listed as follows: 1) the protective configuration accelerates; 2) the amount of fault information increases; 3) the grid topology

structure and diagnosis model are more complex; 4) the malfunction information is prone to appear; 5) the diagnosis result is uncertain. Considering the above mentioned, diagnosis model is constructed by using hierarchical modeling idea. Firstly, the main network and redundant network subnet-model are constructed. Afterward, diagnosis model of coupling network is constructed on the basis of the subnets. Compared with the diagnosis model of single TSFPN, this model reflects better the characteristic of grid topology structure and dynamic characteristic.
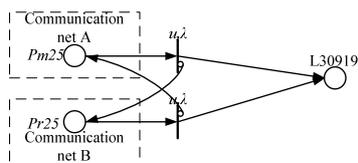
Figure 2 shows a local main electrical connection scheme in 750kV substation, For Wuhai No.1 line, the TSFPN redundant diagnosis model is constructed as shown in Figure 3.
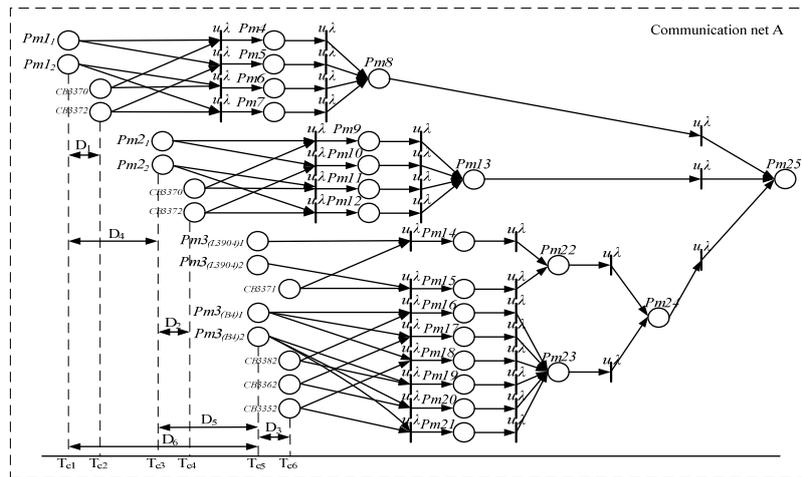
(a) Diagnosis model of main network
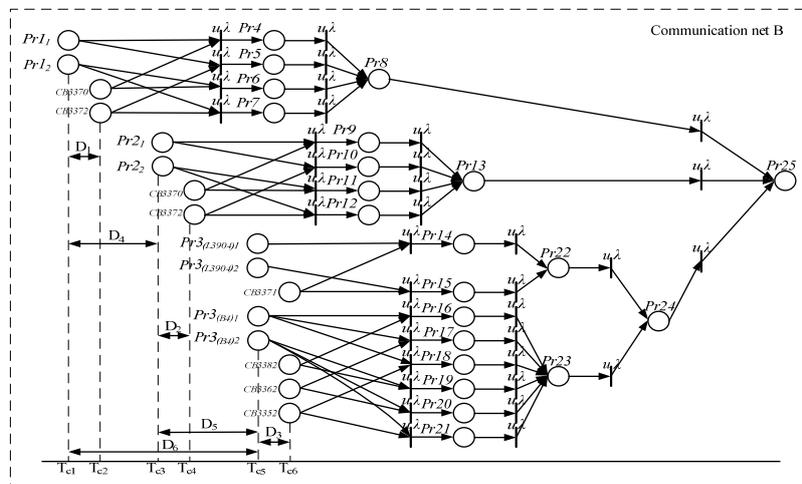
(b) Diagnosis model of redundant network

(c) Diagnosis model of coupling network

Figure 3. Redundant diagnosis TSFPN model of line 30919

In this model, the time sequence information is added to fault diagnosis to improve the description and diagnosis accuracy of the diagnosis model.

(1) The diagnosis subnet-model of main network and redundant network, can be seen in Figure 3(a) and (b). $p_{ij(X)1}$ and $p_{ij(X)2} (i = m, r; j = 1, 2, 3)$ are primary protection, local backup protection and remote backup protection corresponding to the first set of protection, the second set of protection of the main network and the redundant network, respectively. Where the subscript X is the correlated component of fault component. CB is breaker.

(2) The diagnosis model of coupling network can be seen in Figure 3(c). The maximum credibility of output place in the main network and redundant network is considered as the credibility of component.

2.4. Initial Information Valuation of Redundant Diagnosis Model
2.4.1. Information Entropy

According to information entropy theory [12-13], if X contains finite random events which denotes the state characteristics of an uncertain system, let $p_i (i=1,2…,n)$ be the probability of x_i, and $\sum_{i=1}^{n} p_i = 1$, where n is the number of event, thus the amount of self-information of any event x_i on finite field X is given by:

$$I(x_i) = -\log_2 p_i \qquad (4)$$

Mathematical expectation of random variable $I(x_i)(i=1,2,3,…n)$ is defined as the amount of average self-information on the set X, called information entropy of X, that is:

$$H(X) = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad (5)$$

2.4.2. Initial Information Valuation

In order to obtain more accurate diagnosis results, the information is decomposed into the fault-state group and the fault-characteristic group. The fault-state group is fault symptom set which may occur, and fault-characteristic group is the alarm event set corresponding to fault symptom. According to the collected action information of protective device and breaker, the correlation degree between fault-state group and fault-characteristic group is determined by using information entropy in the time sequence constraint condition and the credibility of fault state group obtained when fault characteristic group is known.

After the fault occured, fault state group $A = (a_1, a_2, \cdots, a_n)$ is determined by diagnosis model, where a_i is $\{ Pm1_1, Pm1_2, Pm2_1, Pm2_2, Pm3_{(L3904)1}, Pm3_{(L3904)2}, Pm3_{(B4)1}, Pm3_{(B4)2}, CB3370,$ $CB3372, CB3371, CB3382, CB3362, CB3352 \}$ and the fault characteristic group is determined as $K = (b_1, b_2, \cdots, b_r)$ corresponding to fault state group, where b_j is {zero sequence protection, pilot protection, distance protection, overvoltage protection}. The credibility information entropy of fault state a_i (denoted by $H(a_i)$) is given by:

$$H(a_i) = -p_i \log_2 p_i \qquad (6)$$

The credibility of initial information is the information entropy about a_i with respect to b_j. The uncertainty is more apparent due to the malfunction information of protective device or breaker in the course of grid fault. So it is necessary to define a comprehensive index which can make full use of the information in fault-characteristic set. Therefore, the joint entropy [8-10] about a_i obtained from b_j can be defined as:

$$I(A, K) = H(K) + H(K | A) \qquad (7)$$

Apply Equation (6) to Equation (7), then obtain:

$$I(A,K) = -p(b_j)\log_2 p(b_j) - p(b_j \mid a_i)\log_2 p(b_j \mid a_i) \tag{8}$$

Where $p(b_j)$ is the occurrence probability of fault characteristic b_j, while $p(b_j \mid a_i)$ is the occurrence probability of b_j with respect to a_i.

As the probability of event is not readily available in project, the engineering method [8] is used in this paper. Suppose that the probability of fault state and fault characteristic is equal, then obtain:

$$p(b_j) = \frac{1}{r} \qquad j = 1,2,\cdots r \tag{9}$$

$$p(b_j \mid a_i) = \begin{cases} \dfrac{n(A \cap K)}{n}, a_i \neq b_j \\ \quad 0 \quad, a_i = b_j \end{cases} \tag{10}$$

Where r is the number of fault characteristic b_j, $n(A \cap K)$ is the number of time sequence action in fault characteristic b_j with respect to a_i. Apply Equation (9) and Equation (10) to Equation (8), then obtain:

$$I(A,K) = \frac{1}{r}\log_2 r - \frac{n(A \cap K)}{n}\log_2 \frac{n(A \cap K)}{n} \tag{11}$$

Note that $\log_2 \dfrac{n(A \cap K)}{n}$ does not exist when $n(A \cap K)=0$, therefore, the limit of $\dfrac{n(A \cap K)}{n}\log_2 \dfrac{n(A \cap K)}{n}$ is calculated, that is, $\lim\limits_{n(A \cap K) \to 0^+} \dfrac{n(A \cap K)}{n}\log_2 \dfrac{n(A \cap K)}{n} = 0$.

The credibility of the initial information is determined by joint entropy *I(A,K)*. The bigger value of *I(A,K)* is, the smaller uncertainty of initial information is. In other word, the more accurate diagnosis result is.

2.5. Initial Information Time Sequence Constraint Checking of Redundant Diagnosis Model

According to the protective configuration principle, the protection devices have the setting values of time. For instance, the time delay of primary protection is between 0 and 20ms, the time delay of breaker is between 20 and 40ms, the time delay of protection devices is 0.5s with an error of ±5%. In order to check time sequence relationship and correct initial-information credibility, the time sequence constraint is calculated by using the constraint relationship between the protection and breaker.

1) Check whether the time distance constraint [20, 40] can be satisfied between the action time of protection devices and the tripping time of its corresponding breaker.

2) Check whether time distance constraint [475,525] can be satisfied between the primary protection and local backup protection, whether time distance constraint [950,1050] can be satisfied between the primary protection and remote backup protection, whether time distance constraint [475,525] can be satisfied between the local backup protection and remote backup protection.

3) Check whether time interval constraint $T(t_{CB})$ of the breaker tripping time corresponding to protection can be satisfied. Calculate the time sequence constraint by using protective information satisfied time constraint checking and take advantage of the time distance constraint between the protection and breaker.

4) It is unnecessary to correct the credibility of corresponding place for the missing information of the protection devices and breakers.

2.6. The Reasoning of Redundant Diagnosis Model

The reasoning of redundant time sequence fuzzy Petri net is based on credibility and the reasoning procedures are carried out individually as follows.

(1) Check time sequence constraint relationship between protective device and breaker, and correct the initial-information credibility on the basis of checking result.

(2) Calculate synthetic input credibility denoted by $E = M_{i0} g_i$ in transitions, where $E = [e_1, e_1, \cdots, e_n]$ and n is the number of awaiting trigger transition.

(3) Compare the equivalent fuzzy input credibility with the transition threshold, that is $G = E \cap^O \lambda_i$, where G is a m-dimensional column vector. If the synthetic input credibility is greater than the threshold, then $g_i = 1$; otherwise, $g_i = 0$ ($i = 1, 2, \cdots, m$), where m is the number of triggered transition.

(4) Remove the input of synthetic input credibility which is less than the threshold and obtain $H = E \, e \, G$, where H only contains synthetic input credibility of triggered transition.

(5) Calculate the credibility of fuzzy output denoted by $M_{i1} = H \otimes O_i$, where M_{i1} is a m-dimensional column vector, m is the number of triggered transition.

(6) Perform iterative computation from step 2 to step 5 repeatedly.

(7) Obtain output results M_{ik} until $M_{ik} = M_{i(k-1)}$.

In order to describe the reasoning of a TSFPN, the following operators [14] are used.

1) g : $C = AgB$, such that $c_{ij} = \sum_{k=1}^{l} a_{ik} g b_{kj}$;

2) $\otimes$: $C = A \otimes B$, such that $c_{ij} = \max_{1 \le k \le l}(a_{ik} g b_{kj})$;

3) $\cap^O$: $C = A \cap^O B$, if $a_{ij} \ge b_{ij}$, then $c_{ij} = 1$; otherwise, if $a_{ij} < b_{ij}$, then $c_{ij} = 0$.

4) e : $C = A \, e \, B$, such that $c_{ij} = a_{ij} g b_{ij}$.

3. Results and Discussion

Case: Wuhai No. 1 line contains two sets of protective device as shown in Figure 2. The type of the first protection devices is RCS-931BM, the second protection is CSC-101A and 3372 and 3370 breaker protective device are RCS-921A. When a fault occurred on Wuhai No. 1 line, current differential protection of RCS-931BM operates at 60ms, pilot protection of CSC-101A operates at 31ms, phase C trips at 41ms and recloses at 706ms in RCS-921A for 3372 breaker, phase C trips at 42ms and recloses at 1307ms in RCS-921A for 3370 breaker, 3372, 3370 breaker trip at 65ms and reclose after a delay. Afterward, the fault is removed.

Table 1. Initial Information Credibility of Redundant Diagnosis Model

initial information		n	r	n(A∩K)		initial information credibility	
main network	redundant network			FPN	TSFPN	FPN	TSFPN
$Pm1_1$	$Pr1_1$	14	4	1	0	0.772	0.5
$Pm1_2$	$Pr1_2$	14	6	1	1	0.703	0.703
CB3370	CB3370	14	11	3	3	0.791	0.791
CB3372	CB3372	14	11	3	3	0.791	0.791
$Pm2_1$	$Pr2_1$	14	4	0	0	0.5	0.5
$Pm2_2$	$Pr2_2$	14	6	0	0	0.431	0.431
$Pm3_{(L3904)1}$	$Pr3_{(L3904)1}$	14	4	0	0	0.5	0.5
$Pm3_{(L3904)2}$	$Pr3_{(L3904)2}$	14	5	0	0	0.464	0.464
CB3371	CB3371	14	11	0	0	0.314	0.314
$Pm3_{(B4)1}$	$Pr3_{(B4)1}$	14	4	0	0	0.5	0.5
$Pm3_{(B4)2}$	$Pr3_{(B4)2}$	14	2	0	0	0.5	0.5
CB3382	CB3382	14	11	0	0	0.314	0.314
CB3362	CB3362	14	11	0	0	0.314	0.314
CB3352	CB3352	14	11	0	0	0.314	0.314

According to the proposed diagnosis method, suspicious fault components of Wuhai No. 1 line, Wugu No. 2 line, 330kV No. 4 bus can be detected by searching fault region. In Figure 3, the initial-information credibility is determined by using information-entropy, the time sequence constraint is checked and the initial-information credibility is corrected by using the relationship between the acted protection and breaker. The results are shown in Table 1.

Suppose that the input arc weights of transition is 1/n as shown in Figure 3, where n is the number of input arc. The credibility of suspicious fault component can be obtained through TSFPN reasoning as shown in Table 2.

Table. 2 Fault Credibility of Suspicious Component

suspicious fault component	fault credibility		actual fault component
	FPN	TSFPN	
Wuhai No. 1 line	0.7815	0.747	
Wugu No. 2 line	0.6455	0.407	Wuhai No. 1 line
330kV No. 4 bus	0.6455	0.407	

It is demonstrated by the above case that the proposed method can not only evaluate and analyze the action information of the protection and breaker intuitively, but also identify the malfunction information effectively and obtain a certain result.

4. Conclusion

As alarm information is not consistent with time sequence information and diagnosis result is uncertain, the fault diagnosis method of substation with redundant protection configuration based on time sequence fuzzy Petri net is proposed. In this method, the component redundant diagnosis-model based on time sequence fuzzy Petri net can be decomposed into main and redundant subnet-model by using dual-net characteristics of 750kV substation, in which the initial-information credibility is determined by using information-entropy. The time sequence constraint is checked and the initial-information credibility is corrected by using the relationship between the acted protection and breaker. The results show that the proposed method is more accurate compared with the fuzzy Petri net taking no account of time sequence factor, which can not only identify the malfunction information, but also obtain a certain result.

References
[1] DOU Xiaobo, HU Minqiang, WU Zaijun. Configuration and redundancy of communication networks in digital substations. *Electric Power Automation Equipment.* 2008; 28(1): 38-43.
[2] GuoYan Chen, Xianggen Yin, Kai Zhang. Communication modeling for wide-area relay protection based on IEC 61850. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2012; 10(7): 1673-1674.
[3] TANG Lei, SUN Hongbin, ZHANG Boming. *Online fault diagnosis for power system based on information theory.* Proceedings of the CSEE. 2003; 27(7): 5-11.
[4] GUO Wenxin, LIAO Zhiwei, WEN Fushuan. An analytic model for power network fault diagnosis with the temporal information of alarm message taken into account. *Automation of Electric Power Systems.* 2008; 32(22): 26-31.
[5] GUO Wenxin, WEN Fushuan, LIAO Zhiwei. An analytic model for power system online alarm processing based on temporal constraint network. *Automation of Electric Power Systems.* 2009; 33(21): 36-43.
[6] KANG Taifeng, WU Wenchuan, ZHANG Boming. *Temporal abductive reasoning based diagnosis and alarm for power grid.* Proceedings of the CSEE. 2010; 30(19): 84-90.

[7]   WANG Lei, WAN Qiulan. Extended time petri net applied in action logic simulation of protection and automation equipment in DTS. *Automation of Electric Power Systems*. 2005; 29(6): 71-74.
[8]   YANG Jianwei, HE Zhengyou. Power system fault diagnosis approach based on time sequence fuzzy Petri net. *Automation of Electric Power Systems*. 2011; 35(15): 46-51.
[9]   P Srikanth, Ashwani Kumar Chandel. Inverse S-Transform based decision tree for power system faults identification. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2011; 9(1): 99-106.
[10]   Jean Francois Condotta, Gerard Ligozat. *Ultimately periodic qualitative constraint networks for spatial and temporal reasoning*. Tools with Artificial Intelligence. Hong Kong. 2005: 583-588.
[11]   Hoong Chuin LAU, Thomas OU. *Robust temporal constraint network*. Tools with Artificial Intelligence. Hong Kong. 2005: 81-88.
[12]   Kang HG, Seong PH. A methodology for evaluating alarm processing systems using informational entropy based measure and the analytic hierarchy process. *IEEE Transactions on Nuclear Science*. 1999; 46(6): 2269-2280.
[13]   Angel Cataron, Razvan Andonie. *How to infer the informational energy from small datasets*. Optimization of Electrical and Electronic Equipment (OPTIM). Brasov. 2012: 1065-1070.
[14]   PTT Binh, ND Tuyen. *Fault diagnosis of power system using neutral petri net and fuzzy neural petri net*. IEEE on Power India Conference. New Delhi. 2006.