Fault Diagnosis for Substation with Redundant Protection Configuration Based on Time-Sequence Fuzzy Petri-Net

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Abstrak

Adanya inkosistensi pewaktuan, konfigurasi proteksi ganda dan karakteristik ketidakpastian hasil diagnosis stasion cabang 750kV, makalah ini mengusulkan sebuah metode diagnosis kegagalan pada stasiun cabang dengan konfigurasi proteksi redundan berbasis jaringan Petri kabur runtun waktu. Pada metode ini, komponen kegagalan tentang pengetahuan redundan direpresentasikan menggunakan dua set informasi terlindungi. Atas dasar itu, komponen model diagnosis redundan berbasis jaringan Petri kabur runtun waktu dibangun, yang dapat diuraikan ke dalam model subnet utama dan redundan. Pada model ini, kredibilitas informasi awal ditentukan dengan menggunakan entropi informasi, batasan waktu diperiksa, dan kredibilitas informasi awal dikoreksi menggunakan hubungan antara proteksi dan pembongkar yang berlaku. Dibandingkan dengan metode diagnosis jaringan Petri kabur yang tidak memperhatikan batasan waktu, metode ini tidak hanya dapat mengidentifikasi informasi kerusakan, tetapi juga mendapatkan hasil tertentu.

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

Abstract

Due to timing inconsistency, dual protection configuration and uncertainty diagnosis result characteristics of 750kV substation, fault diagnosis method of substation with redundant protection configuration which based on time sequence fuzzy Petri nets is proposed. In this method, redundant knowledge about fault component is represented by using two sets of protected 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 this model, initial-information credibility is determined using information-entropy, timing constraint is checked, and initial-information credibility is corrected using the relationship between acted protection and breaker. Compared with fuzzy Petri net diagnosis method take no account of timing constraint, this 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, in which the safe and reliable substation is of great significance for ensuring its stable operation. 750kV grids use dual protection configuration, in other words, two sets of protection are in parallel operation and redundant [1], and its station level and bay level communicate by means of dual Ethernet. 750kV substation plays an important role in 750kV grid, which includes 750kV, 330kV, and 66kV line. Once fault occurs in substation, huge alarms are sent to control center due to the complexity of the line. So it is very necessary to detect quickly and accurately the fault for an operator, and locate and recover it. And hence, it is very important to study fault diagnosis system of substation in safe and stable operation of grid.

At present, domestic and foreign scholars have done a lot of work in fault diagnosis. Introducing information theory solves the uncertainty in the power system fault diagnosing process, which turns diagnosis problems into combinatorial optimization of the minimum information loss [2]. In [3] the concept of dynamic association path has been put forward, and a

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new analytical model of fault diagnosis which takes full advantage of temporal information, and which can reasonably describe timing relationship between protections and breakers under complex protective configurations, is constructed. The alarm processing analytical model [3] based on timing information is constructed, which not only is able to analyze specific events that the alarm generated and time interval in this event, and which can identify abnormal or omission alarm messages. In [5], using time constraint and abductive reasoning rule describes timing relationship and logical relation between alarm information, and proposing time abductive reasoning method based on alarm information, can identify breakpoint alarm, mistaken alarm and missing alarm, and reduce the uncertainty of alarm result. Studied data structure and algorithm of extended time Petri net (ETPN) [6], using ETPN simulates action process of relay protective device. Following [7] analyzed the characteristic of the power system fault diagnosis model based on time sequence fuzzy Petri net (TSFPN), given rapid correction method of model changes with grid topology structure, and taken advantage of timing property of protection and breaker action information. However, there are still some limitations: 1) It researches substation system with single-net single-configuration; 2) It only considers the action priority of protection and breaker, and sets its credibility respectively; 3) The model was not well employed timing constraint of protection and circuit breaker, which can lead to more similar diagnosis results.

The further research works are listed as follows: 1) It is necessary to research substation system with dual-net dual-protection configuration; 2) In the model, made full advantage of alarm information, using information entropy determines initial information credibility; 3) timing constraint is checked, and initial-information credibility is corrected using the relationship between acted protection and acted breaker, which obtain a certain result. On that basis, 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. The Definition of Timing Constraint

2.1. Time Interval Constraint

t_i is the occurrence time of event p_i, and can be decomposed into definite time point and indefinite time point. The latter can be defined as $T_C(t_i) = [t_i^-, t_i^+]$, and denotes the occurrence time of event satisfying time interval constraint, that is $t_i \in T_C(t_i)$, otherwise, it does not satisfy. When $t_i^- = t_i^+$, t_i becomes a definite time point [4].

2.2. Time Distance Constraint

t_i and t_j are the occurrence time of events p_i and p_j, and $d(t_i, t_j)$ denotes time distance between two time points, which is 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 $D(t_i, t_j) = [\Delta t_{ij}^-, \Delta t_{ij}^+]$, and denotes the occurrence time of events satisfying time distance constraint, that is, $d(t_i, t_j) \in D(t_i, t_j)$, otherwise, it does not satisfy. 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 [4].

2.3. Time Constraint Calculation

Suppose that events p_i, p_j, p_k happen one after another at $t_i, t_j, t_k (t_i < t_j < t_k)$, respectively, then three constraint calculations [13-15] concerning the time interval constraint and distance constraint could be obtained as follows.

2.3.1. The time interval constraint for the forward event

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

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

2.3.2. The time interval constraint for the backward event

Given $T_C(t_j) = [t_j^-, t_j^+]$ and $D(t_i,t_j) = [\Delta t_{ij}^-, \Delta t_{ij}^+]$, and from Figure 1(b), the time interval constraint denotes by $t_i = t_j - d(t_i,t_j)$, and can be obtained as equation (2).

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

2.3.3. The sum of two time distance constraint for multiple events

Given $D(t_i,t_j) = [\Delta t_{ij}^-, \Delta t_{ij}^+]$ and $D(t_j,t_k) = [\Delta t_{jk}^-, \Delta t_{jk}^+]$, and from Figure 1(c), the time distance constraint denotes by $d(t_i,t_k) = d(t_i,t_j) + d(t_j,t_k)$, and can be obtained as equation (3).

$$
\begin{aligned}
D(t_i,t_k) &= D(t_i,t_j) + D(t_j,t_k) \\
&= [\Delta t_{ij}^-, \Delta t_{ij}^+] + [\Delta t_{jk}^-, \Delta t_{jk}^+] \\
&= [\Delta t_{ij}^- + \Delta t_{jk}^-, \Delta t_{ij}^+ + \Delta t_{jk}^+]
\end{aligned} \quad (3)
$$

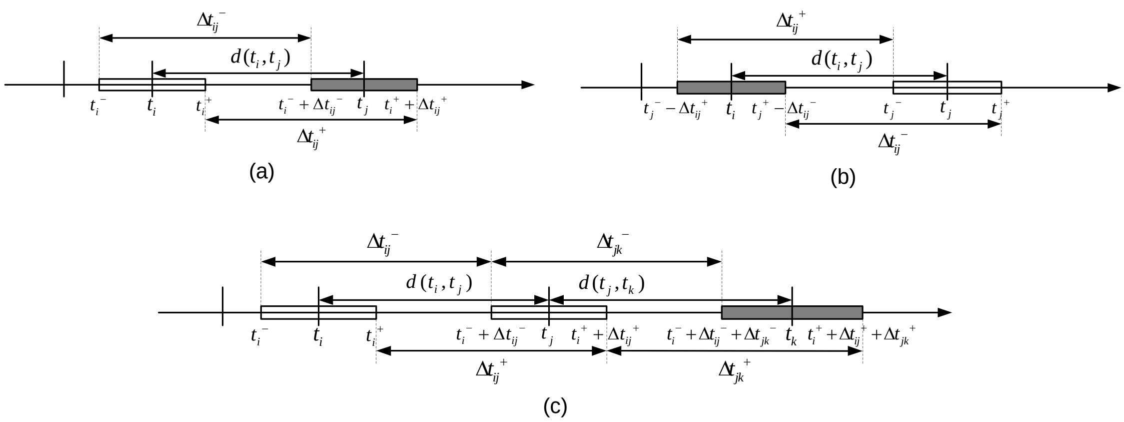


Figure 1. The time interval constraint, (a). the forward event, (b). the backward event, (c). The sum of two time distance constraint for multiple events

3. TSFPN Redundant Diagnosis Model

3.1. Redundant Knowledge Representation

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

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 places, p_{ij_1} and $p_{ij_2} (j = 1,2,3)$ are,

respectively, primary protection, local backup protection and remote backup protection corresponding to the first set of protection and the second set of protection of component.

(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 transitions.

(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 correspond protection action and breaker tripping time, where n is the number of original place.

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

(5) $I_i : P_i \times T_i \to \{0,1\}, (i = m, r)$ 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) $O_i : T_i \times P_i \to \{0,1\}, (i = m, r)$ 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. $M(p_{ij})$ denotes the credibility of proposition in $p_{ij} \in P_i$, and describes the uncertainty of it.

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

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

(10) $^{a}{}_{i} (i = m, r)$ is confidence threshold [7] of the main network and redundant network in transition.

3.2. Redundant Diagnosis Model

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

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) protective configuration accelerates; 2) the amount of fault information increases; 3) grid topology structure and diagnosis model are more complex; 4) be prone to malfunction information; 5) the diagnosis result is uncertainty. Considering the above mentioned, diagnosis model is constructed 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 diagnosis model of single TSFPN, its model better reflects the characteristic of grid topology structure and dynamic characteristic.

Figure 2 shows a local main electrical scheme in 750kV substation, For Wuhai No.1 line, its TSFPN redundant diagnosis model is constructed as shown in Figure 3.

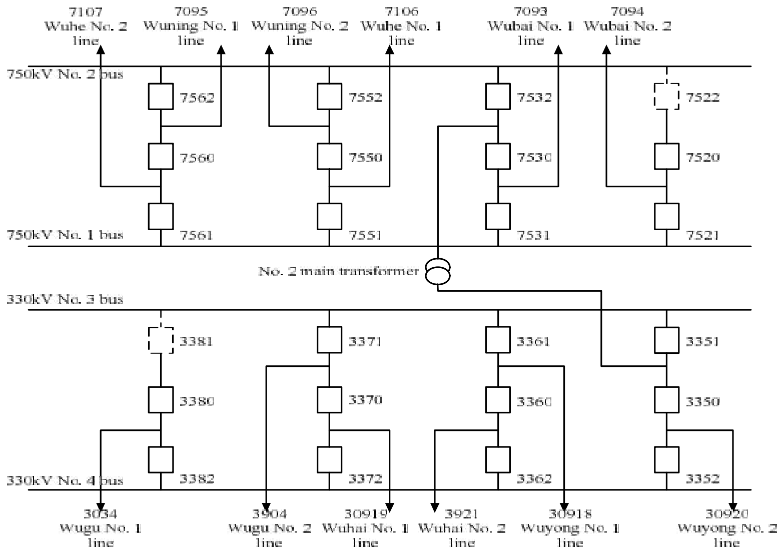
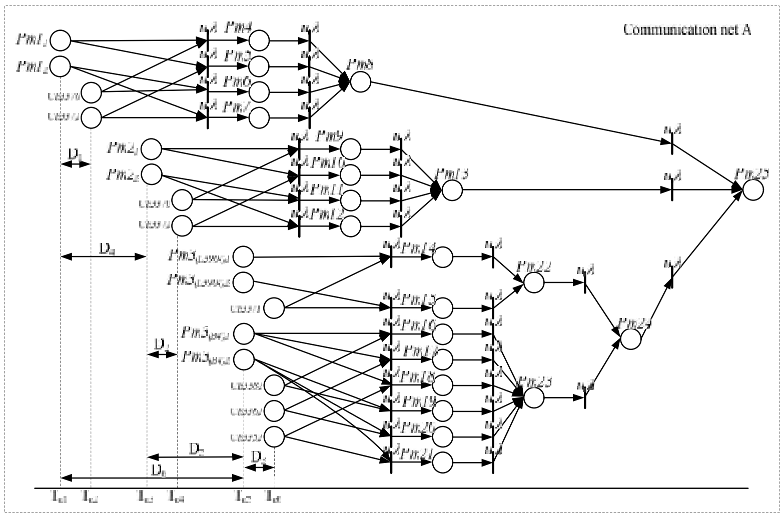
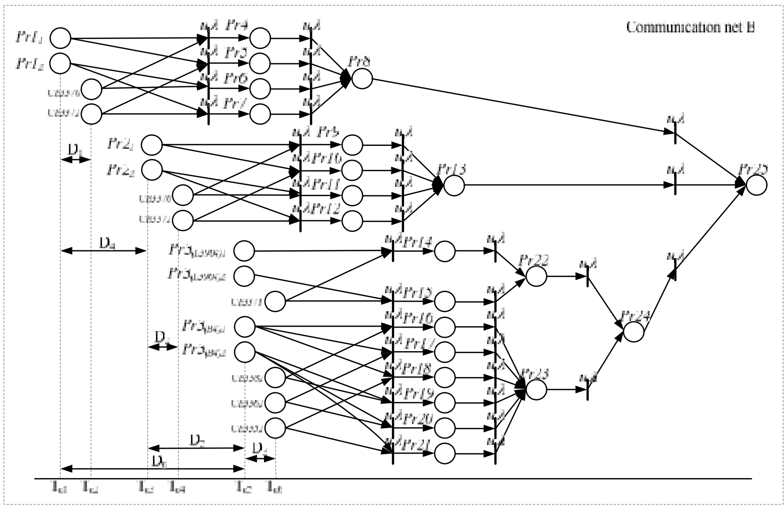


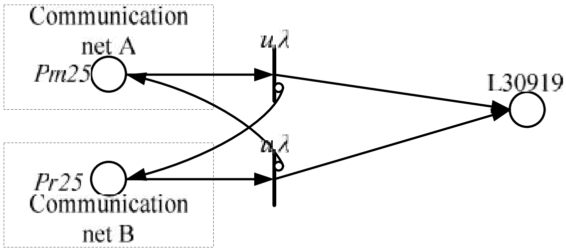
Figure 2. Local main electrical scheme of 750kV WuSheng substation



(a)



(b)



(c)

Figure 3. Redundant diagnosis TSFPN model of line 30919 , (a). Diagnosis model of main network, (b). Diagnosis model of redundant network, (c) Diagnosis model of coupling network

In the model, timing information be added to fault diagnosis to improve the description and diagnosis accuracy of the diagnosis model.

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

(2) Diagnosis model of coupling network, as shown in Figure 3(c). The maximum of output place credibility in the main network and redundant network is considered as the credibility of component.

3.3. Initial Information Valuation of Redundant Diagnosis Model

3.3.1 Information Entropy

According to information entropy theory [2], if X contains finite random events denotes the state characteristic for 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 events, thus the amount of self-information of any event x_i on finite field X is given by equation (4).

$$I(x_i) = -\log_2 p_i \tag{4}$$

Mathematical expectation of random variable $I(x_i)(i=1,2,3,\ldots n)$ is defined as the amount of average self-information on the set X, called information entropy of X, as equation (5).

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

3.3.2. Initial Information Valuation

The information is decomposed into the fault-state group and fault-characteristic group to obtain more accurate diagnosis result. The fault-state group is fault symptom set 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, using information entropy analyzes correlation degree between fault-state group and fault-characteristic group in the timing constraint condition, and obtains the credibility of fault state group when fault characteristic group is known, that is, the credibility of initial information.

After the fault occur, 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 $K=(b_1,b_2,\cdots,b_r)$ correspond 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 equation (6).

$$H(a_i) = -p_i \log_2 \mathrm{p}_i \tag{6}$$

The credibility of the initial information is the information entropy about a_i obtained from b_j . The uncertainty is more apparent due to the malfunction information of protective device or breaker in the course of the grid fault. For this, It is necessary to define a comprehensive index which makes full use of the information in fault-characteristic set, so that the known information of entry decision is the largest, and system decision is more reasonable. Therefore, the joint entropy [8-10] about a_i obtained from b_j is defined as equation (7)

$$I(A,K) = H(K) + H(K \mid A) \tag{7}$$

Equation (6) applied to Equation (7), then obtain equation (8).

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

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

Taking into account the probability of events is not readily available in real project, the engineering method is used [8]. Suppose that the probability of fault state and fault characteristic are equal, respectively, then shown as equation (9) and (10).

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

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

where, r is the number of fault characteristic b_j , $n(A \cap K)$ is the number of timing action in fault characteristic b_j with respect to a_i . Equation (9) and Equation (10) applied to Equation. (8), then shown as equation (11).

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

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

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

3.4. Initial Information Timing Constraint Checking of Redundant Diagnosis Model

Protections have the time setting values, according to the protective configuration principle. 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 protections is 0.5s, and an error of ±5% is considered. Used timing constraint relationship between protection and breaker carries on time constraint calculation for the forward and backward, in order to check whether such timing relationship can be satisfied, and correct initial-information credibility for the acted protection and breaker through checking result.

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

2) Check whether time distance constraint [475, 525] can be satisfied between primary protection and local backup protection, or, check whether time distance constraint [950,1050] can be satisfied between primary protection and remote backup protection, or, check whether time distance constraint [475, 525] can be satisfied between 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. The constraint can carry on timing reasoning calculation for the forward and backward by using protective information satisfied time constraint checking, and taking advantage of the time distance constraint between protection and breaker.

4) For protections or breakers were not observed, the credibility of its corresponding place does not require correction.

4. The Reasoning of Redundant Diagnosis Model

The reasoning of redundant time sequence fuzzy Petri net is a reasoning with credibility which describes reliant degree of a proposition or rule, and its reasoning procedures are carried out individually as follows.

(1) Check timing constraint relationship of protective device or breaker, and correct its initial-information credibility on the basis of the checking result.

(2) Calculate synthetic input credibility is denoted by $E = M_{i0} \cdot I_i$ in transitions, where, $E = [e_1, e_1, \cdots, e_n]$, n is the number of awaiting trigger transition, and the multiple fuzzy input of a transition is solved by an equivalent fuzzy input only has a weighting coefficient, according to its credibility and the weight coefficient, that is, $\sum_{i=1}^{n} M(p_i) \times w_i$.

(3) Compare the equivalent fuzzy input credibility with the transition threshold, which denotes by $G = E \cap^{o} a_i$, where, G is m-dimensional column vector, if the synthetic input credibility is greater than the threshold, then $g_i = 1$, otherwise, $g_i = 0$, for $i = 1, 2, \cdots, m$, where m is the number of triggered transition.

(4) Remove the input of synthetic input credibility is less than the threshold, which denotes by $H = E \,\mathrm{e}\, G$, where, H only contains synthetic input credibility of triggered transition through calculation.

(5) Calculate the credibility of fuzzy output, which denotes by $M_{i1} = H \otimes O_i$, where, M_{i1} is m-dimensional column vector, and m is the number of triggered transition, which can directly obtain the credibility of conclusion after the first round of reasoning.

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

(7) Obtain output result M_{ik}, when the credibility of proposition will not change through reasoning, $M_{ik} = M_{i(k-1)}$.

In order to describe the reasoning of an TSFPN, the following operators [11-12] are used.

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

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

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 : $C = A \,\mathrm{e}\, B$, such that $c_{ij} = a_{ij} \cdot b_{ij}$.

5. Illustrative Example

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

Table 1. Initial information credibility of redundant diagnosis model

Initial Information				$n(A \cap K$		initial information credibility	
Main Network	Redundant Network	n	r	without timing factor	timing factor	without timing factor	timing factor
$Pm1_1$	$Pr1_1$	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

Table 2. Fault credibility of suspicious component

suspicious fault component	fault credibility		actual fault component
	without timing factor	timing factor	
Wuhai No. 1 line	0.7815	0.747	Wuhai No. 1 line
Wugu No. 2 line	0.6455	0.407	
330kV No. 4 bus	0.6455	0.407	

According to the proposed diagnosis method, finding fault region, can obtain suspicious fault components that are Wuhai No. 1 line, Wugu No. 2 line, 330kV No. 4 bus. In the model, initial-information credibility is determined using information-entropy, and timing constraint is checked, initial-information credibility is corrected using the relationship between acted protection and acted breaker. The results are as shown in Table 1.

Suppose that input arc weights of transition are 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.

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

6. Conclusions

Because alarm messages are not consistent with timing information, and diagnosis result is uncertainty, fault diagnosis method of substation with redundant protection configuration based on time sequence fuzzy Petri net is proposed. In this method, component redundant diagnosis-model based on time sequence fuzzy Petri net can be decomposed into main and redundant subnet-model by using dual-net characteristic of 750 kV substation. In this model, initial-information credibility is determined using information-entropy, and timing constraint is checked, initial-information credibility is corrected using the relationship between acted protection and acted breaker. The result shows that the method is more accurate. Compared with fuzzy Petri net diagnosis method takes no account of timing constraint relationship. it can not only identify the malfunction information, but also can obtain a certainty result.

Acknowledgements

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