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Fault diagnosis method based on Petri nets considering service feature of information source devices ☆

Hongbo Cheng [a,b], Zhengyou He [a,*], Qi Wang [a], Jianwei Yang [a], Sheng Lin [a]

[a] School of Electrical Engineering, Southwest Jiaotong University, Chengdu, Sichuan Province 610031, China
[b] School of Electrical Engineering, East China Jitaotong University, Nanchang, Jiangxi Province 330013, China

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ABSTRACT

The Petri net is a powerful tool for fault diagnosis, yet at present the determination of the certainty factor and weight of Petri net initial place is on basis of an insufficient reality. This paper mainly presents a calculation method of the certainty factor and weight of Petri net initial place by use of reliability. The reliability of information source devices is proposed by using two-parameter Weibull distribution, minimum vertical and horizontal residual sums of squares are used to estimate parameters of the reliability, then these reliabilities are used to measure the initial information certainty, and the relative values of reliabilities are used to determine the weights of places during reasoning. As an example, we use this proposed method to diagnose fault of devices of a power supply system. And the result of the example shows that the degree of diagnostic results confidence are related to service time of the source device, which makes the result more consistent with actual operating conditions.

1. Introduction

The occurrences of system faults are unavoidable and therefore fast and accurate fault diagnosis has fundamental significance for reducing the influences and losses caused by such accidents.

Petri net and Fuzzy Petri net (FPN) have attracted much attention in fault diagnosis [1–3]. They have rigorous mathematical definitions, intuitive reasoning processes that are consistent with the occurrence and development of faults, and have good tolerance for data uncertainty [4]. Importantly, FPN gives a confident degree of its diagnostic result in the form of probability, that makes the results more convincing and more realistic [5,6].

However, as FPN deals the uncertainty of source information with long-term statistical average values and considers the failure rate as a constant value [7,8], the actual reliability of the operating device at a specific time cannot be accurately evaluated. For instance, in fault diagnosis of electrical power system, the operating information of protective relays and circuit breakers are provided as the inputs of a Petri net, and the average correct operating rates of relays and breakers are used to indicate the certainty factors of their initial places, and the transition is triggered by comparing its certainty factor with

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* Corresponding author. Tel.: +86 28 87602445.
E-mail addresses: waitingbo@126.com (H. Cheng), hezy@swjtu.cn (Z. He), wangqiclark@126.com (Q. Wang), jwyang@swjtu.cn (J. Yang), linsheng-1@163.com (S. Lin).

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threshold, thus the final fault possibility is obtained by reasoning. This is the common used method at the present time [9–11]. By using FPN, some characteristics of fault diagnosis in an electric power grid are presented as follows:

(1) The confidence level of diagnostic result is related to the certainty factors of initial places. In fault diagnosis of a power grid, the certainty factors of initial places are usually denoted by the correct operating rates of relays and breakers. Actually, the correct operating rates are closely related to the reliabilities of the devices. Therefore, the diagnostic result of FPN will be related to the reliabilities of relays and breakers.
(2) At present, the correct operating rate of a device is an average value of statistical data. While the average value covers the variation of the certainty factor of information from a relay or breaker, it cannot represent actual reliability of a relay or breaker at a time, that makes the confidence degree of fault diagnosis results reduce.
(3) The weights of relay and breaker information in the reasoning are relatively subjective, as lacking an effective basis of determination.

Thus, the reliabilities of relay and breaker have great influences on the results of power grid fault diagnosis. A higher reliability of a device is, a greater certainty of its information should be, and this information should have a greater weight in reasoning, those would make diagnostic result more accurate.

In this paper, we aim to determine the certainty factor and weight of an initial place objectively. The service feature of information source devices such as relay and breaker is described by reliability which is the basis of determination of the certainty factor and corresponding weight in reasoning.

2. Fault diagnosis method based on FPN

The FPN assigns a real number between [0,1] to place and transition respectively. These two numbers are used to indicate the certainty factor of the place and the occurrence probability of the transition. A FPN can be defined as the following [12]:

$$S_{FPN} = (P, T, D, \mathbf{I}, \mathbf{O}, \alpha, \beta, Th, \mathbf{U}, W) \tag{1}$$

where

$P = (p_1, p_2, \ldots, p_n)$ is a finite nonempty set of places;
$T = (t_1, t_2, \ldots, t_m)$ is a finite nonempty set of transitions;
$D = (d_1, d_2, \ldots, d_n)$ is a finite set of propositions, which meet $P \cap T \cap D = \phi$;
I: $P \to T$ is an $m \times n$ input incidence matrix defining the directed arcs from places to transitions, $I = \{\delta_{ij}\}$ ($\delta_{ij} = 1$ if there is a directed arc from P_i to T_j and $\delta_{ij} = 0$ if there is no directed arc from P_i to T_j, for $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, m$);
O: $T \to P$ is an $m \times n$ output incidence matrix defining the directed arcs from transitions to places, $O = \{\gamma_{ij}\}$ ($\gamma_{ij} = 1$ if there is a directed arc from T_j to P_i, $\gamma_{ij} = 0$ if there is no directed arc from T_j to P_i, for $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, m$);
$\alpha: P \to [0,1]$ is the certainty factor of place to transition, which reflects the credibility of the information of places;
$\beta: P \to D$ is an association function representing a bijective mapping from places to propositions;
$Th: Th \to [0,1]$, where $Th = \{\lambda_1, \lambda_2, \ldots, \lambda_m\}$, λ_i is the threshold value of transition T_i;
U is matrix of certainty factor, $U = diag(\mu_1, \mu_2, \ldots, \mu_m)$ where $\mu_j \in [0,1],\ j = 1, \ldots, m$ indicates the probability of trigger of transition T_j;
and $W = W_I \cup W_O$ is the set of input and output weight, where $W_I = \{w_1, w_2, \ldots, w_n\}$ denotes the weights of input places, $W_O = \{\mu_1, \mu_2, \ldots, \mu_n\}$ denotes the weights of output places.

In FPN diagnosis, the flow relationship between the operation information of a relay or breaker and the device failure is used to diagnose the fault of electric power grid, and the result confidence is derived according to the certainty factor of original operation information.

In FPN, if $\sum_j \alpha(p_{Ij}) \cdot w_{Ij} > Th(t),\ j = 1, 2, \ldots, n$, then transition t can fire and a new certainty factor can generate in the follow-up place

$$CF(t) = \begin{cases} \sum_j a(p_{Ij}) \cdot w_{Ij}, & \sum_j a(p_{Ij}) \cdot w_{Ij} > Th(t) \\ 0, & \sum_j a(p_{Ij}) \cdot w_{Ij} < Th(t) \end{cases} \tag{2}$$

The piecewise function $CF(t)$ can be approximated by use of a continuous function $G(x)$:

$$G(x) = x \cdot f_a(x) \cdot \mu \tag{3}$$

where

$$x = \sum_j a(p_{Ij}) \cdot w_{Ij}, \tag{4}$$